# Environmental History of the Rhine–Meuse Delta

## An ecological story on evolving human–environmental relations coping with climate change and sea-level rise

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*Cover illustration*: The river Lek at Elshout (Kinderdijk) ca. 1850, painting by Johannes Weissenbruch (1822–1880), Teylers Museum, Haarlem. It is generally believed that the cultural landscape of the Rhine–Meuse Delta had obtained its maximum biodiversity around 1850, before the complete regulation and canalization of the large rivers, and before the introduction of artificial fertilizer and barbed wire.

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# Memory of Holland

*Thinking of Holland*
*I see wide-flowing rivers*
*slowly traversing*
*infinite plains,*
*inconceivably*
*rarefied poplars*
*like lofty plumes*
*on the skyline in lanes;*
*and submerged in the vastness*
*of unbounded spaces*
*the farmhouses*
*strewn over the land,*
*tree clumps, villages,*
*truncated towers,*
*churches and elm trees -*
*all wondrously planned.*
*the sky hangs low*
*and slowly the sun by*
*mists of all colours*
*is stifled and greyed*
*and in all the regions*
*the voice of the water*
*with its endless disasters*
*is feared and obeyed.*

*H. Marsman (1936)*
*Translation Paul Vincent*

# Contents

# Preface

This book presents the environmental history of the Delta of the lowland rivers Rhine and Meuse, an ecological story on evolving human–environmental relations coping with climate change and sea-level rise. It offers a combination of in-depth ecology and environmental history, dealing with exploitation of land and water, the use of everything nature provided, the development of fisheries and agriculture, changes in biodiversity of higher plants, fish, birds, mammals and invasive exotics. It is the first comprehensive book written in English on the integrated environmental history of the Delta, from prehistoric times up to the present day. It covers the legacy of human intervention, the inescapable fate of reclaimed, nevertheless subsiding and sinking polders, 'bathtubs' attacked by numerous floods, reclaimed in the Middle Ages and unwittingly exposed to the rising sea level and the increasing amplitude between high and low water in the rivers. The river channels, constricted and regulated between embankments, lost their flood plains, silted up, degraded and incised. Cultivation of raised bog deposits led to oxidation and compacting of peat and clay, resulting in progressive subsidence and flooding; arable land had to be changed into grassland and wetland. For millennia muscular strength and wind and water powers moulded the country into its basic form. From 1800 onwards, acceleration and scaling up by steam power and electricity, and exponential population growth, resulted in the erection of human structures 'fixed forever', and severe pressure on the environment. The present-day Delta is a large wetland several metres below sea level, where humans 'keep their feet dry' only by the application of advanced technical means. The synthesis presents a blueprint for future management and restoration, from progressive reclamation of land in the past, to adaptation of human needs to the inevitable forces of nature.

A river delta essentially forms a gradient between the sea and the river proper, and elaborating on the ecological history of the Rhine–Meuse Delta assumes both knowledge of the estuarine environment as well as of the river environment. During my career I have worked for almost 25 years on estuarine ecology and management, and for roughly 15 years on the rivers proper. I realise that the aspects I have emphasised in this book, as well as the case studies I have worked out, mirror my subjective choices. This book is meant as a contribution to the environmental history of the Rhine–Meuse Delta, and I hope that my work will challenge other scientists to falsify my conclusions and to add their own chapters to the blue-green story of the man-made Delta.

I am indebted to many persons for support in the production of this book. I thank my son Arjan Nienhuis, landscape architect (Zaltbommel), for stimulating discussions and for his share in the final chapter on the future of the rivers. Joep Dirkx (Natuurplanbureau Wageningen), Petra van Dam (Free University Amsterdam) and Johan van Rhijn (Open University Heerlen) offered me information on the status of environmental history in the Netherlands. Klaas Bouwer, Gerard van der Velde (both Radboud University Nijmegen), Gerard de Ruiter (Nieuwegein), Willem van der Ham (‘s-Gravenhage) and Aart Vos (Zaltbommel) provided me with relevant literature. Herman van Dam (Amsterdam) enabled me to consult the archives of the Netherlands Society of Aquatic Ecology (Municipal Archives Amsterdam). Jan Bervaes (Zaltbommel) provided information on the medieval history of the Bommelerwaard. Roelof Loenen Martinet (Wageningen) placed at my disposal the family archives of the naturalist J.F. Martinet. Jolanda Hiddink and Lidwien van der Horst of the Department of Graphic Design Radboud University Nijmegen, worked up my sketches into high quality figures. Rob Lenders (Radboud University Nijmegen) and two anonymous reviewers scrutinised the manuscript. I also thank Tamara Welschot and Judith Terpos of Springer Publishers for their efforts in seeing this book to publication. Lastly, I especially want to thank my wife Arine for putting up with me while I was writing this book.

Piet H. Nienhuis

# Chapter 1
# Introduction

## 1.1 Developments in Environmental History; Motives to Write this Book

Environmental history is the study of humans and nature and their past interrelationships in the broadest sense. Environmental historians base their understanding of human and nature relations primarily on historical methodology, but often borrow from the work of scientists and scholars in fields outside of history. As a result, many scholarly contributions pertinent to environmental history are written by professionals who typically would not identify themselves as historians, and as an aquatic ecologist I am one of those scientists. Professional, integrated environmental history has now been in the making for roughly one generation. It is well recognised that the most influential empirical and theoretical work has been done in the USA, which is also where most of the first teaching programmes emerged and where the large majority of environmental historians are active. The other region with an equivalent number of major universities is Europe, but interchange of ideas on this continent is suffering from the numerous languages used to express beta–gamma integration (Sörlin and Warde, 2005). In 1999 the European Society for Environmental History was founded, counterpart of the American society, aiming at stimulating the dialogue between humanistic scholarship, environmental science and other disciplines in Europe. Indeed, a recent series of essays in the journal *Environmental History* (2005, volume 10, number 1) on the future of the field were written almost entirely by people based in the USA; Europe's contribution being an essay by Petra van Dam (2005) lamenting the difficulties caused by the language of the discipline being English.

The geographical features of a low population density, large stretches of 'wilderness', a mobile 'frontier' and a strong tradition of the 'outdoors', have all been significant for the reception and growth of environmental history in North America. This is also perhaps true of other regions where environmental history has gained a foothold: Australasia, and within Europe, in Scandinavia, in the Alpine countries and in Scotland. Certainly, both the threat of natural forces and the widely recognised ability of humans to radically transform their environments in the relatively recent past seem to have contributed to these global trends. Until very recently, themes within environmental

P.H. Nienhuis, *Environmental History of the Rhine—Meuse Delta,*

history have been largely rural or to do with impacts of human activity on the rural or supposedly ‘natural’ environments, even when the forcing agent stems from urban development. In continental Europe, environmental history’s impact has often been related to local peculiarities, such as the history of water management in the Netherlands, forestry in Germany and the Nordic countries, or pollution in regions of rapid 19th-century industrialisation (Sörlin and Warde, 2005).

It may be suggested that the integrated approach to environmental history has not yet come to full maturity in the Rhine–Meuse Delta (see Figs. 1.1 and 1.2 for position of the Delta), likely owing to the complexity of the subject and to the way the education system at our universities is organised, strictly according to scientific disciplines. (I could only write this book after my retirement in 2003).This lack of integration may be true, but in its disciplinary approach environmental history in the Netherlands is much older than in the USA, for example, in the fields of environmental health care and nature protection. The Dutch Society against Water, Soil and Air Pollution was erected in 1909. It had a long and standing tradition, and numerous publications dominantly in Dutch appeared in the course of the 20th century. The society played an important role in research of water pollution directed to rivers and surface waters. It took several initiatives for legislation with respect to environmental pollution. The organisation merged in 1978 into the action-oriented Foundation Nature and Environment. The archive is a goldmine of facts and data on the environmental history of the Delta not yet published in English (www.iisg.nl/archives).

Publications on nature protection also have a long tradition in the Delta. The journal *De Levende Natuur* (*Living Nature*) was founded in 1896 by the teachers Jac. P. Thijsse and E. Heimans, and this periodical appeared to be the most important medium for articles about nature protection and nature study in the period before World War II. In 1903 for the first time the word ‘natuurbescherming’ (nature protection) was used in *De Levende Natuur* (Van der Windt and Harle, 1997). In 1905 the Society for the Preservation of Nature in the Netherlands (Vereniging tot Behoud van Natuurmonumenten) was founded. In 2006 this organisation had 913,000 members, it owns 370 nature reserves with a total area of 95,000 ha, and is the most powerful nature conservation organisation in the Delta (www.natuurmonumenten.nl).

Being on familiar terms with water and land–water interactions was anchored in the collective memory of many inhabitants of the Delta. My wife Arine published a genealogical book (Nienhuis-Snaterse, 2008) on her ancestors who lived in the Central Delta from the 16th century onwards, and numerous old trades in her family can easily be associated with the history of the wetland of the river Rhine: fisherman, decoy man, water-miller, shipbuilder, driver of a towing-horse, cooper, farmer, farmer hand, reed-cutter, peat-cutter, member of the polder board and ferryman. Lowland rivers and polders have inspired many pictorial artists, musical composers and writers through the ages (e.g. Schmidt et al., 1995). Many regional novels contain a wealth of hidden environmental history on exploitation of aquatic resources, navigation with sailing boats, dyke breaches caused by drift ice, the consequences of unpredictable river floods, poverty and hard labour, ‘the fear of the Lord’ and much more (e.g. Van Schendel, 1933; Coolen, 1934 [33rd print in 1977]; Ooms, 1950; Van Toorn, 1999).

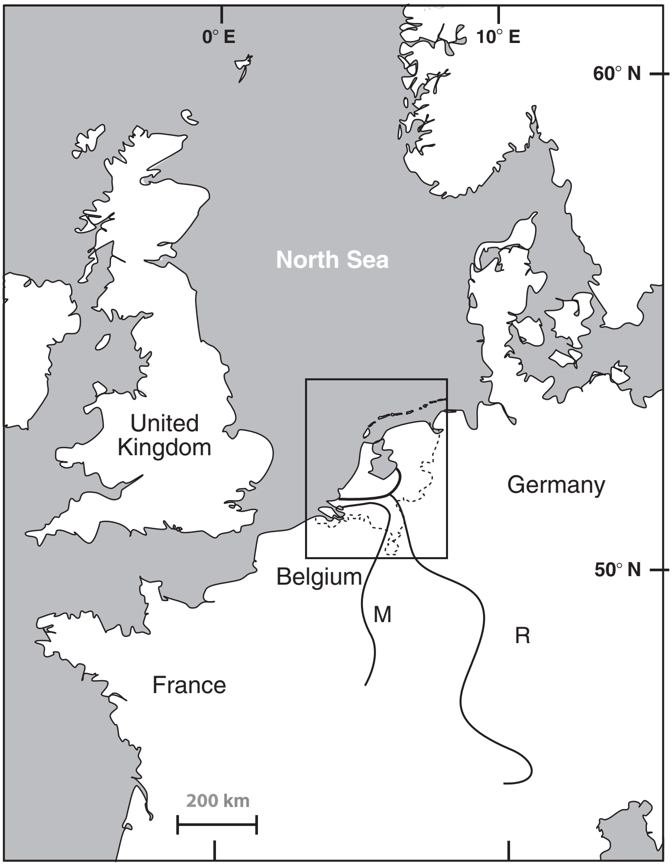

**Fig. 1.1** Position of the rivers Rhine (R) and Meuse (M) in Western Europe. Detailed maps of the catchments are published in Chapters 12 and 13. The Delta is positioned in the inset, see Fig. 1.2

The Netherlands has a book on the 'green history' written in Dutch by Van Zanden and Verstegen (1993), and since 1996 the 'Jaarboek voor Ecologische Geschiedenis' (Yearbook for Ecological History) of the 'Vereniging voor Ecologische Geschiedenis (Society for Ecological History) has been published. From 1986 onwards the modest journal 'Contactblad Net Werk voor de Geschiedenis van Hygiëne en Milieu' (Journal Net Work for the History of Environmental Health Care and Environment) functions as an indispensable source for a detailed reconstruction of environmental history. Thus far however, these publications are mainly written in Dutch and have not crossed borders unto an international audience. In 2003 'Environmental Science', journal of integrative environmental research, evolved from the Dutch predecessor 'Milieu' (Environment), associated with the Netherlands Association of Environmental Professionals (VVM), but up to now the

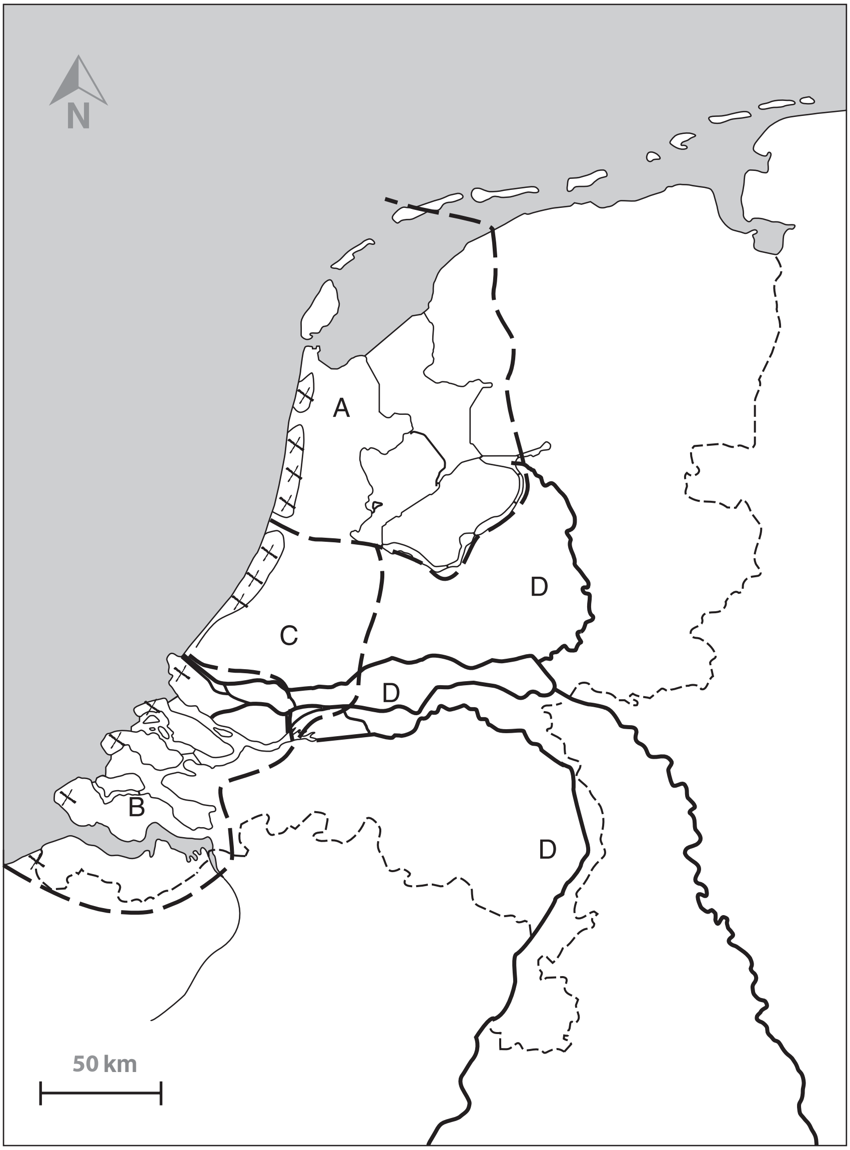

**Fig. 1.2** The Delta of the rivers Rhine and Meuse, projected on a present-day map of the Netherlands. The Delta is arbitrarily divided into the NW Delta, including the former Zuiderzee (A), the SW Delta (B), the Central Delta (C), and the area of the Large Rivers Rhine and Meuse (D), crosses = coastal dunes

contributions to environmental history of the Delta are close to nil. The history of water management of the Netherlands is fairly good, covered by several authors (e.g. Van de Ven, 2004; Ten Brinke, 2007), mainly written from the state of mind of ‘how a small country performs great actions’. But water management is only one side of environmental history, and a critical analysis of the effects of the making of the Delta on landscape structure and ecosystem functioning is lacking in the literature: an ecological story on evolving human–environmental relations coping with climate changes and sea-level rise. In conclusion, an English book on integrated environmental history of the Rhine–Meuse Delta does not exist. That was my first motive to write this book.

## 1.2 Additional Motives and Aims of the Book

Until the late Middle Ages the reliability of ‘data’ sampled on whatever field of environmental history is restricted. From the 17th century an increasing number of data on river management, land use, agriculture and fisheries became available, collected with ever-advancing measuring methods. ‘Ecological’ (the word did not exist) evidence per se remained scarce until the 20th century. The naturalists in the 18th and 19th century were the first to publish in more detail on nature items. The societal need for accessible knowledge about ‘nature’ was small, and the distinction between ‘nature’ and land and water exploited by man was hardly made. In the low man-made Delta little wilderness was left, and ‘wasteland’, i.e. not-cultivated land and water was used for the harvest of many useful products, such as wood, fish and game. According to Holmes (2006), we know surprisingly little about the way wetland communities have been affected in past centuries by natural or man-induced extreme events, and whether these changes are short- or medium term, or permanent. Only very recently, from 1950 onwards, a growing stream of publications on the regional ecology saw the light, including not only (the almost vanished) natural landscapes in the Delta, but also the semi-natural, man-made landscapes. Focused on the large non-tidal rivers in the Delta, an arbitrary choice of regional publications can be listed: Weidema et al. (1974) about the river polders in the Central Delta, Van Diggelen et al. (1992) on the Land van Heusden and Altena (referring to the oldest flora of the region from 1898 by C.A. Backer, present in the Rijksherbarium Leiden), Jonkers (1991) on the Vijfheerenlanden, Manders (1981) on the Land van Maas en Waal, Van Balken et al. (1978) on the Bommelerwaard, Van Heiningen (1971) on the Land van Maas en Waal and Caspers (1992) on the flora and fauna in the Meuse basin (referring to the flora of Van Hoven from 1848).

Now, in the 21st century, superficial interest in natural history is topical; people have a lot of spare time, and the publication of numerous books on popular items of ecology obviously fills a gap, for otherwise the market would not be washed over with these issues. An increasing number of appealing books on plant and animal life show, in glossy pictures, all the wonders of nature that can be observed during ‘armchair’ excursions. Societies for nature conservation, either national (Nature Conservation Society, Bird Protection Society; Nature Education Society, etc.) or regional (Provincial Landscape Societies; Regional Nature Conservation Societies, etc.) organise excursions and issue field guides, comprising walking routes and cycling tours, and geographic and historic routes. Up to now the superficial interest of civilians in nature is unrestrained, and the frontiers of this market have not been reached. We have to realise that this development is only roughly 40 years old, that is, ‘five minutes to twelve’ in our prehistoric and historic quest for the environmental history of lowland rivers.

Economic growth and prosperity most often are at the expense of the natural environment. Nevertheless, this book is not a litany on the deterioration of ‘nature’ in a Delta shaped by man. During the environmental history of the Delta, humans changed the ‘natural’ landscapes into semi-natural or cultural ones, and in the course of time these acquired an intrinsic value. There is an old saying, ‘God created the world, but the Dutch created their country’. The most valuable Dutch landscapes in international and national terms are those whose historic evolution is still recognisable from their topographic patterns and their plant and animal life. These comprise the old marine clay landscapes in the Southwest (SW) and Northwest (NW) Delta, large parts of the peat grassland landscapes in the Central and NW Delta and the larger part of the area of the Large Rivers (Fig. 1.3). It is exactly these landscape types that form the subject of this book. Polders reclaimed from peat lakes pumped dry, old polders on marine clay and land reclaimed from peat, all of which are situated in the lowest parts of the country, have international significance. Over 95% of the polders in NW Europe are situated in the Delta. Peat reclamations with strip plots, originated during the ‘cope ‘exploitation, and old marine clay polders with dwelling mounds are mainly restricted to the Netherlands. Large-scale land consolidation after World War II and earlier river regulation measures, however, have spoiled many old man-made landscape structures in the low-lying Delta. In contrast, the Pleistocene cover-sand landscapes in the Delta (Fig. 1.3) have a low international value, because that type of landscape is amply available in Europe (Farjon et al., 2001; www.mnp.nl). The Dutch government has a great responsibility to maintain the remainder of the typical and internationally rare landscapes, moulded by the rivers and the sea. Knowledge of the environmental history of these unique landscapes is a prerequisite for future management. The second reason to write this book was to feed the conservation and restoration strategy directed to typical and internationally rare Delta landscapes.

The general aim of this book is to give a comprehensive overview of the environmental history of the lowland rivers Rhine and Meuse, in fact, an ecological story on evolving human–environmental relations coping with climate change and sea-level rise. Prehistoric and historic changes in river landscapes, in ecosystems and in the diversity of plants and animals have my first consideration. These changes have mostly been caused by use and exploitation of nature by man. History focuses on humans, on man and his noble or awkward deeds (see Section 1.3.4.). My book does not focus on man per se, but on the results of his actions in the ‘green’ and ‘blue’ environment. The book delves neither in the development of the ‘red’

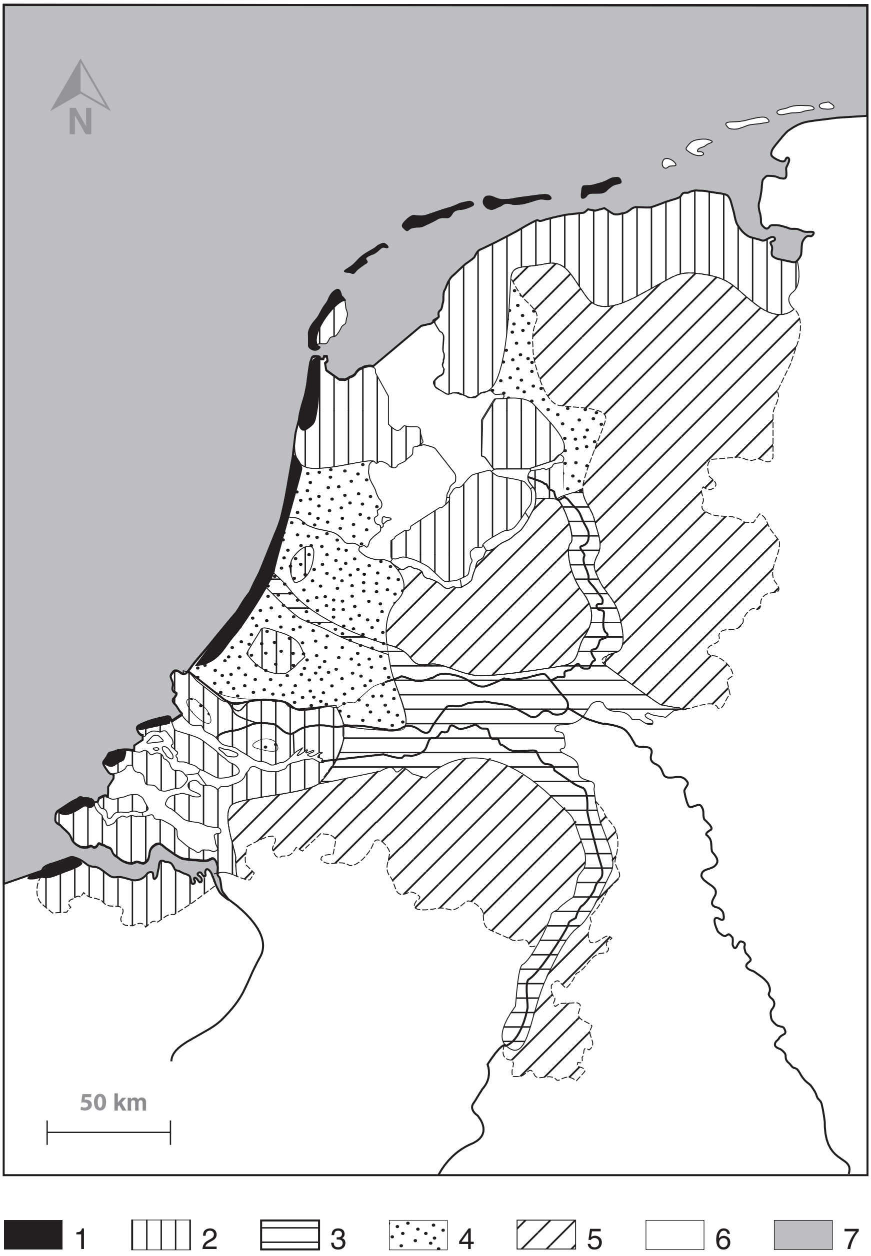

**Fig. 1.3** Landscape types in the present-day Delta, characterised by the composition of the soil (www.bosatlas.nl). If there were no dykes and pumping stations, about 65% of the Delta would be flooded periodically by the sea and/or by the rivers, i.e. all landscape types except the Pleistocene cover-sands, and the coastal dunes. The marine clay deposits and peat-bog areas are situated below NAP (Dutch Ordnance Datum) or slightly above that datum level. The river clay deposits are situated above NAP, but they run the risk of being flooded when a river is in spate (www.rdnap.nl). 1 = marine coastal dunes; 2 = marine clay; 3 = river clay; 4 = peat bog; 5 = Pleistocene cover-sands; 6 = non-tidal water; 7 = tidal water

built-up environment, nor in policy, politics or in economy, but again in the resulting effects of all these disciplines on nature.

The making of the Delta from 3500 BP to 1800, will be described, a time in which muscular strength and water power moulded the country into its basic and still-recognisable form. The further making of the Delta from 1800 to 2000, characterised by acceleration and scaling up by steam-power and electricity, led to the formation of the Delta in its present shape. Through the ages dominant phenomena were the numerous storm floods and river floods, and how humans have coped with these incidents or disasters: the fate of the riparian inhabitants has more often been sealed by neglected maintenance of the protective embankments than by the changing climate. The exploitation of land and water, and particularly the transition land–water, runs as a continuous thread through environmental history, as will be elucidated with stories on fisheries, agriculture and use of seagrasses. History is made by humans, and consequently, some attention will be given to a number of men and women vital to the land- and waterscape, from the historic naturalists to the present-day aquatic ecologists. A view on biodiversity changes in the Delta through the ages will be illustrated with examples of higher plants, fish, birds, mammals and invasive exotics. The Delta comprises only a small part of the catchments of the international rivers Rhine and Meuse, and a few chapters have been devoted to the Delta in wider geographic perspective, in particular focussing on transboundary water and soil pollution and rehabilitation measures The last chapter of the book contains the synthesis, the lessons learnt from the past, and the wider perspective, some ideas about the future of the rivers. The future is to the next generation: of this chapter my son, Arjan, is co-author. As a landscape architect, he is involved in several river rehabilitation projects and schemes for the future physical planning of the Delta. The environmental history of the Delta will continue. A gradual change is to be seen, from the defensive strategy, that is, to claim as much land from the sea and the rivers as possible, to an offensive strategy, to adapt the human needs to the inevitable forces of nature.

Environmental history of lowland rivers is a broad field, and although I tried to cover the entire arena, my focus is biased by my knowledge of the subject, and consequently some aspects might be underestimated, and some other aspects may have got too much attention in the eyes of reviewers. So be it. It is a fact, however, that the environmental history of Delta lowland rivers is a challenging subject waiting to be explored further.

## 1.3 General Considerations

The environmental history of the Delta is embedded in some major physical, demographic and administrative developments, mainly beyond my focus. A few general considerations concerning these developments should be given, however, returning in almost every chapter of the book.

## *1.3.1 The Definition of the Delta*

The Delta of Rhine and Meuse (in short, the Delta) is situated in NW Europe; it comprises the most stream-downward sections of these large European rivers, debouching into the North Sea in the Netherlands (Fig. 1.1). Long before the Netherlands came into existence (Section 1.3.4), the rivers Rhine, Meuse (and Scheldt) and the North Sea have shaped that piece of land. Therefore, consequently the physical term 'Delta' is used instead of the administrative limitation 'the Netherlands' that came only into use in the 19th century. The Delta is arbitrarily divided into the area of the Large Rivers Rhine and Meuse, and its subdivisions Nederrijn-Lek, Waal-Merwede and IJssel and Maas, where river clay deposits dominate; the NW Delta, including the former Zuiderzee and part of the marine clay deposits in Friesland; the SW Delta, where marine clay is the dominant terrestrial deposit, touching upon the influence of the river Scheldt; and the Central Delta, the peat bog land (Figs. 1.2 and 1.3). Dutch geographic names are used throughout the book, unless international waters are indicated (Rhine, Meuse, North Sea, Wadden Sea, etc.).

The concept 'polder' is typically Dutch, and a bit of the polder-vocabulary is indispensable in the context of this book. A polder is a low-lying tract of land that forms an artificial hydrological entity, enclosed by embankments known as dykes. Polders in the SW, NW and Central Delta constitute areas of land reclaimed from a body of water, such as a lake or the sea, and are consequently situated below the surrounding water level. A distinction is made between areas reclaimed by embanking salt marshes, land gained on the sea, and areas reclaimed by pumping dry lakes, the drained lakes (see Fig. 5.9). A 'waard' is a river polder, that is, a polder entirely enclosed by rivers, and surrounded by a ring-dyke ('bandijk'), a dyke expelling the influence of river water. River polders are situated in the area of the Large Rivers.

The northernmost part of the Delta does not belong to the delta of the Rhine in the strict sense. It is an area shaped by the sea, mainly consisting of marine clay deposits. Circa 2,500 years BP, humans have settled there on natural levees and later on man made dwelling mounds. In the Middle Ages large areas were embanked. The area is geomorphologically but also historically characterised by gradients between land and water. Long after man started to protect large areas of fertile ground by embankments, storm floods threatened the reclaimed land and ravaged the human settlements unto the town of Groningen. Nowadays, massive seawalls form a sharp border between inhabited land and water. A special issue of Helgoland Marine Research (2005, volume 59, number 1) is devoted to the ecological history of the Wadden Sea, mainly focusing on the present Wadden Sea, the estuary disconnected from the inhabited land (Lotze et al., 2005). The comprehensive environmental history of the dynamic Wadden Sea and 'Wadden land' of the past is waiting to be exemplified.

### 1.3.2 The Demographic Developments Underlying the Ecological History

The Delta was, and still is shaped by humans. A salient feature of the Delta is the growth of the human population through the ages. The population increased slowly in the period 800–1800, from 0.1 to 2 million people, on average 0.2 million per century. A rapid increase took place from 1800 to 1900, from 2 to 5 million inhabitants, an average increase of 3 million per century. From 1900 to 2000 the population increased extremely rapidly from 5 to 16 million, that is, 11 million in a century. The prognosis is that the population will increase to 17 million in 2035, and further will decrease to 16.9 million in 2050, which is a major break with the current tendency (Fig.1.4; www.cbs.nl). The causes of these demographic developments are only slightly touched upon, because they are largely beyond the subject of this book. The consequences of the exponential population growth, however, have been decisive for the layout and the use of the Delta and demographic shrinkage will be of crucial importance for the future use of land and water. In several chapters these effects are a matter of consideration.

### 1.3.3 Sea-Level Rise and Ordnance Datum

Sea-level rise is a complicated process: not only the sea level is rising after the last ice age (65 m in 10,000 years; Fig. 2.2), but at the same time the land is sinking. Sea-level rise should therefore be considered as relative sea-level rise. Northern Europe was pushed downwards under the increasing pressure of the 4 km thick ice mass during the last ice age. The semi-fluid interior material of the earth underneath northern Europe escaped to the borders of the massive ice cap and this resulted in an upwards pressure of a large area bordering the ice mass, including the Rhine–Meuse Delta. When the ice mass melted and retreated to the north the reverse process took place. In the past 10,000 years Scandinavia has risen more than 300 m, and in contrast with this process the Rhine–Meuse Delta has sunk; and there is yet another process complicating the relative sea-level rise. The Delta is slightly tilting into the direction of the North Sea. The coastal areas of the North Sea and the Wadden Sea are sinking several centimetres per century, whereas the Pleistocene eastern and southeastern parts of the Delta are coming up with roughly the same rate. Real-time measurements of physical and chemical parameters only started at the lowest point of the Little Ice Age, around 1830, and that is a drawback for the interpretation of recent climate change events. No wonder that many data series show an upwards trend, viz. temperature followed by $CO_2$; we simply do not have enough data to look back over even a very small-scale climate cycle. All data sampled in the past were proxy data, indirect measurements based on pollen grains, tree rings, market prices of resources, historic data and old maps, with all implicit difficulties of interpretation (Kroonenberg, 2006).

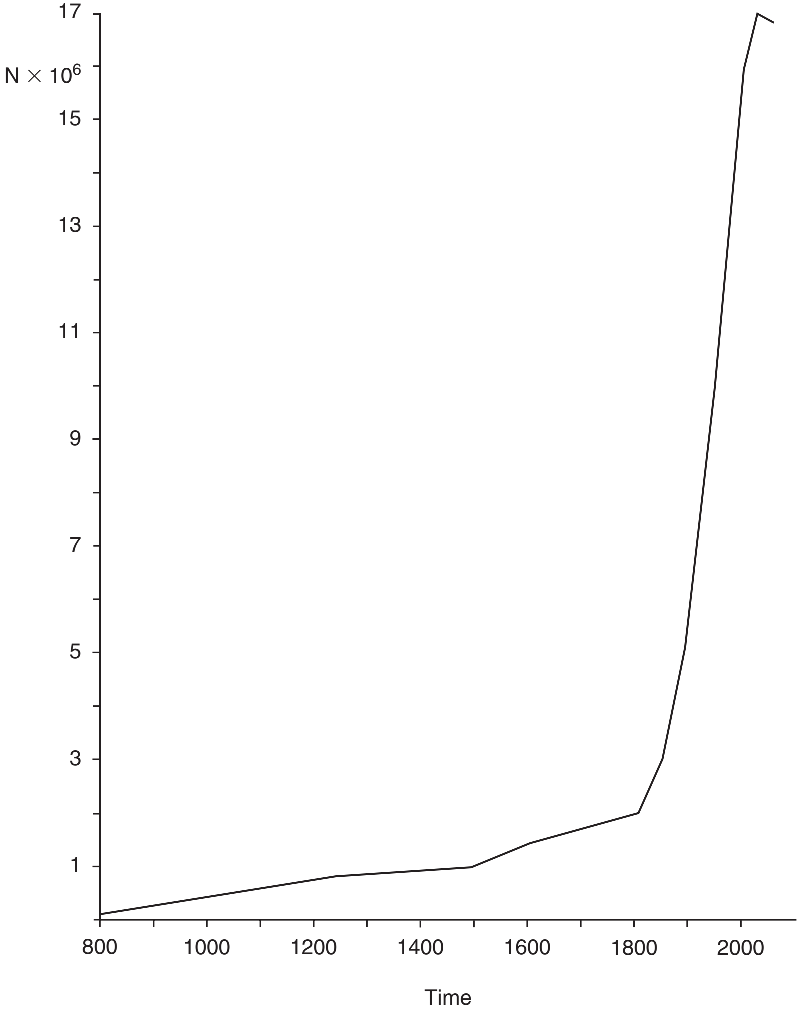

**Fig. 1.4** The development of the human population in the Netherlands (N × $10^6$) over the period 800–2000, and a prognosis for the period 2000–2050. The predicted decrease of the population after 2035 is a significant break with the current trend (www.cbs.nl). The decrease in population during the pest epidemics, particularly in the 14th century, is not indicated, because data for the entire country are unreliable (cf. Slicher van Bath, 1960)

The Amsterdam Level (AP) was introduced in 1683–1684 as a reference level related to the average high water level in the IJ at Amsterdam. This level was marked in several sluices in Amsterdam, where fixed stones were provided with a horizontal groove. At the end of the 19th century the ordnance datum was determined in a more accurate way. Between 1875 and 1894, the Normaal Amsterdams Peil (NAP) (Normal Amsterdam Level) was introduced as a reference level related to a defined sea level. NAP 0 m level is approximately equal to average sea level at the North Sea. Nowadays, NAP is visualised by thousands of bolts fixed in dykes, bridges and buildings, of which the exact level in relation to NAP is regularly ascertained (cf. Fig. 1.3). The Dutch Ordnance Datum NAP is adopted by several European countries, which facilitates comparisons of flood levels. Although NAP was only introduced in the 19th century, I will refer to that datum from prehistoric times onwards, enabled by palaeographic excavations of reconstructed river landscapes from the past, and by comparison of historic flood levels with recent high water levels. The disadvantage of this reference remains that the Delta is subsiding and the sea level is rising (www.rdnap.nl).

### *1.3.4 The Constitution of the State of the Netherlands*

The Delta of the rivers Rhine and Meuse is nowadays called the Netherlands, but the limitation of the country, as depicted in Figs. 1.2 and 1.3 is of a rather recent date (1840). The history of the state, in this context reduced to a number of (disputable) facts, however, is indispensable for the proper understanding of the environmental history of the lowland rivers.

AD 703: Foundation of the diocese of Utrecht; prince-bishops of Utrecht had secular power over part of the diocese.
AD 922: Foundation of the earldom of Holland.
1096: Foundation of the (earldom later) duchy of Gelre.
1106: Foundation of the duchy of Brabant.
1581: Foundation of the Republic of the Seven United Netherlands.
1813: Foundation of the Kingdom of the Netherlands.
1840: Limitation of the borders of the present provinces in the Netherlands.
(www.ru.nl; 'Het museum van de vaderlandse geschiedenis')

Much progress in water management was accomplished in the past by the dedication to a central government, but many conflicts between regional rulers have frustrated the efforts to conquer the 'water wolf'. About progress: the successful 'cope' exploitation of the raised bogs of the Central Delta from AD 950 onwards (Chapter 3), was directed by the bishop of Utrecht and the earls of Holland. About conflicts: the quarrels on water management affairs between the earldom of Holland and the duchy of Gelre have to be traced back to the political superiority of the earls of Holland, compared to the dukes of Gelre. The Diefdijk between the Vijfheerenlanden in the west (Holland) and the Neder-Betuwe and Tielerwaard in the east (Gelre) (Fig. 3.9), was built by the earls of Holland in 1284 to avoid flooding of their territory when the Rhine was in spate and flooded the Betuwe. The borderline between the diocese of Utrecht and the duchy of Gelre was partly formed by a valley, a marshy bog-peat area in between ice-pushed ridges in the west (Utrecht) and in the east (Gelre). In the south, the Nederrijn penetrated far inland (Fig. 3.4), and in the north a number of brooks, originating on the Veluwe, discharged their water into this valley. This border area has long been an area of political conflicts. An example: the walled town of Bunschoten on the river Eem was several times razed to the ground after the inhabitants violated their treaty with the bishop of Utrecht and collaborated with the enemy, the duke of Gelre (www.provincie-utrecht.nl).

From the Middle Ages onwards the river Maas has formed the border between the duchy of Gelre and the duchy of Brabant. Until far in the 16th century both duchies were in a state of permanent war, and often Gelre had the upper hand. The Maas, its discharge being ten times smaller than that of the river Waal, was used as an overflow when the Waal was in spate (Beerse Maas at Heerewaardense Overlaat and Beerse Overlaat; Fig. 5.4), a position sustained by the political quarrels between the border states. After 1581 Gelre was a fully fledged province of the Republic, Brabant was not. Brabant was a ‘generaliteitsland’, that is, it was enrolled by the Republic, placed under the jurisdiction of the States General, but it had no right to vote. Consequently, the Maas could be considered the ‘slave’ of the Waal: the river was frequently saddled with the burden of flooding caused by the river Waal in Gelre. Long after 1800, when the position of the two provinces Gelre and Brabant became more or less evenly matched, the overflow function of Brabant still existed. The Heerenwaardense Overlaat was closed at the end of the 19th century and the Beerse Overlaat was only closed in 1942.

# Part I

# Human Occupation and Management of a Fertile Delta

# Chapter 2
# Prehistory and Early History of the Delta

## 2.1 Introduction

Prehistory covers the period of the existence of mankind without written documents. In the Delta of the rivers Rhine and Meuse this points to the period preceding the Roman times, roughly from 250,000 years BP onwards. The early history (proto-history) covers the period in which written sources are scarce or fragmentary, i.e. the transition period between prehistory and the period that is commonly called 'history'. In the Delta, early history comprises the Roman period (15 BC to AD 430) and the period of the Merovingian and Karolingian rulers (roughly from AD 430 to 1000).

An attempt to describe the environmental aspects of the prehistory and early history of the lowland rivers Rhine and Meuse is a confrontation with a poignant lack of information. How little do we know from that period? The most reliable records come from geological, palaeogeographical and palynological research, and from scanty archaeological excavations. The first written sources date back to the Roman period, but these are subjective, often second-hand observations of educated military men and historians. After the Roman period, until roughly AD 800–900, again, there is a great lack of written documentation.

The rough outline of the basins of Rhine and Meuse is the work of nature, the deposition of the ice-pushed ridges and the cover-sand layers during the Saalien ice age, 250,000 to 140,000 years ago, and the steady sea-level rise after the last Weichselien ice age, from roughly 15,000 years ago onwards (Van den Broeke, 1991a). The shaping and re-shaping, gain and loss of land, exploiting or counteracting the forces of nature is the work of man. Eventually, the Delta is a man-made country.

This chapter covers the dawn of the Delta. It deals with the continuous marks of human impact, originally scanty by hunters and dwellers, but becoming more intensive when man settled, starting his agricultural practice, roughly 7,000 years BP, and concurrent exploitation of the closed forest (or open forest?) landscape. Pre-Roman 'water management' works have been excavated, such as drainage systems, thrown up living mounds and protective dykes.

The period of the Roman occupation showed an explosion of 'civilisation'. The river Rhine formed the northern border of the Roman Empire. Impressive Roman waterworks

P.H. Nienhuis, *Environmental History of the Rhine—Meuse Delta,*

were carried out and the exploitation of the river floodplains was intensified. The growing population (partly military) triggered a growing demand for food. Deforestation and exploitation of the inaccessible raised bog and fen area in the west behind the barrier dunes started to have a quantitative impact on the natural river basins.

A relapse in the exploitation of the river landscape set in around AD 400 and lasted until *ca.* AD 800, owing to changing cultural habits, and natural causes. Transgressions of the North Sea swallowed large parts of the Delta, partly to be attributed to the accelerated rising sea level. Slowly advancing water management kept in step with the decreasing rise (but nevertheless, rise) of the sea level: the embankment of human dwellings and arable fields. This chapter shows that the initial outline of the present river landscape was shaped before the year AD 1000, in contrast with the prevailing opinion (cf. Van de Ven, 2004) about the history of water management in the Netherlands.

## 2.2 From the Old Stone Age to the Roman Period

### *2.2.1 The Dawn Of the Delta*

The general features of land and water in the Delta (what is now called the Netherlands) were shaped in the Pleistocene era, in geological terms a recent period, starting several hundreds of thousands of years ago. During that entire period sediments from the upper reaches of the rivers Rhine and Meuse found their way down to the North Sea basin. The continually replacing braiding and anastomosing river courses deposited a thick layer of sand and gravel in the low Delta, locally several hundreds of metres thick (Fig. 2.1, Table 2.1).

The first inhabitants of the Delta left their traces approximately 250,000 years ago, during the Saalien ice age (250,000–140,000 years BP; Table 2.1). Remnants of campsites of these dwellers were found in a cave near Maastricht (Fig. 2.10), on the edge of the marshy floodplain of the river Meuse, close to higher-situated forests (Roebroeks, 1989). In a later phase of the Saalien, approximately 150,000 years ago, the climate became more grim. The northern part of the country was slowly covered under a hundred-metre thick sheet of land ice. The moving ice tongue pushed masses of sand, gravel and boulder clay (crushed and disintegrated boulders) forward. While the ice sheet slowly moved southwards, average temperatures in July dropped to zero. The presence of ice sheets during the glacial period strongly influenced the landscape of the northern half of the country (Fig. 2.1a). Along the present river IJssel, Nederrijn and Meuse (Fig. 2.1d; Fig. 2.10) boulder clay and sand were pushed up to hundreds of metres-high ridges (Dutch: ‘stuwwallen’; nowadays these ice-pushed ridges are only 8–60 m high, owing to wind and water erosion). Deep valleys were scoured, either by melt water, or by the ice itself. Many of these valleys can be recognised in the present stream patterns. No traces of human occupation are known from that period.

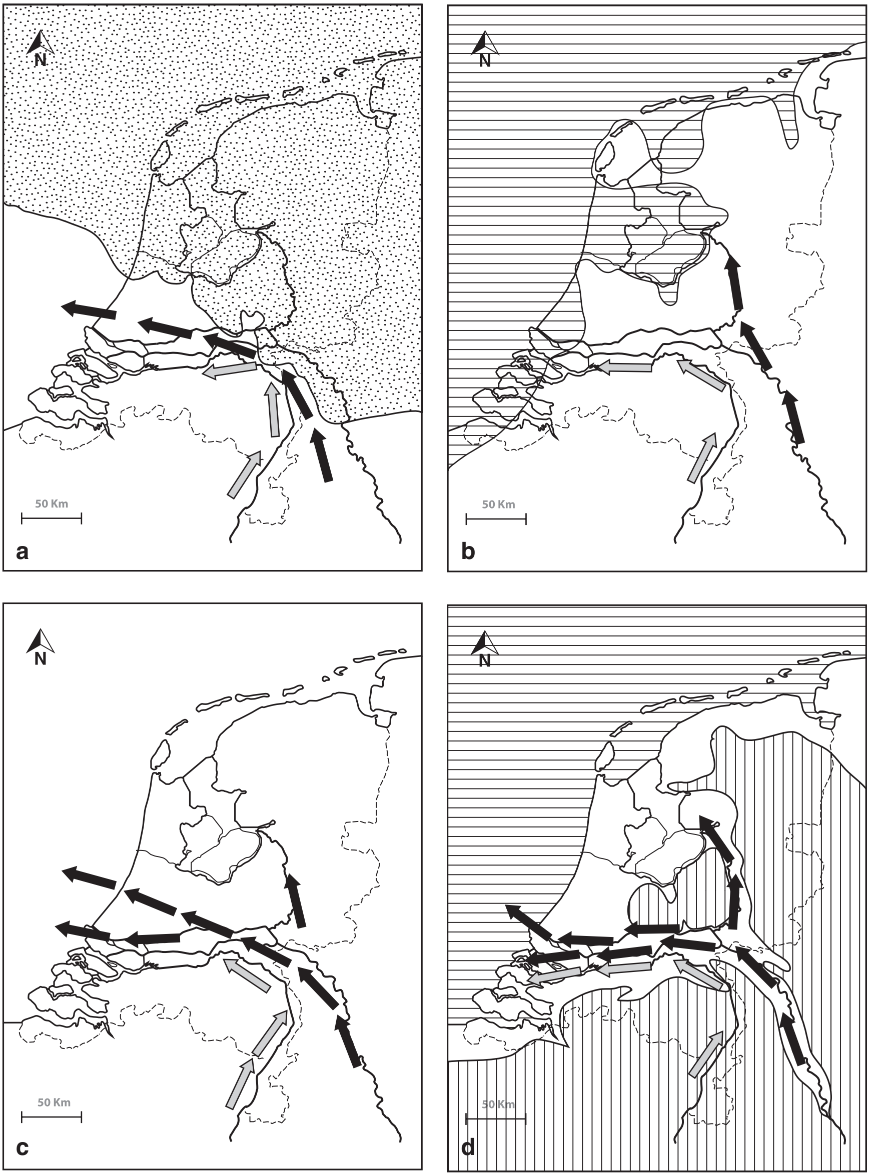

**Fig. 2.1** (a) Palaeographic reconstruction of the extension of the land-ice cover in the Saalien; (b) extension of marine Eemien deposits (horizontally hatched) in the warmer interglacial period; (c) at the end of the last Ice Age, the Weichselien, the North Sea dry, sea level at NAP − 130 m; (d) the extension of the North Sea in 2000 (horizontally hatched); the area of the Netherlands below NAP + 1 m protected by dykes (white), that would otherwise be flooded, either by the sea or by the rivers; Pleistocene cover-sand and ice-pushed ridges (vertically hatched) intersected by the main rivers. The reconstructions are projected on a recent map of the Netherlands. Geological periods of the eras are mentioned in Table 2.1. Grey arrows: main course of the river Meuse; black arrows: main courses of the river Rhine (derived from Berendsen, 2000)

During the subsequent interglacial period, the Eemien (140,000–120,000 years BP) temperatures in July rose to 20°C, followed by a sea-level rise to NAP + 2 m (Fig. 2.1b; Table 2.1), and consequently large parts of the Delta were covered with marine clay. The Eemien was followed by the Weichselien ice age (120,000–12,000 years BP; Fig. 2.1c; Table 2.1), during which the sea level again drastically retreated. At the end of the Weichselien, the country has changed into a treeless, arctic desert, almost permanently swept by snow blizzards and sandstorms. The North Sea retreated hundreds of kilometres westwards; 18,000 years ago the sea level was situated 130 m lower than it is nowadays. Strong winds blew enormous masses of sand over large parts of the country. These Aeolian cover-sand ridges and fine-grained loess deposits are still decisive for the topography of the present-day landscape (Van den Broeke, 1991a).

At the end of the Weichselien ice age, roughly 15,000 years ago, the average temperature rose again: the dawn of the present geological period, the Holocene. Ecological changes marking that period are rather well known owing to correlations between $^{14}$C-dated extinction patterns and proxy data for climatic/environmental changes on the one hand, and the appearance of modern humans and upper

**Table 2.1** Geological and archaeological time periods, based on archaeological, dendrochronological and $^{14}$C measurements, from the dawn of human settlements in the delta of Rhine and Meuse up to and including the early Middle Ages. The periods (in years BP) are arbitrarily delineated, based on Van den Broeke (1991a). The dating of Pleistocene eras, as well as the estimates of the average air temperature in July are based on assumptions

| Geological period | Temperature average July (°C) | Archaeological period |
|---|---|---|
| Holocene | | |
| | | Early Middle Ages<br>1,600–1,200 |
| | | Roman time<br>2,015–1,600 |
| Sub-Atlanticum<br>3,000–now | <20 | Iron Age<br>2,800–2,015 |
| Sub-boreal<br>5,000–3,000 | <20 | Bronze Age<br>4,000–2,800 |
| Atlanticum<br>7,500–5,000 | <20 | New Stone Age<br>7,300–4,000 |
| Boreal<br>9,000–7,500 | 15–<20 | Mid Stone Age<br>10,800–7,300 |
| Pre-boreal<br>12,000–9,000 | 10–15 | |
| Pleistocene | | |
| Weichselien<br>120,000–12,000 | End 0–5 | Old Stone Age<br>$>10^6$–10,800 |
| Eemien<br>140,000–120,000 | 20 | |
| Saalien<br>250,000–140,000 | End 0–5 | |

palaeolithic artefacts on the other. Climate change is now believed to be responsible for the extinction of a number of large mammals, and not, as older hypotheses postulated, extermination by hunting humans (Guthrie, 2006). As a result of the sudden increase in temperature at the end of the Weichselien the sea level rose quickly, 1–2 m per century, which led to the deposition of marine clayey sediments on top of the Pleistocene deposits on the coastal plains of the North Sea. On the landward side of these coastal plains marshy areas originated, as a result of the rising groundwater levels, and stagnating river water. In a later stage, these areas grew to large raised bogs with peaty soils. From that time onwards, traces of human occupation in the Delta became more and more common. The arctic desert gradually changed into a tundra vegetation, followed by a forested landscape, originally dominated by birches, and later on by birch and pine forests. Roughly 10,000 years ago, during the pre-Boreal and Boreal periods, the climate change persevered, and the sea level rose to approximately 65 m below NAP (Fig. 2.2). During the Atlanticum, roughly 7,000 years ago the average temperature in July was approaching 20°C (Table 2.1), and the sea level rose to 15 m below NAP (Fig. 2.2). New species of herbs, shrubs and trees settled continuously in the Delta of Rhine and Meuse, as a result of the improvement of the climate. Pollen diagrams from prehistoric floodplain wetlands revealed that the tree species appeared in a characteristic sequence, as a consequence of their speed of migration from warmer southern areas. Hazel was the first tree to appear, followed by oak, elm, lime, ash, alder, beech and finally in the first millennium BC, hornbeam. Gradually closed forests developed, originally with pine and birch, but in the Atlanticum the mixed deciduous forest started to dominate (Van den Broeke, 1991a).

According to Brown (2002), it is tempting to try to assess the natural condition of NW European floodplains by taking a snapshot of floodplains at around 6,000 years BP which is just prior to significant catchments deforestation and any management of floodplain or river conditions. The picture from the past is one of a woodland-dominated mosaic with disturbance regimes caused by channel change, particularly avulsion, tree-throw and biotic factors. Disturbance caused by wind-throw was particularly common on floodplains because of the restricted rooting depths of the trees. The result would have been frequent fallen and partially fallen trees, all increasing organic debris loading and promoting the damming of channels by large woody debris. The importance of tree-throw was probably greater with smaller channel floodplains, whereas with larger floodplains riverbank erosion is probably the main source of woody debris. Beavers were common throughout NW Europe, and their dam-building activities would have had a profound effect on headwater streams and the secondary arms of major channels (Brown, 2002).

During the Old Stone Age and the Middle Stone Age (10,800–7,300 years BP; Table 2.1) man was a hunter and gatherer, dwelling around in the low-lying Rhine–Meuse Delta (Box 2.1). Halfway the New Stone Age (5,400 years BP) temporal settlements were established at elevated, suitable places such as open spots at the edges of the forests. Cattle and pigs were kept in stables and provided with litter from the forests where beech and oak occured. Brook valleys were overgrown with alder-brake and willows. Man created open spots in the forests by burning and cutting

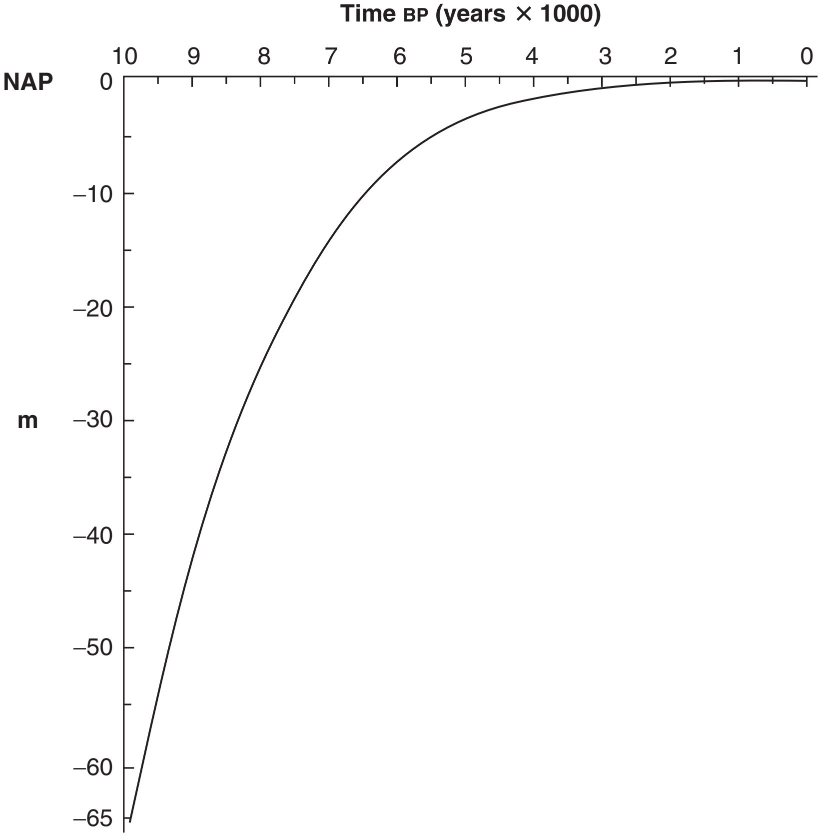

**Fig. 2.2** Sea-level rise during the Holocene after the Weichselein ice age, palaeogeographic reconstruction based on $^{14}C$ analyses in the Rhine–Meuse Delta. Horizontal axis: time in years (× 1,000) BP; vertical axis: sea-level rise in metres, relative to the approximate present mean sea level at NAP (adapted from Louwe Kooijmans, 1985 and Zagwijn, 1986). Slight oscillations, i.e. accelerated sea-level rise or retreat have not been indicated

down trees, and started temporal agricultural practice in a process of shifting cultivation. During the Bronze Age (4,000–2,800 years BP) and Iron Age (2,800 years BP – when the Romans came to the Delta, 2,015 years BP) settlements grew and permanent fields were exploited (Celtic Fields). In the meantime, roughly from 6,000 years BP onwards, sea-level rise considerably slowed down, and at the start of the Roman period the mean sea level was only a few metres below NAP (Fig. 2.2; for recent effects of sea-level rise versus subsidence of the land, see Fig. 2.1d and Chapter 3). There was a growing need for arable land and firewood, and consequently deforestation increased quickly. Written sources from that period on landscape and nature do not exist. The first descriptions of our country are known from Roman sources (During and Schreurs, 1995).

**Box 2.1** A hunting camp in the reed marsh at bergschenhook (Fig. 2.3)

In a deep polder near Bergschenhoek, just north of Rotterdam (Fig. 2.10), a canoe-pond was dug in 1976, as part of an amenity project. The bottom of the pond was situated at 8 m – NAP. The dragline stuck some artefacts, and fortunately, the work was stopped. Closer examination by archaeologists revealed numerous fish-scales and fish-bones, bones of birds, wooden debris and remarkably well-preserved remnants of fish-traps. A reconstruction of the site points to a temporary hunting camp, dated back to 6,300 years BP, situated in a reed marsh with firm peaty areas with alder trees. Small farmers presumably living on an elevated river-dune some distance away, came here winter after winter to hunt migratory waterfowl and to set fish-traps. The main purpose of the dwellers was to hunt waterfowl; they used large bows of yew-wood and ash-wood arrows. In the camping place a large variety of bird-bones have been identified: tundra swan, goosander, widgeon, mallard, teal, great bittern, tufted duck and common golden-eye. In their fish-traps the hunters mainly caught eel, but also bream and roach. Pike was caught with a fish-spear. The fish-traps were made of twigs of red cornel, held together with plated ropes of mat-rush. Based on these findings, Bob Brobbel made an artist impression of this prehistoric family (Fig. 2.3 borrowed from Louwe Kooijmans, 1985).

### 2.2.2 *Closed Forest or Park Landscape*

Floodplain deforestation in NW Europe began on a limited scale in the New Stone Age 6,000–5,300 years BP, but the almost complete deforestation of floodplains, where this occurred, did not take place until the early to middle Iron Age around 2,700–2,100 years BP. There were, therefore, at least 2,500 years when floodplains were partially deforested and there is increasing evidence that at least in the early stages this might have taken the form of floodplain parkland. For example, the finding of a variety of Coleoptera from a palaeochannel in the Culm valley, SW England, indicate both cleared and woodland conditions *ca.* 3,000 years BP with trees, dead wood and grazing. These data suggests that these river woodlands were ecologically complex with up to half of all timber dead or long-lived, a similar structure to pasture woodland comprising a greater variety of species than has been assumed (Brown, 2002).

Is it possible to reconstruct the original river and floodplain landscape of the Rhine–Meuse Delta, and how has man changed this landscape by the introduction and development of agricultural practice? Direct evidence for an answer to this question is unknown to me, and only indirect interpretation of facts is perhaps leading

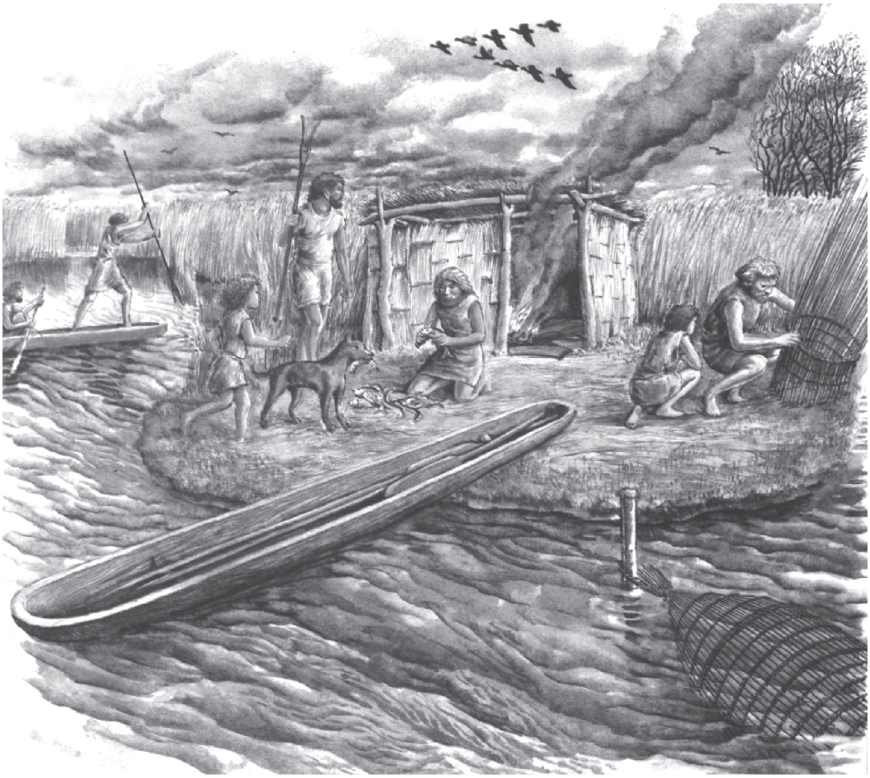

**Fig. 2.3** Artist impression of a reconstructed hunting camp in the reed marsh near Bergschenhoek, 6,300 years BP (Louwe Kooijmans, 1985)

us to some clues. The findings of fossil pollen are one of those facts. Geo-historic research in natural river levees of fluvial areas along the Delta Rhine revealed pollen diagrams from cores dating back to around 3,500–2,700 years BP. The profiles showed an almost closed hardwood floodplain forest with small open spots in the vegetation, either caused by minor human activities or by natural grazing. Natural river levees carried a forest with a high species diversity including *Fagus sylvatica*, *Corylus avellana*, *Tilia cordata*, *Betula* sp., *Acer* sp., *Carpinus betulus*, *Fraxinus excelsior* and *Pinus sylvestris* (De Klerk et al., 1997a). Palynological studies of deposits in a residual channel and flood basin of a former Rhine tributary revealed reed marshes similar to the present-day vegetation dominated by *Phragmites australis* and *Typha angustifolia*. After river activity ceased, the flood basin changed into an eutrophic mire with a vegetation development largely resembling the patterns of present-day processes of growing solid by peat formation, a succession of reed and sedge swamps, and eventually alder and willow coppice. The duration of these terrestrialisation phases, encompassing 1,000 years, points to a continuous rise of average water levels (De Klerk et al., 1997b).

The classic interpretation of analysed pollen diagrams shows that an almost closed natural forest was dominating the river landscape. Vera's (1997, 2002) theory is that the prehistoric landscape in the Delta was not a closed forest, but an open parkland, with grassland, bushes, brushwood and patches of trees. The succession in this landscape was ruled by the grazing and trampling of large wild-hoofed animals, like the aurochs, wisent, wild horse, red deer, roe, elk and wild boar. Vera (1997) suggested that the grasslands in this park landscape contained all species of animals and plants that we know nowadays from the semi-natural grasslands. Their distribution in Central and Western Europe was not ruled by the actions of man in nature, but by the presence of large grazing ungulates. In order to study how man has changed nature by the introduction of pre-industrial agriculture, Vera (1997) postulated that the existence of a park-like landscape is the starting point. This is in contrast with the traditional theory, as defended by Van der Maarel (2002) and many others, stating that the existence of closed forests is the prehistoric starting point, and that application of pre-industrial agricultural practices is a prerequisite for the continued existence of many plant and animal species bound to the semi-natural (agricultural) landscape.

To my opinion the truth may be somewhere in between both theories. But neither the park-like landscape with large, natural grazers, nor the closed, primeval forest do exist anymore, which implies that both images are based on theories. Both the 'closed forest' theory as well as the 'park landscape' theory have realistic features in the context of the development of river floodplain landscapes. Brown (2002) is inclined to sustain the floodplain parkland theory. Hydrologic and geomorphologic dynamics in natural river floodplains prevent the growth of dense, closed forests. Occasional floods and concomitant erosion processes uproot patches of trees, and the deposition of sand and silt rejuvenates the vegetation, and prevents the succession of wild shoots of trees. Thousands of years ago, when the ungulates could still freely move between the forests and the river floodplains, it is most likely that they frequently grazed the lush river-meadows (cf. Chapters 3 and 19). Nowadays, roe deer are still grazing and hiding in floodplain wetlands. Managed populations of red deer and wild boar are kept nowadays in fenced forest reserves on the higher sandy grounds, at a far distance from the main rivers. Red deer are by nature forest dwellers, however, they are highly adaptive. Their selection of habitat is mostly linked to the availability of food, but other factors such as weather can also influence movement. Red will retreat to higher ground or deeper woodland during the height of summer, returning to lower or more open ground when food becomes scarce and the weather inclement. Red deer are grazers by preference, however good grass is not always available; therefore, many other food sources are taken advantage of. These include rough grasses (*Molinia caerulea*) and rushes (*Scirpus cespitosus*) as well as heather and dwarf shrubs. Heather is of particular dietary importance during the dormant winter months, especially when snow covers the ground (www.deer-uk.com). Wild boar live not only in broadleaved woodland, but also in reed marshes, and alder-brake. The animals are omnivores, rooting in litter for nuts, roots, fungi, small animals and carrion (cf. Chapter 19).

### *2.2.3 From Hunters to Settlers*

As said before, during the New Stone Age a gradual change from hunters to settlers took place in river land. An increasing number of excavations reveal that the entire basins of Rhine and Meuse were sparsely populated in pre-Roman times. Natural levees along rivers, river dunes and sandy outcrops were the most suitable places to build farms. Grinded stone (and later on bronze) chopping utensils were used for the felling of trees and primitive ploughs for farming the fields. A large number of small, self-sufficient farming communities developed, and the sandy and loamy soil of their elevated dwelling places was cultivated to grow agricultural produce and to keep cattle (Table 2.2). The proximity of open water provided the farmers drinking water for man and cattle, and the floodplains were used to graze cows. Forests were still plentifully available, and the oak mast was good feed for the pigs. Pollen grain analyses at various places showed deciduous forest on the levees, with oak, elm, lime and alder (Louwe Kooijmans, 1985; Teunissen, 1990).

**Table 2.2** Scheme of introduction of domestic animals and agricultural crops. (Adapted from Bloemers et al., 1981)

| Biota | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| **Mammals** | | | | | | | |
| Dog | | O | O | O | O | O | O |
| Goat | I | I | I | O | O | O | O |
| Sheep | I | I | I | O | O | O | O |
| Pig | | I | I | O | O | O | O |
| Cow | | I | I | O | O | O | O |
| Horse | | | | I | O | O | O |
| Cat | | | | | I | O | O |
| Rabbit | | | | | | I | O |
| **Poultry** | | | | | | | |
| Chicken | | | I | I | I | O | O |
| Goose | | | | | I | O | O |
| **Corn** | | | | | | | |
| Wheat | I | I | I | O | O | O | O |
| Spelt | | | | I | I | O | |
| Barley | | I | I | I | O | O | O |
| Millet | | | | | I | O | O |
| Rye | | | | | I | O | O |
| Oats | | | | | I | O | O |
| **Pulse & oilseeds** | | | | | | | |
| Pea | | I | I | O | O | O | O |
| Lentil | | I | O | O | | | |
| Linseed | | | I | O | O | O | O |
| Gold of pleasue | | | | | I | O | O |
| Poppy seed | | | | | | O | O |
| Pigeon-bean | | | | | I | I | O |

I = The first indication for domestication; O = domesticated occurrence in NW Europe. A = late Old Stone Age; B = Mid Stone Age; C = New Stone Age; D = Bronze Age; E = Iron Age; F = Roman time; G = early Middle Ages.

Most animals and plants originally came from the Middle East.

Extensive archaeological research revealed tens of settlements in the Delta of Rhine and Meuse, particularly on levees along tidal creeks or on elevated bog-peat sites. Well-preserved remnants of farms have been located, dating back to the Bronze Age and the Iron Age, sometimes rather voluminous (20 × 6 m), built around a skeleton of oak and ash beams, with living space and stables for cattle and pigs, separated by wattle-work, made of twigs and branches of ash, willow and birch. Bronze and iron utensils, pieces of pottery, beaten flint and carved bones and horns of animals were found in and around the farms. Arable land was scarce. Pollen diagrams from the late Stone Age reveal that the forests covering the levees and the alder-brake in the lower basins, were rather dense, showing hardly any signs of agricultural practice. Lots of charred grains of wheat, barley, millet, oats and linseed were found, however (Table 2.2). This points perhaps to a kind of barter trade where grain was exchanged for wildfowl. Hunting was important. A large variety of mammals were chased: red deer, roe, wild boar, and also fur animals like beaver, otter, polecat and pine-martin. An occasional brown bear also belonged to their hunting trophies (Bloemers et al., 1981; Louwe Kooijmans, 1985; Carmiggelt, 2001).

The bronze utensils that were used in the Delta during the Bronze Age, certainly must have been imported from elsewhere. Bronze is an alloy of copper and tin, and the closest copper and tin mines where exploited in Central Europe and in some places in England. Remarkably few traces of iron reworking during the Iron Age were found in the Delta, although bog ore was rather abundantly available in brook valleys and moors. Wood to produce charcoal was also available in large amounts; charcoal was needed to heat the ferruginous earth in the iron foundries up to 1,500°C, to produce cast iron. It is suggested that the scarcity of iron utensils found in prehistoric settlements is mainly due to their high affinity for corrosion. The production of iron has had a considerable impact on the environment. To keep the iron foundries at the desired temperature took an enormous amount of wood, and progressive deforestation in the Netherlands already started in the Iron Age (Bloemers and Van Dorp, 1991). Van Zon (2002) calculated that 6 t of iron ore were needed for the preparation of 1 t of ordinary iron. The smelting-furnaces were fed with charcoal, and hence for processing 1 t of iron, 4 ha of forest had to be cleared.

The Delta was poor in metal resources, and barter trade was common use in the Iron Age and during the Roman epoch. The Greek geographer Strabo, who lived in Rome (as quoted in Bloemers and Van Dorp, 1991), mentioned a considerable number of products that might have been used as media of exchange for copper, tin and iron, such as cattle, fells, leather, grain, honey, bee-wax, salted fish, meat and cheese. A much desired trade-in was sea salt from the North Sea coast of the Rhine–Meuse Delta. Sea salt was used as preservative for many purposes, such as the salting of meat and dairy produce. Brine was also used during the preparation of leather from animal fells. Evidence from remnants of salt-works found in the coastal zone suggests that there was a lively trade in sea salt during the Iron Age and early Roman times. Salt was transported in specific earthenware vessels that have been found more than 250 km land inwards, mainly in and around the Meuse basin (Van den Broeke, 1986).

### *2.2.4 Prehistoric Water Management*

The first prehistoric 'water management' measures documented, date back to the Bronze Age (archaeological findings in Bovenkarspel, NW Delta; Fig. 2.10). Colonists built their farms on elevated sandy levees, surrounded by reed marshes and alder-brake, and beyond the influence of tidal movements. Excavations showed that a system of trenches bordered their arable fields. In the mid-Bronze Age (3,500 years BP) these trenches were dug in an attempt to drain the soil, and later on, when the farmers repeated their measures to scoop out the ditches, the mud was used to elevate the sites where they had built their farms. The struggle against the continuous threat of flooding was given up finally, and the dwellers left the place (Van den Broeke, 1991b).

The construction of dykes is far much older than suggested in classic textbooks (e.g. Cools, 1948; Bloemers and Van Dorp, 1991) which dated the building of the first dykes in the 7th or 8th century. Recently, in 1999, a 40 m stretch of an old dyke was excavated in Peins (Fig. 2.10), in a small estuary in the NW Delta, dating back to 100–200 BC (www.rug.nl/archief1999; J.G.A. Bazelmans). This dyke is now coined as the oldest dyke in the Netherlands, built before the Romans came. It was already known that the marine clay deposits in the NW Delta were populated from 2,700 years BP onwards. Hundreds of artificially built dwelling mounds have been found spread over an area of hundreds of square kilometres (Fig. 2.9). The continuous threat of floods forced the farmers to heighten the mounds, for which they used household garbage and soil from the surrounding marshes. The fertile grasslands of the salt- and brackish marshes were well-suited for the grazing of cattle. Until now, it was assumed that the farmers imported their corn and other arable products from higher grounds, but the finding of the dyke at Peins suggests that the farmers must have been self-supporting. The reconstruction of Bazelmans shows that the farmers enclosed areas of the salt marshes that were accreted to above mean high water, with a small dyke. The reclaimed land was than cultivated and transformed into arable land. The farmers have built the dyke during the summer months out of turfs of grass, 1.25 m high, initially 2 m wide, and made wider year after year. The ring-dyke obviously could stand mild winter storms, allowing the farmers to use their fields from spring to autumn.

## 2.3 The Roman Period

### *2.3.1 River landscape in the early Roman period*

How may the catchments of Rhine and Meuse be characterised when the Romans invaded the northerly countries, around the beginning of our era? Written documents were not available, of course, and the picture that may be reconstructed is mere speculation: freely braiding rivers, bordered by dense forests (or more open forest and partly deforested spots?). Scattered human settlements were to be found on elevated sandy places, and agricultural practice was getting slowly under way. The vast area of roughly 20,000 $km^2$ was bordered by sandy beach barriers, marshes and moorlands intersected by river mouths in the west, ice-pushed sand and pebble ridges in the north and elevated Pleistocene sand in the south and in the east. Palaeographic reconstructions of the Delta during Roman times (Fig. 2.4) reveal an almost closed girdle of barrier dunes along the coast of the North Sea. This barrier complex had rows of sandy dunes and beach plains parallel to the seacoast, sealing off the marshy hinterland from the sea. The dune ridges were intersected at a few places by rivers debouching into the North Sea, in the far south the river *Scaldis* (Scheldt) and more northerly the three outlets of Rhine and Meuse, the estuaries, *Helenium*, in the southwest, the main branch of the Rhine, *Rhenus* (nowadays named Nederrijn, Kromme Rijn and Oude Rijn), at Katwijk (Fig. 2.10) in the north, and a branch in the north, called *Flevum*. Meandering side channels filled the area between the Rhine–Meuse Basin proper and the estuaries in the south with river water (Fig. 2.4).

In the course of centuries the area behind the barrier dunes, fed by the freely braiding and meandering rivers, gradually changed into a freshwater marshland intersected by numerous small rivers and creeks. Thousands of square kilometres grew solid by peat formation, and large bog-peat areas rose several metres above sea level. This period of peat formation continued until AD 350. Then the climatic conditions changed rather drastically. A palaeographic reconstruction of the western part of the Delta around AD 100, based on pollen diagrams (Fig. 2.5), shows that the peat area was divided by rivers and smaller streams into separated cushions of peat. The raised bog-peat areas were almost inaccessible, surrounded by the low-lying peat bog and fens. Fens (neutral or calcareous peatland) had rivers flowing into them from the upland. Fen rivers, in their natural state, had broad, definite channels meandering through both peat and silt. The channels were lined with silt deposited by the rivers; they had natural embankments of silt, called levees, which confined the rivers during all but exceptional floods. The highest parts of the fens were overgrown with dense marshy woodland, comprising alder, birch and willow species. The lower fens and (acid) peat bogs had a vegetation of trees, marsh plants, sedges and reed. The most elevated parts, the proper raised bog areas, drained via little streams into the larger streams. The vegetation consisted of bog-moss, *Sphagnum* species, and at the highest spots heath moor (Louwe Kooijmans, 1985, as sketched by Bitter, 1991a).

### *2.3.2 How the Romans Saw the Delta*

The annexation of Northwestern Europe by the Roman Empire meant the confrontation of local tribal communities with a complex society, that developed around the Mediterranean Sea, where the use of writing played a vital role. The Roman occupation accelerated and dominated the developments in the region until the early 5th century, including the cultivation and exploitation of the barely touched river landscape.

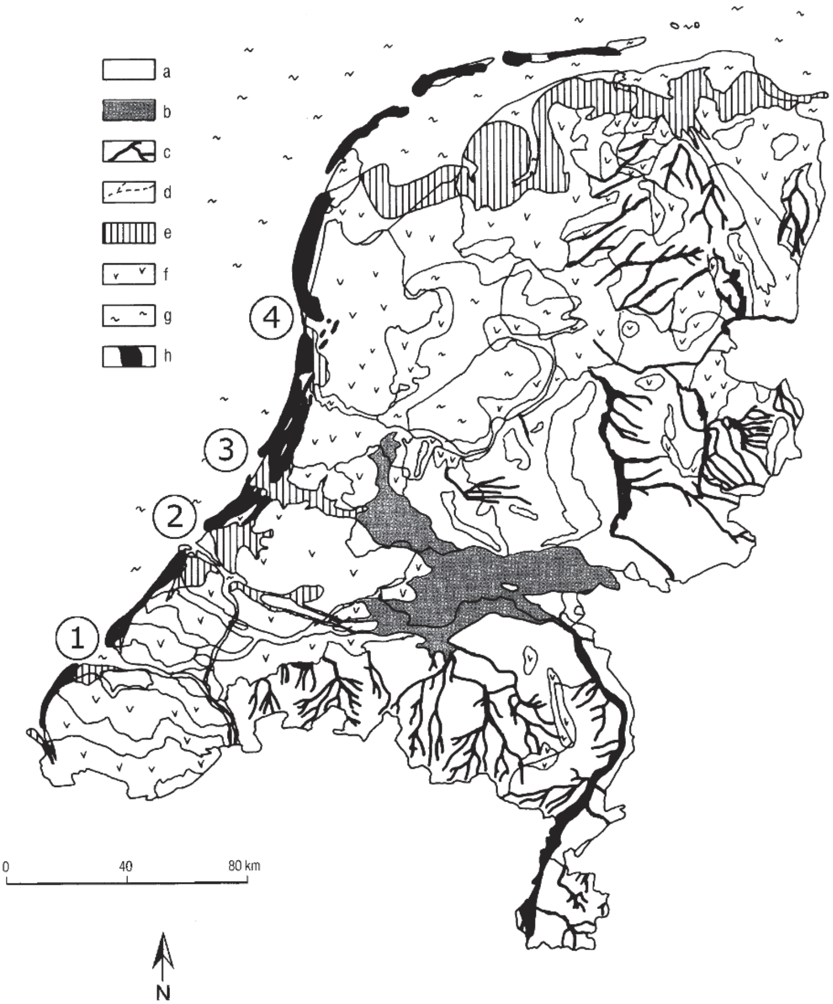

**Fig. 2.4** Palaeographic reconstruction of the lower catchments of Rhine and Meuse around 1900 years BP, projected on a present map of the Netherlands (Van Es et al., 1988, in Van den Broeke,1991a); (a) boulder clay, cover-sand and loess deposits pushed by ice (Saalien ice age) and blown by strong winds (Weichselien ice age); (b) river deposits; (c) river and brook valleys; (d) possible watercourse; (e) marine deposits; (f) peat formations; (g) water and tidal flats; (h) coastal dunes; river dunes. Main river outlets, intersections of the barrier dunes: 1 = *Scaldis*; 2 = *Helenium*; 3 = *Rhenus*; 4 = *Flevum*

When the Romans came to the Rhine delta, in 15 BC, this meant the start of historical records. The written sources we know, however, are scanty and often only indirectly related to life in the Rhine–Meuse Delta, and these certainly contained no objective information about the landscape they lived in. That is the reason why the

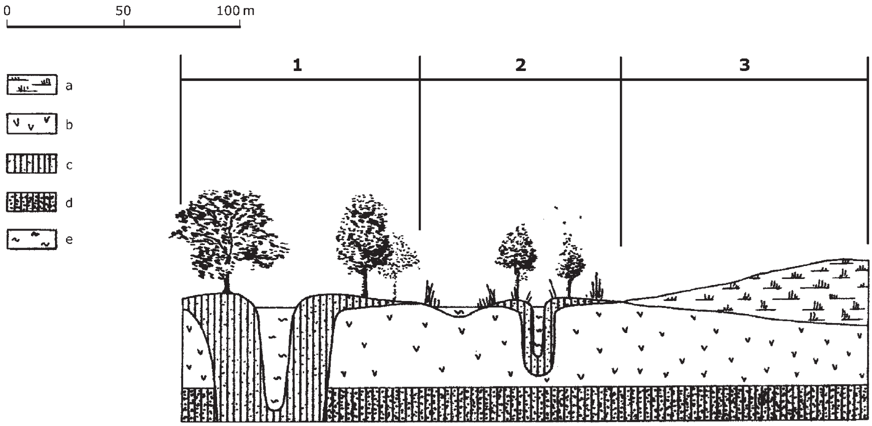

**Fig. 2.5** Schematic section of a pristine peat formation, as indicated in Figs. 2.4 and 2.8 behind the barrier dunes, reconstructed on the basis of pollen diagrams by Louwe Kooijmans (1985), in Bitter (1991a). From left to right (1) the river with elevated sandy-clayish levees, overgrown with willow, alder, birch, elm and ash; (2) lower fens and peat moor with reed marsh; peat moor intersected by a river creek and bordered by levees, overgrown with sedges, reed, alder and willow; (3) raised bog peat with bog moss and at the highest places heath moor. (a) Raised bog peat built up by bog mosses; (b) peat bog of reed and sedges; (c) clay deposits; (d) sand and clay; (e) water

Roman period is still called proto-history, and not history (Bloemers and Van Dorp, 1991).

There is some evidence seen through the eyes of educated Romans, pointing to the strategic significance of the Large Rivers (Hettema, 1938). Caius Plinius the Elder (AD 23–79) who spent some time in military service under governor Corbulo in Lower Germania, described in his *Historia Naturalis* the state of the country as follows: “The ocean plunges twice a day with enormous waves over the land, and observing this eternal struggle of nature, one wonders whether this piece of land belongs to the sea or to the dry land. Miserable people live on hills, or better, on living places elevated by man” (Bechert, 1983). Roman observations repeatedly notice ‘miserable circumstances in life’, people living on artificial dwelling mounds, under very primitive conditions, twice a day threatened by flooding. The Roman historian Cornelius Tacitus (AD 55–120) described several military campaigns in the Rhine–Meuse Delta in his *Annales*, and in his *Germania* (*De origine et situ Germanorum*) published in AD 98, he gave an ethnographic survey of the populations living north of the Rhine and the Danube, however, not based on his own observations. Other authors were the geographers Strabo and Ptolemaeus (*Geographica*) and the Roman general Julius Ceasar who wrote the *Commentarii de Bello Gallico*, a report written in AD 51 about his campaigns. Julius Ceasar was mainly responsible for the incorporation of NW Europe into the Roman Empire (During and Schreurs, 1995).

### 2.3.3 The Border of Germania Inferior

Until the invasion of the Romans small, rural Celtic–Germanic settlements dominated in the Delta. Shortly after their entry the Romans introduced their system of governance south of the Rhine, just as they did in other parts of their empire. Urban settlements became the centres of government, religion and economy in the region, sustained by non-agrarian activities such as trades and services. The larger urban centres, the *municipa*, gained municipal rights, from where the province, the *civitas*, was ruled, and consequently the countryside was made fully inferior to the towns, concerning their administration and economy. The town of Köln (now in Germany) situated on the river Rhine (Fig. 2.6) became the capital of the province *Germania Inferior*; it was also the largest town, counting approximately 50,000 inhabitants. The Romans built a bridge, crossing the Rhine of 400 m long and 10 m wide, based on 19 stone pillars (www.livius.org).

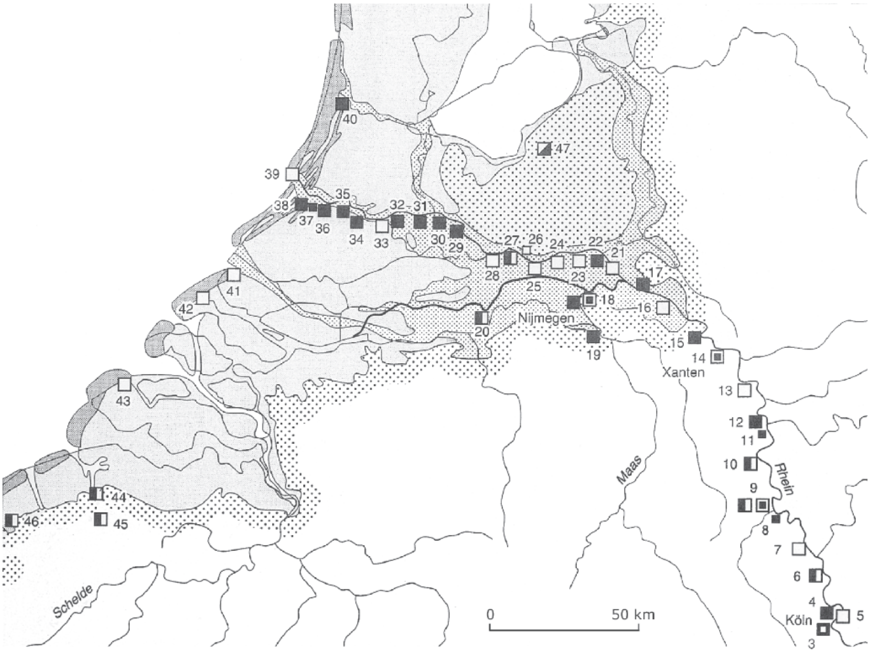

**Fig. 2.6** Part of the *limes*, the northern border of *Germania Inferior*, the largest linear archaeological structure in Europe, along the southern border of the river Rhine. *Castra*: Köln (3, 4, 5), Xanten (14) and Nijmegen (18). *Castella* (black squares), possible *castella* (white squares) and *castella* built after 69 (half black, half white squares); *castella* mentioned in the text: Loowaard (21); Driel (23); Vechten (29); Woerden (32); Zwammerdam (34); Leiden (36); Katwijk (39) (Derived from Bechert and Willems, 1995)

Nijmegen on the river Waal (Rhine) (Figs. 2.6 and 2.10) grew into a capital town, gaining market rights in the 2nd century, and later on municipal rights (*Municipium Batavorum Noviomagus*). In the 2nd century AD, Nijmegen counted approximately 5,000–6,000 inhabitants. Smaller urban settlements, the *vici*, gained no municipal rights. From the year AD 47 onwards the river Rhine, *Rhenus*, shaped by the (presently called) Nederrijn, Kromme Rijn and Oude Rijn (Figs. 2.6 and 2.10), functioned as the most northerly borderline of the Roman province *Germania Inferior*, Lower Germania. For over 200 years the Rhine-border appeared to be a stable northern border of the Roman Empire. The Romans built large military fortifications, *castra*, and smaller army camps housing less than 500 soldiers, *castella,* along the southern bank of the river Rhine (Fig. 2.6). The *castra* were in fact large army camps, walled legionary settlements with a hierarchical order of buildings and functions. They comprised, next to wooden sheds and houses, a considerable number of stone houses, built of bricks or natural (lime)stone, and the roofs were tiled (Colenbrander et al., 2005). The rural settlements had only small wooden farms and houses. Along the Dutch part of the river Rhine alone, probably at least 18 *castella*, were built in order to defend the *limes*. Along the Rhine (presently in Germany) dozens of other *castella* were founded (Fig. 2.6). The *castella* and the *vici* along the Rhine had a population between 400 and 900 inhabitants each, and the population in the rural settlements remained less than 100. In the area of the Large Rivers, the eastern part of the Delta alone, some 300 small settlements have been located based on archaeological findings (Fig. 2.7). The entire population of *Germania Inferior* was estimated at 0.5 million inhabitants (Bloemers, 1991; Bitter, 1991a). For reasons of comparison: in the same area now live approximately 40 million people.

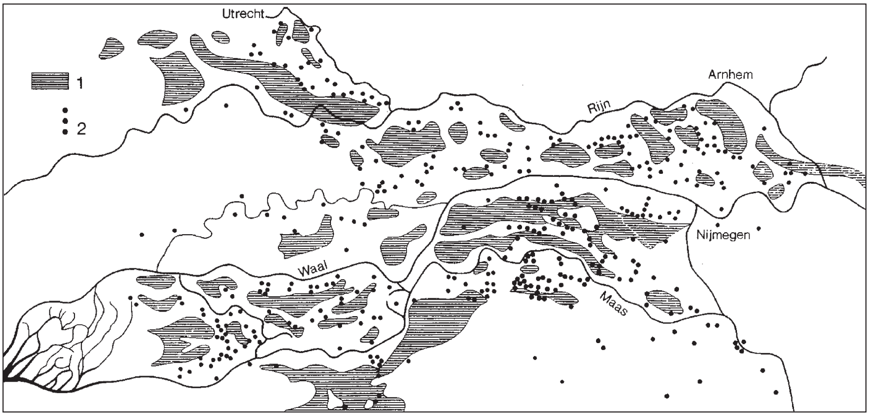

**Fig. 2.7** Human settlements in the area of the Large Rivers, the eastern part of the Rhine and Meuse basins, in the 2nd and 3rd century AD. 1 = low-lying flood basins; 2 = settlements on natural levees and elevated sandy channel belts along river courses (Derived from Modderman [1955] in Van Es [1972])

### 2.3.4 The Roman Waterworks

During the early development of the market economy in the Delta the Romans created an extensive new infrastructure, a system of waterways and roads, harbours and storage yards. Existing rivers and watercourses were adapted so that trade ships could sail from one harbour to the other. Rowing, poling and towing of boats was also common practice. The streets in the larger towns were paved with stones or metalled, whereas the country roads were unimproved. The network was originally built for the quick transport and supply of army divisions, but soon the roads were also used for economic purposes. The course of the main roads may be reconstructed, although not on scale, from the *Tabula Peutingeriana*, a medieval copy of a Roman roadmap, from the *Itinerarium Antonini*, a Roman travel guide. The geographic map is depicting most of the *municipa*, *civi* and *castella* (*castra*) from the Rhine in Germany to Katwijk (Fig. 2.6) on the coast of the North Sea (Bechert and Willems, 1995). The main transport routes for goods were the waterways (reconstructed from the distribution of remnants of imported pottery). Natural watercourses were regulated to make them navigable. Around AD 47 the *fossa Corbulensis* was constructed, a canal presumably coinciding with the present Vliet, connecting the *Helenium*, the (Roman) estuary of Meuse and Waal (Fig. 2.4) with the (present) river Oude Rijn in Leiden (Fig. 2.6). Close to the *castella* of Zwammerdam and Woerden on the Oude Rijn (Fig. 2.6) a number of Roman vessels were excavated and among them several flat-bottomed vessels of more than 20 m long, most likely used for bulk transport of grain, wine or building material. Presumably, Gallo–Roman earthenware from southern origin, that is found spread over the Delta, was transported in these boats as ballast-cargo (De Weerd, 1988).

The arrival of the Romans marked the start of a period of increasing opportunities to make better use of the Delta, particularly for military purposes. The Roman historian Tacitus (as quoted in Harbers and Mulder, 1981) mentioned ‘the waterworks of Drusus’, the building of a dam and the digging of a canal under command of the Roman general Drusus, between 12 and 9 BC. The dam was constructed probably at the most easterly bifurcation point of the river Rhine in the Netherlands, east of Nijmegen (Fig. 2.6). The exact location of the dam, however, is still under discussion (Van Es et al., 1988). If the dam really was constructed, then this was probably the first large-scale hydraulic engineering work carried out in the Rhine–Meuse Delta. The dam was intended to shift the distribution of a large part of the water from the river Waal to the river Nederrijn (Fig. 2.10) in order to create a more or less natural line of defence against Germanic attacks from the east, and to enhance the navigability of the trade route to the north (present IJssel; Fig. 2.10). The Rhine and IJssel basins had slowly silted up and it is likely that during extremely dry periods the rivers ran dry at shallow places. Connected to the building of the dam, it is believed that Drusus was responsible for digging one or two (or perhaps more) artificial channels (*fossae Drusianae)* connecting the Rhine with the river IJssel, intended to be used as waterways for the transport of troops and goods to the north. Based on the reconstruction of Harbers and Mulder (1981), the most likely position of the channel was east of Driel (Fig. 2.6) where the distance between Rhine and IJssel was the shortest. The cutting of the narrow natural levees was presumably not an extremely difficult challenge for the Romans. The exact position of the *fossae* cannot be reconstructed anymore because the present course of the Nederrijn has wiped out most traces. There are varying opinions in the literature about the position of the 'canals', best be interpreted as waterway improvements of existing, natural river channels rather than as completely artificial channels.

A possible location of the *fossa Drusiana* is the upper course of the IJssel, as a connection between the Rhine at Loowaard and the Oude IJssel (Figs. 2.6 and 2.10; Ramaer, 1928), a theory sustained by Teunissen (1980) based on pollen diagrams. Hettema (1938) coined the river Linge, between (what is now called) the Pannerdensch Kanaal and Tiel (Fig. 2.10) as a possible canal of Drusus. This stretch of the Linge has indeed been excavated, but only in the 13th or 14th century, presumably for the drainage of the cultivated low-lying river basins in the area between Nederrijn and Waal (Harbers and Mulder, 1985). A fourth, but improbable location for the *fossa* was the river Vecht (Figs. 2.6 and 2.10; Volgraff, 1938), but this location is more than 60 km west of the Drusus dam, where the favourable effects of the increased Rhine discharge has long been lifted.

### 2.3.5 Exploitation of the River and Floodplains

At a strategic place on an elevated ice-pushed ridge the Romans founded Nijmegen (Fig. 2.6), a major *castrum* along the Rhine, gradually growing into an important city. Nijmegen, founded in AD 5, is in fact the oldest city in the Netherlands (2,000 years celebration in 2005). For the Romans everything outside (*foris*) the town and its civilisation was *forestis*, the wasteland and the forests where the barbarians lived. According to Tacitus, in his book *Germania* (as cited by Bouwer (2003), 'these creatures were belligerent, went out shooting, and wasted a lot of time over vanity, sleeping and eating'. For the Romans, the provinces of *Germania Inferior* were conquered countries. Although little is known about the Roman economy in the outer areas of the empire, it is obvious that agricultural practice was rather important. The taxes from the provinces (i.e. all the conquered areas beyond Rome) was an indispensable source of income for the Roman emperors to pay their gigantic armies (Bouwer, 2003).

The Romans cultivated their territories more intensive than any settler had done before. The ice-pushed ridge at Nijmegen and the river floodplains nearby were most attractive for permanent occupation: the river proper was used for trade and military purposes, on the fertile floodplains cattle could graze, alder and willow coppice provided wood for fuel and utensils, natural sources higher up in the sandy hills provided drinking water and the dense forests had several important economic functions. The trees were used for timber, and for fuel, hunters were active in the forests, and fertile areas were cultivated for food production. Analyses of pollen profiles at early Roman settlements near Nijmegen indicate dense oak forests, where beech, holly and birch covered large areas, with hazel and maple along the edges. Continued occupation shows that the relative number of tree pollen quickly decreased, while the share of corn, grasses and weeds increased. Notwithstanding the fact that the area was still attractive for settlers after the Romans left around AD 400, the number of tree pollen strongly increased again (Teunissen, 1988, 1990).

The Romans founded farms of considerable size, the *villae rusticae*, large complexes comprising a stone main building, several outbuildings and arable fields, surrounded by a ditch or a fence. The farmers cultivated a variety of products, mainly for the urban and military centres. Several crafts were experienced, as witnessed by traces of smoke-houses, smithies, potteries and weaving-looms. The Romans also introduced the first larger-scale industrial activities in the Rhine Delta. Large piles of wood were used in the brick-kilns, tile-furnaces and potteries, using loam and clay from the floodplains (Bouwer, 2003).

Between 1892 and 1947 one of the largest *villae* in the country was excavated. It concerns the *villa* complex near Voerendaal, close to the river Geul, a small tributary of the river Meuse (Figs. 2.6 and 2.10), which was built in the second half of the 1st century on the site of an older, native village. In the course of the 2nd century, two wings were added to the main building, which was then tens of metres wide. The inhabitants lived luxuriously: there was a bathhouse, several rooms were heated and the rooms of the servants were fairly comfortable as well. Several walls were decorated with Italian-style fresco's. Of course, there were storerooms, granaries, gardens, barns and stables. A small wall separated the terrain (180 × 215 m) from the surrounding corn fields (www.livius.org/ga-gh/germania/inferior07.html).

But the Romans not only founded *castra* and *villae*, but also smaller settlements were erected. Numerous archaeological findings from the Roman period indicate a relatively dense pattern of settlements that were almost, without any exception, located on natural levees and sandy channel belts along channels and meanders of the Large Rivers (Fig. 2.7). It is believed that the vast raised bogs in the west between the outlet of the Rhine in the north (*Rhenum*, Oude Rijn) and the southern estuarine outlet *Helenium* formed a rather deserted inaccessible area. Archaeological evidence, however, is far more difficult to gain due to the much thicker layers of sediment and peat than in other parts of the Delta.

### 2.3.6 Growing Demand for Food: Cultivation of the Raised Bog

During the first centuries of the Roman occupation the agricultural practice of the farmers, north and east of the borderline, did only change slowly. Extensive arable farming on the Celtic fields – the shifting cultivation where some fields were cultivated, while other fields were abandoned – had gradually changed into 'infield–outfield' agriculture. Better ploughs made better tillage possible. The farms were surrounded by intensively used small pastures and gardens, around the settlement were the arable fields and more remote the extensively used hay fields and meadows. The entire settlement was surrounded by forests or wasteland where firewood, construction wood and fruits were collected, and were cattle grazed. Our knowledge of the cultivated crops is mainly based on findings of charred and un-charred seeds and fruits, while pollen analyses gave additional information on agricultural practice. The main crops were barley and beans, and to a lesser extent millet and wheat. Besides that, vegetables, herbs, flax and gold of pleasure were cultivated for the production of oil. In addition, strawberries, raspberries, blackberries and hazelnuts were collected in the surroundings of the settlements. Archaeological findings only show wild fruits; the growing of fruit was not practiced in the German areas, in contrast with the Roman provinces (Bloemers and Van Dorp, 1991).

During the Roman occupation, the need for the production of food increased. The interregional corn trade must have taken place on a considerable scale, because there were thousands of soldiers in the forts along the Rhine, who needed more food than *Germania Inferior* could produce. To make the production of corn possible not only on the higher fields, but also beyond the influence of the rivers, the wastelands behind the coastal dune barriers were gradually developed. This area was dominated by large cushions of bog peat, which rose several metres above sea level. Peat, which is essentially wet vegetable mould, can be reclaimed by digging parallel ditches and draining the fields. These ditches are known to have existed on the island Walcheren in the SW Delta (www.livius.org). The development of the peat moors must have resulted in fertile fields, but was not without risk. The dangers became apparent in the 4th century when during periods of progressive sea-level rise (transgression phase) the sea flooded large parts of the peatland.

In Roman times, the bog-peat area in the SW Delta was populated along both sides of the Schelde estuary and river, the entrance to the strongly Romanised Flanders (now Belgium; Fig. 2.10). Perhaps the Romans had also exploited the raised bogs at the mouth of the river Meuse. There is archaeological evidence that the building of small dams, or levees, to avoid the flooding of arable fields dates back to Roman times. De Ridder (1999, 2001) described the excavation of, what he called, 'the oldest Delta works of Western Europe', near Vlaardingen on the Meuse estuary (Fig. 2.10). There a dam was unearthed, built around AD 175, in a tidal creek to avoid the fields of being flooded. The dam was penetrated by the oldest 'sluice' or culvert ever found, dated between AD 75 and 125, on the basis of the remnants of pottery. The culvert consisted of hollow trunks of trees, with a diameter of 35 cm, penetrating the dam, and provided with a wooden recoil-valve, to prevent the rising sea to inundate the fields, but to facilitate the draining of the fields at low water. Except in Vlaardingen these early waterworks have been found at several other places in the Delta, suggesting a regional invention, instead of a Roman innovation. It is likely that the farmers already have built longer stretches of levees, but archaeological traces of these works are difficult to prove.

There are also indications that the entire bog-peat area between *Helenium*, the Meuse outlet in the south, and *Rhenus*, the Rhine outlet, was systematically exploited in the course of the 2nd century AD. Trenches have been located that could be followed over a distance of more than a kilometre. These trenches were dug mainly to drain the peat area, but they could also have been used as borders between properties. These large-scale planned cultivation patterns are suggesting interventions by the Roman government. The Romans benefited by large-scale cultivation of the bog peat. The tens of thousands of soldiers that were encamped in the Delta had to be fed, and considering the high costs of the transport of corn, it is likely that arable fields were exploited as close to the army camps as possible. These large-scale cultivations in the 2nd century remind us of the large-scale cultivations of the Dutch fens by the dukes of Holland from AD 985 onwards (De Ridder, 2001; see Chapter 3).

To feed the numerous soldiers, a constant supply of food was important. 'Puls' (a kind of porridge), common food for soldiers and many ordinary people, was based on spelt (kind of wheat) with herbs, vegetables, meat or fish (Table 2.2). The storeroom of the richer people contained corn, olive oil, preserved fruits, meat, fish sauce, salt, wine and mead. The cultivation of fruit trees started in Roman times (apples, prunes, cherries). Archaeological research has also revealed that the Romans introduced the walnut tree. The need for food of the army must have been decisive, because almost all shells have been found in and near fort and fortresses. Beets, apricots, almonds, chickpeas, medlars, pears and plums were other innovations. The stones of peaches have also been found, in military settlements, of course, but it is possible that these fruits were imported from the south, because peaches can easily be transported. The Romans also introduced new herbs: dill, coriander, mint, celery, fennel and rue.

Findings of bones show that cows, sheep, goats, pigs and horses were used for many purposes (Table 2.2). Cattle provided pulling power to farm the arable land; all animals provided food and resources like fur, fells, wool, horn, tendons and dung. During the Roman age, several new animals arrived in the Rhine–Meuse Delta. Peasants learned to use mules as draught animals, to employ cats to catch mice and to enjoy the beauty of peacocks. And finally, gourmets started to appreciate the Guinea fowl, Roman snails and fallow deer (www.livius.org).

### 2.3.7 The Collapse of the Roman Empire

The Roman Empire collapsed early in the 5th century. There is still a lot of speculation about the causes of this drastic change. When the Romans occupied *Germania Inferior*, they encountered a number of Celtic–German tribes that were incorporated in the empire. Some tribes were absorbed in the new system and were rather loyal to the rulers; others furiously reacted from the beginning. One theory is that the Romans strived to stabilise the border areas between the German tribes in the north and east and their fortified *limes*. This stabilisation was reached by diplomatic contacts, resulting in agreements and client-relations, as described by Tacitus (Bloemers and Van Dorp, 1991). As material expression of those alliances, goods were exchanged between the Romans and the German tribes. In the beginning, Roman prestige goods like glass, pottery and jewels were exchanged, e.g. for meat and leather. In the framework of their border-policy, the Romans were presumably forced to export grain and other food products, because of regular outbreaks of famine, drought and consequent crop failure and exhaustion of the German fields. The growing population in the empire forced the Romans to limit the export of food and to raise their taxes.

Another aspect was that the German soldiers in Roman forces became familiar with the Roman tactics, armament and richness among the civil population. From the 3rd century onwards there was an increasing rebellion against the Roman dominance. The neighbouring tribes acted more and more aggressively, resulting in invasions and plundering of the countryside. The rural areas south of the *limes* became dangerous places to live, and gradually the farmers in the *vici* and *villae* abandoned their fields and moved towards the safer towns. This resulted in an ongoing decrease in the production of food. The vulnerable policy of the Romans to live in repressive tolerance with the occupied tribes ended up in an ecological crisis. The Roman Empire did not collapse suddenly, but it was gradually eroded from the inside, as well as from the outside. The collapse came when the Romans were forced to withdraw their legions to Italy, to defend Rome against the attacks of the Goths' armies. The *limes* could then easily be surpassed by German tribes. The fall of Rome in AD 476, the centre of the civilised world, marked the end of the empire (Bloemers and Van Dorp, 1991).

Rather than considering internal and social factors, environmentalists prefer ecological explanations, blaming environmental degradation or climate change as being responsible for the collapse of the Roman Empire. Around AD 450, parts of Europe did indeed experience rapid cooling. This period corresponds with worldwide accounts of a significant climate downturn due to a mysterious dust-veil event. The cause of this cooling is still unknown, but some researchers speculate that it was either the result of a massive volcanic eruption, or due to some cosmic dust loading at the stratosphere. Tree-ring data from Europe and North America indicate a significant temperature drop around AD 536. They also show that the tree-ring widths returned to pre-AD 535 scale in the late AD 540s, suggesting that the climate downturn lasted for some 15 years. Other research suggests that the cold period began as early as AD 500 and lasted for more than 200 years. Evidently, there is no consensus about whether the Roman Empire tumbled because of a climatic downturn, or as a consequence of a multitude of other factors (Peiser, 2003).

## 2.4 After the Romans, the Period from AD 400 to 800

### *2.4.1 Constraints by Sea-Level Rise*

Until Roman times, the massive growth of bog peat in the western part of the Delta could still keep abreast of the sea-level rise, but eventually the barrier dunes could no longer protect the hinterland against the influence of the sea (compare Figs. 2.4 and 2.8). Fig. 2.4 shows a palaeogeographic reconstruction of the Rhine–Meuse catchments around the year AD 100, projected on a recent map of the Delta. The western part of the Delta was dominated by large areas of peat moor, which rose several metres above sea level and above the level of the rivers. Large bog-peat layers had formed in between the river branches and small estuaries. The moors were already locally reclaimed and drained by trenches and ditches, dug by early inhabitants to create arable fields. The main differences, comparing Figs. 2.4 and 2.8, approximately 900 years later, are the effects of transgressions of the North Sea. In AD 100 the bog-peat moors were occurring from Belgium in the south to the Wadden Sea in the north (see Fig. 2.10 for present situation), sheltered behind an almost closed girdle of barrier dunes. During the period from AD 300 to 800 continuing sea-level rise breached the closed barrier dunes in the south, tore apart the vulnerable peat deposits and covered the remnants with a thick layer of marine silt; the contours of the archipelago of the SW Delta of Rhine and Meuse became visible.

Comparable transgressions took place in the northern part of the Delta, but not necessarily at the same moments in time as in the south (Augustyn, 1992). From numerous excavations it is known that dwellers have lived for centuries on elevated levees in salt marshes, using the fertile grasslands to graze their cattle. Figure 2.9 shows a reconstruction of the development of a dwelling mound in the tidal area of the NW Delta, from a small settlement in the Iron Age unto an extensive village in the Middle Ages. The first dwellers settled there in approximately 600 BC on a levee in the salt marsh, and heightened their living place with household garbage. The continuous threat of tidal floods forced the farmers to heighten their dwelling mound again and again with natural clay that was amply available. Excavations showed that after repeated flooding and subsequent sedimentation the mound was heightened and extended again several times in the period 200 BC to AD 950. From 1050 onwards, the necessity to elevate the mound fell into disuse, owing to the building of a dyke, embanking larger parts of the former salt marsh (Knol, 1991a).

In Fig. 2.8, around the year AD 1000, several outlets of the rivers Rhine and Meuse can be recognised, namely the estuaries in the southwest (*Helenium*), the *Rhenus* (what is now called the Oude Rijn) near Katwijk and the IJssel discharging into the Zuiderzee, which provided the tributary of the Rhine River with its estuarine outlet. The catchment of the river Dommel, debouching in the river Meuse, shows up in the southern part of the country (see Chapter 3).

Many places where the Romans had lived in the Delta became depopulated around the 4th century AD, caused by transgressions of the sea that wiped out the settlements and covered the sites with a layer of clay. This period of accelerated sea-level rise lasted almost 500 years, from approximately AD 300 to 800. There are reasons to believe that almost the entire peat-moor area behind the barrier dunes became uninhabitable (Fig. 2.8). Regular floods, both from the sea and from the rivers occurred, as witnessed by numerous dwelling mounds along the small rivers intersecting the bog peat (e.g. along the river Alblas, near Oud-Alblas; Fig. 2.10), and the marine deposits (salt marshes) in the north and in the southwest. There is evidence that in *ca*. AD 860 storm floods hit the Central Delta, wiping out large forest fields. Deep in the clay layers around Zoeterwoude (south of Leiden; Fig. 2.10) the remains of large trees have been found (www.huurmanscoop.nl).

**Fig. 2.8** Palaeographic reconstruction of the lower catchments of Rhine and Meuse around 1,000 years BP, projected on the present map of the Netherlands (Van Es et al., 1988, in Van den Broeke, 1991a); (a) cover-sand deposits pushed by ice (Saalien ice age) and blown by strong winds (Weichselien ice age); (b) river deposits; (c) river valleys and valleys of brooks; (d) possible watercourses; (e) marine deposits; (f) peat formations; (g) water and tidal flats; (h) coastal dunes; river dunes. 2 = *Helenium*; 3 = *Rhenus*; 5 = IJssel delta

## 2.4.2 Peat and Salt

There is some debate in the literature about the degree of cultivation of the peat moors, before sea-level rise wiped out most traces of human occupation. Van de

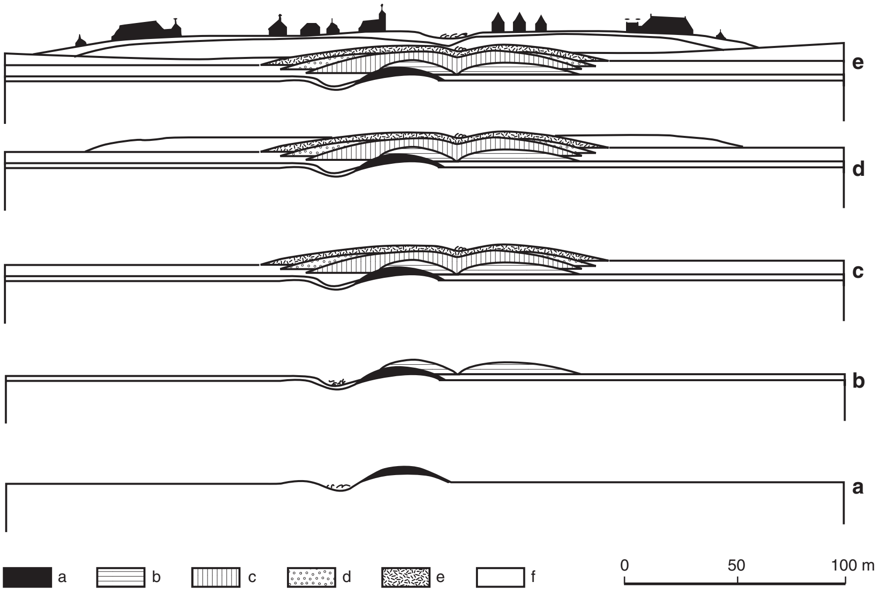

**Fig. 2.9** Reconstruction of the development of a dwelling mound in the tidal area of the NW Delta (after Knol, 1991a). (A) The first people settled approximately 600 BC on an elevated levee in a salt marsh and heightened their living place with household garbage; (B) the mound has been elevated by natural clay deposits; (C) the mound has again been elevated and extended by human actions to avoid flooding (200 BC–AD 700); (D) after repeated flooding and subsequent sedimentation the mound has been elevated and extended again (AD 950); (E) from AD 1050 onwards the necessity to elevate the mound fell into disuse, owing to the building of a dyke, embanking larger parts of the former salt marsh (not visible in the figure). (a–b) Natural levee, elevated with household garbage and marine sediments; (c–e) elevations by human actions and irregular flooding during Roman times and early Middle Ages; (f) final elevations, late Middle Ages

Ven (2004), in his textbook on the history of water management and embankments, states that around AD 800 the landscapes in the Delta were hardly influenced by man. Considering the number of people living in the Delta around AD 800 (*ca.* 0.1 million), this might be true, but qualitatively Van de Ven's statement seem incorrect to me. There is evidence that from Roman times onwards the bog peat was systematically exploited. Draining and subsequent cultivation of peat bogs led to lowering of the ground level, owing to oxidation of the organic matter, and compacting of the soil. When during periods of transgression the sea flooded the marshes, a layer of marine sand and silt was deposited, and saltwater penetrated the peat layers. In the Middle Ages, salt was produced at many places along the coast of the North Sea. The salt was either gained by forced evaporation of seawater, or by the burning of salt peat. Millions of tonnes of peat was used during this process of 'selbernen' (making salt by burning peat). The massive digging of peat and the consequent lowering of the ground level made the land of course more vulnerable to attacks by the sea. It is believed that human activities, the greed to gain salt, have enhanced the process of land use. There are indications that in the SW Delta man disturbed the equilibrium between land and sea already in Roman times, but it is not sure whether the peat was used for gaining salt (Ovaa, 1975; Vos and Van Heeringen, 1997). *Plinius*, in his *Historia Naturalis*, has mentioned the use of peat as fuel in the Delta from AD 47 onwards (www.huurmanscoop.nl).

The salt trade was important in the early Middle Ages. Salt was a prominent exchange good. But the question is: what is the advantage of salt peat as a resource above seawater? Salinities in salted-up peat moors are considerably higher than the average salinity of seawater. By drying and consequent burning of the peat the salt content of the ash will increase again. Obviously salted-up peat could easily compete with seawater. We may assume that much of the salt peat was used to fuel the pans in which the ash mixed with water, the salt solution, was reduced by evaporation. Archaeological findings of salt-works show that these activities must have taken place at a rather large scale. Historical data confirm that short-term inundations with seawater improved the value of peat areas for salt production (Leenders, 1989). The salt-saturated peat was then exploited and removed, and that gave the sea even a better access to the hinterland. Gradually, the sea gained more and more influence over the land, and a severe storm could then easily destroy the remainder of the land (Van Geel and Borger, 2002). It is generally believed that from the 8th century onwards the peat area behind the barrier dunes has increasingly been cultivated. The larger part of the peat areas in the Central Delta were transformed, and systematically cultivated in the period between AD 950 and 1250 (Bloemers and Van Dorp, 1991) during a regression phase with relatively lower sea levels than during the preceding period (Bungenstock et al., 2004). In later centuries, large parts of the SW Delta were drowned again by severe storm floods (Chapter 9). It is not clear whether the exploitation and draining of the bog peat by man from the early Middle Ages onwards, has enhanced this process, or whether it is the result of a purely natural process of sea-level rise.

### 2.4.3 Initial Outline of the Present River Landscape

Little is known about the period AD 400–800; there are hardly any written documents from that period, and we are almost entirely committed to archaeological findings, and botanical (pollen grains) and zoological remnants. The human population decreased. It is postulated that the vacuum of power that existed after the fall of the Roman authority led to a large-scale migration of Germanic peoples (called the Great Migration) over Western Europe. It is said that exhaustion of arable fields occurred, and there were outbreaks of epidemics. The first pandemic, although restricted mainly to the Mediterranean Basin and consisting primarily of bubonic plague, left an indelible mark on early medieval Europe. The first outbreak was in AD 541, and because it was recurrent, it helped keep population levels below those before the plague. The demographic historian J.C. Russell has estimated the total population loss in Western Europe from AD 541 to 700 at 50% to 60% (Gottfried, 1985). I do not know whether the repeated outbreaks of plague have decimated the local human population in the Delta.

It is said that the Franks, the people that dominated the countries left by the Romans, were far less urbanised than the Romans were. They lived in villages spread over the countryside. From pollen diagrams and artefacts it could be reconstructed that the increasing influence of the sea (transgressions) resulting in regular floods far land inwards, forced the farmers to abandon their arable land. The fields lay fallow, and the forests took their pre-Roman position in one or two generations. The discovery of a Frankish farm in Gennep (south of Nijmegen; Fig. 2.10), on a complex of river dunes, where the river Niers enters the Meuse, revealed significant traces of the way of living of the Franks. The reconstruction showed that the farm comprised large barns, built around AD 450. Cattle and horses grazed along the river, higher up were arable fields and still higher up dense deciduous forests (Heidinga and Offenberg, 1992).

To my opinion, the end of the 8th century heralded the start of a new period in the ecological history of the Delta, because changes in the river landscapes were set in motion, of which nowadays many traces are still recognisable in the field. The climatologically favourable circumstances and a lower sea level during the regression phase (*ca.* AD 800–1200) allowed humans to cultivate and exploit the bog peat and marine and fluvial deposits in the Delta (see Chapter 3). Next to ecological processes, social factors played their role as well. Charles the Great (AD 768–814) is the best known king (later emperor) of those days. He was the first post-Roman ruler who organised a regular army, with knights and soldiers. The knights got the loan of a piece of land, so that the farmers that worked on the land 'enjoyed' protection, and could provide the knights in kind of food and other resources. This feudal system has been the basic pattern during centuries in Western Europe, and has, in fact, been decisive for the development of the countryside, in the Delta dominated by agricultural practice. After the devastation and the tribal migrations of earlier centuries, the human population grew again in the 8th century, and the foundation of a central authority, resulted in relatively stable living conditions. The number of rural settlements grew quickly, the size of the farms increased, and the clayey areas – salt marshes, river valleys – were gradually cultivated for agricultural purposes. The surplus of arable products allowed more and more people to cease farmers work, and to practice a handicraft, or carry on a trade. Early medieval trade centres arose (e.g. Dorestad on the confluence of Lek and Kromme Rijn; Fig. 2.10). The increasing prosperity meant a stimulus for trades and industries (pottery, glass, metals), and the Large Rivers and the North Sea became the traffic arteries for international trade (Bloemers and Van Dorp, 1991). Economic progress means almost necessarily ecological breakdown. I postulate that from approximately AD 800 onwards a gradual but continuous conversion was imposed on the natural landscape, changing the environment into what we nowadays call the semi-natural Delta landscape; the start of that process is mainly driven by climate change and retardation of sea-level rise.

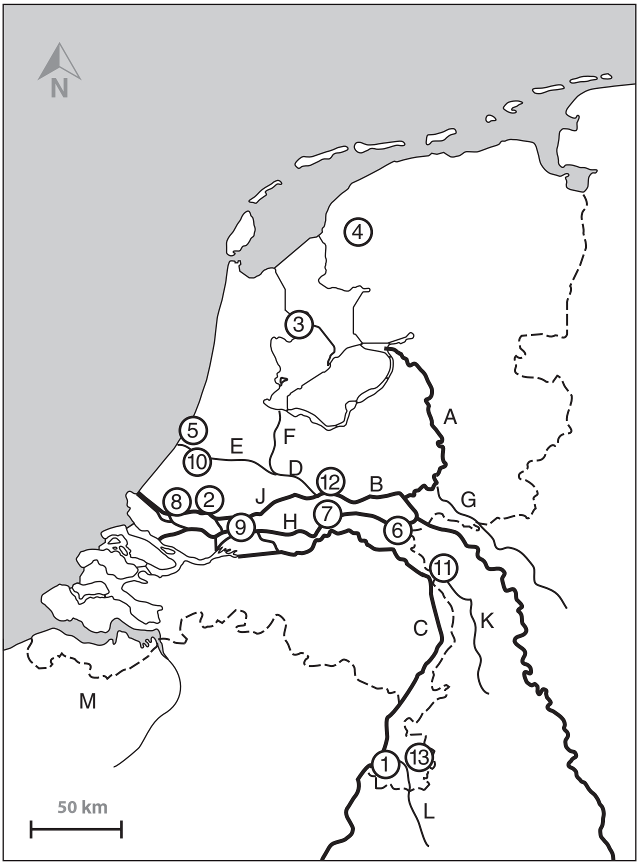

**Fig. 2.10** The Delta projected on a present-day map of the Netherlands, comprising the geographic names of prehistoric and early historic settlements and rivers mentioned in the text. 1 = Maastricht; 2 = Bergschenhoek; 3 = Bovenkarspel; 4 = Peins; 5 = Katwijk; 6 = Nijmegen; 7 = Tiel; 8 = Vlaardingen; 9 = Oud-Alblas; 10 = Leiden; 11 = Gennep; 12 = Dorestad; 13 = Voerendaal; A = IJssel; B = Nederrijn; C = Meuse (Maas); D = Kromme Rijn; E = Oude Rijn; F = Vecht; G = Oude IJssel; H = Waal; J = Lek; K = Niers; L = Geul; M = Flanders

## 2.5 Conclusions

– The first inhabitants of the Delta left their traces approximately 250,000 years ago, during the Saalien ice age, on the edge of a marshy floodplain of the river Meuse. The country became inhabitable during a subsequent warm period of sea-level rise (to NAP + 8 m), followed by the Weichselien ice age (sea level NAP −130 m), that ended roughly 12,000 years ago.

- At the end of the last ice age, the air temperature in July rose from 0–5°C to 15–20°C, approximately 7,000 years BP. The low Delta situated in between higher cover-sand deposits was then characterised by freely braiding rivers, debouching in vast peat moor and elevated bog-peat areas, behind ridges of barrier dunes parallel to the sea coast, over a distance of hundreds of kilometres. At several places the rivers intersected the dunes, discharging into the North Sea. The land was covered with dense forests and – as some scientists assume – parkland kept open by large grazers.
- Archaeological findings from the New Stone Age, 6,300 years BP, revealed a hunters and fishermen campsite in the Delta, with remains of the same species of waterfowl and fish as we know nowadays. From pollen diagrams (2,700 years BP) a vegetation of water-plants and floodplain forests could be reconstructed resembling very much the present-day species composition.
- The first prehistoric 'water management' measures dated back to the Bronze Age (3,500 years BP), a system of trenches to drain the arable fields, surrounding farm sites. Recent archaeological excavations show that the oldest man-made dyke dated back to 100–200 BC, and the 'oldest delta works' (levees and culverts with recoil-valves) dated back to AD 100. In the 2nd century AD the bog-peat area was systematically cultivated.
- The Roman occupation from 15 BC to roughly AD 400, meant the start of (scanty) historical records. The river Rhine was the northern border of the empire, and the Romans had a considerable impact on the natural water systems: they adapted waterways, and built and exploited harbours, storage yards, fortified towns, fortresses and large farms. Progressive deforestation is mentioned from the Iron Age onwards (2,500 years BP); to keep the iron foundries at the desired temperature took vast amounts of charcoal.
- Roman descriptions mentioned the 'waterworks of Corbulo and Drusus', comprising the canalisation of watercourses and the building of dams diverting the course of the main rivers. There is some disagreement about the exact position of the waterworks, but the dam and canal of Drusus are probably the first large-scale hydraulic engineering works in the delta.
- The period AD 300–800 is characterised by accelerated sea-level rise, making the larger part of the Delta inhabitable; the Delta became depopulated, there were outbreaks of plague and the remaining farmers lived on man-made dwelling mounds in the floodplains.
- The 10th century is generally taken as the start of water-management measures in the delta of Rhine and Meuse. Recent archaeological findings, however, showed that from pre-Roman times onwards measures have been taken to 'manage' the rivers and estuaries. The Romans gave an advanced impulse to water management, and with ups (regressions of the sea) and downs (transgressions) these measures were continued by the then inhabitants of the Delta.
- From *ca.* AD 800 onwards, a gradual but continuous conversion was imposed on the natural landscape, changing the environment into what we nowadays recognise as the semi-natural or cultural landscape. The start of that process is mainly driven by climate change and retardation of sea-level rise.

- These changes are characterised by a steady increase of the human population (from 0.1 million in AD 800 to 16 million in 2000), increasing cultivation of floodplains for agricultural purposes, continuing deforestation, and an ongoing fixation of the river landscape by levees and dykes.

# Chapter 3
# The Delta in the Later Middle Ages (800–1500)

## 3.1 Introduction

Chapter 2 – 'Prehistory and early history of the Delta' ended in the beginning of the 9th century, a period with a growing human population, and increasing prosperity in the Delta. How did the river landscape look like in the later Middle Ages? We do not know in any detail; piece by piece the images of the landscape have to be reconstructed from archaeological excavations and indirect descriptions. Huizinga's (1919) famous and authoritative study about life and death in the 14th and 15th century does not provide many clues. During those centuries the House of Burgundy ruled large parts of northern France, Belgium and the Netherlands. It was the time of three fixed classes in society, ordained by God, the nobility, the clergy, and the working class, farmers, craftsmen and labourers. The mental attitudes of people were dominated by religious images and descriptions. The flamboyant splendour of noblemen and clergymen was fixed 'forever' on canvas and in stone buildings. Monastric orders, and particularly the Cistercians, where the shock troops of forest clearing and farming (Williams, 2003). The story about the great poverty of the lowest class, living in straw thatched huts, working hard during harvest time and suffering from bitter cold and darkness in winter, is a jigsaw puzzle in which many pieces are still missing.

The aim of this chapter is to focus on the river landscape of the Rhine–Meuse Delta in the later Middle Ages, the period from 800 to approximately 1500. Realistic and reliable data on river 'ecology' (the concept did not exist) are not available. The only way to be informed about the changes in the river landscape is the indirect way. Relevant information will be distracted from weather and climate statistics, i.e. initial retreat of the sea, after 800 followed by accelerated sea-level rise. Another source of indirect information is formed by the development of the medieval society. The 'cope'-cultivation changed the raised-bog wilderness in the Central Delta in a few centuries into a meticulously laid-out wetland landscape. Written documentation about medieval urbanisation and the exploration of international trade routes are also welcome indirect sources. Several other aspects, such as the gain and loss of land, the building of flood defences and dykes and the development of agriculture will be described in Chapters 9 and 7, respectively. The history of the river fisheries will be covered in Chapter 8. To end this chapter, the approximate year 1500 is chosen

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because changes in societal processes at the end of the Middle Ages might be assumed to have accelerated changes in the river landscape.

## 3.2 The Black Death

An eco-historic survey of the late Middle Ages cannot pass the horrendous epidemics that struck the human population: between 1350 and 1500 regular outbreaks of plague in Europe decimated the population. Around 1350 the Rhine–Meuse Delta suffered losses of 30–35% of human lives from the Black Death, losses so great that the reclamation of lands along the Zuiderzee (Fig. 3.3) came to a halt after 300 years of dyking, draining and damming (Gottfried, 1985). In the Delta at least 14 repetitive plague cycles from every 4–12 years are known from the period 1350–1500. The same occurred all over Western Europe: the continental pattern suggests that plague came at least two or three times a generation and was sufficiently virulent to keep the population levels low. The best estimate is that from 1349 to 1450 the European population declined between 60% and 75%, with the bulk of the depopulation in rural areas (Gottfried, 1985). Slicher van Bath (1960) stressed the relative meaning of population figures in the Middle Ages. His assumptions lead him to a decrease in population of *ca*. 40% in between 1300 and 1400. Abandoning of settlements and fields was not uncommon, and nature gained the lost terrain within a few years. Pollen diagrams from Delta habitats show that forest growth returned in those periods, replacing the cultivated vegetation (Teunissen, 1988).

Shortage was, however, the mother of medieval invention. Depopulation put a premium on new techniques that could save work time. A good example is the fishing industry (Bridbury, 1955). Fishing was big business in the later Middle Ages, as fish was an important source of protein in most people's diets, especially during Lent. Before the Black Death, fishermen had to come ashore to salt (i.e. preserve) their catch. But, around 1380, Dutch fishermen perfected a method of salting, drying and storing their catch aboard ship. This allowed them to stay at sea longer, sail farther from shore and bring home more fish.

The economic changes brought by depopulation can also be seen in trade patterns. Before the plagues, western commercial routes were dominated by Italians and, to a lesser extent, by the Hanseatic League in northern Germany. In 1300, Europe's long-distance trade routes converged around the towns of the Delta, where the Italians controlled most of the transactions by using superior business skills and the stable, gold-based currencies of Venice and Florence as their mediums of exchange. By 1500, this had begun to change, with Northerners playing a larger role and a trade imbalance draining the resources of the South. It was a period of transition, in which northern Europe played an increasingly important commercial role, and in which the centre of economic activity was shifting from the Mediterranean to the northwest (Gottfried, 1985; Hammel-Kiesow, 2004).

Gottfried (1985) compared the impact of the Black Death, the greatest historical ecological upheaval, to that of the two world wars of the 20th century. But the Black Death, compounded as it was by subsequent epidemics of the second pandemic and unstable weather patterns, wrought even more essential change. Civilisations are the result of complex combinations of institutional, cultural, material and environmental characteristics. When these underpinnings are removed, the civilisations collapse. The environmental crisis of the late Middle Ages caused existing social and political systems to stagnate or to regress. Deep-rooted moral, philosophical and religious convictions were tested and found wanting. Generally, traditional standards seemed no longer to apply. According to Gottfried (1985) the effects of this natural and human disaster changed Europe profoundly, perhaps more so than any other series of events. For this reason, alone, the Black Death should be ranked as the greatest biological-environmental event in history, and one of the major turning points of Western civilisation.

## 3.3 Weather and Climate

Historical accounts, with direct and indirect information concerning the weather, have contributed to an important extent to the reconstruction of the climate in the Middle Ages (Le Roy Ladurie, 1967). This certainly applies to the period after 1100, for which sufficient data are available for statistical analysis. Thus for the period after 1100, Alexandre (1986) and Lamb (1982) have indicated, for countries around the southern North Sea, the relation between severe and mild winters, and between dry and wet summers, for each decade, with a view to discerning trends. But also incidental data from previous centuries are a welcome source of information. For most of these data there is the objection that they cannot be quantified; at most they can be translated into such qualifications as ‘cold’, ‘wet’, etc. This certainly applies to direct references to the weather. If the writer of a chronicle mentions that a particular winter was cold, then this means that people were then accustomed to milder winters. Moreover, in these kinds of reports exaggeration is not unusual, certainly if the weather was responsible for unpleasant occurrences. The extremities of the weather were also magnified out of all proportion as time increased between the event and its being recorded, often after the information had been passed on for the umpteenth time. Above all it was mainly the abnormal weather situations that reached the ‘press’. It is therefore dangerous to deduce trends from reports of this kind: there is a good chance that the weather conditions mentioned were precisely not representative of the period concerned, for example, why should someone mention that a winter was cold, if all winters were cold? (Heidinga, 1987).

Indirect data, such as the time when the crops were harvested, the mention of good or poor vintages, etc. are often a more objective gauge, at least insofar as they are clearly associated with the climate. Natural catastrophes such as floods can also be used, with due caution, as indicators of certain climatologic conditions. Floods along the coast, however, may be the result of incidental storms that were by no means representative, while the disastrous effects may also have been determined by other factors. River floods are more reliable indicators, insofar as they were caused by exceptionally high rainfall over a long period, and not by a sudden thaw or the occasional cloudburst. From the data that Gottschalk (1971) collected concerning storm surges and river floods in the Delta, it appears that in the 10th and 11th century remarkably few river floods have been mentioned. At the end of the 11th century the number of floods increased again, initially mainly in the winter, but in the second half of the 12th century there came series of years during which all the seasons were too wet. Data such as these must be handled with caution on account of their limited statistical value and the fact that disastrous river floods could also have been caused by other circumstances, like deforestation of the surroundings and, in later times, the building of the dykes (see Chapter 9).

Also, the reverse situation was possible: rivers drying up. Unfortunately there are hardly any reports about this phenomenon. References to ice drift on rivers and lakes, especially where this is a rare occurrence (e.g. on the Thames), form reliable indicators of severe winters. Temperature changes of a more structural nature can be deduced from data on the distribution of ice-floes in the north of the Atlantic Ocean. Only rarely in the 9th and 10th century, and not at all in the 11th and 12th century, mention was made of ice-floes off the coast of Iceland; this in contrast to the 13th and 14th century, when ice-floes were a frequently occurring phenomenon. From this it could be concluded that in this part of the world there was a relatively mild climate during the 11th and 12th century (Lamb, 1982).

According to Heidinga (1987) it is hazardous to deduce meteorological or climatologic data from incidents or circumstances where people have been involved. Nevertheless, Lamb (1982) and Pfister (1988) freely make use of data of this kind. Reference is often made, for example, to famines, that in many cases must indeed be attributed to failed harvests, caused by bad weather (mainly wet summers). Yet, there are other biological and culturally determined variables that could have been equally influential in this respect. It is suggested that the famine of 1005–1006, that according to the chronicles was of unparalleled severity and that afflicted great parts of Europe, had a climatologic cause. Precisely what this was remains unknown.

The fluctuations in temperature in different parts of the northern hemisphere can in principle also be demonstrated on the basis of the distribution of certain plants and animals, the shifting of tree-lines, the behaviour of glaciers, etc., but these data are less reliable and vague because the connection with temperature is often indirect: other factors also played a role, and delaying mechanisms were involved. Generally speaking these data, that have in fact partially been reworked by Lamb (1982), confirm the following picture for the northern hemisphere: a relatively warm 8th century, a cooler period in the 9th century, followed by a warm period (the ‘little optimum’) which seems to have been at its peak in Greenland slightly earlier than in England and America. Also of general occurrence was the cooler period between 1200–1350, that culminated in the ‘Little Ice Age’ between 1350 and 1850. The average temperature difference between the optimum and the Little Ice Age was probably hardly more than 1–2°C. There is general agreement that the colder period came to the end in about 1850, but opinions are greatly divided about when it began. Some people place the beginning as early as the 14th century, others in the 15th century, and others again in the 16th century. The growth of the glaciers during this ‘Little Ice Age’ was not a continuous process. There were a number of very irregular fluctuations, but it is nevertheless possible to speak of a general trend of glacial expansion (Gottschalk, 1977; Heidinga, 1987). In Chapter 9, the relation between floods and climate changes will be further discussed.

## 3.4 Reclamation of Peat Bogs

### *3.4.1 Climate Change and the Exploitation of the Raised Bogs*

In the early Middle Ages a very great part of the Delta was covered with raised bogs (compare Figs. 2.4 and 2.8). The present-day surface area of the bogs projected on the reconstructed map from the Middle Ages is only a remnant compared to the past, since in the course of time much of the bog-land has become either submerged, or has been dug away. The widest belt of raised bog extended between the Pleistocene soils in the east and the dune barriers from the SW Delta, via the Central Delta to the NW Delta, covering (what is presently called) the Wadden Sea, over a distance of hundreds of kilometres (Fig. 3.3, Fig. 2.4). Large parts of this bog-land comprised tussocks of ombrotrophic raised bog. With sufficient rainfall these consist of large spongy masses of un-decayed or hardly decayed peat of reed and sedges, with a vegetation cover of mainly oligotrophic bog-moss, *Sphagnum* species. To enter such a living, raised bog on foot was a perilous undertaking. In dry periods, however, the moisture-loving *Sphagnum* species lose their dominant position and give way to Ericaceae and grass species.

Before the 10th century people lived in bog-land only by way of exception. A few traces have been found of very early bog reclamation at Assendelft, northwest of Amsterdam (Fig. 3.3), in the Assendelver polders (Brandt et al., 1987). In the early Iron Age there were a few occupied places scattered over the raised bog, but only where the growth of peat had stagnated as a result of natural drainage. In the late Iron Age and early Roman period there was also some occupation of the drained areas of reed or sedge bog. Archaeological evidence suggests that the inhabitation diminished, however, around AD 200 due to the wide-scale growth of bog peat. It may be assumed that after that time the larger part of bog was abandoned for many centuries.

There is historical evidence that once again, in the Carolingian period, people had settled here and there in the bog-land, an occupation too was probably made possible by natural drainage. From the 10th century onwards, however, we see a completely different development: not just a few suitable places were chosen, but the whole region of bog was systematically brought under cultivation. This westward-moving wave of colonisation and reclamation activities in the Delta could hardly have been associated with natural drainage of the region. There are two possibilities: either the bog dried out due to lack of precipitation and thus became passable, or the bog was artificially drained.

It is true that since the Middle Ages the inhabitants of the Delta have become great experts in draining wetlands. In the 10th century, however, when they still had very little experience in this field, it is debatable whether they were capable of establishing a wide-scale drainage system that permitted the reclamation of such a large part of the bog during a short time span. Unfortunately, the excavations in the Assendelver polders of a few 10th–11th century sites were carried out on too small a scale to give any insight into the drainage pattern at that time. Yet it is obvious that natural circumstances – stagnation of the growth of peat and mineralising of the top layer as a result of a long-lasting deficit in precipitation – stimulated reclamation, and that drainage ditches initially only had a supplementary function. Artificial drainage would then only later have become a system out of sheer necessity, because the climatologic conditions changed and the surface level of the previously reclaimed areas of bog had subsided and compacted due to oxidation of the organic peat deposits. Evidence in support of this model is that the time at which wide-scale bog reclamation activities began, coincides precisely with the driest period of the Middle Ages. Naturally this does not alter the fact that man himself was the most important factor: after all it was his decision to enter this inhospitable environment, even though it had dried out (Hallewas, 1984). It is not impossible that the deterioration of conditions in the coastal dune region, and the fact that the bog area became accessible, had one common cause: the drought in the 10th century. It can thus be stated, according to Heidinga (1987), that climate changes appear to have played a crucial role in the history of the cultivation and inhabitation of the Delta.

### 3.4.2 Systematic Exploitation of the Raised Bogs and Land Subsidence

Van Dam (2001) came up with an additional explanation of the drastic change in landscape structure around the 10th century, i.e. the increase of the human population. Between 800 and 1250 the population of the Delta (what is now called the Netherlands), increased from 100,000 to 800,000 inhabitants. Part of the expanding population settled in the marshy peat bogs, and started to drain and to cultivate the peat. The thick layers of bog peat were situated 1–3 m above sea level, and the digging of ditches led to natural drainage of the surrounding area. At the dryer parts of the bogs crofters grew small crops of agricultural products. During the periodic dredging of the watercourses the mud was dumped on the banks, thus creating narrow strips of land for the cultivation of corn and hemp. Until the early 15th century the amount of barley and rye grown was sufficient to feed the entire population. Gradually a number of villages developed into towns, and the first signs of environmental pollution became noticeable. Increase of the human population and intensification of agriculture forced man to exploit the peat-bog areas even more extensively.

Between the 10th and the 14th century the marshy grounds were colonised from the elevated, sandy outcrops in the river landscape. The forests were felled, trenches and ditches were dug to drain the grounds, and settlers started to grow corn on the drained peaty and clayey fields. To increase their rye and wheat production the land was systematically cultivated. Large parts of the peat areas were exploited in a relatively short period of time, between 950 and 1150. The existence of a strong central government played a dominant role in this remarkable historic process. The counts of Holland, who owned the larger part of the wilderness, realised the value of the unexploited peat areas, and they took initiatives for the issue of land according to a standard procedure, the ‘cope’-agreements. The ‘cope’-settlements were systematically planned reclamations, comprising a number of lots with standard width (approximately 112 m), and a fixed length (1250–1400 m). Cultivation practice of centuries ago is still determining the size and position of the grassland lots as we know them nowadays (Bitter, 1991c; Fig. 3.1).

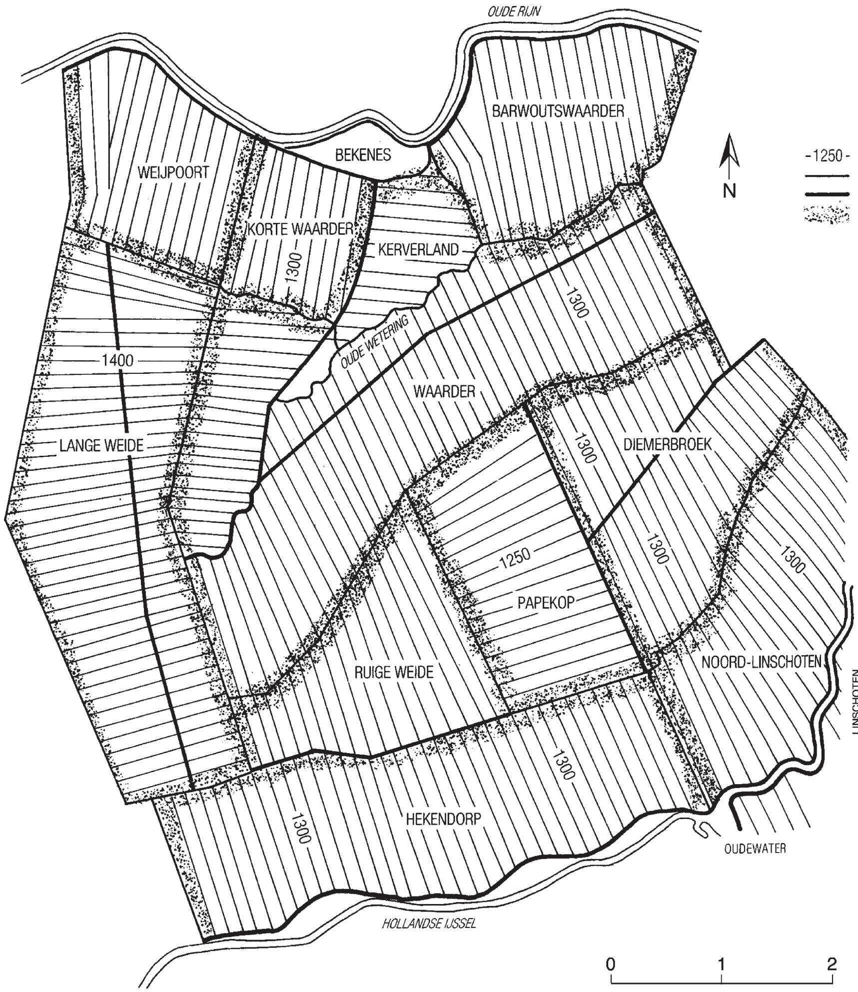

**Fig. 3.1** The ‘cope’-allotment reclamation of the peat area in between the Oude Rijn and the Hollandse IJssel (see Fig. 3.9). (a) The reclaimed lots have a standard length (1,250–1,400 m, as indicated in the figure), and width (112 m). (b) The thin parallel lines are draining ditches, the borders between the lots. (c) The thick black lines are old roads. (d) Border areas of reclaimed peat bogs (Van der Linden, 1982, in Bitter, 1991c). The cope-contracts date back to the 12th and 13th centuries, and the landscape structure has in principle not changed from then

The colonists of the ‘cope’ settled on their land, built primitive farms preferably on the elevated banks along a stream or a small river and brought their land under cultivation, which mainly meant exploitation of the peat resources. Starting in the 13th century the exploitation of peat was done on a large scale and systematically. Initially, only the surface layers of the bog peat were used for peat extraction. The peat was used as fuel for a number of energy devouring industries, such as beer breweries, brickyards and salt-works, and for the heating of houses. Until 1500 the peat was dug from the oligotrophic ombrogeneous raised-bogs, and the peat excavations left shallow holes that overgrew after some time, and could then be used as hay fields or meadows. Later on, the eutrophic peat bogs dominated by marshlands and woodlands, close to the main rivers, and less suitable for providing fuel, were also exploited. The lowering of the groundwater level during the cultivation of the peat moors had unexpected consequences. The peat compacted and oxidised, leading to a lowering of the ground level. The subsidence forced the farmers to deepen the drains and ditches further and to dig canals to lower the groundwater table in order to keep the land suitable for agriculture. This of course led to further subsidence of the surface. The permanent need to lower the groundwater table provoked an irreversible subsidence process. In the course of the 13th century water problems became a real nuisance. The process of land subsidence had increased to such an extent that large areas bordering the sea were flooded during high tide (cf. Fig. 3.2). Besides the man-induced subsidence, accelerated natural sea-level rise also affected the drainage problem. People started to block watercourses and to build primitive sluices to prevent their settlements from being flooded, either by the sea or by the rivers (Bitter, 1991c). Many Dutch towns owe their name to these damming activities: Rotterdam, Amsterdam, Monnickendam, Edam, etc. It was in that period that the first water management organisations, the water boards, were founded (Van Zanden and Verstegen, 1993).

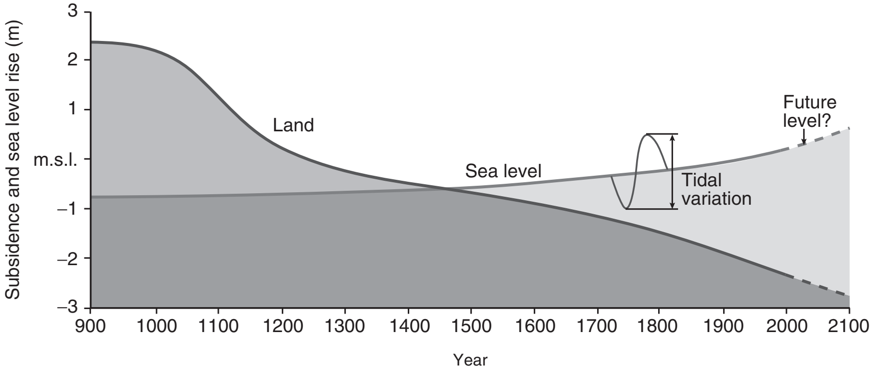

**Fig. 3.2** Outline of the counteracting processes of land subsidence and sea-level rise in the peatlands and fens of the Central Delta (Huisman et al. 1998). m.s.l. = mean sea-level, approximately NAP. It is postulated that the processes tilted around AD 1450, thereafter land subsidence continued below mean sea level

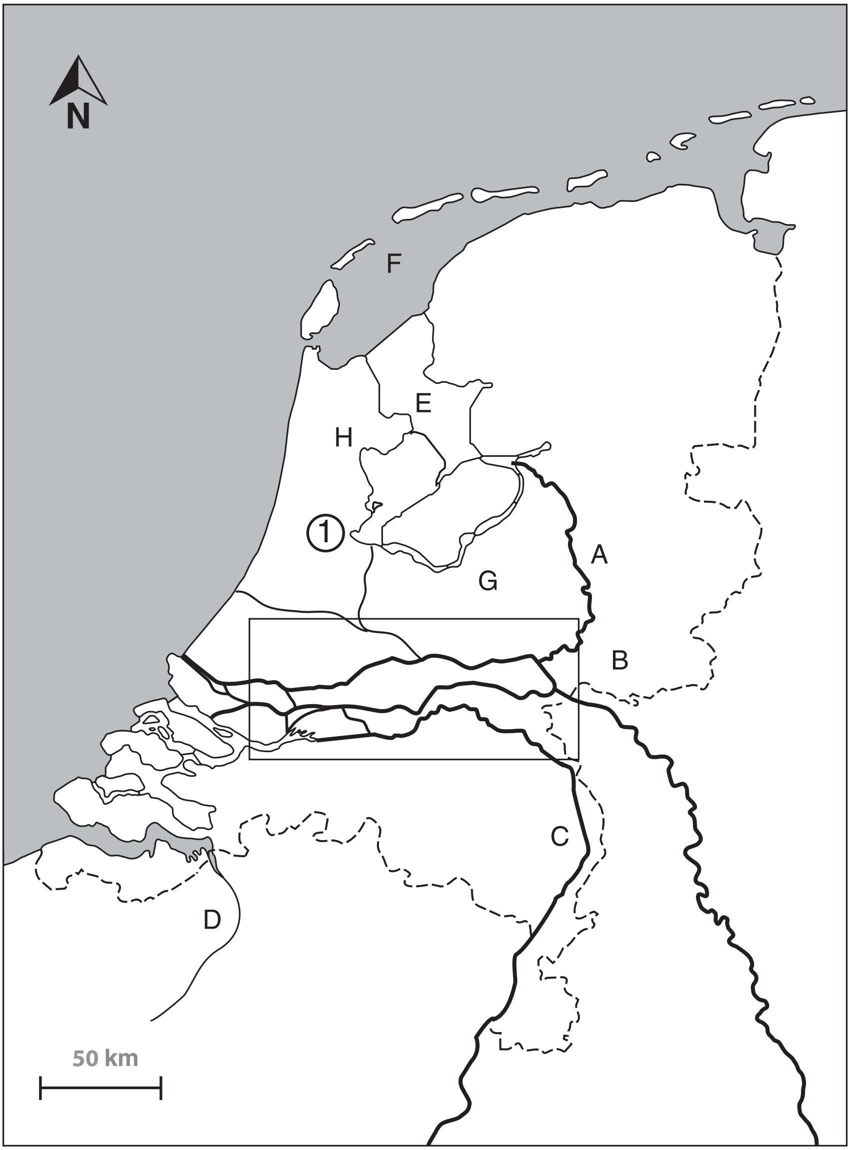

**Fig. 3.3** The Delta projected on an actual map of the Netherlands. Geographic names indicated, mentioned in the text in the period 800–1500. 1 = Amsterdam; A = IJssel; B = Rhine (in the Delta Rijn); C = Meuse (Maas); D = Scheldt river and Westerschelde estuary; E = Zuiderzee; F = Wadden Sea; G = Veluwe; H = West Friesland with Westfriese Omringdijk. Inset: the area of the Large Rivers, see Fig. 3.9

Around 1400 roughly at the end of the transgression phase of the rising sea, a new crisis arose, which has been decisive for the further development of the Central Delta. Owing to the ongoing subsidence, the peaty ground level became increasingly less suitable for the growing of corn, which forced the farmers to change to cattle farming. However, the conditions for proper farming deteriorated, the groundwater levels rose steadily and the workers adapted their trade to the changing circumstances. Peat digging was still lucrative, with additional inland fisheries, bird catching in decoys and eggs collecting. Initially the peat bogs were exploited onto the groundwater level. Peat from raised bogs, however, was already exhausted in earlier centuries, and from the early 15th century onwards bog peat situated below the water level was also exploited. The third form of peat, drag-peat scooped from the bottom of water bodies, was amply available, but the quality was inferior compared to peat from raised bogs. Owing to the massive digging of peat, large land areas became eroded by wave attack and disappeared under water, creating large, shallow lakes. The wetlands and lakes that originated during the peat digging, expanded more and more during storms, and became a threat for the surrounding settlements (Bitter, 1991c; Van Dam, 2001). The invention of a new technology, the wind–water mill around 1350 opened up a new era of land reclamation, and subsequently, many fens were pumped dry in the course of the centuries. These reclaimed marshlands, in fact drained lakes (‘droogmakerijen’), are nowadays scattered all over the former peatlands (Fig. 5.7).

The development of the large peat lakes in the Middle Ages, created after centuries of too greedy peat extraction, is one of the best known examples of massive ecological damage at the countryside induced by man in the early modern times. Because this was a gradual process, the phenomenon was not perceived as a disaster. From numerous official documents, issued by governing boards, it appears that this annihilation of landscape was already alarming in the late 16th century. The main motive of the exploiters was not concern for the preservation of nature or landscape, but the fear that the loss of (culture-) land would lead to a decrease of the yield from taxes. Peat extraction and the peat trade gave temporal prosperity to the local population, but eventually they killed the goose that laid the golden eggs. The water mass that replaced the peat introduced poverty among the population. The inhabitants were forced to change their trade to fishing, hunting, poaching and bird-catching, trades which earned them only a small income (Van Dam, 2001).

In summary, the history of the peat areas in the western part of the Rhine–Meuse delta shows the intricate relation between man and nature. Several phases can be distinguished: the period of the great reclamations between 950 and 1350, characterised by large-scale and systematic peat exploitation, and the development of arable farming; the crisis between 1400 and 1550, in which subsidence of the soil and consequent flooding events forced the farmers to live at subsistence level. The offensive against the ‘water wolf’ came between 1550 and 1650, and continued to roughly 1850, when marshes and shallow lakes were reclaimed and pumped dry. In the 16th century, important improvements in water management became apparent, particularly in the technique of building large windmills that were able to drain a number of inland peat lakes (see Chapter 4). The drained peat bogs produced excellent grass, which meant in fact the start of the dairy cattle farming, as we still know it nowadays (Van Zanden and Verstegen, 1993).

The combined impact of sea-level rise and concomitant subsidence of the surface level of the ground resulted in an increase in the scale of mitigating intervention over the course of centuries. Figure 3.2 shows, schematically, that in the late Middle Ages around 1450, the process 'sea-level rise versus land subsidence' in fact tilted. The Central Delta until then above the level of the sea became a compacted, low-lying and flood-prone area, and until the present day it is a continuous struggle against these aggravating and counteracting phenomena. The repetitive interventions in the natural (water-) systems in support of the growing socio-economic interests and the development of the institutional structure of the Netherlands, is a central theme in past, present-day, and future water management (cf. Chapters 20 and 21).

## 3.5 The Large Rivers

### *3.5.1 Early River Management*

In prehistoric times, the first dwellers in the Delta settled high and dry in the dune areas of the coastal barriers, on the ice-pushed Pleistocene ridges of (a.o.) the Veluwe (see Section 3.5.2), and also in the area of the Large Rivers, the eastern elevated part of the Delta (Fig. 3.3). The latter apparently inaccessible wetlands attracted settlers because of the vast areas of fertile soil and waters rich in fish. Thanks to the presence of natural levees, channel belts, consisting of sandy channel deposits, or river dunes, Pleistocene ridges of sand protruding above the surrounding marshes, the farmers could settle on relatively dry and safe places. The vast peat areas in the western part of the Delta, in between the dunes and the river landscape proper were inaccessible and dangerous, and their exploitation got underway only centuries later (Chapter 2).

From the Bronze Age onwards initial 'water management' works were executed in the Delta. Farmers dug drainage systems to dewater their arable fields, and they threw up small protective levees to mitigate the impact of floods. The throwing up of many small levees in the area of the Large Rivers was not meant in the first place to protect the human settlements against river floods, but more to protect their lower-situated cultivated land against the erosive forces of vast flowing river water and rainwater. These primitive levees, the cross-dykes ('zijdewenden' or 'dwarskades'; cf. Section 9.3.4.), are therefore situated perpendicular to the main flow of the river (Fig. 3.9). In order to protect their settlements situated on channel belts or natural levees, against river floods, the levees were elevated with clay and sand, again and again. In the course of time it became necessary to connect and to heighten the dykes around the settlement systematically, and gradually the ring-dyke surrounding the entire embanked river-polder ('waard') came into existence. This explains the winding nature of many present-day river dykes (see Chapters 7 and 9 for details). Already early river 'management' measures, viz. the building of levees bordering the river basins, led to the narrowing of floodplains. Gradually the riverbeds became constricted between these man-made earthen dykes, and during river floods these vulnerable constructs were frequently overtopped or broke during ice drift. The rivers gradually lost large areas of their floodplains by the actions of man, enhancing the amplitude between high water and low water. This problem became immanent soon after the first dykes surrounding the polders were closed, in the early 14th century (Hesselink, 2002; see Chapter 9).

The area of the Large Rivers between Nijmegen–Arnhem and the subsiding peat area in the Central Delta (Fig. 3.9) had an inclination from NAP + 10 m to NAP + 1 m, over a distance of less than 80 km. This, of course, resulted in unstoppable masses of water during peak floods, flowing downstream riverbeds, narrowed by human actions, viz. the building of dykes along their entire length. The peat area between the rivers Lek and Merwede, the Alblasserwaard and the Vijfheerenlanden (Fig. 3.9) was protected by cross-dykes against superfluous river water flowing downstream. The cross-dyke between the Vijfheerenlanden and the Betuwe and Tielerwaard, the Diefdijk (Fig. 3.9), was built in the 13th century, and was gradually strengthened to become a water-retaining levee. Hence this structure is not a dyke surrounding, and thus protecting a river-polder, but a dyke perpendicular to the east-west flowing rivers. When the river dykes of the lower Betuwe and Tielerwaard (Fig. 3.9) were broken, the downstream water mass could be retained here. It marks the long struggle between the earls of Holland in the west and the dukes of Gelre in the east. Avoidance of flooding west of the Diefdijk meant accumulation of the river water and consequent misery east of the dyke. The same levee meant safety for Holland and inundation for Gelre (Jonkers, 1991; Van de Ven, 2004).

### *3.5.2 Where the Rhine Touches the Ice-Pushed Pleistocene Ridges*

The medieval settlements on the Veluwe were situated in proximity of open water, or where the groundwater could be reached by drilling a well. The ideal situation was having the farm on the transition from the higher grounds to the brook, were both arable land and grassland could be maintained. In the later Middle Ages the area of usable land was extended by cultivation of the wet brook valleys, and accessible parts of the alder-marsh were transformed into grassland for grazing cattle and as hay fields. These fields were originally in common use by several farmers, accessible during the dry summer months and during periods of frost. In Fig. 3.4 (after Vervloet, 1995) a late medieval reconstruction of the southwestern border area of the Veluwe along the Nederrijn (Figs. 3.3 and 3.9) is depicted, showing a closed beech-winter oak forest on the Pleistocene ice-pushed ridges (the forests of Sysselt are situated 57 m + NAP). These forests were already mentioned in a document written in 996, as property of a monastery (Geldersch Landschap-Geldersche Kasteelen, 2003). Figure 3.4 (left panel) shows open spots where small settlements were founded on the transition from the higher sandy grounds to the lower alder and sedges-marshland, grading into the ash-elm forest, with alder, interspersed with

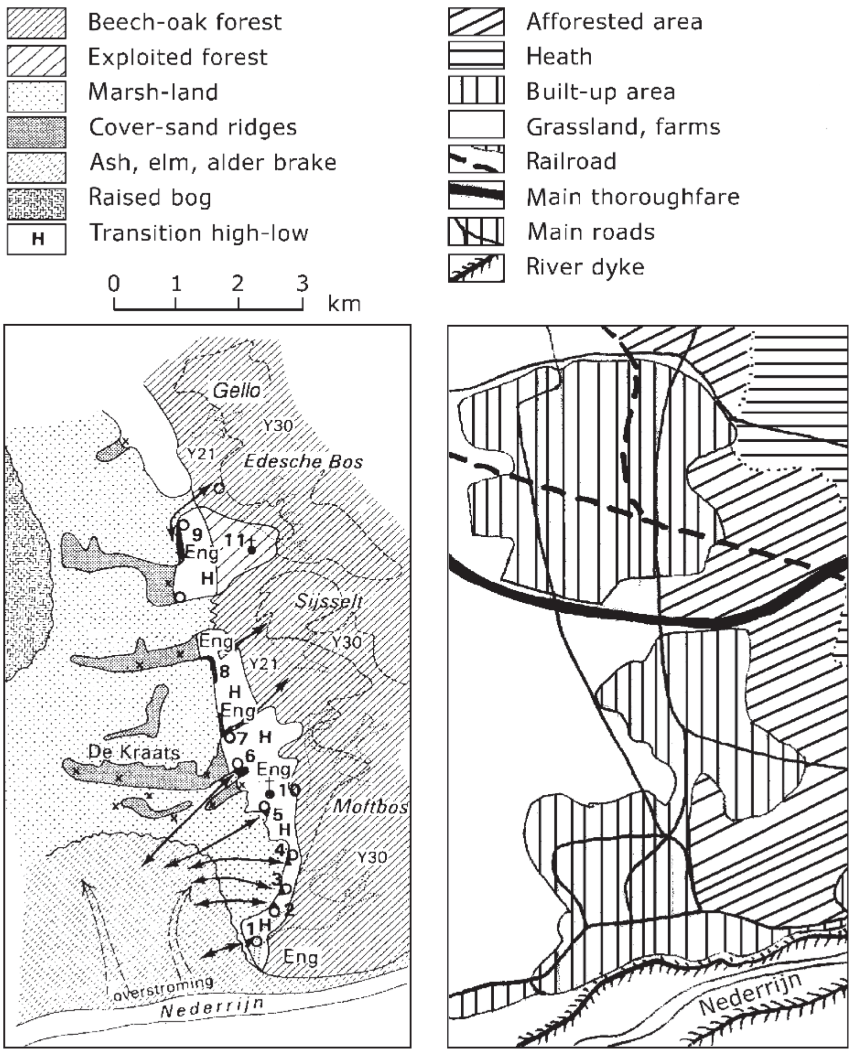

**Fig. 3.4** Left panel: a late medieval reconstruction of the Gelderse Vallei (Fig. 3.9: GV), bordering the Nederrijn in between two Pleistocene ice-pushed ridges (adapted from Vervloet, 1995). The Nederrijn had free entrance to the marshlands and floodplain forests of the Gelderse Vallei during floods ('overstroming'). The numbers indicate human settlements; the arrows indicate the free range of wildlife between the river floodplains and the higher grounds and natural forests. Right panel: the Gelderse Vallei in AD 2000, completely isolated from the main river Nederrijn. Conspicuous elements: built-up areas and urban sprawl, a network of main roads and secondary roads, cultivated forest plantations on the high grounds and grassland in the former marshes (Adapted from www.bosatlas.nl). See text for further explanation

small elevated cover-sand ridges overgrown with marshland. This gradient from the higher sandy grounds to the lower marshlands is situated in a glacial valley, in prehistoric times partly eroded by the river Rhine. It is a classical example of an ice-pushed ridge, surrounding a glacial basin, the Gelderse Vallei (Fig. 3.9). Cattle and wildlife moved between the lower river valleys and the higher grounds, depending on the time of year. At high discharges of the Nederrijn, the vast marshes with ash-elm-alder forest were inundated. The human settlements were situated high and dry, but the brook and the main river were close by (Vervloet, 1995). The marshlands in the valley, fed by brooks from the Veluwe massive and by the river Nederrijn, developed into vast peat bogs with outcrops of raised-bog. In the 15th century the exploitation of the peat started, and the draining of the marshlands, the cutting of turf and transport of the fuel became an important trade, which lasted almost two centuries. Watercourses were dug to drain the peat bog, and to transport the lumps of turf to the river Rhine where further transport was arranged. Gradually the draining and digging of the peat led to compacting and subsiding of the marshes, and the river Nederrijn gained more and more access to the valley. In the late Middle Ages, the Gelderse Vallei was disconnected from the river by a dyke. Repetitive dyke bursts and subsequent flooding of the entire valley, forced the water managers to heighten and strengthen the levee time after time.

Figure 3.4 (right panel) gives an impression of the situation in 2000. The river Nederrijn is constricted between high dykes, and completely isolated from its surroundings. Although there are (invisible) groundwater and seepage flows from the Veluwe to the river, the physical transition between the river and the higher grounds is completely lost. The settlements in olden times grew into towns, and in the urban area depicted in Fig. 3.4 now live approximately 200,000 inhabitants, and there is great urban pressure on the countryside. Instead of draining onto the river Nederrijn in the south, the remaining lowland brooks all drain on an artificial canal that is connected with the (former) Zuiderzee in the north. The water household in the area is completely regulated by numerous weirs. At present the landscape in the Gelderse Vallei is characterised by intensive cattle farming, pig-breeding and poultry farming. The area is crossed by an east–west motor-highway, and a major traffic road along the river. Small nature reserves and some stately estates are left (Fig. 3.4).

The contrast between Fig 3.4 (left panel) and Fig. 3.4 (right panel) is representative for the major changes that occurred in the Delta river landscape from the Middle Ages to the modern times. The main determinants for these inversions are the increase in the human population and concomitant changes in land use, the transformation of natural ecosystems (in this case peat bogs and river floodplains) into fully controlled artificial ecosystems (in this case mainly grassland and maize fields).

### *3.5.3 Differences Between East and West*

In the past 8,000 years the riverbeds of Rhine and Meuse have frequently changed their geographic position, as could be reconstructed from palaeogeographic surveys. Already at the end of the Middle Ages, however, the harnessing of the riverbeds, and particularly the closure of the ring-dykes surrounding the river-polders (‘waarden’), was so far advanced that the river basins of Rhine and Meuse occupied roughly the same macro-geographic position in the Delta as they do nowadays. The country, however, was still ‘empty’ (Van der Woud, 2004). On a meso- and micro-scale, of course, regulation works, height and position of the levees after a dyke burst, avulsions (shifts in the position of a channel), developments in demography and land use and other infrastructural characteristics, have continuously changed the appearance of the river landscape until the present day.

Berendsen (2000) gave a useful geographic classification of the river basins in the Delta (Fig 3.3):

1. *The Meuse valley*. The river Meuse flows from the higher grounds in France and Belgium (elevated more than 100 m + NAP), down to the North Sea (Chapter 13). The Meuse terraces were formed during the Pleistocene era, and are situated on a higher level than the present river. In the course of the Pleistocene the riverbed has incised into the underground. The Holocene deposits in the southern valley are very thin, because the entire riverbed is situated above the ‘crossing of the terraces’ close to Nijmegen where the riverbeds change from net incision to net sedimentation (Fig. 3.5). Downstream of Nijmegen sedimentation prevails, and the river deposits increase in thickness from 1.5 m to more than 20 m.
2. *The IJssel valley*. The Holocene deposits along this river are rather thin, notwithstanding the fact that the river branch is situated downstream of the crossing of the terraces. This is explained by the fact the river IJssel started to flow through the IJssel valley only after the year zero.
3. *The Rhine basin*. The drop of the river Rhine from the German border to the North Sea, over a distance of 140 km, is roughly 13 m. The larger part of the river basins consist of Holocene fluvial deposits, situated at the surface. These deposits can be distinguished in: (1) natural (sandy and loamy) levees along a river channel; (2) channel belt deposits, consisting of sandy channel deposits, usually

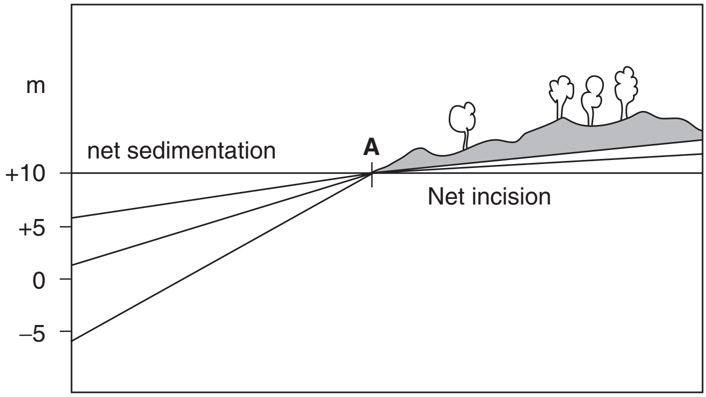

**Fig. 3.5** The crossing of the terraces of the river Meuse (A). Vertical axis: 0 = NAP level. Explanation, see text (Adapted from Berendsen, 2000)

incised into older peat (or sand) deposits; (3) flood basin deposits, consisting of heavy clay, on a layer of older peat; (4) deposits resulting from bursts of natural levees (crevasse channel and splay), consisting of a mixture of gravel, sand and sandy clay (Fig. 3.6 from Hesselink, 2002). The difference in elevation between the levees and the flood basins is only a few metres, but the hydrological and ecological differences are remarkable. The elevated levees are rich in calcium and have a favourable water household for agricultural use, i.e. not to dry during summer and not to wet during winter. Land use was (and still is) characterised by arable fields and in later centuries by orchards. The relatively lowly situated flood basins have a homogeneous clay profile, poor in calcium. The water household is unfavourable because the clay is hardly penetrable for water. The land use was (and still is) characterised by grassland and osier fields (alder and willow coppice). In Chapters 7 and 9 more details will be presented about the ecological history of this landscape.

The Rhine and Meuse basins of the Large Rivers in the Delta can arbitrarily be divided into two parts (Fig. 3.9):

(a) East: Rijk van Nijmegen, Land van Maas en Waal, Betuwe, Tielerwaard and Bommelerwaard, characterised by wide channel belts and small flood basins. Sandy river deposits prevail: large complexes of river dunes are present, particularly well developed around the river Meuse, up to the eastern part of the Land van Maas en Waal, and in the Rijk van Nijmegen where tens of metres high ice-pushed glacial deposits are noticeable (Fig.3.9).

(b) West: The sedimentation processes in the river basins roughly west of the line Utrecht-‘s-Hertogenbosch (Fig. 3.9) have been influenced by sea-level movements. This peri-marine area is characterised by narrow channel belts, wide peaty flood basins and clayish river deposits. Here and there parts of ancient river dunes protrude above the peat deposits, these are the oldest settlement sites (e.g., Alblasserwaard – Oud Alblas). The extensive wetland and bog-peat areas in the Central Delta were cultivated during the ‘cope’-exploitation in the 11th–13th century (Section 3.4.2), and either disappeared under water in the course of time (Chapters 4 and 5) or are in use as grassland.

The river Rhine enters the Delta east of Nijmegen and is artificially divided over the rivers Waal, Nederrijn (after 1707) and IJssel. The draining of the river-polders occurred from the late Middle Ages onwards almost everywhere artificially. The southernmost Rhine river area (Land van Maas en Waal, Bommelerwaard) drain into the Meuse, because this river is situated on *ca.* 1 m lower level than the Waal (Fig.3.9).

Old branches of the river Rhine, such as the (1) Kromme Rijn – Oude Rijn (in Roman times the main connection with the North Sea), (2) the Hollandse IJssel and (3) the Linge played an important role as medieval trade routes, but already in the late Middle Ages their river discharge function was gradually diverted to the Waal–Merwede, and Nederrijn–Lek, and consequently the latter rivers were protected by dykes, ever-increasing in height (Fig.3.9). (1) The Kromme Rijn was

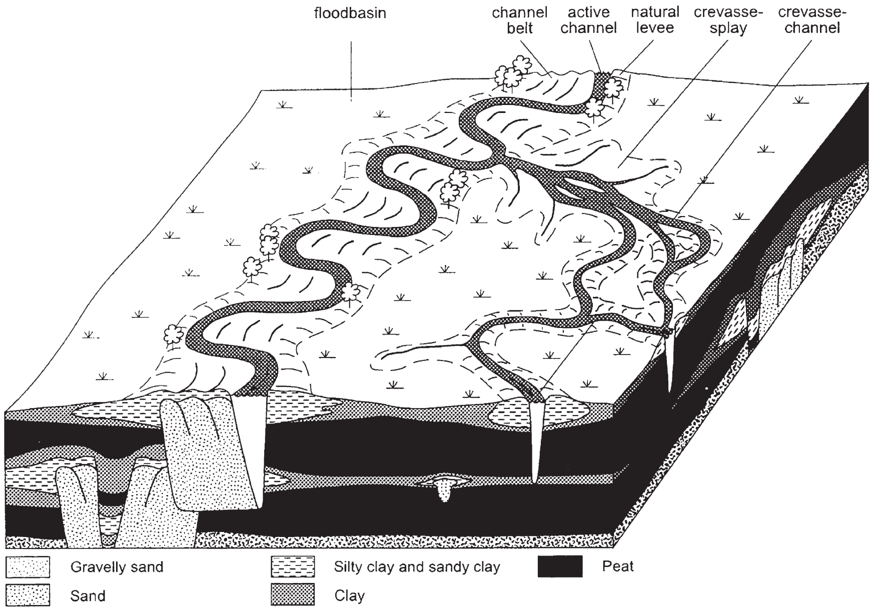

**Fig. 3.6** Model of the floodplain of the Delta Rhine before the building of embankments, showing several fluvial deposits (1–4 as mentioned in the text), on peat deposits (Hesselink, 2002)

never embanked; this river was already in 1122 dammed up near Dorestad (Wijk bij Duurstede). (2) Levees along the open river Hollandse IJssel, which originates at Vianen and debouches east of Rotterdam in the Lek, were already thrown up in the 12th century, and in fact before 1150 this river was embanked entirely. For centuries the Hollandse IJssel formed a main branch of the river Rhine, but because this river was dammed in 1285–1290, the levees have not been heightened thereafter. Since then the discharge function was diverted to the river Lek. Between 1300 and 1450 the draining of the peatlands gradually shifted from the Oude Rijn area to the Hollandse IJsel area, and a considerable number of canals, drainage channels and trenches were dug and sluices were constructed from the second half of the 14th century onwards. Gradually, the dammed river Hollandse IJssel became shallow and parts of it grew solid by peat formation, which decreased the carrying capacity for water remarkably. (3) The floodplains along the small Linge river, originally running from Tiel to Gorinchem, and later on extended in between the Nederrijn and the Waal, another important trade route, were protected with levees, but because this river was dammed up in 1305–1307, the dykes have not been heightened thereafter (Fig. 3.9) (Berendsen, 2000).

In summary, around 1350 all main branches of Rhine and Meuse were embanked (Fig. 3.9) and consequently the unhindered drainage of superfluous water from the ‘waarden’ ceased. The ‘waarden’ were protected against unwanted river floods from the ‘outside’, but at the same time the ‘inside’ water problem aggravated. Moreover, in the Central Delta the continuing subsidence of the ground-surface forced the landowners to enhance their drainage systems. The invention of the polder watermill brought a solution to this problem, and rather soon large-scale use of this new technology was made, for example, in the Oude Rijn area east of Leiden, 15 watermills were built and set in operation already before 1500 (Giebels, 1988).

The closure of the ring-dykes around the ‘waarden’ in the late Middle Ages gradually introduced yet another problem that would become a major burden. River floods became a regular nuisance: during peak discharges the water level in the riverbed, between the dykes, rose higher and higher owing to the building of river dykes and the annihilation of vast areas of floodplain (see Chapter 9). In hindsight we may say that man has created his own flood problem that is worrying water managers until the present day, and decisions about the building or reinforcement of levees and dykes were mostly taken after flooding disasters. Van de Ven (2004) suggests that the foundation of water boards, governmental bodies charged with the execution of water management, was the most important administrative development in the 13th century. These institutions could force local authorities to maintain the levees and sluices, and the drainage system of an entire dyke-ring.

## 3.6 Trade Routes in the Late Middle Ages

### *3.6.1 Trade Routes Water-Oriented*

The main trade routes at the end of the Middle Ages took without exception advantage of the existing river systems (Fig. 3.7; De Rek, 1973). The main rivers Meuse and Rhine (via IJssel, Nederrijn-Lek and Waal), and Scheldt were the paramount routes for foreign trade. The old Kromme Rijn – Oude Rijn route was closed at the end of the 12th century, and the Hollandse IJssel was dammed in *ca.*1285. A well-developed trade route crossing the Delta, the wool route from England via Calais to Leiden, was in use, and another important route led via the Zuiderzee to the Baltic states (Fig. 3.7). All market places and pre-industrial settlements were water-oriented. Trade over land, to the north and to the east was very restricted; there were only a few good roads, and most transport lines over land were of bad quality.

Around 1250 a considerable number of canals were already dug, creeks and gullies were dammed, or provided with sluices, in order to control the rising water outside the polder. These sluices were technically outstanding constructions (Fig. 3.8), consisting of wooden beams and shelves, and equipped with wooden valves or doors. The weaker point was the foundation technique; the insight in the properties of soil characteristics and groundwater flows was insufficient in those days

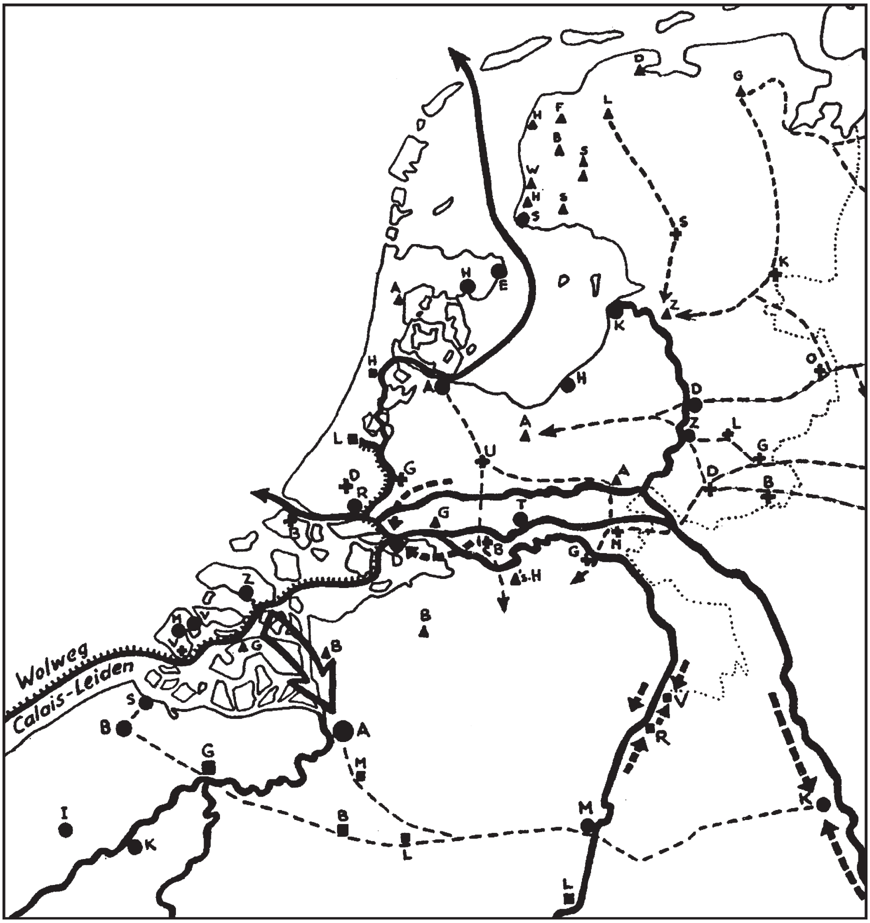

**Fig. 3.7** Map of the Delta at the end of the Middle Ages, showing the main trade routes, coinciding with the rivers (thick black lines). Dashed lines = trade routes over land. Black dots = main international trade harbours; squares, triangles and crosses = various smaller trade markets. Along the river IJssel: K = Kampen; Z = Zwolle; D = Deventer; Z = Zutphen; along the river Nederrijn: A = Arnhem; along the river Waal-Merwede: N = Nijmegen; T = Tiel; B = Zaltbommel; G = Gorinchem; along the Meuse (Maas): M = Maastricht; R = Roermond; 's-H = 's-Hertogenbosch; along the wool trade route Calais to Leiden, from south to north: D = Dordrecht; R = Rotterdam; G = Gouda; L = Leiden; H = Haarlem; A = Amsterdam (De Rek, 1973)

(Van de Ven, 2004). To build a lock with lock-gates on both sides and with a lock-chamber in between was a technical masterpiece. A large lock has been found at Spaarndam in the river Spaarne close to Haarlem (Fig. 3.7). It was part of the important shipping route from the SW Delta via the inland waters and canals to Haarlem and further to the Zuiderzee (Fig. 3.7), avoiding the risks of the erratic and stormy North Sea.

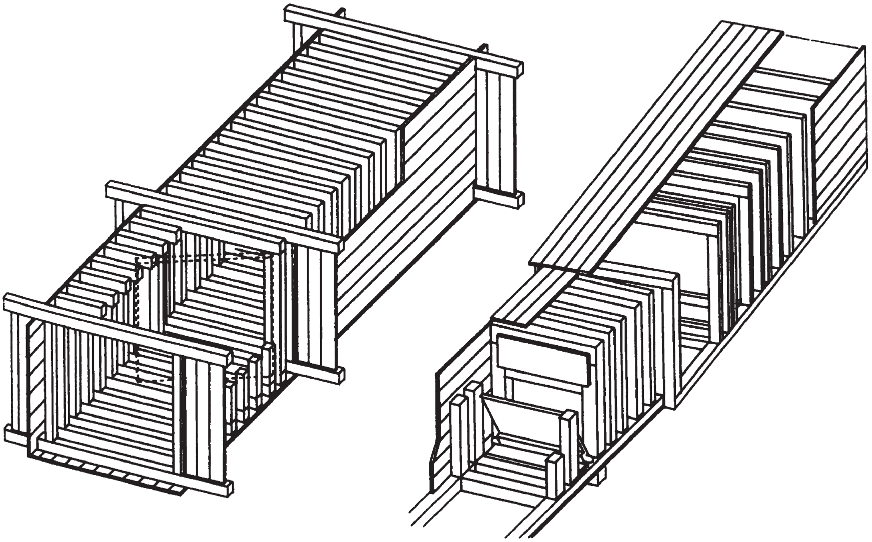

**Fig. 3.8** Reconstruction drawings of two wooden culvert-sluices (3 × 3 m.) dating back to the 13th century, equipped with valves and doors. The culverts were situated penetrating a medieval levee at the mouth of the river Rotte (near the present city of Rotterdam). The remnants have been excavated respectively in 1942 (right) and 1991 (left) (Van de Ven, 2004)

### *3.6.2 The IJssel Trade*

It is generally assumed that the IJssel formed the continuation of the Oude IJssel (Fig. 3.3) and that only later on a connection became established between the Rhine and the Oude IJssel. The actual point in time at which the IJssel started to function as a branch of the Rhine is a debated issue, connected to the assumed digging of the Drusus canal, the Roman connection between the Rhine and the IJssel (cf. Chapter 2). It is not sure whether the river IJssel had a navigable connection during Roman times with the Almere, an expanding semi-tidal lagoon, bordered by vast peat areas. During transgressions of the sea the Almere lagoon grew, and became a tidal inland sea, the Zuiderzee (Fig. 3.3). Palaeographic reconstructions covering the period AD 300–750 show that at that time the tidal delta of the river IJssel connected the river to the Zuiderzee (Berendsen, 2000).

Considering the existing trade routes it is unlikely, according to Heidinga (1987), that the IJssel formed a navigable waterway from the Rhine to the north in the 7th and first half of the 8th century, while it is certain that this was indeed the case in the second half of the 9th century. In the late Middle Ages the IJssel became the obvious trade route from the Rhineland to the Baltic Sea region. Deventer was an important trading centre in the Northern Netherlands in the 10th and 11th century; only in the 12th century was it surpassed in this respect by Utrecht. The inhabitants of Deventer were active in the Rhine trade and in the overseas trade

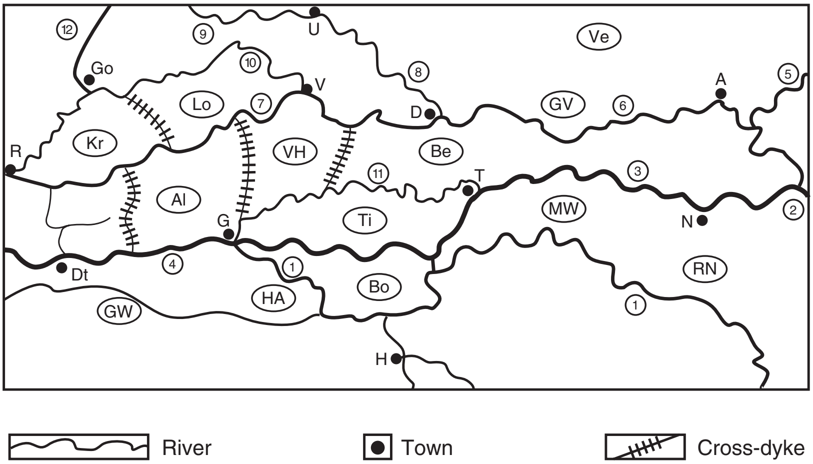

**Fig. 3.9** Reconstruction of the area of the Large Rivers around 1350 (inset from Fig. 3.3). All rivers were completely embanked, and the ring-dykes around the river-polders were completed, resulting in the ground plan of the present-day river system, with the exception of the Grote Waard, that was flooded in 1421, and since then only partially reclaimed (derived from Lambert, 1985 and Van de Ven, 2004). A = Arnhem; D = Dorestad; U = Utrecht; V = Vreeswijk; Go = Gouda; R = Rotterdam; N = Nijmegen; T = Tiel; G = Gorinchem; H = ‘s-Hertogenbosch. 1 = Meuse (Maas); 2 = Rhine (in the Delta Rijn); 3 = Waal; 4 = Merwede; 5 = IJssel (Oude IJssel not shown); 6 = Nederrrijn; 7 = Lek; 8 = Kromme Rijn, dammed in 1122 at Dorestad; 9 = Oude Rijn; 10 = Hollandse IJssel, dammed in 1285–1290 at Vreeswijk; 11 = Linge, dammed in 1305–1307 at Tiel; 12 = Gouwe; Ve = Veluwe; GV = Gelderse vallei; Be = Betuwe; VH = Vijfheerenlanden; Al = Alblasserwaard; Lo = Lopikerwaard; Kr = Krimpenerwaard; RN = Rijk van Nijmegen; MW = Land van Maas en Waal; Bo = Bommelerwaard; Ti = Tielerwaard; HA = Land van Heusden en Altena; GW = Grote Waard, including the present HA. Important cross-dykes protected the water-board areas from floods coming upon them from upstream. The cross-dyke between Vijfheerenlanden and Betuwe is the Diefdijk (1284); the cross-dyke Zouwendijk (1277) separates the Alblasserwaard from the Vijfheerenlanden

with England and especially Scandinavia and the Baltic Sea region. In the IJssel region, in the course of the 12th–13th century, Deventer had to compete with other towns: Zutphen, Zwolle and especially Kampen (Fig. 3.7). In this period the IJssel undoubtedly formed the main artery of commercial traffic in the northern Delta, stimulated by the Hanseatic league, a large medieval organisation of tradesmen. The Hanseatic league covered a large area, from the lower Rhine (Köln), via the IJssel, and the Zuiderzee, along the North Sea (rivers Thames and Elbe) to the Baltic Sea coasts. Its stimulus was the growing demand for trade goods, triggered by the increasing human population in Western Europe between 1,000 and 1,300, and the economic role of growing towns as centres of the non-agricultural production and trades. The tradesmen sailed in convoys over sea and sold, e.g. salt and herring (there were 140 Lent days per year), and returned to the Delta with corn, flax, hemp, tar, wax, furs and many other products (Hammel-Kiesow, 2004).

### 3.6.3 Iron, Forests and Rivers

A remarkable early industrial activity in which the Large Rivers played an essential role, was the extraction of iron ore and the production of iron, dating back to the 7th century, and presumably already experienced in Roman times. This trade, particularly the export, was very much favoured by the presence of navigable rivers. The iron ore extraction was originally concentrated in the southern part of the Veluwe, an elevated area of Pleistocene cover sands and glacial deposits (Fig. 3.3; Fig. 2.8; Chapter 2). Two sources of iron ore were available, 'klapperstenen' and iron bog ore. 'Klapperstenen' (literally: 'rattling stones'), are lumps of limonite, that is, sand-grains cemented together by iron ore as concretions in sand or sandstone that occur in ice-pushed glacial deposits in various regions including the Veluwe. Iron bog ore originates where iron-bearing groundwater keeps on coming into contact with the aerated sand deposits, so that oxidation occurs and eventually an iron layer becomes built up (iron [bog] ore $xFe_2O_3$ $yH_2O$). The production of iron on the Veluwe, which is only known to us from archaeological evidence, must have been very important for the economy of the Veluwe and the connected Rhine branches, and the social stratification within this area, up until *ca.*1200 (Heidinga, 1987).

The heyday of the iron trade of the Veluwe must be placed from the 7th to the 10th century: the period of population expansion and flourishing trading activities in the Delta, and also the period when the iron producers of the Veluwe were essentially in a monopolising position here as far as surplus production was concerned. Undoubtedly, a considerable proportion of the produced iron was transported not only along the river Rhine to the south, but also via the Lek, the Kromme Rijn and the Oude Rijn to the west, and across the Vecht to the north (Figs. 3.3 and 3.9). The biggest customer in this period was probably Dorestad (Wijk bij Duurstede) (Fig. 3.9). The trading of iron via the IJssel traffic appeared to have been of less importance and probably only took place in the late 8th and in the 9th century. As the transport of bulk goods on the Large Rivers increased, the constraint of the geographical distance between the producer and consumer increasingly diminished.

Why the iron industry on the Veluwe came to an end in the course of the 12th century is not altogether clear. It might have been a combination of the competitive exploitation of remote resources and enhanced foreign trade. The most important reason for the end of the iron industry on the Veluwe was probably shortage of fuel. In the smelting furnaces enormous quantities of charcoal were burnt. The reconstruction of an iron smelting process at a central Veluwe spot revealed a large slag heap (i.e. refuse from the iron smelter, amounts of slag and fragments of furnace walls), where at least 650 t of charcoals were burnt, that would have required the felling of more than 100,000 trees. It was thus the iron industry that was primarily responsible for the severe deforestation of the Veluwe that was conducive to sand drifting on a vast scale. It is noteworthy that the earliest incidences of sand drifting have been ascertained in or near the iron-producing region (Heidinga, 1987).

### 3.6.4 Urbanisation in the Late Middle Ages

In Chapter 2, it is explained that the end of the Roman occupation ushered the loss of urban structures, in particular the towns. The centuries following the Roman period were characterised by decentralised authorities, spread over the country. In the course of the Middle Ages, however, the process of urbanisation started again, and – with ups and downs – continues until the present day, a process that has been decisive for the ecological history of the Rhine–Meuse Delta. All important medieval trade markets were founded on a river. It is therefore necessary to devote a few paragraphs to the early urbanisation in the Delta.

Already during the Roman period the Delta of Rhine and Meuse was relatively densely populated (Fig. 2.7), but the late Middle Ages must have been a glorious time for the river area, considering the numerous (expensive!) brick buildings that have survived the ages. The Romanesque period (1050–1200), which was heralded by the stone churches, encompassed both large cathedrals (Maastricht on the Meuse; Fig. 3.7) and smaller village churches. While Gothicism (1254–*ca*.1600) had started to replace Romanesque in the north of France since the middle of the 12th century, it took almost another century before the style reached the Rhine–Meuse Delta. Here, it marked both profane and religious medieval architecture, but most of the style's surviving buildings are churches. The former cathedral of Utrecht on the Kromme Rijn is one of the first Gothic churches in the Netherlands. The construction of this church started in 1254, and it took decades to finish it (www.archemon.nl).

Brick churches were erected on the most elevated, stable spots in the floodplain, natural levees and sandy channel belts. They functioned as a refuge for people from the settlement in times of flood peril. The reward for the local population living under flood-prone circumstances was fertile soil and plenty of wood. A considerable number of towns and villages in the Delta of Rhine and Meuse proudly have smaller or larger Romanesque and Gothic churches, nowadays well-preserved landmarks in an agricultural setting of pastures, maize fields and orchards.

Rackham (1986) studied the environmental history of the English countryside. The history of the wetlands in Lincolnshire and Cambridgeshire is to some extent comparable with the development of large parts of the Delta of Rhine and Meuse. I think that Rackham (1986) hit the nail on the head when he formulated: 'Wetlands are a classic example of how historians can be lured into error by paying undue attention to the written word, especially in its more abstract and literary form (cf. what Roman writers published about the Dutch Delta – Chapter 2). Fens have had a bad press, and the material discomforts of fenland were copied and elaborated down the centuries by upland writers who despised a way of life that was not their own. Fen-men were depicted impressionistically as a race apart, fiercely independent, ague-ridden, web-footed, who lived precariously on birds and fish. This story has been repeated on countless occasions down to our own time. But how is it to be reconciled with the glorious churches and the great abbeys and other magnificent medieval buildings in Lincolnshire and Cambridgeshire? All these show that the real heyday of fenland was in the 12th and 13th centuries, a time when fenmen, remote from political upheavals, enjoyed civilised prosperity and could afford splendid architecture. Most of the capital works already existed by 1250 and are known chiefly from archaeology. The greatest fenland engineering work of any period is not documented at all; from written records we would hardly know of its existence'.

Bitter (1991b, d) distinguished three urbanisation phases. The first phase concerns the economic specialisation in the early Middle Ages, expressed in the foundation and growth of trade markets. This development induced an early urbanisation in the period 950–1250, particularly along the main trade routes. The second phase is covering the 13th and the first half of the 14th century, in which important economic changes together with the active role of the territorial (regional) authorities enforced an avalanche in urban developments. In the second half of the 14th century a third phase emerged, in which the development of some towns stagnated, and in contrast sea harbour towns saw a spectacular development.

1. The period 950–1200: early urbanisation. Until the 8th century the rural economy of the Delta was mainly self-sustaining, to that extent that the farmers produced food, furniture, cloths and tools for their own use. In the course of time more and more craftsmen separated from the dominant rural settlements and settled in trade centres, preparing tools and luxury articles from foreign resources, such as milling stones and ironware. These local trade centres functioned as nuclei for the early urban developments in the 11th and 12th centuries, all of them situated along the main trade routes, the rivers; along the Meuse: Maastricht, Roermond, s-Hertogenbosch (see Chapter 11) and Dordrecht; along the IJssel: Arnhem, Zutphen, Deventer, Kampen and Zwolle; along the Waal: Nijmegen, Tiel, Zaltbommel and Gorinchem; along the Rhine (Kromme Rijn – Oude Rijn): Utrecht and Leiden, and several harbours along the Zuiderzee (Fig. 3.7).
2. The period 1200–1350: explosive growth. It was again the development of the economy that formed the stimulus for the ongoing urban developments. The economy expanded, the number of people to be sustained grew and the need to use remote resources grew also. There was yet another economic incentive which favoured the development of the towns, compared to the countryside. The territorial authorities, the owners of the land, realised the importance of revenues from toll-rights and market-rights, and they enhanced their income by the provision of municipal rights to the expanding towns. Around 1200 large parts of the Rhine and Meuse basins were already deforested, because of the insatiable need for wood, both for timber and fuel, which meant that timber had to be imported from stream upward parts of the Rhine. An important trade that favoured the growth of urban centres was the textile trade. The processing of raw wool, the weaving and dyeing of woollen products, was an expanding trade offering labour to thousands of craftsmen. Wool from England and Scotland, being of better quality than the local wool, was imported as a bulk resource (see Fig. 3.7: the wool trade route from England via Calais to Leiden). Following the rigorous changes in the landscape, particularly in the western part

of the country, exploitation of the raised bogs, cultivation of arable land, subsidence of the land, water nuisance, land loss, etc., farmers were forced to change their original trade to peat digging and cattle farming. In order to feed the growing population this led to a greater dependence on imported corn, which was mainly sailed in from the Baltic countries.

The foundation and the growth of the town of Gouda, the 'wettest' town in the Delta, situated in the centre of the peat marshes, is a good example of prosperous development, fully decided by the presence of natural resources and navigable watercourses. The town of Gouda is strategically situated on the Hollandse IJssel and the Gouwe, an artificial channel connected to the Oude Rijn (Fig. 3.9). Around the year 1000 the area was still not brought under culture. The marshy land was covered by an impenetrable marsh forest and intersected by creeks and peatland rivulets. The Gouwe was a narrow peat-river, and along its banks the early peat extractions took place probably from the 9th century onwards. The town was founded on an elevated sandy outcrop in the low-lying peatlands of the Gouwe. While the settlement Gouda was growing, the demand for proper trade routes was increasing, and around 1225 the Gouwe was connected with the Oude Rijn by means of a canal. Tidal movements twice a day on the Hollandse IJssel forced the town council already in the 13th century to build sluices between the harbour and the inner town. Merchandisers between Flanders and France in the south, and Holland and the Baltic Sea in the North used the route through the town, leading to prosperity for Gouda already around 1350 (Fig. 3.7). The entire economy of Gouda was dependant on the shipping route through the city, the Gouwe. A quarter of the workmen of Gouda worked on a ship and most of the remaining craftsmen earned a living in trades connected to the inland navigation (peat traders; sail-makers; market-porters; beer-brewers; cloth-manufacturers; financiers). The 80-years War (1568–1648) gradually destroyed the Gouda economy, because the inland navigation to the south became idle, owing to political measures that made the vital Flamish selling market inaccessible for trades from the north (Sprokholt, 2004).

3. 1350: Stagnation and new developments. The explosive growth of many Dutch river-towns in the 13th century made way for stagnation in the second half of the 14th century. Causes for this phenomenon have to be searched in the changes in navigation. Because pictures and descriptions of ships were rare and without details until the 16th century, ship-archaeology has to provide most information (Elmers, 1972). Until the 12th century small, shallow ships were used both for river trade as well as for coastal navigation. The growing economy demanded bigger ships, and in the 13th and the 14th century the 'kogge' a larger trade-ship with several decks and a greater capacity sailed both the rivers and the coastal areas. In the 14th century specific ships were developed for seagoing trade, but these ships were too heavy-draught to sail the rivers. Consequently, this led to transhipment of goods at the river mouths. The inland navigation on Nederrijn, Lek, Waal, Merwede, Meuse (Fig. 3.9) and Schelde (Fig. 3.3) with smaller boats was then separated from navigation on the North Sea and the

Baltic Sea, and along the coasts of France, Portugal, Spain and other Mediterranean countries. This led to stagnation in the growth of the river-oriented market towns. In contrast, towns that had a navigable connection with the open sea, like Kampen, Dordrecht and Amsterdam (Fig. 3.7) have expanded their activities (Bitter, 1991d).

## 3.7 Land Loss

### *3.7.1 Land Loss Owing to Human Occupation*

There are no direct records of river floods before 1200. This makes sense because, at that time, rivers were largely not provided with dykes. The overtopping of the riverbank by a flood was not considered a disaster. The first river flood that has been recorded in historical sources is the breach of the dyke at the northern side of the river Lek in 1233 (Van de Ven, 2004). This is in sharp contrast with the loss of land in the coastal areas of the Delta, under dominant influence of the sea. Between 800 and 1,250 large areas in the NW and SW Delta were lost. For a long time this land loss was ascribed to oscillations in sea-level rise, transgressions of the sea. Other experts were of the opinion that storm surges increased in number and in force. Van de Ven (2004) is of the opinion that owing to a combination of factors, of which human occupation in the most important one, the massive loss of land in the late Middle Ages can be explained. It is a common belief that the larger part of the coastal areas in the Delta is land that was reclaimed from the sea, but the opposite is true. In fact, we unwittingly allowed the sea to take vast areas that were originally situated above the level of the sea.

Centuries-long cultivation and draining of the coastal peat moors caused large parts of the coastal areas to compact and to subside, and in many areas the surface level was gradually lowered over a distance of some metres (see also Chapter 2). In the peat areas proper the reclamation and exploitation of peat was the main goal; in the clay-on-peat areas in the SW Delta it was mainly caused by peat cutting from underneath the clay deposits. Due to this continuous lowering of the surface level large areas fell a prey to tidal forces. On the rhythm of the tidal currents the sea inlets were scoured out, and because of these eroding forces the sea regained access to the now lower-situated land. Storm surges that could encroach via the widened and deepened sea inlets accelerated the process of increased sea influence. It is therefore not surprising that after the year 1000 devastating storm surges, originating on sea, were regularly recorded. In a continuous struggle to defend their fertile land the settlers tried to mitigate the threat of being flooded by building higher and stronger levees. At the end of the 16th century land loss was at its deepest point, and in the centuries thereafter, vast areas of land were reclaimed again and embanked (Chapter 9).

According to Van de Ven (2004), in the late Middle Ages the potential structure and the skills of water management in the Rhine–Meuse Delta had emerged, and it was only a matter of continuing along the pegged-out lines of reclaiming land from the sea and from the rivers, and building ever-stronger and ever-higher dykes. The consequences of the subsidence of the ground level in the reclaimed polders and 'waarden' were partly compensated by the introduction of the technique of draining by means of wind–water mills, by building locks, sluices and weirs, to control water levels, and by digging ditches and major watercourses for the effective run-off of water. From autumn to spring, however, large parts of the Delta remained inundated, owing to superfluous rainwater, seepage and high groundwater levels.

### *3.7.2 The Zuiderzee*

In the early Middle Ages the NW Delta was covered with vast raised bogs, peat moors and fens (Chapter 2). In the period between AD 750 and 1300 the majority of the peat marshes were cultivated, in a way comparable to the 'cope'-exploitation, described in Section 3.4. Before 1250 almost all present towns and villages were founded. Very little is known from that period, because there are hardly any written documents available, but the labourers, for sure, got through an enormous amount of work. Technically speaking, the first step in the exploitation of the bogs was the digging of a complex of draining ditches, and to that purpose numerous parallel trenches were cut, as can be reconstructed from excavations and from present-day characteristics of the landscape (Knol, 1991b). Kwaad (2005) calculated that an area of 800 km$^2$ of peat moors was exploited, which meant the manual digging of roughly 8,000 km of draining ditches. After that the marshlands were devoid of their natural vegetation, including the cutting of sods from the soil, and grubbing-up of the tree stumps. Only after these toilsome actions the colonists could spend their time to the cultivation of corn.

Around 1200 the peat surface was so far-levelled and subsided that the drainage of rainwater became a problem, and that subsequent storm surges attacked the land. It became necessary to throw up levees and to protect the reclaimed fields by ring-dykes. The continuous struggle against the sea that started in the 12th century never ceased, and continues until the present day. The well-known Westfriese Omringdijk (see Fig. 4.5) was finished in 1250, and it suffered from several dyke-bursts in subsequent centuries. In the early 15th century the first small windmills came in operation, facilitating the draining of the polders. Around 1550 the farmers started to drain the smaller lakes, and later around 1600 the larger ones (Chapter 4).

In the second half of the 12th century, presumably during the storm-flood of 1170 the peat area in the NW Delta was engulfed by the sea and (what is later called) the Zuiderzee was formed. Repetitive storm-floods ravaged the area, and the tidal gullies connecting the Zuiderzee with the Wadden Sea (Fig. 3.3) deepened and widened in the period 1150–1250. Gradually, it can be said, that the NW Delta was attacked in the back by the North Sea. The small peat brooks Schermer and

Beemster were widened and deepened by scouring currents and wave forces, and grew into inland lakes, connected to the growing Zuiderzee. In the 14th century these lakes have been disconnected from the Zuiderzee one after the other by closure dams (see Chapter 4; Cools, 1948; Knol, 1991b; Van de Ven, 2004).

### *3.7.3 The South-Western Delta*

The gaining of salt from salt-saturated peat (‘selnering’) in the SW Delta was already known from Roman times onwards (Chapter 2), but it became a large-scale and professional business in the later Middle Ages; large quantities of salt were exported to foreign countries. The cut lumps of peat were dried, and burnt to ashes (‘sel’), transported to the salt-works, where the ‘sel’ was mixed with seawater, heated and processed to pure brine. Peat digging (‘darinck delven’) became thus a lucrative trade, and thousands of hectares of peatland have been dug off in the course of years. The deeper the sea penetrated into the peat massive, the more the peat became saturated with salt, which raised the economic value of the resource considerably. The removal of the protecting peat barrier on the seaward side of the levees surrounding the gained polders, however, increased the potential danger of being flooded by the sea. Gaining peat meant short-term profit for the landowners, but on the other hand it increasingly meant a threat for the safety of the human population and their goods behind the dykes. This dilemma was often decided in favour of the landowners, and consequently large parts of the embanked land were taken by the sea again (Van der Ham, 2003). In terms of ecology, the original peat cover disappeared gradually, and the estuaries as we know them nowadays emerged.

The most threatening method was called ‘vlettingen’. The peat diggers gained their resource preferably close to the dyke, because of the short transport lines. They transported the wet raw material with a rowing boat (‘vlet’) to the shore for the further processing of salt. The exploitation of peat banks close to the shore resulted in increased wave attack on the foreshore, which in turn enhanced the vulnerability of the levee. Another method which did great damage to the newly gained polders was throwing up levees of peat around an area, varying between 5 and 29 ha, that had to be exploited by the peat cutters. When the peat was removed, the sea was given free play, and via the excavated holes the tides could even more easily penetrate land inwards. Ecologically, the digging of peat did great damage to the environment, but economically the trade was very lucrative. The desire to make profit led even to risky circular arguments: by providing concessions for peat digging to the landowners, dyke repair and maintenance could be financed by the authorities (Van der Ham, 2003).

A classic example of the devastating effects of human greed is the destruction of the Grote Waard during the legendary storm-flood of 18 November 1421, known as the St. Elisabeth flood. The polder Grote Waard was embanked piece by piece in the 12th and 13th century (Fig. 3.9), a toilsome process that started with the building of small rural settlements on natural levees and channel belts along the main rivers.

Thrown-up earthen embankments protected the cultivated arable land until the next flood, which forced the farmers to improve their levees. The gained land was extensively drained, and this led inevitably to compacting and subsiding of the ground level. The vast peat areas surrounding the Grote Waard were gradually exploited, and this trade became even more profitable than the exploitation of arable land. The gaining of peat, cut in small lumps and dried, provided an excellent resource for fuel. As discussed above, in the later Middle Ages yet another way of exploitation of peat became of great economic importance, the ‘selnering’. The Grote Waard was threatened from two sides, the sea and the rivers. It has been recorded that the polder was hit by a major storm-flood or river flood at least every 25 years after 1134. The drama of 1421 cast its shadow before: subsiding of the embanked grounds which made them vulnerable for inundation, insufficiently maintained dykes not capable to protect the land, sea-level rise and exploitation of the vast peat areas in the SW Delta resulting in progressive attacks of storm floods from the sea. The entire polder Grote Waard was inundated in 1421, comprising a vast area of land of 400 $km^2$ east of Dordrecht, including the greater part of the present Biesbosch (cf. Chapters 10 and 18) and the Land van Heusden en Altena (Fig. 3.9; Van der Ham, 2003; Van de Ven, 2004). In Chapter 9 the consequences of the St. Elisabeth flood will be further elucidated.

The storm-flood of 1421 was a memorable one, but other devastating floods would follow. The storm-flood of November 1530, ‘St. Felix Quade Saterdagh’, swallowed large parts of the SW Delta. A most devastating flood was the ‘Allerheiligenvloed’ on November 1, 1570 that flooded large parts of the SW Delta (Chapter 9). The immense forces of tidal currents, the processes of erosion and sedimentation, and the increased frequency of storms led to the impressive loss of land along the Westerschelde, the gateway to Antwerp. The loss of embanked polders, originally attributed to the over-exploitation of peat, was too great a problem for the late medieval people. Before 1500 man could simply not cope with the forces of nature in an intrinsic dynamic and continuously changing estuarine landscape, owing to lack of knowledge and the absence of technical know-how (De Kraker, 1997).

## 3.8 Conclusions

- During the period 800 to 1500 the rough outline of the river landscape of the Delta was shaped: the ring-dykes around the river-polders (‘waarden’) were closed, and the ‘cope’-allotment was completed. However, very little has been documented from that period, and our knowledge is mainly based on archaeological findings, and late medieval historical reconstructions.
- Natural levees and sandy channel belts were relatively densely populated in the early Middle Ages. Numerous (still existing) towns and villages date back to (post-) Roman settlements. Impressive Roman and Gothic brick buildings indicate civilised prosperity, in an intense process of urbanisation and exploitation of the river floodplains. All medieval trade markets were founded on a river.

- In the Middle Ages an increasing quantity of wood was used as building material, and for fuel, actions which decimated the forests in the basins of rivers and brooks.
- Owing to sustained actions of reclamation, the riverbeds became gradually constricted between man-made earthen dykes. The rivers lost large areas of their floodplains by the actions of man, enhancing the amplitude between high water and low water. This problem became immanent soon after the first dykes surrounding the polders were closed, at the end of the 13th century.
- At the end of the Middle Ages the harnessing of the riverbeds, particularly the closure of the ring-dykes surrounding the river-polders, was so far advanced that the river basins of Rhine and Meuse occupied roughly the same macro-geographic position in the Delta as they do nowadays, however, in a still ‘empty country’.
- Around 1350 all main branches of Rhine and Meuse were embanked, and consequently the unhindered drainage of superfluous water from the ‘waarden’ ceased. The ‘waarden’ were protected against unwanted river floods from the ‘outside’, but at the same time the ‘inside’ water problem aggravated.
- Between the 10th and the 14th century the vast moorlands and raised bogs in the western part of the Delta were colonised. Large parts of the peat areas were systematically exploited in a relatively short period of time, between 950 and 1150. The ‘cope’-cultivation, changed the raised-bog wilderness into a meticulously laid-out wetland landscape.
- The drastic change in landscape structure around the 10th century is to be attributed to the increase of the human population. Between 800 and 1250 the population of the Delta, increased from 100,000 to 800,000 inhabitants. Climate changes are supposed to have played a crucial role in the history of the land-reclamation processes.
- Owing to the massive draining and digging of peat, large land areas compacted and subsided, became eroded by wave attack and disappeared under water, creating large, shallow lakes. The development of these peat lakes, created after centuries of too greedy peat extraction, is one of the best known examples of massive ecological damage induced by man. Because this was a gradual process, the phenomenon was not perceived as a disaster.
- Centuries-long cultivation and draining of the coastal peat moors caused large parts of the sea bordering areas to compact and to subside, the surface level was gradually lowered over a distance of some metres, and large areas fell a prey to tidal forces of the rising sea.
- Between 800 and 1250, large areas of land in the NW and SW Delta were lost, owing to a combination of factors, of which human occupation in the most important one. It is a common belief that the larger part of the coastal areas in the Delta is land that was reclaimed from the sea, but the opposite is true. In fact, we unwittingly allowed the sea to take vast areas that were originally situated above the level of the sea.
- The loss of embanked polders, to be attributed to the over-exploitation of (salt-saturated) peat, was too great a problem for the late medieval people. Before 1500

man could simply not cope with the forces of nature in an intrinsic dynamic and continuously changing estuarine landscape, owing to lack of knowledge and the absence of technical know-how. The invention of a new technology, the wind–water mill in the early 15th century opened up a new era of land reclamation.

- The Black Death (around 1350 and later outbreaks) should be ranked as the greatest biological-environmental event in the early history of the Delta.

# Chapter 4
# Technical Achievements in River Management (1500–1800)

## 4.1 Introduction

Until the late Middle Ages there was, of course, no organised 'river management'. Local problems demanded local solutions (Chapters 2 and 3). But the water problems that challenged the early inhabitants of the Delta expanded, and regional institutions were created, water boards having authority in matters concerning water management, such as the building and maintenance of dykes, draining and water regulation during peat reclamations and the development of the polders. The oldest water board dates back to 1255, Hoogheemraadschap Rijnland covering a large part of the Central Delta (Van Tielhof and Van Dam, 2006), and this makes these Dutch regional institutions one of the oldest democratic entities in the world still existing. During centuries the authority of the water boards was decisive for the measures taken to solve water problems. But the paradox is that this kind of 'water management', i.e. draining and dredging of peat-lakes, and harnessing rivers between higher and stronger levees, unbridled natural forces neither foreseen nor experienced before, i.e. land subsidence and increasing risks of river floods. Counteracting regional interests, centuries-long river abuse and neglect, and the failure of regional solutions to water problems regarding water discharge and navigation, led to the foundation of 'Rijkswaterstaat' in 1798, and that governmental body became the national authority for river management (Chapter 5). In the 18th century, 'Rijkswaterstaat' was preceded by a river-oriented institution in which several water boards participated, aiming at an inventory of the status of the river processes and measures to be taken (literally the status of the water = 'waterstaat', a term formulated by Cruquius in 1727;Van den Brink, 2003). Around 1800 river management became a national priority, instead of a regional one.

This chapter covers the period 1500–1800, characterised by technical achievements in water management, and ending at the advent of the industrial revolution. The introduction of technical improvements reached the Delta relatively late, around 1850, compared to England, where the invention of the steam engine around 1770 in fact heralded a new era. Until the 19th century, muscular strength of humans and animals (horses), sustained by wind- and water power, were the only sources of power that modelled and transformed the natural wetlands into semi-natural and

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cultural ‘waterscapes’. It was a time during which hundreds of kilometres of canals were dug by hand, thousands of hectares of peat were drained and dredged by hand, hundreds of kilometres of dykes were built by hand and numerous peat-lakes were reclaimed, facilitated by hundreds of wind-watermills. It was the time when writers started to document the trivial, daily events, for example, Constantijn Huygens (1596–1687), the famous writer, poet and diplomat, daily counted roughly 200 barges passing along the canal at the backside of his mansion Hofwijck, close to’s-Gravenhage, and he set his clock right on the track-boat that passed his house at eight o’clock in the evening (www.dbnl.org).

It was a time when waterways formed far out the most extensive and reliable network for transport of humans and goods. Socio-economic relations to and fro across rivers were very strong. But the capricious rivers silted up, and became unnavigable, and long canals, parallel to the rivers were dug in the early 19th century to enhance transportation (Chapter 5). It was a time of increasing mobility wherein a fleet of trading barges transported goods and passengers all over the Delta, and further to numerous international destinations. The track-boat, the passenger boat towed by horses or men, had its heydays in the period 1630–1700; in that period hundreds of kilometres of straight track-boat canals were dug. Owing to a lack of transport alternatives this network continued to be in use until 1850. Traffic over land was toilsome till far in the 19th century. The rivers were embanked, but the ‘waarden’ enclosed by the ring-dykes that had to be crossed by stage coaches and carriages, suffered from inundation and badly kept roads.

This chapter covers one of the most prosperous periods in the history of the Rhine–Meuse Delta, the 17th century, the Golden Age. It deals with the expensive and technically outstanding reclamations of peat-lakes and embankments of salt marshes. It covers the origin and the heydays of the windmill technology, and the track-boat for passenger transport, nowadays still seen as ‘typically Dutch’. It is also a period in which the first reliable descriptions of landscape and waterscape features, useful (and less useful) fish, and other animals and plants were published (see Chapter 8).

## 4.2 Dredging of Peat

The exploitation of the massive raised bogs and peat moors in the Central Delta, described in Chapter 3, has led to irreversible compacting and subsidence of the ground level. By digging trenches, water was removed from the upper layers of the soil, and owing to their own mass these layers were compacted. The de-watered bog rose above the groundwater level, and was exposed to the air, and started to shrink and to oxidize. Moreover, the pressure of (primitive) gear to cultivate the land enhanced the sinking of the ground level: All these factors together led to subsidence of the surface area of several decimetres per century. The groundwater level rose steadily, intensified by the relative sea-level rise, and hence corn-growing gradually became impossible. Around 1500, large parts of the western Delta were lowered down to sea level (Van Dam, 2001).

Starting in the 10th century the exploitation of peat was done on a large scale and systematically. In the beginning of the 16th century the raised bogs were almost fully exploited, and gradually turned into fens with peat-bog on the bottom. From that time onwards the peat was more and more scooped out of the shallow water, using a hand drag, a long stick with a net or a basket at the end. From a barge or a plank the wet spoil was pulled out of the water with the hand drag and thrown into the barge (Fig. 4.1). The scooping device allowed the workers to extract the peat more than a metre below the surface of the water. After that the drag-peat was spread evenly across a 'legakker', a baulk of land reserved for this purpose, and tamped down. When the peat had dried sufficiently, it was cut into the required shape. Finally, the turfs were stacked up in

**Fig. 4.1** A peat-cutter standing in his barge, using the hand drag, to dredge the peat from under the water surface (Etching from Luiken, 1694)

piles for further drying. Besides the 'legakkers', narrow strips of land with roads and linear settlements were left untouched (Van de Ven, 2004).

Peat dredging mainly took place in the Central Delta, later on in the NW and SW Delta as well (Fig. 4.2). How much peat was dredged can be derived from old

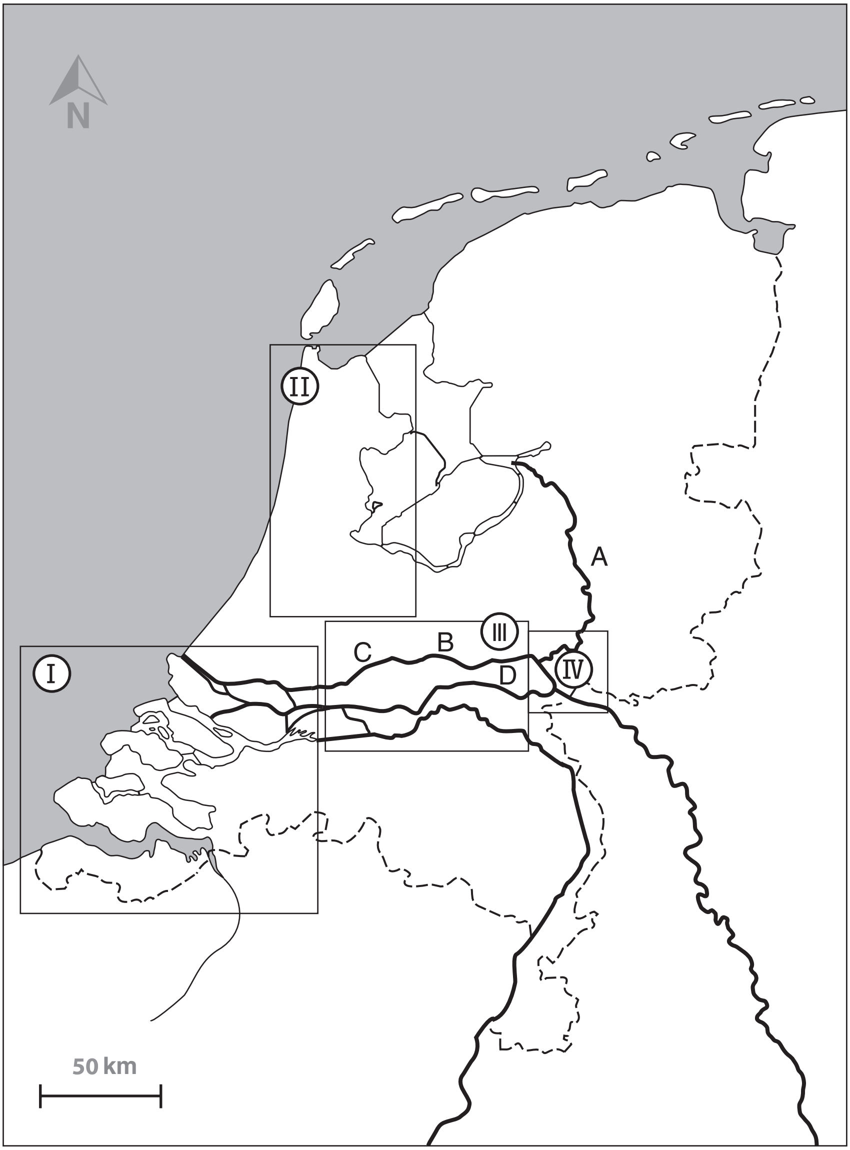

**Fig. 4.2** The Delta projected on an actual map of the Netherlands: A = IJssel; B = Nederrijn; C = Lek; D = Waal. Inset I: Fig. 4.4; inset II: Fig. 4.5; inset III: Fig. 4.11; inset IV: Fig. 4.8

archives, for example, in the area of Reeuwijk, northwest of Gouda (Fig. 4.4) statistics were kept from the period 1680 to 1860. The largest amounts of peat were dug in between 1770 and 1820, an annual production of 20,000 to 35,000 'roedes' (1 'roede' is *ca.* 14 $m^2$), i.e. 28–49 ha, indicating the speed with which the land disappeared under water. And these are only the statistics of Gouda. In other localities the peat was dug with the same speed. Peat digging was hard seasonal labour. The turfs (square lumps of peat) should not freeze, and this meant that one could start the digging of peat only after winter. Moreover, the turfs needed a couple of months to dry. There were in fact only 3 months a year, from early April to the end of June when the peat could be dug. During that period the mass of wet peat should be drained and compacted, cut in separated turfs and regularly turned upside down to enhance the drying process, then stacked up and loaded in peat barges. This labour-intensive work occupied 7 men and women per 1.4 ha of peatland from spring to autumn, and at the height of the season additional seasonal workers from other parts of the country were engaged (Kamermans, 1999).

The introduction of peat dredging has had both positive and negative effects. A positive effect was that dredging was a labour-intensive and capital-extensive branch of industry, providing work for many people and meeting the high demand for fuel. A negative effect was that dredging led to quantitative loss of land. The land that had been dredged turned into water and the remaining strips of ground could only be used as hay fields. In the course of time, due to the dredging of peat, numerous broads were formed in the Central and NW Delta. The broads were separated from each other by narrow baulks carrying the roads and buildings. Under the influence of wind and the wash of waves, the strips of ground disappeared at many places and the broads expanded into lakes. Needless to say, human settlements became very vulnerable to storms, eroding the remaining peatland. Some villages drowned and disappeared under water. Another problem was the continuous subsidence of the remaining strips of peat. An example is the village of Hazerswoude northwest of Gouda, situated within a reclamation dating back to 1765. In 1646 a church was built in this village with the floor and the entrance door on the ground level of that time. As a result of subsidence of the subsoil, the church door is now situated about 2 m above ground level. The town of Gouda underwent the same fate. In 1635 the water had encroached on the land surrounding the town to such a degree that dredging of peat was prohibited within a radius of 3 km around the town. Another negative effect was that peat dredging was only economically interesting in the short term. The lost lands, once turned into water, lost also the larger part of their economic value, and in the end only reclamation by pumping the lakes dry could check the danger of expansion of these lakes effectively (Van de Ven, 2004).

## 4.3 Windmills, 'Typically Dutch'

Windmills are said to have existed in Holland from about 1200. From time immemorial, wherever the land was inhabited, corn was grown. And where corn was grown, it also had to be ground for the preparation of bread. In the most primitive stage the corn was ground between two stones which were operated by manpower. In later ages cattle power was employed, as in the horse-mills, and finally the forces of nature were harnessed: wind and water. Watermills propelled by the running water of brooks, which occurred only in the eastern and southern parts of the country on the Pleistocene cover-sand grounds, probably existed before the windmills; their construction was much simpler than the building of a wind-watermill.

The oldest known document containing a reference to windmills is considered to be the privilege which was granted to the citizens of the town of Haarlem in 1274. But the real development of the windmill should be placed towards the end of the 16th and in the 17th century, and this growth was quite stormy. In those days windmills were as important for the Delta as are the numerous factories in the industrial regions nowadays. The invention of the art of printing had started an enormous demand for paper; imports of colonial produce had given rise to great activity and prosperity; new arable land had to be drained and opened up, and everything contributed to the high tide of the Dutch Golden Age (Stockhuyzen, 1962).

After 1400, when major sea-defences were built, and the connection of several waters with the open sea had been dammed up, it became possible to drain marshes and lakes. For this purpose wind-watermills were used, and accordingly they were built in constantly increasing numbers. Originally these were not yet the large mills as we know them, which date especially from the 17th century, but smaller ones. As windmills grew better and larger their water-lifting capacity increased and they became more numerous. In the 17th century the engineers in the Rhine–Meuse Delta made more and more progress in water management, and the windmills have played an all-important part in that enterprise for more than two centuries. Accelerated sea-level rise and unbridled peat digging had caused tremendous loss of land, and the inhabitants of the lowland Delta regained part of that land with the aid of wind-watermills. The drained lakes (‘droogmakerijen) and the ‘waarden’ surrounded by ring-dykes owe their existence, as well as their development, in the most literal sense to the draining capacity of windmills (Besselaar, 1974; Stockhuyzen, 1962).

The origin and development of the Alblasserwaard (Fig. 4.4; Fig. 3.9) is a good example to illustrate this statement. The ‘history’ of the Alblasserwaard started after the last ice age, roughly 10,000 years ago. The first humans settled in prehistoric times on wind-blown elevated river dunes protruding above the surrounding tundra-landscape and braiding rivers. After the Roman era the area became depopulated, but from the year 1000 onwards systematic draining and reclamation of the existing peat-moors transformed the marshy wetland into a regulated ‘waard’. The Alblasserwaard’s earliest long drainage canals were dug in the 11th century. In the late 13th century, a man-made ring-dyke already surrounded almost the entire area. Several river floods afflicted the ‘waard, and in the aftermath of a major flood in 1726, it became obvious that a considerable number of drainage mills were indispensable to keep the feet of the inhabitants dry.

The first wind-watermills were built in the 17th century, but their draining capacity soon proved to be insufficient. In 1738 a row of eight round, stone mills was built on the eastside of the main drainage channel at Kinderdijk (Fig. 4.4), connected to the water storage basin, and 2 years later, the same number of mills was erected on the west side, parallel to the first row. As the years went by, this complex grew with the addition of new mills, locks and pumping stations. This innovative hydraulic irrigation system acquired a reputation and became known as 'drainage by stages' (Fig. 4.6), a system of low- and high-storage basins, eventually draining off the water into the river Lek. First, the mills drained water in the lower storage basins and polders. Then, they channelled it to raised reservoirs. Lastly, the excess water passed through half a dozen of locks before draining into the river (Van de Ven, 2004).

The development in the early 18th century of the 'vijzelmolen', which could evacuate water from depths of up to 4 m working on the principle of the Archimedes' screw, added another dimension to the windmill technology (Fig. 4.3). It is assumed

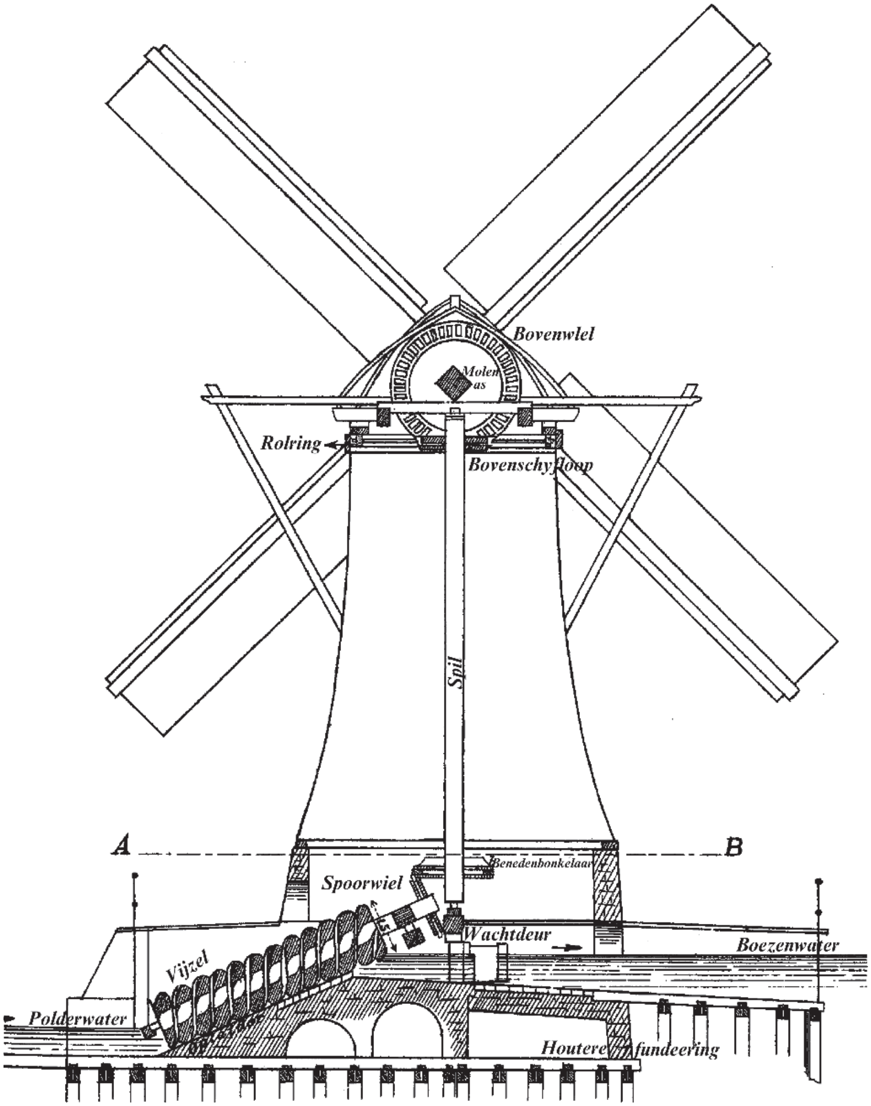

**Fig. 4.3** Cross section of a wind-watermill, the 'vijzelmolen' working on the principle of the Archimedes screw; to the left the polder to be drained, to the right the mill-race (Van de Ven, 2004)

that around 1860 some 9,000 windmills were at work in the Delta, the largest number that ever existed, and among them a considerable number of wind-watermills. After that time the number of mills decreased steadily, at first slowly, later on more rapidly. Towards the end of the 18th and in the early part of the 19th century the discovery and application of steam power caused a radical revolution in social economy, and this initiated the end of the supremacy of windmills as prime movers for all purposes. The introduction of the steam-pumping stations meant an important breakthrough for the water economy of the Delta. Until the 19th century large parts of the countryside of the low-lying Delta were flooded during winter and spring, simply because the (many) windmills could not cope with the drainage of the superfluous water. The use of pumping engines, however, allowed the water managers to almost totally regulate inland water levels, and the typical 'water landscape' in winter disappeared gradually. The first large-scale application of pumping engines was during the reclamation of the Haarlemmermeer around 1845 (see Chapter 5).

Now in 2007 the windmill is still considered as 'typically Dutch', and not unjustly. Although it can be said that windmills comparable with the Dutch design are to be found in other European countries as well (England, Belgium, France, Denmark, Germany, Finland), it has to be observed that their number is relatively small there. The Dutch windmills have suffered a terrible fate. From the 9,000 to 10,000 windmills in operation in 1860, today, just 900 remain. Indeed, it is nothing short of a miracle that so many mills in the Alblasserwaard at Kinderdijk have been preserved. In 1950, the Polder Administration was preparing to tear down all the mills that were 'out of service'. Replaced by diesel-powered hydraulic pumps that could evacuate water much faster, they were perceived as useless and too expensive to be maintained. But the worldwide renown they have acquired will help to assure their future. The Kinderdijk landscape symbolises an endangered species, the typical Dutch windmill. But for the people of the Delta, it also symbolises their never-ending struggle to keep their land dry. UNESCO inscribed the Kinderdijk network of windmills on the World Heritage List in 1997. The 19 remaining mills are still in operating condition. The site and its upstream and downstream polders, equipped with natural drainage systems, rivers and streams, windmills, pumping stations and spillways, have remained virtually unchanged since the 18th century. Today this typically Dutch landscape is officially protected as a cultural monument and a nature reserve (Van Duijnhoven, 2000).

## 4.4 Gaining Land from the Sea

The 16th century was a turbulent period for the lands of the SW Delta; their coasts were battered by frequent storm surges, with resultant widespread loss of land, leaving only the medieval cores of the island untouched. And also here, just like in other parts of the country, the windmill technology combined with improvements in the construction of seawalls, turned the balance. The 17th century is the period of two steps forward (reclamations) and one step backwards (land loss). The reclamation improvements in the Golden Age were so impressive that the dyke-builders were asked to practice their skills abroad, in England (Duursma et al., 1982). Notwithstanding serious setbacks, such as recessions during wartime and the expansion of the devastating shipworm that weakened many wooden dyke revetments (see Chapter 9), the archipelago in the southwest, as it existed until 1953 (Fig. 4.4), was gradually shaped particularly in the 17th and to a lesser extent in the 18th century. During the two centuries, roughly 130,000 ha of new land was reclaimed by embanking tidal salt marshes. In the 17th century (the Golden Age) alone, all over roughly 90,000 ha of land were gained on the sea in the SW Delta (Van Veen, 1950; Figs. 5.6 and 5.7).

Dordrecht had suffered greatly from the St. Elizabeth's flood of 1421 and the new creeks through the Biesbosch tapped the Merwede waters above the town, and consequently the old river channel passing Dordrecht became unnavigable at ebb

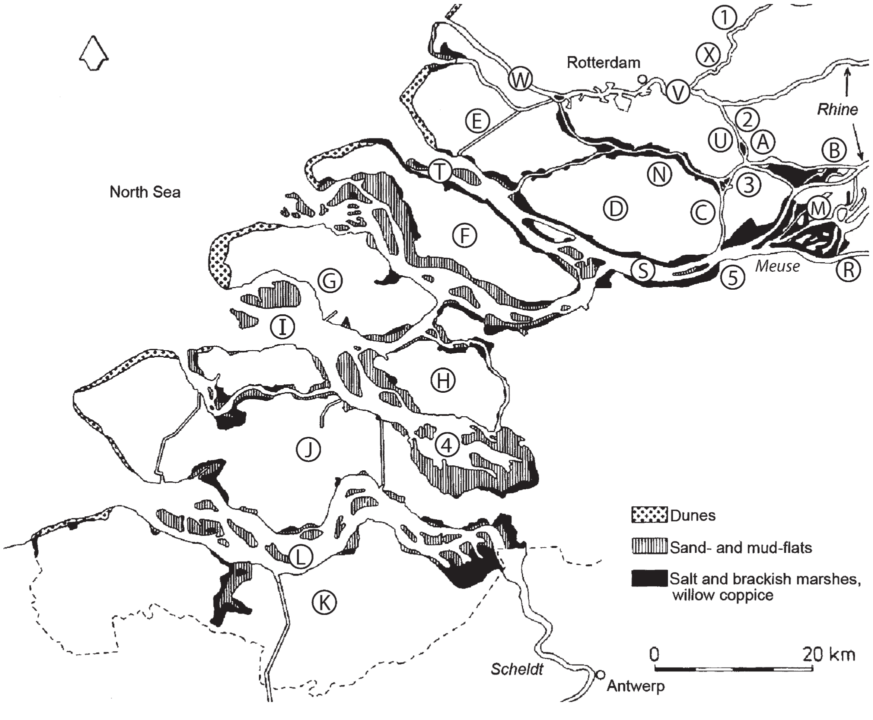

**Fig. 4.4** The SW Delta from the late 19th century to 1953, the resultant of the reclamations gained on the sea in 16th–19th century. 1 = Gouda; 2 = Kinderdijk; 3 = Dordrecht; 4 = Reimerswaal; 5 = Moerdijk. A = Alblasserwaard; B = Merwede; C = Dordtsche Kil; D = Hoekse Waard; E = Voorne-Putten; F = Goeree-Overflakkee; G = Schouwen-Duiveland; H = Tholen; I = Oosterschelde; J = Zuid-Beveland; K = Zeeuws-Vlaanderen; L = Westerschelde; M = Biesbosch (part of former Grote Waard, Chapter 3); N = Oude Maas; R = Bergse Maas; S = Hollands Diep; T = Haringvliet; U = Noord; V = Nieuwe Maas; W = Nieuwe Waterweg; X = Hollandse IJssel

tide. Repeated attempts to close the Biesbosch creeks proved abortive, and it was only when a natural channel was enlarged and deepened, the Dordtsche Kil (Fig. 4.4), that the town was able to resume its role as a major river port and centre of the timber trade and shipbuilding (Lambert, 1985).

The damage done by the St. Elizabeth's flood was slowly repaired. Some polders were successfully added to the Hoekse Waard already in the 16th century. To the west, Voorne and Putten were gradually enlarged, and by 1600 most of Flakkee had been reclaimed, although it remained separated from Goeree by a channel until the 18th century. Schouwen, and Duiveland were dyked together. Tholen, itself an amalgam of islets, survived though severely tested by the storm surges. In 1530 large areas of land (where nowadays the Oosterschelde is; Fig. 4.4), weakened by reckless peat digging, were swallowed by the sea. The walled town of Reimerswaal, situated in the centre of the drowned land, survived, but was deprived of all its transport connections with the mainland. Eventually, after decades of attempts to reclaim the area, followed by devastating storm floods, the town was given up in 1631. The island of Zuid-Beveland lost for good an extensive area in the east (Reimerswaal), but to the west, however, large parts were successfully reclaimed in the 17th and 18th century, and since then the island has grown by piecemeal accretion (Lambert, 1985; Fig. 4.4).

Much of Zeeuws-Vlaanderen, reclaimed by tremendous effort in medieval times, was lost in the 16th century. The whole coastline south of the Honte (now Westerschelde) was repeatedly afflicted by storm-tides, notably the St. Felix flood of 1530 and the Allerheiligen flood in 1570. The area also suffered greatly from deliberate inundations during wartime. Diking was resumed at the end of the 16th century, but lands to the west long lay open to the tides and it was only in the early 17th century that new dykes began to be raised along this coast. This process of successful reclamations continued in the centuries thereafter (De Kraker, 1997; Fig. 4.4; see Chapter 9).

## 4.5 Reclamation of Peat Lakes

In the 16th century the NW and Central Delta comprised a considerable number of lakes that were originated from subsided remains of peat moors, either swallowed by the rising sea, or filled with river water (Fig. 4.5). The fens and peat lakes grew as a result of peat-cutting activities, and a considerable number have been regained from the water by reclamation. The boom in the number of reclamations of lakes and broads had been made possible by the introduction of drainage by wind-watermills in stages (Fig. 4.6). A series of windmills was placed one behind the other and each mill lifted the water a bit higher, until finally it could be discharged into the water collection and transport system (as has been described in Section 4.4, the Alblasserwaard).

The reclamation of a peat lake was a complicated process. Around a lake that had to be drained, a ring-canal was dug and a dyke was built between the ring-canal and the lake. The dyke was built from the sediments that had been dug out of the

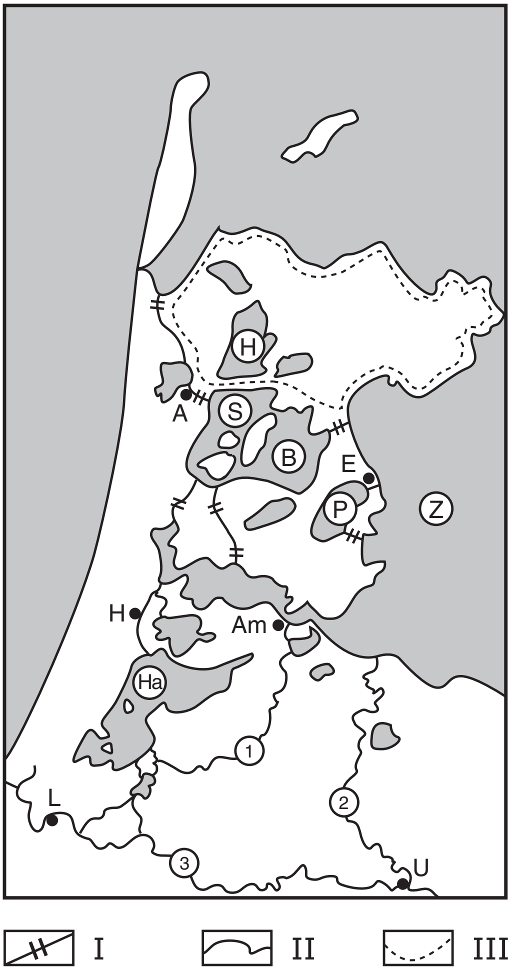

**Fig. 4.5** Part of the NW Delta in the early16th century, showing the lakes that came into existence after centuries of peat digging. All these peat-lakes have been successively drained and reclaimed from the 16th century onwards. A = Alkmaar; E = Edam; H = Haarlem; Am = Amsterdam; L = Leiden; U = Utrecht. H = Heerhugowaard; S = Schermer; B = Beemster; P = Purmer; Ha = Haarlemmermeer; Z = Zuiderzee. 1 = Amstel; 2 = Vecht; 3 = Oude Rijn; I = dammed water course; II = river; III = ring-dyke. The ring-dyke Westfriese Omringdijk, closed in 1250, is indicated. In the 14th century the larger lakes were separated from the Zuiderzee by dams. The open connections remaining, were the harbours of Edam, which was closed off around 1600 by ship locks, and Amsterdam which had an open fairway to the Zuiderzee until mid-19th century (Adapted from Cools, 1948)

ring-canal. Subsequently, the water was pumped out of the lake into the ring-canal by windmills. The peat lakes could be rather deep (*ca.* 5m – NAP), and when the work progressed a drainage by stages was applied (Fig. 4.6). The drainage water was continually pumped into the ring-canal which eventually discharged the water on one of the large rivers and then into the North Sea. When this entire draining process was finished after some years, the newly created polder was provided with drainage ditches, allotted into agricultural units and put into use. Before the wind-watermill era the only possibility of getting rid of the superfluous water was the natural fall by gravity, i.e. during low water at sea or during minor river discharges. But after the introduction of the wind-watermill, it remained necessary, in order to remove the water mass from the polders, to store the water in a big reservoir until it could be drained off into the sea (Van de Ven, 2004).

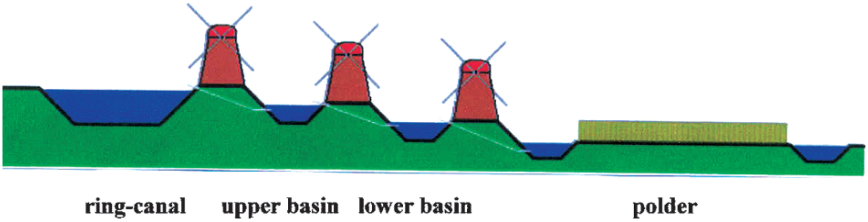

**Fig. 4.6** Drainage of a polder by wind-watermills operating in stages ('molengang'); for explanation see text (www.answers.com/topic/flood-control)

The first reclamation schemes of peat lakes started in 1533, and concerned small shallow lakes. The heydays of the making of the 'droogmakerijen', the drained lakes, were in the 17th century, the Golden Age. In that century it became technically feasible to reclaim large areas of peatland broads and lakes in large integrated projects. The first large-scale drained lake, and also the most famous one, was the Beemster, reclaimed between 1608 and 1612 (see Figs. 4.5 and 4.7). The rational planning and outline of the polder is reminiscent of existing techniques of the medieval drainage and cultivation of the peat bogs. During the creation of the 'droogmakerij' there was a convergence of developments which in a short time span brought about a shift from land reclamation to land planning. The Beemster presents the first instance of a master plan. An autonomous grid of squares was superimposed on the landscape. The allotment of the reclamations took place in a strictly rational and geometrical manner, as can be seen on an old map of 1696 (Fig. 4.7). This rational structuring principle was largely based on the ideal of the Dutch city formulated by Simon Stevin (1548–1620; Box 4.1). The scenic articulation of the layout was primarily expressed in the planting of lanes of trees along the main access roads. Extended lanes of alder and willow trees provided a vertical articulation of the grid in the form of square 'chambers' in the landscape. The square returns consistently in every man-made element of the Beemster, including the country estates and the traditional farmhouses. The rational allotment pattern was an all-powerful ideal in the Beemster. The same design principles can be found in later polders, e.g. Schermer and Purmer (Fig. 4.5), albeit applied more soberly (Vlassenrood, 2005).

**Box 4.1** Water managers in the 16th and 17th century

Simon Stevin (1548–1620)

Mathematician, engineer and town planner; he published a book on the construction of fortifications; he designed wind-watermills and improved the discharge of water from the town of Delft; he filed for a patent on a windmill for an alternate drive using horses when the wind dies down; he invented the sailing land yacht.

(continued)

**Box 4.1** (continued)

Hendrik Stevin (1614–1670)

Son of Simon Stevin; published in 1667 a plan to prevent flooding around the Zuiderzee, by damming the channels between the islands in the Wadden Sea. This plan was technically not feasible at that time, but the idea persisted and in 1889 a study was made of its technical feasibility (see Chapter 5).

Jan Adriaensz Leeghwater (1575–1650)

Hydraulic engineer and carpenter-mill builder, known from the improvement and building of watermills. He had an important share in the planning of the reclamation of the Beemster (1607–1612) and other 'droogmakerijen'. Leeghwater was among the first to advocate reclamation of the Haarlemmermeer; he published his 'Haarlemmermeerboek' in 1643. He launched numerous watermills operated by horses at the siege of 's-Hertogenbosch in 1629.

Menno van Coehoorn (1641–1704)

Medieval fortified towns, surrounded by a stone wall, were self-sustaining. Small arable fields and farms were built inside the walls, and on the walls windmills were built. Many of these towns were originally founded on a smaller or larger river, and the proximity of water was used for measures of infrastructure in times of war. An outer defence canal round the town was fed by the river. Standing timber and brushwood in the river wetlands was used for fuel and many other purposes. River water was also used for deliberate inundations of the surroundings of the town in order to keep the enemy at a distance (see's-Hertogenbosch, 1629). The invention of the canon (*ca.*1450) asked for stronger and more strategic walls around the fortified towns. Menno van Coehoorn, soldier and military engineer, published some books on the art of fortification. The authorities entrusted him the reconstruction of a number of fortresses in the Netherlands. He designed the typical star-shaped fortifications encircling the towns, with bastions, ravelines and an outer defence canal. Many of these structures still exist.

Between 1610 and 1650 an area of broads of roughly 200 km$^2$ were reclaimed in the Central and NW Delta. Besides the large number of successful reclamations in the 16th–18th centuries, there were also many setbacks. For instance, the quality of the soil of the Heerhugowaard (Fig. 4.5) was so disappointing that in 1674 there was serious thought of inundating the reclamation again on the principle that it was better to have good fishing water than poor arable land. Even the most successful reclamation, the Beemster, encountered many setbacks during the reclamation. In 1610 the reclamation was virtually completed when, during a severe storm the Zuiderzee dykes burst and the Beemster was flooded. Work had to be started all over again. It was decided to heighten and strengthen the ring-dyke, to prevent flooding disasters in the future. This proved to be a success, and the ring-dyke stood several later storm surges. Another setback was the subsidence that occurred, particularly during the first

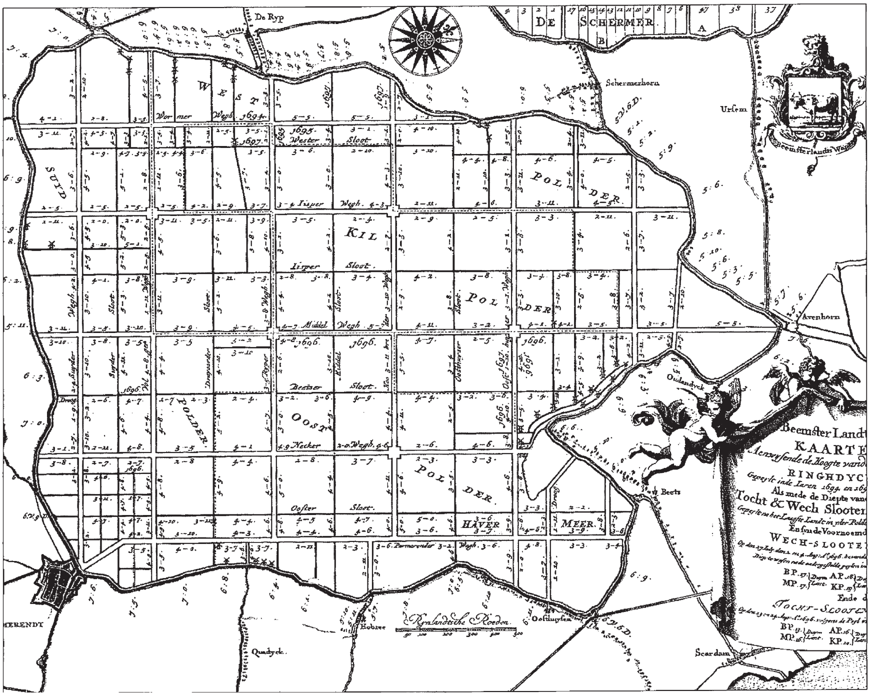

**Fig. 4.7** Map from 1696 of the Beemster, reclaimed in the period 1608–1612 (*ca.* 10 × 8 km), showing the rational and geometrical allotments (Van de Ven, 2004)

decades after a reclamation, as a result of physical ripening of the soil, draining and settlement. As a result ditches and canals had to be deepened constantly and deeper drainage was needed. About 20 years after the Beemster had been reclaimed, around 1632, the existing drainage in three stages had to be extended with a fourth stage. Furthermore, an extra series of windmills was built to improve drainage (Van de Ven, 2004).

There were only a few new ‘droogmakerijen’ reclaimed after 1650, viz. caused by the depressed state of agriculture, and the failure of earlier schemes to yield returns which lived up to expectations. Consequently, between 1650 and 1775, the annual area of new land drained was less than at any time since the Middle Ages. Peat digging, on the contrary, continued with unabated vigour. It temporarily provided a meagre livelihood but brought great poverty in its wake. The remaining area of cultivable peat moors was considerably reduced and depopulation followed since the peat cutters moved away once the fuel reserves were exhausted, and the diggings filled with water. When reclamation was resumed in the early 19th century, most projects were undertaken more for flood protection than for profit (Lambert, 1985).

## 4.6 Hydrology and Geomorphology of Rivers

Nicolaas Cruquius (1678–1754), a surveyor from Delft, rang the alarm bell in 1727 on the severely disturbed balance between land and water in the Delta. If nothing is done to restore the precarious equilibrium between sea-level rise and land subsidence of the Central Delta, then the country would be transformed into one large inland lake within a few decades, he said. The indications of this catastrophe were clear. The steady silting-up of the riverbeds of the lower reaches of Meuse and Lek, resulted in higher water levels, and an increase in the number of river floods. Then there was the silting-up of the outlet of the river Meuse, the Oude Maas south of Rotterdam (Fig. 4.4). In front of the estuarine river mouth extensive sandy shoals were formed, threatening to close off the river entrance to the harbour of Rotterdam. Another threat of the rising water was the uncontrolled expansion of the 'water wolf' Haarlemmermeer (Fig. 4.5; see Chapter 5). Cruquius' gained some success with his warning. One of the results was a concerted action of water boards to produce a detailed mapping of the main rivers Meuse, Merwede, Lek and Linge and their floodplains, published between 1729 and 1765. All spatial units that could be recognised in the field were drawn on these maps. And goods maps were indispensable for hydraulic engineers, because they revealed the weakest spots in the water defence system, and focussed attention on concrete measures (Van de Brink, 2003).

It was indeed true that during the 17th and 18th century the hydrological and geo-morphological situation of the large rivers gradually changed, leading to an untenable situation around 1800. Particularly during summer vast shallow areas, and spots falling dry developed in the riverbeds. The continued silting-up and heightening of the river basin not only gave problems for navigation, but the neglected rivers beds hindered the regular discharge of polder-water. The levees along the rivers were reinforced and heightened again and again, and more powerful watermills were built to cure these problems. The gradual deposits of sand and silt elevated the riverbed above the adjacent polder-land behind the dykes, and large scale seepage from the river to the low-lying basins occurred, turning the soil of the 'waarden' into marshy and useless ground.

These gradual hydrological and geomorphologic changes regularly ushered in flooding catastrophes (Chapter 9). When after a period of severe frost the thaw set in, it was crucial that the drift ice on the river was kept in motion. When the ice mass was stuck, the mass grew quickly, was pushed over the dyke, and severely damaged the dyke, prone to flooding. This crisis situation escalated when after a period of severe frost the thaw had set in Germany, and in the Delta it was still freezing. Most disasters in the period mentioned, occurred in a period of thaw, following severe frost (see Chapter 9). The connection with the increasing silting-up is obvious, the annual transport of ice was severely hampered by the shallows in the riverbed. The presence of shallows was not the only reason for the frequently occurring river floods. The winters at the end of the 18th and the early 19th century were remarkably colder than present day's winters. In the Rhine-Meuse Delta the winter temperature dropped around 1750, showing a minimum in the decennia around

1800, and increasing again until ‘normal’ levels were reached around 1850. These severe winters are now recognised as part of the Little Ice Age that lasted from roughly 1550 to 1850 (Le Roy Ladurie, 1972).

There might be a connection between the silting-up of the riverbeds and the Little Ice Age. A colder climate may imply less rainfall, and more importantly that precipitation accumulates in the high mountains in the form of ice and snow. The Alps had indeed in the 19th century very extensive glacier fields, which disappeared after 1900 (Ward and Uehlinger, 2003). In the centuries preceding 1900, when the precipitation accumulated in solid form in the mountains, the discharges of the rivers should have been diminished. Less water means lower current velocities in the lowland Rhine branches, connected to more evenly spread sand and silt deposits that could not reach the North Sea. Presumably around 1700 a critical margin was passed, leading to accumulating effects: the silting-up itself is slowing down the water currents. Although the line of arguments is hypothetic, and in contrast with other data (cf. Chapter 9), it is striking hat the first measures fighting the silting-up of the rivers in favour of the river-traffic were taken already in the early years of the 18th century.

The discharges of the river Nederrijn and hence of the river IJssel became so low, that these rivers lost their significance for trade and defence purposes. The construction of the Pannerdens Kanaal in 1707 (Fig. 4.2) introduced a new bifurcation of Rhine water, over three branches of the river Rhine, the Waal, the Nederrijn and the IIssel (Fig. 4.8), resulting in an increasing amount of water to be discharged via the IJssel and the Nederrijn. The construction of this new canal, however, did not succeed in stabilising the distribution of Rhine water. The river dykes of the Nederijn-Lek were not designed for these increasing amounts of water, leading to fatal dyke breaches and flooding in the years thereafter (e.g. 1747). Moreover, the Nederrijn continued to silt up; between 1700 and 1750 the riverbed was heightened by 1 m. Anticipating more sustainable solutions of these major water problems, the water boards discussed the construction of a number of overflows and retentions basins, in order to get rid of the superfluous river water. In the meantime the threat of being flooded in one of the ‘waarden’ remained unabatedly in force (Van der Woud, 2004; Van den Brink, 2003).

## 4.7 Transportation and Navigability

### *4.7.1 Waterways and Navigation*

It is customary to start a review about traffic and transport during the past centuries in the Rhine–Meuse Delta with an ode to the waterways. The longstanding absence of an efficient system of roads on land is usually seen as a consequence of the strongly developed system of waterways. Even the initially slow development of the Dutch railroad system in the mid-19th century seems to be triggered by the

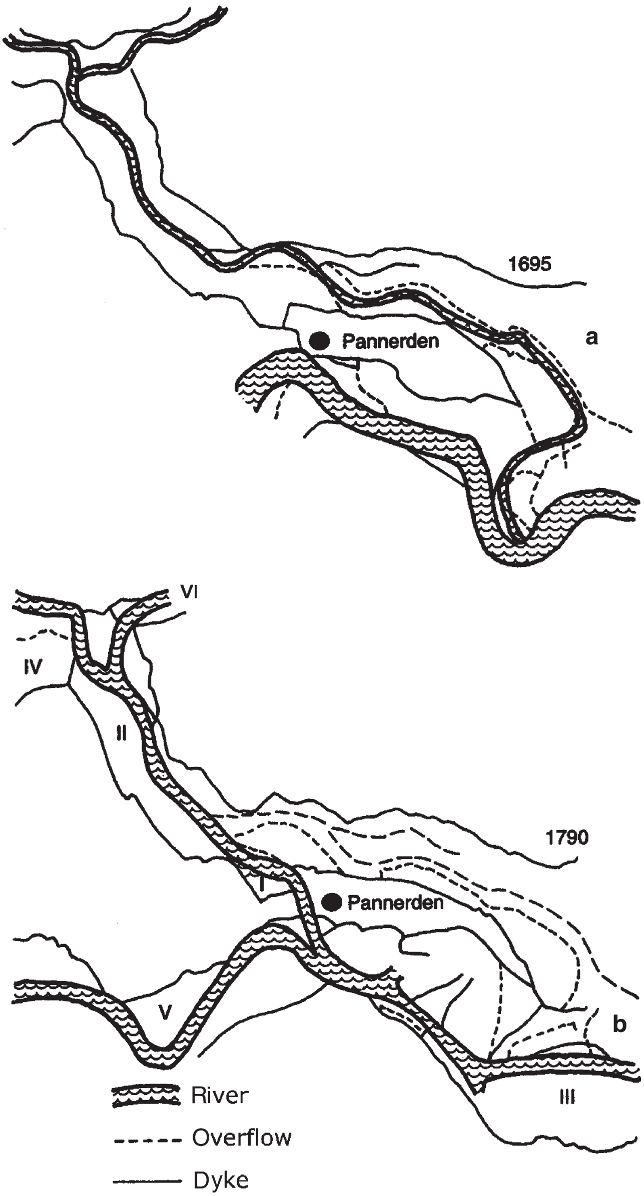

**Fig. 4.8** Around 1695 the Waal discharged 90% of the water of the river Rhine, the remainder flew through the Oude Rijn (A) (upper panel). The Pannerdens kanaal (I) was dug in 1707, dividing the Rhine (Bovenrijn, III) discharge over the Waal (V), Nederrijn (II–IV) and IJssel (VI); B = Spijkse overlaat (lower panel) (Adapted from Huisman et al., 1998)

superb connections over water. Van der Woud (2004) is critical with regard to this commonplace. The large number of artificial water courses in the Delta is not only related to the large need for transport capacity. In the low-lying Delta of the Large Rivers these channels functioned in the first place as water courses for the retention and discharge of superfluous water. In the second place, the soil that became available during the digging of the water courses was used to heighten the surrounding lots, or to build levees and dykes. This was not only practiced at the countryside; for example, the digging of the famous rings of canals in Amsterdam, constructed in the 17th century, provided large amounts of soil, used to prepare the adjoining lots for the construction of the impressive mansions (see Chapter 14).

The network of water courses, initially designed, step by step to manage the retention and the run off of river-water and rainwater, has stimulated the intensive traffic over water. The lesser waterways, built originally to meet purely local needs, formed no unified inland waterway system. As waterborne commerce grew in volume, they proved to be increasingly inadequate. Fixed bridges and narrow locks and sluices restricted the utility of the inland waterways. Despite the use of several devices, e.g. the mud-rake, to keep the deposits in suspension, the canals were of limited depth and usable only by smaller craft, mainly shallow barges.

Around 1800 most inland waters had a water depth of only 1.5–2 m; to dig deeper channels was obviously considered a waste of labour and maintenance costs. It is remarkable, according to Van der Woud (2004) that the responsible public authorities during the centuries before 1800 took only a few measures to level the consequences of extreme wet and dry climatic conditions, particularly when these efforts are compared to the multitude of actions that were taken for the construction and maintenance of levees and dykes. Ruled by the prevailing climate the water level in the country fluctuated: during autumn and winter the water courses were relatively wide and deep, but during summer they were narrow and shallow. The economic deficits both during winter and during summer as a consequence of the malfunctioning of the waterways must have been quite substantial. During periods of frost it was almost impossible to lift the congestion of the ice-covered waterways, and consequently the provision of the market places came to a halt. The malfunctioning of waterways during periods of drought, however, could have been partially lifted by active water management. Except in incidental cases, however, the water regime was accepted as a natural phenomenon and navigation was adapted to those circumstances. An example: the critical water depth along the river IJssel between Zwolle and Kampen was only 65 cm during summer, and consequently only vessels with a draught of less than 60 cm were used. During winter the water depth was 1.3 m allowing the use of heavier draught vessels (Brade, 1844).

What counted for the small inland waterways, counted also for the large rivers Rhine and Meuse. The river Meuse, a rain-fed river, and very susceptible to dry summers, often had a channel of only 60 cm water depth, and consequently lost her significance as a shipping canal. In the course of the 17th and 18th century the lJssel and Rhine badly silted up and became frequently unnavigable at times of low water. In dry seasons, where the Rhine entered the Delta, the river had only 1.5 m of water and cattle strayed across the channel to the opposite bank. Riparian owners built groynes to protect the dykes and to speed up silt accumulation for the brickworks lining the banks. Only in the later 1700s did the authorities take steps to remove such hindrances and to employ bucket dredgers to maintain a sufficient depth of water. The rivers Waal, Merwede, Nederrijn, Lek and IJssel (Fig. 4.2) caused great trouble to navigation when the water level dropped below an average depth. The shallowest parts were situated near Tiel in the river Waal, where the water depth regularly was less than 1.5 m; to overcome this obstacle some ships had to be hauled (Nusteling, 1974). During the extremely dry summer of 1857, the large rivers could initially only be sailed by shallow draught vessels; the water level, however, dropped even further and the entire river navigation came to a standstill. In fact, a number of the navigable rivers in the Netherlands ran dry periodically.

Considering these circumstances, rafts were frequently used vehicles on the rivers. In this context the impressive timber rafts floating from the Black Forest in Germany to the staple market in Dordrecht should be mentioned. The timber was mainly used for shipbuilding. The largest of these timber rafts were 300 m long, 40 m in width and 2.5 m high. They were navigated by 400–800 rafters, who kept the vessels in mid-stream with their sculls. With their wooden barracks on top the gigantic timber rafts resembled floating villages, and it needs no argument that these transports carried a substantial risk (Petrejus, 1974).

Around 1800 there was a network of many waterways in the country, especially in the low-lying parts, comprising natural streams, river branches, rivulets, but also numerous artificial canals (cf. Chapter 5). Exceptions excluded, until 1800 the public authorities did not interfere in the natural water table – low in summer, high in winter – in order to improve the traffic over water. It was in fact far in the 19th century that water managers purposeful paid attention to the normalisation of water levels and discharges in the inland water courses. During the early decades of the 19th century many new canals were dug, and older canals were widened, deepened and straightened, serving larger ships then the track-boat.

### *4.7.2 Wax and Wane of the Track-Boat*

As trade expanded and industrial requirements for raw materials and peat fuel grew, the inland waterway system was slowly modified. Apparently, there was already a regular barge service between Amsterdam and Utrecht (Fig. 4.5) in the 14th century (Harten, 1978), but, in general, inland water carriage ran to no regular pattern. Skippers waited for a full cargo before setting sail, so departure and arrival times were uncertain the more so as several skippers might be competing for the available freight. The need for a quicker and more reliable service became pressing, and in the period 1580–1660 the inland waterway system underwent a rapid transformation to give the Delta the most coherent, regular, and cheapest transport network in Europe (Lambert, 1985).

The first stage was the expansion of regular goods services (‘beurtvaarten’) between city and city, and city and village. In return for a monopoly of water carriage between two towns, skippers provided a regular service, whether or not they had a full cargo. Thus, in the late 16th century daily or hourly services between the main towns in the central part of the Delta came into existence, and plans were also made to improve the water connections between these towns. This phase was marked by the deepening of canals and the building of greater locks. But travel was still constrained by the weather. The barges relied on sail, and timetables could be disrupted by calms and gales, frost and flood.

The second stage came in a period of barely 30 years (1630–1660) when an extensive network of ship-canals ('trekvaarten') was dug. This resulted from the introduction of the track-boat or towing barge ('trekschuit'), mainly meant to transport passengers (Figs. 4.9 and 4.10). The first track-boat connections appeared to be so successful that from 1640 onwards a real track-boat mania developed. Till far in the 19th century the track-boat remained a reliable means of transport for many people (www.20eeuwennederland.nl/thema's/wegennet). The great advantage over the trading barge was its independence of wind. Capable of carrying both cargo and passengers, the towing barge was initially drawn with a rope by a number of men (soon replaced by horsepower), and being thus released from dependence on the wind, it provided a much more regular service. By 1665 a 600 km network of ship-canals served the whole of the western and northern Delta, and it became possible (with changes) to travel from Bruges (Belgium) in the south to Emden (Northern Germany) in 4 days and nights.

The towed passenger boat was a very popular means of transport, and its services were both regular and frequent. The average speed was approximately 7 km $h^{-1}$. That might seem slow, but considering the status of the roads, and the many delays that arose on the way the stage-coach was no faster means of travelling. The

**Fig. 4.9** A track-boat, (towed passenger boat) which had its heydays in the 17th and early 18th century; the driver and the towing-horse are to be seen on the right (C.C. Fructis, Gemeentemuseum, Arnhem)

**Fig. 4.10** The author on the towing path along the Damsterdiep (Groningen, N Delta), 06–07–04, standing next to an historical monument, a ‘rolpaal’, a vertical cylindrical axis, a guide rail for the towing rope with which the track-boat was pulled (Photograph Arine Nienhuis)

distance between Amsterdam and Utrecht, roughly 30 km, took the track-boat 5 h (Van Leeuwen, 1998). Rotterdam and Delft had hourly links; 10 boats daily plied between Haarlem and Leiden; and by the mid-18th century 800 boats left Amsterdam weekly for 180 destinations. At their most developed, the barges provided deck cabins or saloons where the wealthier passengers could sit in comfort, eat and drink, while on a few services sleeping accommodation was provided in a large communal bed (Lambert, 1985).

The new waterways had other beneficial results. Because towage is easiest in a straight line, the new canals were dug as straight as possible (just like modern motor highways), on average 18 m wide and 2.5 m deep. For good traction the horses needed a sound towpath and bridges over side waterways. Those who could not afford to travel on the barges could use the towpaths, which thus came to form a supplementary and direct communications network. In addition, the villages of crewmen, shipbuilders, sail-makers and sawyers lined the ship canals, while fuel-intensive industries were attracted to the canal side. In the 1660s over 300,000 persons annually used the Haarlem – Amsterdam route, not including pedestrians. Clearly the ship-canals added greatly to the efficiency of the inland transport network. As a result of the preponderance of waterborne transport, the towns in the Delta acquired a special character, with their tree-lined canals, hump-backed bridges, and the mellow red-brick pavements and buildings of their busy commercial quays, boat-yards, rope-walks, weigh- and warehouses. And it was the canals which carried the great volume of raw materials and finished products which flowed to and from the flourishing urban industries (Lambert, 1985).

### 4.7.3 Traffic and Transport Over Land

Until far in the 19th century the Rhine–Meuse Delta was known for its good waterways and for its bad roads over land. In the central part of the Delta in particular, routes were circuitous, since the many waterways and lakes barred the way and frequently entailed long delays at ferries. Only in the later 17th century were roads developed between the main towns in the central part of the Delta. Even around Amsterdam roads began to be paved only in the mid-18th century. Outside of most towns the roads were not metalled which meant that they made hard going, particularly when it was raining. The best way of travelling was no doubt the towed passenger-boat or the trading barge, which could easily compete with the stagecoach. Until the mid-19th century, transport over land in the low-lying Delta was very laborious. A consistent and continuous system of roads did not exist. Most country-roads were unimproved and of inferior quality, and during winter large areas changed into inaccessible wetlands. Heavy rain during summer and thaw during late winter aggravated the problems. The dykes along the rivers functioned as main roads until early in the 20th century. Till far in the 19th century solid bridges over the large rivers did not exist. Narrow canals were spanned by drawbridges, a common picture in cities and larger villages. Every construction in the riverbed would certainly have been demolished during a severe winter. The most busy passages crossing the river were provided with floating bridges, at less busy traverses small ferry boats provided their service. The pontoon bridges were put in safety before the winter. Wintertime was an annually repeated time of economic depression, of time of tedious waiting and stand still (Van der Woud, 2004).

The higher Pleistocene sandy parts of the country, beyond the influence of the rivers, were opened up for national and international trade along a few main roads, from the Middle Ages onwards. The road system mainly consisted of old sandy tracks, the trade routes for the transport of goods (called 'Hessenwegen') and for mail-coaches providing the postal service and the transport of persons (called 'Postwegen'). Around 1800 only 165 km of main roads existed in the Delta, mainly built in the 18th and late 17th century. In 1814, only 450–500 km roads were brick-paved, or covered with natural stones, cobble-stones imported from Belgium, Germany, and after 1850 also from Scandinavia (Barentsen, 1972, 1974).

Before the 19th century topographic maps were rather primitive. Of course there were local or regional maps, but because of their scale and design mutual comparison and matching was impossible. During the French occupation from 1795 to 1813 a national survey was introduced, resulting step by step into a land registry system of cadastral maps. Many regional units of measure were in use during those days, and for reasons of standardisation the 'Rijnlandse roede' (3,7674 m) was introduced as the standard measure. In 1814 a National Topographic Bureau was erected under the jurisdiction of the Ministry of Defence, which underlines the strategic significance of a uniform survey (www.hetleegeland.nl).

Grimm (1775–1781) described his journey in the stagecoach from Utrecht to 's-Hertogenbosch, a distance of 50 km (Fig. 4.11).The stagecoach departed everyday at five o'clock in the morning, as soon as sufficient paying passengers had boarded. It could transport six passengers. The trip lasted to six o'clock in the evening. They crossed the rivers Rhine (Lek), Linge, Waal and Maas. The passengers had not only to pay their fare, but also for their luggage and for passing several toll houses. The roads were bad, unmetalled, covered with muddy sand. They passed meadows with sheep, and fields where flowering poppies coloured the fields red. They crossed small villages where the thatched roofs almost touched the ground. After a ride of 6 h they took the ferry and passed the river Lek. In the Betuwe they travelled over a dyke to Buurmalsen on the river Linge. Grimm noticed many orchards, and he was informed that many of these apples and pears were to be sold in Amsterdam. They crossed the river Linge, and at Geldermalsen, halfway to 's-Hertogenbosch, the stagecoach had to change its horses. They continued their travel to Waardenburg on the river Waal, a village with poor houses with thatched roofs. The river Waal was a more than 200 m wide (estimated by Grimm), quickly flowing stream, and for the crossing of that river the stagecoach was carried by a ship with mast and sail. They reached Zaltbommel, a small fortified town, on the riverbank with a sandy foreshore, and meadows with cattle. The road crossing the Bommelerwaard was really bad, just trampled sand and mud. The trip from Zaltbommel to 's-Hertogenbosch, less than 15 km, took 5 h. They passed several villages, Bruchem, Ammerzoden and Hedel, comprising scattered, poor thatched huts, in a landscape with meadows, arable land

and wide, marshy wetlands. At Hedel they crossed the river Maas, and reached Noord-Brabant, where the landscape had a different appearance: low-lying land crossed by a narrow, winding dyke with the road on top. ‘s-Hertogenbosch could be seen from a far distance. Grimm noticed paved streets, bastions and houses, partly built of stones, partly of wood (Grimm’s route see Fig. 4.11).

The French abbot De Feller followed the same route as Grimm did in May 1775 from Utrecht to ‘s-Hertogenbosch. He dealt extensively with the marshy and impassable area south of Zaltbommel. The roads crossing the Bommelerwaard were very bad, difficult to travel across, flooded and fully out of order during a substantial part of the year. The terrible condition of the roads is repeatedly noticed in travel reports. An ‘English gentleman’ travelled through the Netherlands in 1786. The roads through the Bommelerwaard as well as through the Tielerwaard and lower Betuwe were miserable, muddy and almost impassable. At both sides of the

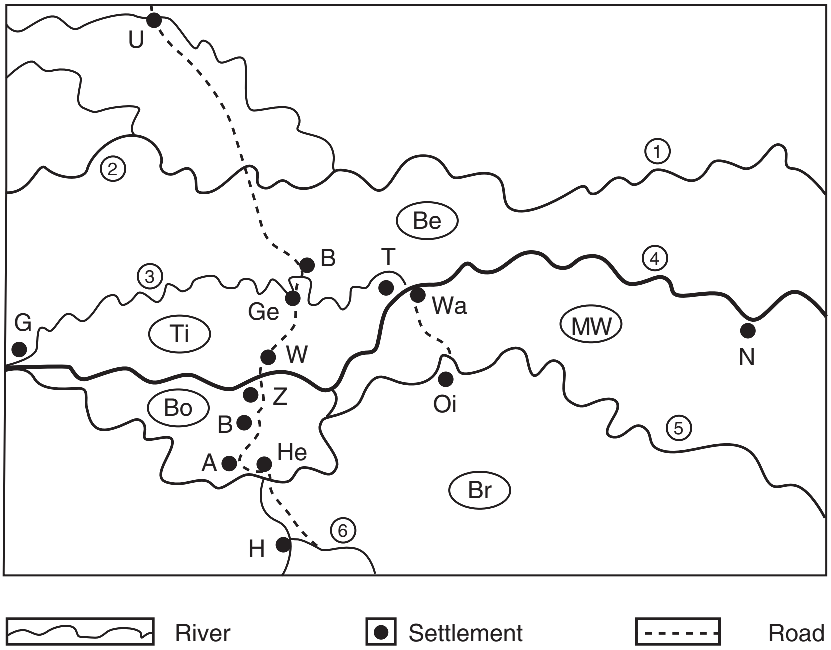

**Fig. 4.11** Traffic and transport over land at the end of the 18th century in the area of the Large Rivers. The travel by stagecoach from Utrecht to ‘s-Hertogenbosch, a distance of *ca*. 50 km, took 13 h, and four rivers had to be crossed by ferry. The travel from Tiel to ‘s-Hertogenbosch over land was a toilsome enterprise. Public roads passing the Land van Maas en Waal were absent, and in Brabant the marshy Beerse Maas had to be crossed (see Chapter 5). G = Gorinchem; U = Utrecht; B = Buurmalsen; Ge = Geldermalsen; W = Waardenburg; Z = Zaltbommel; B = Bruchem; A = Ammerzoden; He = Hedel; H = ‘s-Hertogenbosch; T = Tiel; Wa = Wamel; Oi = Oijen. Be = Betuwe; Ti = Tielerwaard; MW = Land van Maas en Waal; Bo = Bommelerwaard; Br = Brabant. 1 = Nederrijn; 2 = Lek; 3 = Linge; 4 = Waal; 5 = Maas; 6 = Dommel & Aa

road the traveller was surrounded by large, marshy grasslands, almost everywhere inundated. The country was sparsely populated and the people bore signs of great misery and poverty Three quarters of a century later there was really no improvement. Van Lennep travelled in 1823 through the Delta. Once in the Bommelerwaard he mentioned the sticky and muddy roads, where the wheels of the stagecoach got stuck, and as far as one could see, large marshlands extended on both sides along the road (Van Leeuwen, 1998).

### *4.7.4 Socio-Economic Relations Across Rivers*

Van Os (1984) gave a concise survey of the socio-economic relations between riverains in the Land van Maas en Waal, in between the rivers Waal and Meuse, during the 16th to 19th century. He also sketched the connections between human activities on and along the river and the landscape structure. The situation in the Land van Maas en Waal can stand as an example for most of the 'waarden' in the Delta (see Fig. 4.11). Until the building of dykes there was no real need for country-roads. The river was shallow, had a wide bed and sometimes two or three gullies and could easily be sailed with flat-bottomed vessels. Crossing the river was not difficult, during summer on foot or with a small vessel, and during winter over the ice. It was simpler and cheaper to build a boat, instead of a wagon, which needed a horse as power-source. Wind and currents were free of charge and construction and maintenance of the waterway was not necessary. The river Waal connected the main towns of Tiel and Nijmegen with all villages in between on both banks, and opened the country for the German Rhine-trade and the cultural developments in the Rhine basin.

Before the building of the embankments and dykes the inhabitants of the Land van Maas en Waal presumably had close contacts with the Betuwe. 'Waalkanters' (people living at the Waal-side) have a dialect that differs considerably from the vernacular of the 'Maaskanters' (people living at the Meuse-side). The Waalkanters dialect shows strong relations with the phonetic system of the Betuwe dialect, whereas the Maaskanter dialect has more affinity with the Brabant language. The large rivers appeared not to be a language barrier, but on the contrary, functioned as a connecting element, a possibility of exchange. The language barrier proper is situated in the uninhabited, marshy basins, in the central part of the river-polder, separating the 'Waalkanters' for centuries from the 'Maaskanters'. It was only in the 19th century that a few north–south connections were built, with a lot of trouble and little result. In all cases the collection of toll provided the necessary means to maintain the roads.

An example: for economic reasons the town of Tiel wanted to be connected with the town of 's-Hertogenbosch, and in 1848 they started to build a gravel-road, over a narrow dyke, connecting the ferry at Wamel with the ferry at Oijen in Brabant (Fig. 4.11). Halfway the polder in an inn, the town of Tiel collected the toll. Most villages on the Waal-side did not have a through connection with the Meuse-side. The field-tracks from the human settlements into the low-lying, marshy basins came to a dead end at the central water course. At specific places a ford of rubble and gravel was made in the water course, supposed to be marked with stakes. If through-passing travellers chose the wrong connection they could easily lose their way, sink away in the mud and even drown.

The Land van Maas en Waal in fact did not exist. It was not a unity, not only linguistically but also socio-economically: common family names, and shared possessions on both sides of the Waal point to close historical connections, dating back to the Middle Ages. The borderline between the Betuwe and the Land van Maas en Waal was not created by the river Waal, but by humans who built the ever-strengthened and heightened dykes along the river. The building of dykes along both sides of the river Waal separated the interests of the Betuwe from the interests of the Land van Maas en Waal, and this separation has been accentuated by the Reformation, the religious changes in the 16th and 17th century, which still have a major impact on the secularising population.

The construction of dykes canalised the rivers, and took the room for manoeuvre they had in earlier centuries when they were braiding and meandering between their natural banks. The building of levees, however, counteracted the manageability of the rivers, because they enlarged the difference between high and low water, increased current velocities and enhanced the likely possibility for dyke breaches. River floods became more devastating, and more frequent than before. The landowners in the Betuwe reinforced their river dykes after a storm flood, and the landowners in the Land van Maas en Waal, although economically less developed and poorer, were obliged to follow that strategy in order not to be drowned during the next flood. After the Middle Ages the heroic battle against the water-enemy, in fact had changed into a primitive battle of tribe against tribe, and according to Van Os (1984), this fact is seldom stressed in national history books. When the men of the dyke-army at the Land van Maas en Waal side of the rising water gave up their fight, and ran up the red lamp in the church tower, meaning that a dyke-breach was approaching, a shout of joy was raised at the other side of the river: the Betuwe was relieved, this time the water flooded Maas en Waal! Numerous times Maas en Waal got the worst of it, not against the river Waal but against the stronger and higher dykes of the Betuwe. According to Van Os (1984), it would be justified to investigate whether the icy political relations after 1609 between both regions, accentuated by the contrasts in religions (Protestants in the Betuwe, Roman Catholics in Maas en Waal), have been induced by the history of river management.

Moreover, a superior dyke was an excellent means to ‘fight’ the other side of the river. The building of groynes and jetties, perpendicular to the axis of the river, to enhance the sedimentation process, and to gain land, forced the main current to the other side of the river. The farther the groyne protruded into the river, the faster and safer the floodplain grew, and the more erosion took place on the other side of the river. This aggressive and uncontrolled building of groyne, feeding the land-hunger of the landowners, and undermining the banks on the other side, occurred at both sides of the river. The groynes became real obstacles for the boatmen, who were forced to sail zigzag to avoid the poles and wattle-works.

Notwithstanding the opportunistic and hostile relationship during flood events after the 15th century, the river-crossing relation pattern between both sides of the rivers Waal and Meuse had yet another dimension, presumably dating back to the late Middle Ages. Almost all opposing pair of villages had a pedestrian ferry, varying between a simple rowing boat, a sailboat or a proper wire-ferry. Between Nijmegen and Tiel roughly 11 cross-river links existed, and most of them largely survived the change to the 20th century. The building of the large traffic bridges crossing Waal and Maas in the 20th century has changed the functionality of the ferries greatly. Recently, in the 21st century, there is a tendency to reinstall the lost ferries, purely for tourist reasons.

Just as every village had its own ferry, they had their own landing-stage, loading and unloading wharf or jetty. Generally, sailing boats were shallow-draught vessels that could easily moor even when they had to avoid a shoal or a groyne. The river Waal presumably was already before the rise of steam navigation one of the busiest rivers in the Delta. Around 1790 one could sail every day with a trading barge from Nijmegen to Gorinchem, Dordrecht or Rotterdam. In 1837 Hildebrand (reprint 1920) travelled with a steam boat from Rotterdam to Nijmegen, and that took him ‘a long, long day’. Nijmegen was a junction for more than 40 trading barges that maintained regular services with most larger towns in the western part of the Delta. These boats transported goods and passengers, and touched at several villages along the Waal (Van Os, 1984).

## 4.8 Water Defence Lines

The idea of incurring the help of water for military activities, both offensive and defensive, probably stems from prehistoric times. Some well-documented examples are known from the 16th and 17th century. In 1573 the Spanish troops had to raise the siege of the town of Leiden because the surroundings were inundated. The same happened a year later at the siege of Alkmaar (locations in Fig. 4.5). In 1629 the Spanish defenders of the fortification of ‘s-Hertogenbosch used the same strategy, so that the Dutch troops had great difficulty in regaining the town. ‘s-Hertogenbosch ranked as impregnable; it was surrounded by low-lying areas that could be inundated during wartime. The Dutch troops accomplished a seemingly impossible mission: the courses of the rivers Dommel and Aa, that ran through the town (location in Fig. 4.11), and that kept the surroundings of ‘s-Hertogenbosch inundated, were dammed up and diverted from the city into newly dug courses lined with 40 km of ring-dykes surrounding the city The thus created polder with ‘s-Hertogenbosch in the centre, was drained with the aid of hundreds of windmills. The Dutch could now easily conquer the town over dry land, and consequently, ‘s-Hertogenbosch surrendered after 3 months (more details in Chapter 11).

In the course of time several plans were set out in the Central Delta to create a systematic defence line by means of inundations, which out of necessity was not actually established until 1672. In that year England, France and parts of Germany declared war on the Dutch Republic. The greatest danger lurked in the shape of the

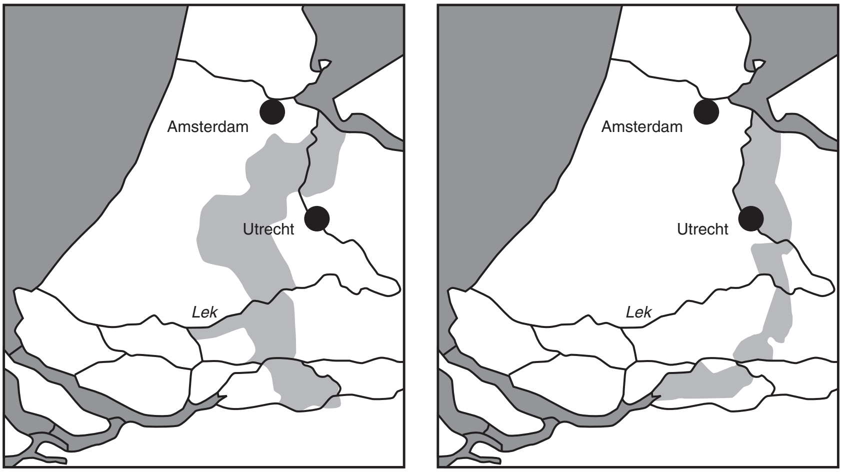

**Fig. 4.12** Water defence lines, areas of land to be inundated during wartime to protect the Central Delta (light grey areas). Left panel: Old Holland Water Defence Line (1672–1815); right panel: New Holland Water Defence Line (1815–1940/1945) (Adapted from Will, 2003)

French army which came marching from the south and east towards the heart of the republic: the central part of the Delta, the province of Holland. To check this advance the water was called in as an ally. A strip of land from the Zuiderzee to the Maas was inundated and so the Old Holland Water Defence Line was created (Fig. 4.12; Will, 2003).

Basically the system of the water defence line was quite simple. The sluices of the innumerable low-lying polders were opened and water was let in, though not too little water, for in that case the enemy troops could wade through. On the other hand, not too much water was allowed to enter the polders, for then the barrier could be taken with ships. A water depth of some decimetres was ideal, hiding many invisible and therefore very treacherous ditches underneath. An enemy advance could only take place along the higher situated dykes and roads. At these places a system of fortresses and entrenchments was constructed. Entrenchments were also laid around most sluices. In 1673 it was decided to turn the provisionally constructed defence line into a permanent one. The water defence line was strengthened and enlarged. At several places special inundation sluices were built, through which the polders could be inundated in a controlled way. Frost during winter created a dangerous situation, and then the ice had to be cut as soon as possible to prevent the whole defence line from losing its effectiveness. The Old Holland Water Defence Line worked well in 1672–1673: the French could not march through, they withdrew and peace was concluded in 1678 (Van de Ven, 2004). In 1815 a second water defence line was constructed, the New Holland Water Defence Line (Fig. 4.12; see Chapter 5; Will, 2003).

## 4.9 Conclusions

- From military history and the history of religion it appears that from Roman times onwards these societal forces contributed substantially to the level of economic prosperity of a region, and hence to the measures taken in the framework of water management. The period 1500–1800 is characterised by technical achievements, much progress but also setbacks, and above all scaling-up of water projects. During prosperous times great projects were undertaken, assuming next to technical innovations a great willingness to invest.
- From *ca.*1450 onwards the land owners in the Delta scaled up the management of the water regime by taking optimal advantage of the new wind-watermill technology. The drained lakes and the 'waarden' surrounded by ring-dykes owe their existence as well as their development to the draining capacity of the windmills. The regulated water household changed the river basins into cultural – or at best semi-natural – landscapes and waterscapes.
- Until the introduction of steam power, in the early 19th century, muscular strength of humans and animals (horses), sustained by wind- and water-power were the only sources of power that modelled and transformed the natural landscapes in the Delta into cultural waterscapes.
- In the riverine parts of the Delta large areas of land were lost owing to the massive dredging of peat. Wind and wave attack on the foreshores accelerated the process of land loss, and hence the creation of peat lakes. In the prosperous Golden Age (17th century) it became technically feasible to reclaim large areas of peatland, and to turn peat lakes into fertile land.
- The continuous battle of gaining and losing land in the coastal parts of the Delta is characterised by the counteracting forces of the rising sea level and the subsiding land, mainly owing to the extraction of (salty) peat. Around 1500 large parts of the coastal Delta were lowered down to sea level. Again and again two steps forward were taken (reclamation) and one step backwards (loss of land of embanked areas). Tens of thousands of hectares of land have been successfully reclaimed in the prosperous 17th century, either applying new embankment techniques, or by piecemeal reclamation of newly accreted areas.
- The paradox of water management: draining and dredging of peatlands, and harnessing rivers between higher and stronger dykes, unbridled natural forces not foreseen and not experienced before: land subsidence, expansion of peat lakes by wind and water forces, increasing risks of river floods. Some visionaries pointed to these problems already in the 17th and 18th centuries (Box 4.1).
- The construction of river dykes canalised the rivers, and took the room for manoeuvre they had in earlier centuries. Levee building counteracted the manageability of rivers; river floods became more devastating and more frequent than before. Maintenance of waterways and dykes was not seen as a supra-regional public task. The natural water regime – high in winter, low in summer – was accepted as a natural phenomenon, and public authorities were not able to interfere in the river basin-wide water table.

- The capricious rivers silted up and became unnavigable, owing to centuries-long river abuse and neglect, counteracting interests, and the failure of regional solutions to flooding problems. The construction of the Pannerdens kanaal (1707) bifurcation was the first large-scale measure to manipulate and to divert the discharge of the river Rhine.
- Thousands of kilometres of waterways formed far out the most extensive and reliable network for transport of humans and goods (trade barges). The trackboat, the passenger boat towed by horses, had its heydays from 1630 to 1700, and was in use until the mid-19th century; hundreds of kilometres of track-boat canal were dug.

# Chapter 5
# River Management after 1800: Complete Regulation and Canalisation

## 5.1 Introduction

The Industrial Revolution, the accelerated development in NW Europe in technical and economic fields, that started in the United Kingdom around 1760, induced great changes in industrial developments, in means of transport, and other applications. The steam engine was introduced in the Delta at the end of the 18th century, but it lasted until *ca.*1850 before steam-power got ample applications (e.g. the reclamation of the Haarlemmermeer) and eventually changed the utility of waterways and rivers. The introduction of the steam-train in the second half of the 19th century, and especially the invention of the automobile around 1900 accelerated this process, and gradually made inland navigation, and hence many waterways inefficient and obsolete.

In the traditional agricultural society of the Delta the new technological progress got under way relatively late. Developments in river management in the 19th century were a continuation of a strategy that had inspired and stimulated the inhabitants of the Delta for millennia: the use, maintenance and improvement of their waterways as economic arteries. For ages waterways were the most important routes for transport of humans and goods, and by dogged perseverance attempts were directed to serve the joint interests of safety and navigability. Safety against flooding demanded regulated rivers, strong and high dykes and straight river channels without obstacles, sandbanks, etc., especially to avoid damage caused by drift ice. Effective transport demanded also a continuous, navigable shipping channel, reliable at low water and at high discharges, used by ships ever-increasing in size.

But the rivers in the Delta did what all lowland rivers do: they silted-up. Where the narrow, fast-flowing Rhine and Meuse rivers in Germany and Belgium entered the wider lowland of the Delta, the currents slowed down and sand and silt settled in the riverbed and in its floodplains. Local dredging could not cure that problem; it only meant a displacement of the sedimentation process. At the end of the 18th century, after a centuries-long process of river regulation, embanking and draining the river polders, the constricted and silted-up river channels became unmanageable.

In this chapter the rigorous measures, especially taken in the 19th and early 20th century, to 'normalise', i.e. completely regulate and canalise the riverbeds, are described. The removal of numerous meanders and sandbanks, the building of

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hundreds of groynes, the digging of lateral canals and bypasses and the building of weirs and ship-locks fully canalised the Meuse and large sections of the Rhine (Nederrijn–Lek). The Waal and IJssel have long been the only free-flowing river branches, but since the 1950s the flow of the IJssel can be regulated by the weirs in the Nederrijn–Lek. The flow in the Waal was restrained in 1971 by the building of the main tap of the Rhine, a large weir system, the Haringvlietdam, close to the North Sea. Awaking interests in recreation and nature conservation in the 20th century did not play any role in the decision-making processes.

The inhabitants of the Delta lived with water. Transport over land was toilsome, and waterways functioned until the early decades of the 20th century as the main routes for transport of humans and goods. A network of hundreds of kilometres of ship canals were already dug in the Delta before the 19th century, especially to facilitate the transport by means of towed barges. But the 19th century is THE century of canal digging, initially with spade and wheelbarrow but increasingly facilitated by steam-power: hundreds of kilometres of shipping canals were dug, in some cases parallel to the silted-up river, in other places connecting the main towns to the river system. Navigation with cargo boats, passenger ships, barges and all kinds of smaller vessels dominated the transport system of the Delta. The booming human population in the second half of the 19th century, and the autarkic need to feed all those people, induced the reclamation project surpassing in acreage all others from the past, the impoldering of the Zuiderzee between 1927 and 1968.

## 5.2 Intensified River Management

Until the first half of the 19th century, before the overall canalisation, the large rivers, the main waterways in the Netherlands, were hardly manageable. In these unrestrained rivers navigability was laborious and unpredictable; regular floods changed the configuration of sandbanks and meanders, and summer droughts revealed shallow, silted-up thresholds. This is (unintentionally) illustrated by the General River Map, a collection of cartographic maps on a scale of 1:10,000, designed between 1829 and 1864. These maps appeared to be useless after their completion, because the large rivers had changed their courses and beds drastically during the past 35 years (Rienstra, 1958). In the context of landscape ecology, however, the river maps appeared to be an important source of information. Old maps from the 16th to the 18th century often give a distorted picture, and they only have local or regional significance. The first General River Map, covering the entire Dutch Rhine system, shows topographic features and land use in a geometrically correct way, and they still are important for reasons of comparison (Wolfert, 2001).

Until the end of the 17th century several channel corrections had been carried out, the Rhine river courses were shortened with *ca.* 23 km, groynes, dams and revetments were built, but these measures served only local purposes, such as the protection of dyke sections. The first major hydraulic engineering works since the Roman era were undertaken at the Rhine bifurcations in the early 1700 s. At the end of the 17th century, the Waal carried by far the greatest part of the Rhine discharge, probably over 90%. Water supply to the Nederrijn and IJssel was so small that navigation became difficult: this is reflected in the shifting of navigation with timber rafts of up to 300 m in length from the Nederrijn to the Waal (Leemans, 1981). The engineering works at the bifurcations of the Rhine were to ensure a better distribution of the total Rhine discharge among its three branches. The digging of the Pannerdens Kanaal, completed in 1707, brought some relief to the false distribution of the Rhine discharge (Fig. 5.1; Fig. 4.8). However, the situation remained still far from stable. Around 1775 the bifurcation of the Nederrijn and the IJssel was reconstructed by digging a new channel in the upper part of the IJssel. From then, the IJssel received about one third of the discharge of the Pannerdens Kanaal which in turn received about one third of the total Rhine discharge. The remaining two thirds of the flow was carried by the Waal, and stabilisation of this situation was more or less achieved by the building of moles (Van Urk and Smit, 1989).

The works at the Rhine bifurcations improved water distribution among the Rhine branches, but floods continued to be hazardous. During the 18th and early 19th century river floods and their devastating consequences were a source of great concern for the Dutch government (see Chapter 9). Several state expert commissions were set up to investigate the mitigation, or better, the solution of this dominant problem in the Delta. In 1806 strict regulations became operative by which it was forbidden to realise works in the river foreland without explicit permission of the central government, such as the building of ferry-jetties, brick factories or houses. Administrative boards or water authorities, with responsibility for integrated river engineering, did not exist in the Rhine–Meuse Delta until the 19th century. Individual landowners built bank revetments and groynes to protect their land from erosion and to increase sedimentation. However, the irregular array of groynes and the presence of many sandbars in the channels, not only impeded the flow of water, but particularly led to the formation of ice-dams. A formal ban on the irregular construction of groynes was already proposed in the early 17th century, and the plan was finally adopted in 1715 (Van Heiningen, 1971). But this plan had little effect, and because of the lack of integration among the water boards the implementation of the new regulations proved to be very difficult. Landowners successfully claimed their rights to build up and develop floodplain areas, as they were accustomed to in the past.

River improvement appeared to be a long-term affair and the turbulent political events in the first half of the 19th century – the period 1800–1815, but also the Belgian upsurge and its aftermath between 1830 and 1839 – impeded long-lasting activities. Furthermore, the state of the public financing did not allow the execution of comprehensive public works. After the flooding of 1809 the ‘Central Committee for Water Management’ was set up, basically extending the plans that had already been developed in the 18th century, and exposing various partly unattainable solutions, such as the creation of a number of lateral overflows along the Rhine branches, and the complete closure of the Nederrijn–Lek in order to increase the discharge of the river IJssel.

In 1821, as a result of the flooding disaster of 1820, another state commission was erected to examine possible solutions for the flooding problem. Before giving

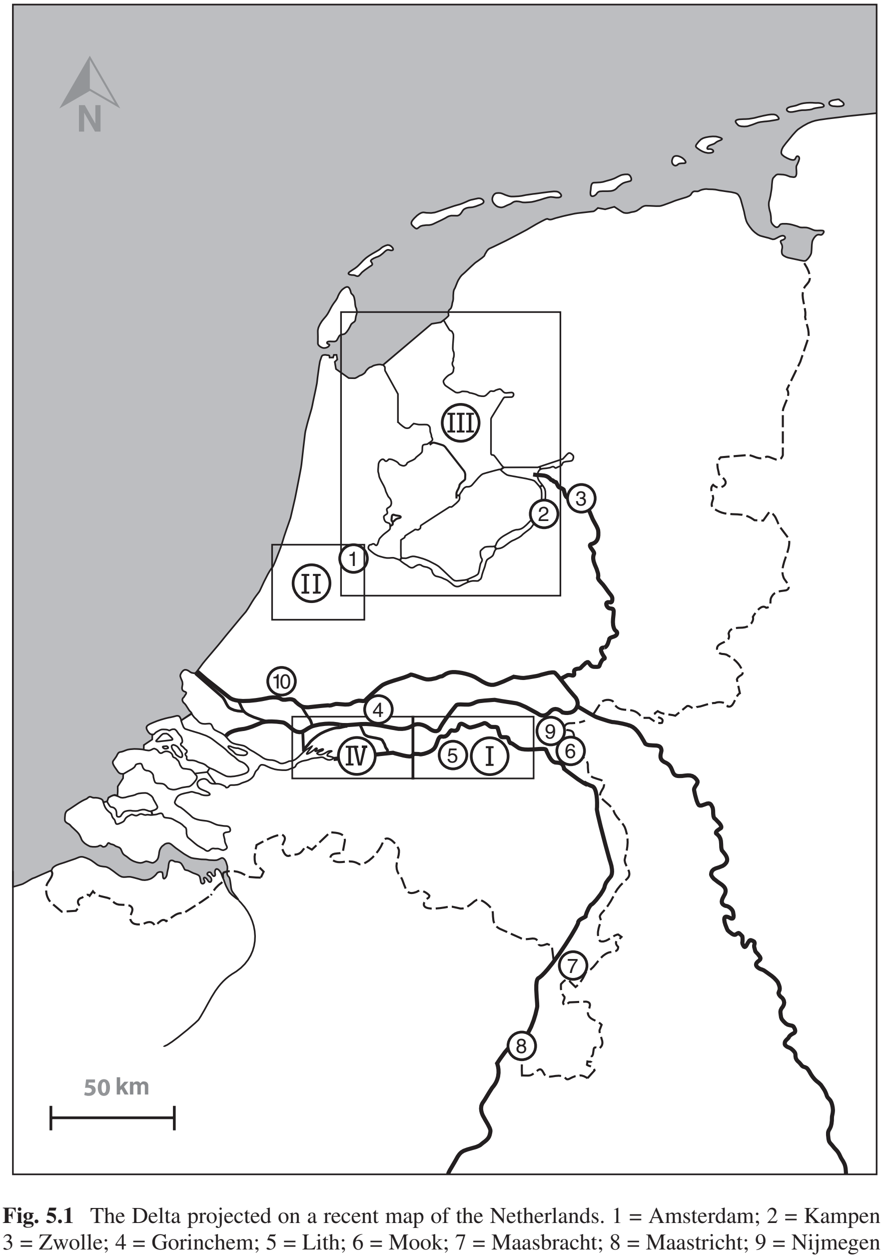

**Fig. 5.1** The Delta projected on a recent map of the Netherlands. 1 = Amsterdam; 2 = Kampen; 3 = Zwolle; 4 = Gorinchem; 5 = Lith; 6 = Mook; 7 = Maasbracht; 8 = Maastricht; 9 = Nijmegen; 10 = Rotterdam. Inset I: Fig. 5.4; inset II: Fig. 5.6; inset III: Fig. 5.7; inset I and IV: Fig. 5.5

its own advice, the commission came with a frank confession '(…) that to its opinion, there is until now no executable and radical solution available or discovered, which will be able to counteract the general natural phenomenon, existing in all rivers, namely the heightening of the river bed…', as a consequence of which the fatalistic-looking conclusion was drawn that '(…) our nation will remain subjected to flooding and ice drift in a similar way as some southern regions are to volcanic eruptions or earthquakes'. The commission explicitly stated that it did not claim to have succeeded in its assignment, and pleaded for dyke strengthening, for removing obstacles from the river foreland, for lateral diversions in the region of the Rijn bifurcations and for diverting the water of the Lek towards the Hollands Diep. The commission further plead for the digging of the Nieuwe Merwede and for improvement of the discharge via already existing lateral diversions of the Maas in Noord-Brabant (see Sections 5.3 and 5.4) (Van de Ven, 2004).

The need for river improvement, to prevent flooding and for international shipping interests was widely acknowledged after 1850. The core of the plans was that each river had to be brought in such a state that it could independently discharge the upstream water and ice. This situation could not be realised at once, but would have to be achieved in the course of years by a series of activities. For that purpose the so-called standard width for the rivers was introduced. This width increased in the direction of the mouth. So the width of the Waal would have to be 360 m at the upstream near Pannerden, and 600 m downstream. The works which would have to be carried out in the river sections, would also have to scour away the islands and shallows. In short, any river would have to be brought to a standard width and have only one continuous bed.

The execution of the projects was favoured because the economic situation had taken a turn for the better in the second half of the 19th century. After 1848 a period of stability dawned in the Dutch political set-up. This made it possible to give undivided attention to river improvement for a considerable length of time. In addition, the public finances had been reorganised and now there were adequate funds to take on these costly projects. Although the major share of this money had been spent on the construction of railways, the sums of money that had been put aside for river improvement were considerable as well. The regulations that came in action in the 19th century have been further extended, leading to the River Act of 1908, ending the uncontrolled growth of incidental and local measures in the river basins (Bosch and Van der Ham, 1998; Van der Ham, 2003; Van de Ven, 2004).

Rehabilitation of the geomorphological processes in the Dutch rivers is only possible in a very limited way, because the standard relations between mean channel width and depth versus discharge of a natural river have been completely disrupted. In a natural river the width to depth ratio is supposed to increase in downstream direction, whereas the relative volume of stored sediment is also greatly increasing. Classical diagrams show a channel width of 500 m at a discharge of 1,500 $m^3$ $s^{-1}$ (Church, 1992). The river Waal, the main branch of the river Rhine in the Netherlands, and an important shipping route between Rotterdam and Germany, with an average discharge of 1,500 $m^3$ $s^{-1}$, has an average channel width of only 170 m.

The width–depth relation of a river channel is a measure for the relation between the forces of the currents and the stability of the river levees and sediment deposits, in other words the geomorphological activity of the river. The Shields parameter is a measure for the strength of the currents in relation to the grain size of the sediment in the riverbed. Together, the width–depth relation and the Shield parameter show the mutual relations between currents and sediment distribution under local

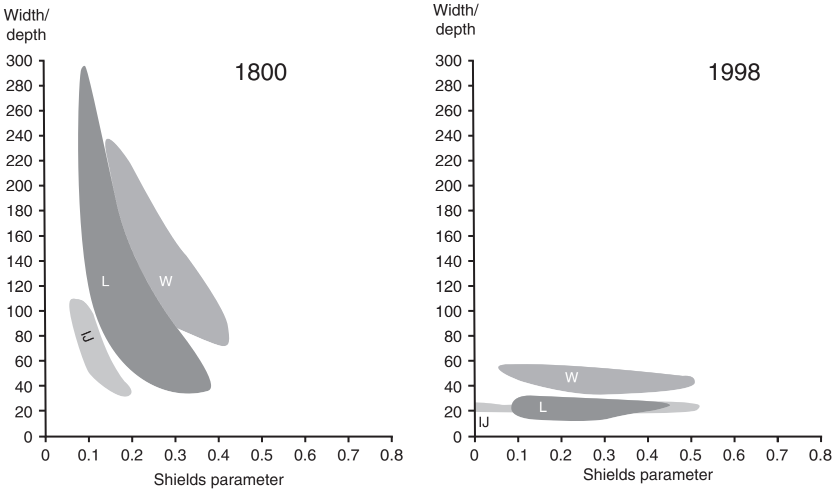

**Fig. 5.2** The relation between the width to depth ratio and the Shields entrainment parameter around 1800 and in 1998, for the rivers Waal, Lek and IJssel (Lambeek and Mosselman, 1998)

circumstances. The deposition of sand on sandbanks and levees along rivers is coupled to the width–depth relation of the river. The larger this relation, the more dynamic the river is and the higher the sandbanks may grow. Islands in the river channel only develop where the river is very wide and shallow, at a width–depth relation of 100 or more. Before 1850 both Waal and Lek showed these high dynamical characteristics; the IJssel was less dynamic. Nowadays, the normalised rivers only show low to very low dynamics. Relatively, the ‘wild’ river Waal is still the most dynamic river stretch left in the Delta. Accretions of sand connected to the bank of the river can originate also at a lower width–depth relation (40 or more). Before 1850 this process counted for all main river branches; nowadays it is only occurring along the Waal and Bovenrijn (Fig. 5.2; Lambeek and Mosselman, 1998).

## 5.3 The Rhine Normalisation

### *5.3.1 Closure of the Upstream Mouth of the Oude Rijn*

In the border treaty of 1816 with Germany, it was determined that the upstream mouth of the Oude Rijn had to remain open, because this overflow of Rhine water could prevent flooding of the German border area. The growing Dutch opposition against this treaty stated that during high river discharges, uncontrolled quantities of water could flow from the Oude Rijn towards the Nederrijn and the Lek. As a concession a low embankment was built as a spillway in the upstream mouth of the Oude Rijn, the Spijkse Overlaat (Fig. 4.8). Until the 1960s, the riverbed of the Oude

Rijn continued to function as a spillway for excess water, causing numerous floods in the region. The overflow of the Oude Rijn was closed in 1960, simultaneously with an improvement of the Pannerdens Kanaal, the digging of a parallel green river, a dry watercourse functioning as a spillway during floods. Since then an optimal water distribution over the different branches of the Rijn has been achieved. The works were executed in such a way that even during spate conditions the Pannerdens Kanaal would discharge one third of the Rijn water from upstream, and the Waal would discharge two thirds (Van de Ven, 2004).

### *5.3.2 The Nederrijn and the Lek*

The river section Nederrijn–Lek from Pannerden to Rotterdam (Fig. 5.3), was radically 'improved' after 1850. Between 1850 and 1896, groynes were built over a distance of more than 62 km. Additionally, two sharp bends were cut off between 1853 and 1873. Towards the end of the 19th century a continuous navigable depth of over 2 m had been achieved for this river section.

A further improvement of the Nederrijn–Lek river stretch was its stringent canalisation. This project had already been decided upon before the acceptance of the Delta project in 1957 (Chapter 10), but its execution was linked to the hydraulic engineering works in the SW Delta. As a consequence of the closure of several estuaries in the SW Delta less Rhine water was needed to fight the salting up of the downstream river sections. Therefore, more Rhine water could be used for the northern part of the Delta, and consequently, more water could be discharged via the IJssel into the IJsselmeer, which could serve to counteract salting up of the NW Delta (the 'invisible Rhine' see Chapters 20 and 21). To provide the river IJssel with more water, a weir and an accompanying ship lock in the Nederrijn at Driel were constructed, and later on two more weirs were built downstream, at a distance of about 20 km from each other, at Amerongen and Hagestein (Fig. 5.3). These weirs were necessary to guarantee sufficient draught for navigation purposes at low discharges of the Nederrijn–Lek (Ten Brinke, 2004; Wijbenga et al., 1993).

### *5.3.3 The Waal*

The Bovenrijn – the river section from the boundary with Germany to Pannerden (Fig. 4.8) – and the Waal–Merwede formed the main shipping route to Rotterdam (Fig. 5.3). Although the Nederrijn and the Lek were international shipping routes as well, all attention was focused on the improvement of the Waal, a.o. induced by political pressure from Germany to improve and maintain the main navigation route from Rheinland–Westfalen to the North Sea. The civil engineering works on the Waal in the second half of the 19th century can only be considered as plain regulation and canalisation of this main river. To stimulate the development of one central

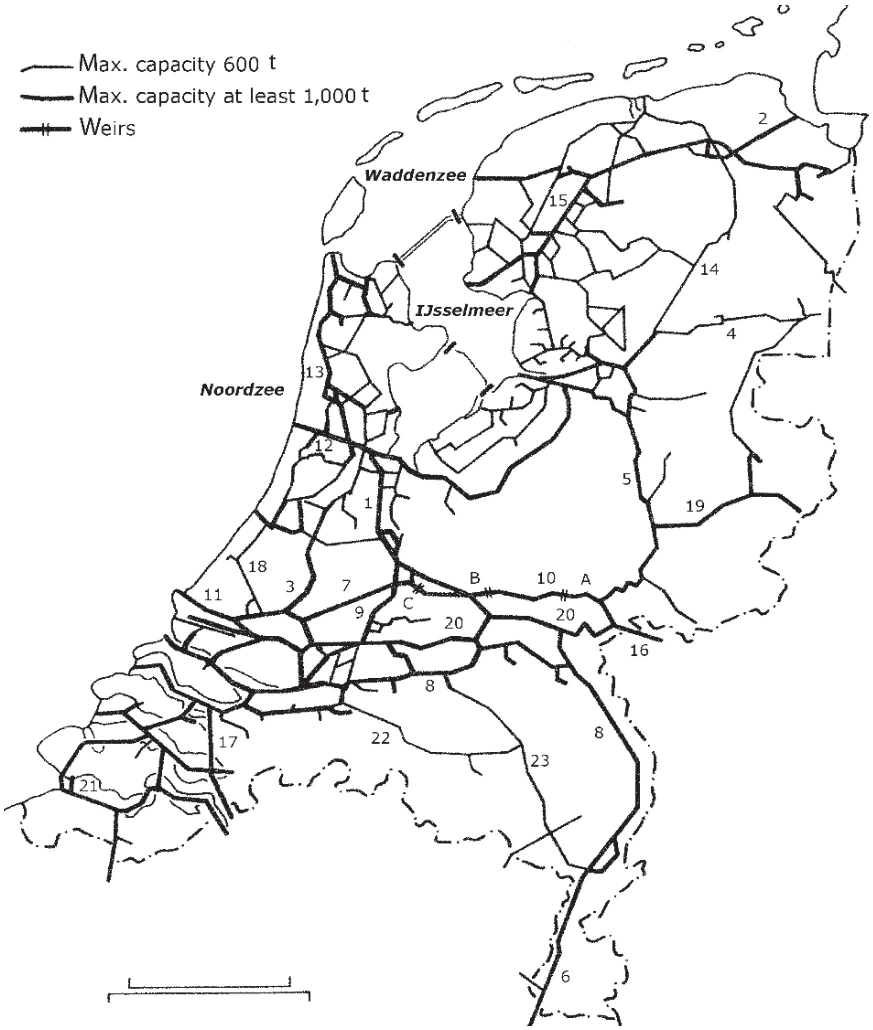

**Fig. 5.3** Principal waterways in the Netherlands in 1980 (Lambert, 1985, derived from IDG Bulletin 1978/79; www.knag.nl). 1 = Amsterdam–Rijnkanaal; 2 = Eemskanaal; 3 = Gouwe; 4 = Hoogeveensevaart; 5 = (Gelderse) IJssel; 6 = Julianakanaal; 7 = Lek; 8 = Maas; 9 = Merwedekanaal; 10 = Nederrijn; 11 = Nieuwe Waterweg; 12 = Noordzeekanaal; 13 = Noord-Hollands Kanaal; 14 = Noord Willemskanaal; 15 = Prinses Margrietkanaal; 16 = Rijn; 17 = Schelde-Rijnkanaal; 1 8 = Schie; 19 = Twentekanaal; 20 = Waal; 21 = Westerschelde; 22 = Wilhelminakanaal; 23 = Zuid Willemsvaart; A (Driel), B (Amerongen), C (Hagestein) weirs on Nederrijn–Lek

channel, a large number of sandbars and islands were either removed or linked to the riverbanks. It was tacitly assumed that the improvement of the discharge of water and ice would also be beneficial for navigation. The main adjustment was the closing of the Kanaal van Sint Andries with a sluice in 1899, which separated the Maas and Waal at Heerewaarden (Fig. 5.4). In this way the Waal downstream of Heerewaarden could remain at a proper depth.

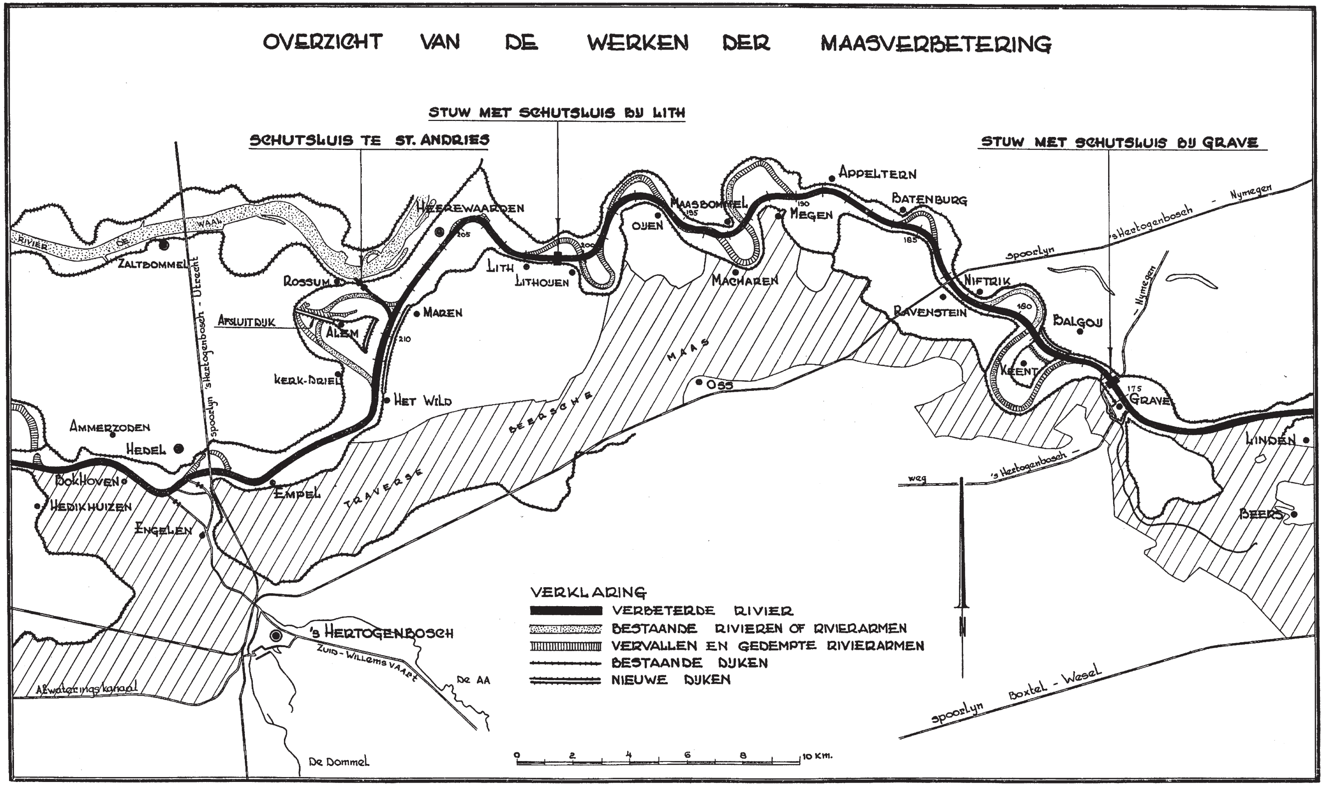

**Fig. 5.4** Normalisation of the river Maas *ca.*1920–1942 (see inset I, Fig. 1). Note the cut off meanders ('bestaande, vervallen en gedempte rivierarmen'). 'Stuw met schutsluis = weir and lock. The spillways between Waal and Maas at Heerewaarden were closed in the period 1882–1904. Hatched area = spillways ('overlaten') and lateral diversion of the Maas, the Beerse Maas, closed in 1942 (De Jonge, 1954)

The river Waal had several gullies, varying in depth and width, offering no optimal discharge conditions. In the period 1850–1870 river regulation works (normalisation) were executed aiming at an improvement of the discharge of water and ice. During these normalisation works one continuous gully at low water was created, and this gully was fixed by the building of stone groynes perpendicular to the main stream of the river, and a standard width of the riverbed of 360–400 m was maintained. In the period 1880–1920, the river Waal was further narrowed for navigation purposes. The narrower the river became the deeper incised the summer bed into the bottom (Lambert, 1985; Van de Ven, 2004). The systematic building of groynes changed the river into a tamed and regulated stream, which gradually amputated the smaller landscape elements: river branches were cut off, secondary channels became dry land, and natural harbours silted-up. For many villages along the Waal the regulation of the river meant the death sentence for the landing stages and jetties, and all activities connected to the local river trades, including the existence of well-patronised pubs (Van Os, 1984).

### 5.3.4 The Merwede

In 1850 regulation works on the upper and lower sections of the Merwede started. A number of creeks in the Biesbosch area were closed, and a new river section was constructed by widening and scouring out a number of existing creeks, the Nieuwe Merwede, connecting the upper Merwede with the Hollands Diep (Fig. 4.4). The Beneden–Merwede and the Nieuwe–Merwede were canalised to a standard width of 200 and 400 m, respectively. Around 1890 the Nieuwe–Merwede could be considered as completed and it could amply drain off the Waal and Maas waters, joined together at Gorinchem (Fig. 5.1), to the sea. The settlement of this essential problem opened the possibility to start working systematically on further river improvement. The river channel from Dordrecht to Rotterdam, called the Noord (Fig. 4.4), was regulated around 1880, and in the period 1882–1883 measures were taken that greatly improved navigation into the Noord from the Beneden–Merwede. The Nieuwe Maas flowing through Rotterdam was adjusted concomitantly with the construction of the Nieuwe Waterweg (Fig. 4.4), which was completed in 1872 and formed a direct channel connection between Rotterdam and the North Sea.

The Boven–Merwede, however, the section from Gorinchem as far as the branch of the Beneden–Merwede, could not be made adequate for navigation. The joining of water from the Maas and the Waal (Fig. 5.5) required this river section to have a width of 600 m. Some works were executed: sandbars were linked with the banks and shallows were dug out, but the situation remained unsatisfactory in this extremely meandering river section. Narrowing the Boven–Merwede could only be considered when the river was no longer encumbered with water from the Maas. Prospects improved when the act to separate the Maas and the Waal was passed,

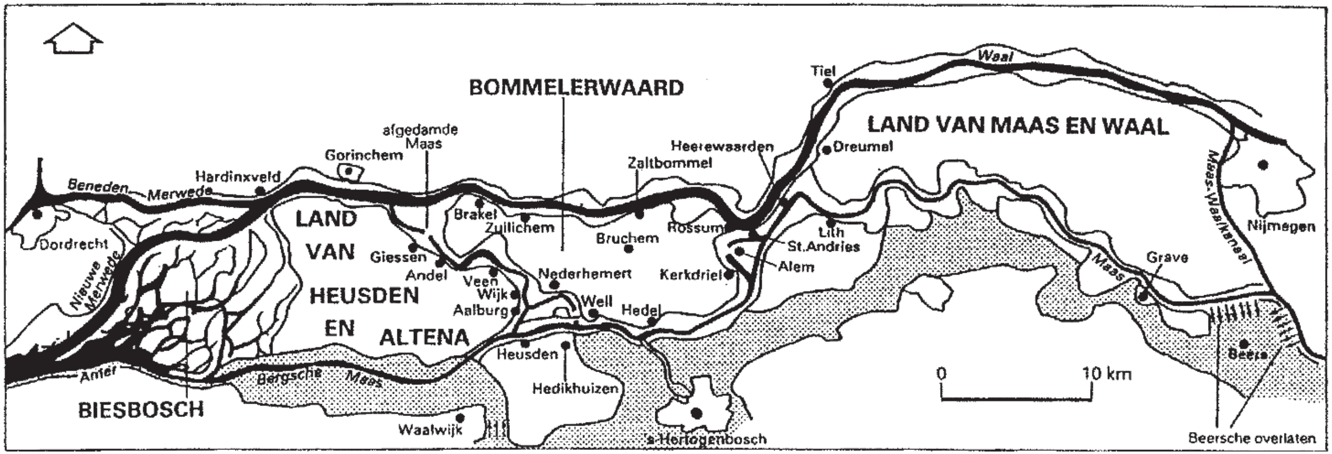

**Fig. 5.5** The area of the large rivers Waal–Merwede and Maas, with geographic names mentioned in the text (Berendsen, 2000). Light grey = Beerse Maas (see inset I and IV in Fig. 5.1)

which provided the digging of the Bergse Maas (Fig. 5.5) as the new Maas mouth. The separation of the Maas and the Waal was completed in 1904 and this made it feasible to regulate the Boven–Merwede sufficiently. In 1916 the canalisation of the Merwede was finished, resulting in the creation of a continuous shipping route between Germany and Rotterdam, and further to the North Sea.

Nowadays continuous navigation along the main axis of the Rhine, the Waal–Merwede, is a prerequisite above all other functions, except safety for the human population. The river Waal–Merwede is one of the busiest rivers in Europe. Every year about 160,000 vessels cross the German–Dutch border, comprising a cargo capacity between 250 and 18,000 tonnes per vessel, carrying 140 million tonnes of freight every year. The Dutch government is continuously improving the navigability of the Waal, by dredging and improved regulation measures. By 2010, a minimum depth of 2.80 m and a minimum width of 170 m are required. At the moment, the aim during low water is to maintain a channel depth of 2.50 m and a channel width of 150 m (www.minvenw.nl; Simons and Boeters, 1998).

## 5.4 The Meuse Normalisation

### *5.4.1 The Grensmaas*

The Dutch Meuse (=Maas) is 250 km long and has a drop of about 45 m from the Dutch–Belgian border to the North Sea (Fig. 5.1). In the south, over a distance of 55 km, the Maas forms, since 1839 the border between the Netherlands and Belgium. For this reason, these parts of the river are known as the Grensmaas (literally, Border Meuse) and Common Meuse, respectively. This section of the river Maas was ‘normalised’ in the second half of the 19th century, and transformed from a wild, meandering gravel river into a narrow channel with uniform width. But the problems remained: the river was not navigable during large parts of the year, and it was flood-prone during high discharges. The Dutch solution for the navigability of the river was the digging of the Juliana kanaal (1935) between Maastricht and Maasbracht, and the Grensmaas lost its function as a fairway (Figs. 5.1 and 5.3). Recently, plans have been developed to re-vitalise the Grensmaas, based on two arguments, a better protection against flooding and the development of ‘new’ nature. From 1992 onwards parties are arguing about the economic aspects of the project. Starting with the successful ‘Plan Ooievaar’ in 1985 (see Chapter 21), there is an increasing societal interest in ‘nature development’ in the Delta, and the Grensmaas river basin is an excellent experimental garden for the development of a semi-natural gravel river, the only one in the Delta. These ideas are fed by the growing resistance against the large-scale mining of gravel, that has transformed the former floodplains of the river into a ‘Swiss cheese’ (see Chapter 13), a landscape with numerous very deep pits filled with water, varying in size from ponds to lakes (Lambert, 1985).

## *5.4.2 The Gestuwde Maas*

The canalisation of the stretch of the Maas between Maasbracht and Lith, the Gestuwde Maas (Fig. 5.1) took place between 1918 and 1942, for example, to stimulate the development of the Zuid–Limburg coalfield (see Chapter 13), but in fact improvements are continuing until the present day (Section 5.4.4.). Since canalisation of the Meuse and the construction of the Maas–Waal kanaal (1927) west of Nijmegen (Fig. 5.5), traffic on the river has increased considerably. Up to Word War II, coal accounted for 60% of freight on the river; in recent decades sand and gravel make up a similar percentage (Lambert, 1985). Between 1930 and 1940 many meanders of the Maas were cut off. In this way the length of the river section between Grave and Heerewaarden was reduced from 42 to 19 km (Figs. 5.4 and 5.5). This part of the river is navigable, and intensively used for transport, agriculture and recreation. The stretch from Maasbracht to Mook (Fig. 5.1) is not dyked. The dyked section of the Maas valley between Mook and Lith, which is liable to flooding, counts as part of the river's high-water winter-bed. Along the stretches of the Maas without dykes, floods bring different problems to those experienced along dyked rivers. The undyked section of the Maas valley is in intensive use and contains numerous villages and hamlets. Consequently, even moderate discharges can cause damage and inconvenience as the river waters will flood the lower parts of the human settlements. Following the flooding of 1995, low ring-dykes were built around the main settlements along this stretch of river. Within these defences, the risk of flooding in any given year is 1 in 50. Thus, the ring-dykes offer much less protection than ordinary river dykes, but can substantially reduce the damage caused by a moderate flood. Once the engineering works planned for the river Maas have been completed, the annual probability of flooding will drop to once in 250 years. Downstream of the Grensmaas river levels can be predicted with reasonable confidence, but at times of extreme flood, however, evacuation of people and cattle will still be necessary (www.maaswerken.nl).

Weirs regulate the distribution of water along the larger part of the Maas, up to Lith. When the discharge at Maastricht (Borgharen) is less than 1,200 $m^3\ s^{-1}$, the weir gates are closed and a relatively constant level is maintained at each of the seven weirs in the river Maas. This situation prevails almost all year round: the weirs are open for an average of only 4 days a year. A system of canals enables water from the Maas to be diverted to agricultural areas and nature reserves. Sometimes, however, there is not enough water in the river to allow optimal distribution to all sections of the 'gestuwde' Maas. At such times, choices have to be made. The aim is always to maintain a flow of at least 10 $m^3\ s^{-1}$ in the Grensmaas; otherwise, irreparable damage would be caused to natural habitats along the river. Lower flows along the Grensmaas would also lead to unacceptable reductions in water quality, since the waste water discharged into the river would not be diluted sufficiently (Middelkoop and Van Haselen, 1999; Lambert, 1985).

### *5.4.3 The Getijde Maas*

The most stream-downward stretch of the river, the 'Getijde' Maas (tidal Maas) downstream of Lith, is canalised in the 20th century. With the improvement of the Rijn branches in the 19th century, the greatest danger of flooding had been averted, and attention was focused on the prevention of flooding along the Maas. The separation of the rivers Rijn and Meuse was decided by an act in 1883. Water levels in the river Waal were generally higher than in the river Maas, regularly leading to flooding of the Meuse and surrounding areas (Beerse Maas; Fig. 5.5). Concomitant with problems generated by the river Maas, there was the possibility that the tributaries Dommel and Aa would come in flood also, because they could not discharge their water during a Maas flood. In 1904 the separation of the Maas and the Waal was completed, by the digging of the Bergse Maas, and the improvement of the connection to the Hollands Diep (Fig. 5.5). The Afgedamde Maas, the connection between the Maas and the Rhine at Gorinchem (Fig. 5.5), was provided with locks, and an embankment was thrown up at Heerewaarden, where Rhine and Meuse ran parallel over several kilometres, only separated by a narrow, slightly embanked strip of land, allowing the free interchange of floodwater (Fig. 5.5).

After the completion of the Maas canalisation works, it was decided in 1942 to seal off the Beerse Overlaat, the eastern entrance of the Beers Maas overflow (Fig. 5.5). Nowadays, the flow of Maas water is unhindered by weirs from Lith down to the Haringvliet dam (1971) and the storm surge barrier in the Nieuwe Waterweg (1996) (Chapter 10). Being linked to the sea by the Nieuwe Waterweg, the river exhibits tidal influence as far upstream as Lith. The locks in the Haringvliet dam serve as a control valve, which is used to regulate water levels in the tidal river area. When flow in the Rijn at the German border is less than 1,700 $m^3 s^{-1}$, the locks are closed. As flow increases, they are gradually opened. In addition, water is distributed in such a way as to ensure that flow in the Nieuwe Waterweg does not fall below 1,500 $m^3 s^{-1}$. Otherwise, the incursion of saltwater would reach undesirable levels. For the benefit of shipping, water managers try not to let the low water level at Moerdijk (Fig. 4.4) drop below sea level. During storms the Haringvliet locks are closed (Middelkoop and Van Haselen, 1999).

### *5.4.4 The Zandmaas and Meuse Route projects*

As a result of the (near) floods of 1993 and 1995 in the Rhine and Meuse basins two ambitious plans to further regulate the river Maas have been developed, the 'Zandmaas' project, the stretch of the Meuse between Maasbracht (Fig. 5.1) and Hedel (Fig. 5.5), and the 'Maas route' project, the entire Meuse route from the locks south of Maastricht, via the Julianakanaal–Lateraalkanaal (Fig. 5.3) and the 'Gestuwde' Maas. Minimising flood-related problems, improving the navigation channel and developing natural habitats are the three main aims of the large 'Zandmaas' and 'Maas route' projects. In pursuit of the first aim, embankments were created as part of the Zandmaas project in 1995. Further measures are planned to increase river capacity and thus reduce high water levels. The planning was that by 2005, the risk of flooding in the areas protected by embankments should be 1/250 in any given year. The navigation channel improvements in prospect are intended to make the entire Maas route suitable for twin-vessel sets. Other important aims are safety and ease of passage for all vessels using the navigation channel (www.maaswerken.nl)

The prime aims of the Maas-works are flood alleviation and improvement of navigation, and 'nature development' in the river forelands as a subordinate third motive. Without compensatory measures, the work being undertaken along the 'Zandmaas' to 'make room for the river' will affect high water levels on the sections of the Maas provided with dykes. Just as other river regulation schemes, the 'Zandmaas' route scheme, is part of an endless spiral of civil engineering measures that should necessarily be executed in the future. One example: The building of additional levees and the widening and deepening of the Maas riverbed will cause a flood wave that will reach 's-Hertogenbosch (cf. Chapter 11) faster than in the past. Hence, future flood alleviation works remain necessary to solve the potential flooding problems of the town of 's-Hertogenbosch, because the rivers Dommel and Aa, tributaries of the river Maas, and running through the inner town, will not be able to dispatch their superfluous water on the Maas, in case of an alarming flood (Middelkoop and Van Haselen, 1999).

### *5.4.5 The Beerse Maas*

The Meuse, a typical rain river subject to sudden spates, presented equally serious water-control problems as the Rhine. Since the Middle Ages the southern Maas dykes between Beers and Grave had included two spillways (Dutch: 'overlaten'), lower sections 800 and 4,200 m long, respectively, by which floodwater was allowed to spill into the adjacent polders. In the course of the centuries these overflows expanded westwards, and the Beerse Maas thus formed was clearly working for much of the Middle Ages (Figs. 5.1, 5.4 and 5. 5). In fact, 's-Hertogenbosch owed its role as a fortress to the swamps which encompassed it (see Chapter 11). Increasing flood danger focussed attention on the Beerse Maas again and again. In 1766 another spillway was built west of 's-Hertogenbosch, permitting the waters to escape westwards, and allowing the floods to empty into an old channel of the Maas, reducing thereby the pressure on 's-Hertogenbosch (Figs. 5.4 and 5.5).

Conditions at 's-Hertogenbosch were further aggravated by the fact that, since the St. Elizabeth's flood of 1421, marine influences penetrated far land inwards and could raise the water levels on both the Maas and Waal as far inland as Heerewaarden, some 15 km above the city (Fig. 5.5). At this point the two great rivers approach most closely, the narrow strip of land between them containing a number of spillways, the Heerewaardense spillways, and two canals. When the Waal was in spate its waters passed via those spillways into the Maas, increasing the pressure on its lower course down to Gorinchem (Fig. 5.5), and the Beerse Maas basins around ‘s-Hertogenbosch were filled to overflowing. Although permission to close the Heerewaarden spillways was given already in the 15th century, little was done before 1730, when one canal was closed. Serious flooding throughout the river region in 1809, 1860–1861, and 1880 gave rise to further schemes of water management. It was decided to separate the Waal and Maas definitely in 1883, and between 1887 and 1896 a new river channel was cut, the Bergse Maas (Fig. 5.5), linking the Hollands Diep with the Maas; this new Maas course was opened in 1904. It was in 1856 that a lock closed the Kanaal van St. Andries (Fig. 5.4), and the Heerewaarden spillways were finally sealed between 1882 and 1904. Thus, only by the early 20th century the Heerewaarden spillways and canals were closed (Lambert, 1985).

Some major river improvement works were executed in the Maas basin between 1825 and 1850, and an important one was the clearing of the traverse of the Beerse Maas and the widening of the spillway west of ‘s-Hertogenbosch. The clearing in the Beerse Maas consisted of digging up the areas of higher ground, lowering embankments which were too highly situated, cutting hedges, and even clearing a forest that was situated close to the eastern spillway. Since 1828 the Beerse Maas could, therefore, be considered as a real lateral diversion of the Meuse (Fig. 5.5), but the Beerse Maas has, however, never worked in this way. In analysing the events during which water flowed over the spillways at the east and west ends of the Beers Maas, it appeared that these periods did not coincide. In many cases only the eastern parts of the Beers Maas functioned as retention area for flood water from the Maas. It also occurred that the back-swamps of the Beerse Maas had already been filled with local seepage and rainwater, without inflow from the river proper (Lambert, 1985).

The overflow areas were almost uninhabited, and especially used as hay fields, and at the lowest spots decoys were managed. Flooding meant enrichment with fertile silt, but too much water on insufficiently drained fields was detrimental to the vegetation. The groundwater level of grasslands during the growing season should at least be 40–50 cm below surface level. Permanently waterlogged soil in the low-lying basins (‘kommen’) became acid and produced inferior hay. In winter the overflow areas were important feeding grounds for waterfowl, particularly ducks and golden plovers. Fowlers sold lapwings for golden plovers which, being a delicacy, fetched a better price (Caspers and Post, 1996).

## 5.5 The Great Age of Digging Canals

The river Maas was very shallow during summertime, and during the rainy season the current velocity of the water made upstream transport almost impossible, and downstream shipping most dangerous. Hence, carrying-trade from Holland to ‘s-Hertogenbosch took place over water, and transport further south took place over land. This forced trans-shipment of goods from ships to land-vehicles gave this city already during centuries her central position in the exchange of freight between the northern and the southern parts of the Delta. The digging of the Zuid–Willemsvaart (Fig. 5.3) meant an improvement of the connection between Rotterdam and the hinterland of the river Maas. This canal became the artificial alternative for the unpredictable, in terms of transport almost useless natural rivers, the Maas and the Dommel, and meant an effective modernisation of the freight traffic. The canal with its length of 123 km, depth 2.1 m, width 18 m, and towing-path along both banks of 4 m, dug between 1822 and 1826, became an impressive transport route between the two capital- and fortress-cities Maastricht (Fig. 5.1) and 's-Hertogenbosch (Fig. 5.4) (Van der Woud, 2004).

While the work on the Zuid–Willemsvaart was in full swing, the improvement of the waterways to and from Amsterdam continued. During the years 1824 and 1825 the old waterway from Amsterdam to Rotterdam, via the Gouwe (Fig. 5.3), and then along the Hollandsche IJssel to Rotterdam, was widened, deepened and straightened at a number of bottlenecks, allowing navigation with larger ships than the track-boat. Much more important for the hinterland of the harbour of Amsterdam was the concomitant improvement of the 'Keulsche Vaart', the waterway to Germany, existing of a number of older canals connecting the city of Amsterdam with the river Lek. These waterways were also dredged and cleaned. The largest contribution to the modernisation of the Keulsche Vaart, however, was the construction of the 23 km long Merwede kanaal (Fig. 5.3) connecting the Lek and the Merwede, allowing the ships from Amsterdam to pass the river Lek, and to continue their navigation along the river Rhine, via the branches Merwede and Waal to Germany (Fig. 5.3).

The western waterways have undergone almost continuous enlargement. In 1931 the entrance to the Noordzeekanaal (Fig. 5.3) was improved by the seaward extension of the harbour moles and the building of the Noordersluis, the world's largest lock. The canal was subsequently widened and deepened up to Amsterdam and, since World War II, has been further enlarged to take bulk carriers of 90,000 t. In 1967 the moles were built 3 km further seaward. The Merwedekanaal proved inadequate and in 1952 was superseded by the Amsterdam–Rijnkanaal (Fig. 5.3). This, in turn, proved to be too small. Widened and deepened, and provided with new locks and bridges, it was opened in its enlarged form in 1981. It forms a greatly improved route from the North Sea via Amsterdam to Germany, carrying over 40 million tonnes of freight annually. The navigability of the river IJssel (Fig. 5.3) has always been a point of serious considerations. That is the reason why, parallel to the river, in between 1829 and 1869 the Apeldoorns Kanaal was dug; this canal, roughly 60 km long, and varying in depth between 0.7 and 1.5 m functioned for years as a reliable but modest competitor of the river (Lambert, 1985).

The normalisation of the Rhine has been discussed in Section 5.3. To cope with the greater volume of traffic, the Rhine was further canalised, between 1958 and 1970. Three weirs in the Nederrijn–Lek (A, B and C in Fig. 5.3), using semicircular 'visor-gates', can hold back the water when necessary but are normally raised to allow shipping and unimpeded passage. Locks adjoin the weirs for use when the visors are closed. The most easterly visor (A) can divert water into the IJssel and thus to the IJsselmeer; a second (B) controls the flow near the important Amsterdam–Rijnkanaal junction; and the third (C), checks the upstream penetration of saltwater (Lambert, 1985). Recently the weirs have been provided with fish-passages.

Especially in the 19th, but continued in the 20th century, hundreds of kilometres of shipping canals have been dug, mainly by hand with the use of spade and wheelbarrow, and increasingly with the aid of steam-power. Inland waterways continue to give a special character to the scene of the Delta. In 1950 there were 7,700 km of navigable canals and rivers. Of these canals about 2,400 km were suitable for ships up to 400 t, and about 1,500 km for ships up to 1,000 t. About 550 km were navigable for vessels above 2,500 t (Van Veen, 1950). In 1950 Van Veen believed that there would be a bright future for most of these canals. He stated (p. 107): ‘When Henri Ford, the automobile king, saw all these canals his advice was to fill them in and to make roads of them. We have no intention of following his advice, for our fleet of inland vessels, about 20,000 before World War II, transport our goods, particularly mass products and heavy piece goods, in a cheap and effective manner’. Van Veen was partially proved to be right. Notwithstanding the fact that in 2002 the total length of main roads in the Netherlands was over 20 times more than the total length of the inland waterways (113,419 km versus 5,046 km), the bulk volume of goods transported via main roads in the Netherlands is only twice the bulk volume transported via waterways (566 million tonnes versus 278 million tonnes in 2002). The transit transport to foreign countries via the rivers and canals, however, is 33% larger than the transit transport via the main roads (132 million tonnes versus 99 million tonnes) (www.minvenw.nl; www.minfin.nl).

Pusher boats each capable of handling four barges are increasingly employed, especially on the Rhine, and more powerful craft capable of propelling six barges are available. Use of the latter will necessitate modifications to the existing locks and channels. To keep pace with the growing volume of traffic and larger size of vessels, the inland waterway system has needed constant modification. On the one hand, some of the smaller canals have fallen out of use. On the other hand, canals have been built or enlarged and the major rivers straightened and canalised.

## 5.6 Introduction of Steam Power

The first steam pump has been introduced in the Delta into the Blijdorp polder near Rotterdam (Fig. 5.1) in 1787. A cumbrous machine, brought in from England, it met initially with much opposition as the farmers feared its noise would discourage their cows from giving milk. But in its first winter the pump coped with all the water in the Blijdorp polder, with the result that the opposition to steam pumping evaporated. From 1800 onwards steam engines were working at many reclamation projects. As steam pumps improved, their greater capacity and independence of the wind made it possible to overcome difficulties of seepage and differences of depth more easily and at less expense than with the old-fashioned windmills. But even steam could not always overcome the difficulties of the environment. Thus the Naardermeer (southeast of Amsterdam, Fig. 5.1), where reclamation was unsuccessfully attempted in the 17th century, was again tackled in the 19th century. A steam engine was installed in 1831 and, after many setbacks the lake bed fell dry in 1883. But seepage remained so great that within a few years the area was once again under water (Lambert, 1985). It survives today as the oldest official nature reserve in the Delta, bought by a nature conservation society in 1905.

The invention of the steam engine changed the pattern of transport along the rivers within 25 years. During the period 1850–1910 a continuous stream of licenses were granted for the installation of steam engines not only in passenger boats, cargo boats and tug boats, but also in brick factories, tanneries, milling-businesses, drying houses for tobacco and vegetables. The development of the steam era meant strong economic growth for some groups of the population, but led, in contrast, to unemployment for others, and, moreover, it changed the river landscape dramatically. To keep the river navigable for heavy-draught vessels, such as paddle steamers, and particularly screw-steamers, the state government started to dredge the main gully of the Waal in the second half of the 19th century. Between 1860 and 1870 a new trade originated in the Maas and Waal area: dredger. Once one starts to dredge the channel, it is silting-up again: in the lower reaches of large rivers the deposition of sand and silt never ends, and often in places where it is not wanted. Before the steam age upstream sailing on the Waal was accommodated by drivers on towing horses, who pulled the boats along a towpath. Brickworks in the flood plains were obliged to allow the towpath to cross their territory. In 1923 it was decided that the trade of the driver on his towing horse did not exist anymore and that towpaths could be abandoned (Van Os, 1984).

According to Van der Woud (2004) the real revolution in the opening up of the ‘empty country’ took place by the construction of the railway system. The revolution meant an acceleration, a turn in the minds of humans and the experience of people, who started to appreciate ‘speed’. The speed of the steam locomotive turned the notion ‘an hour’s walk’ into an old-fashioned saying. The train had an incredible speed for those days of 30–40 km $h^{-1}$, it drove more or less independent of weather circumstances, and it meant a great stimulus for the international trade, and the transport of passengers. The first railway connection in the Netherlands, between Amsterdam and Haarlem, was accomplished in 1839. In between 1869 and 1885 a number of north–south connections, crossing the large rivers were built. The 19th century cast iron railway bridges, hold together by tens of thousands of rivets, are still (noisy!) landmarks in the river landscape.

## 5.7 Reclamation of the Haarlemmermeer

The peatlands in between Amsterdam, Haarlem and Leiden (Figs. 5.1 and 5.6) were drained and exploited in the Middle Ages, resulting in a considerable number of smaller and larger peat lakes. Gradually the shores of these lakes crumbled away

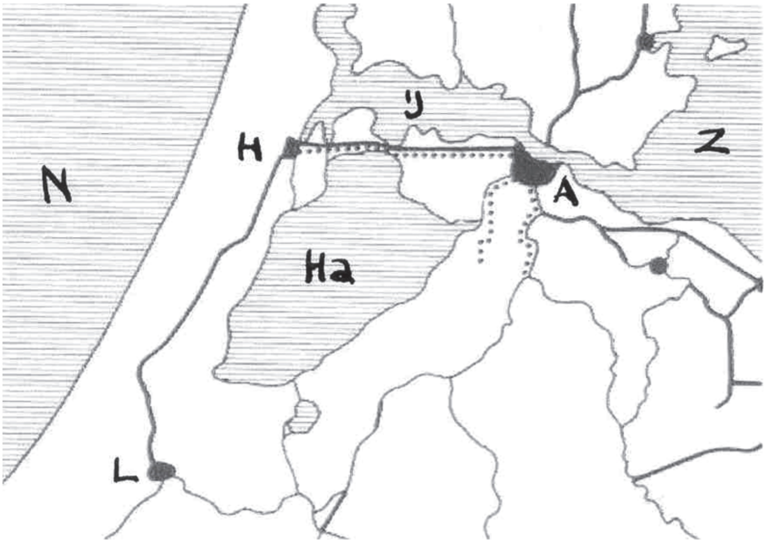

**Fig. 5.6** Haarlemmermeer (Ha) before reclamation in 1852 (see inset II, Fig. 5.1). IJ = IJ inlet of Zuiderzee; Z = Zuiderzee; N = North Sea; H = Haarlem; A = Amsterdam; L = Leiden. Uninterrupted lines = man-dug canals; stippled lines = paved roads. Compare Fig. 4.5

owing to wave attack, and continued peat digging, and eventually a number of lakes united into one large lake, that obtained the size of an inland sea, the Haarlemmermeer (Fig. 5.6). At the end of the 16th century this great lake became a threat for the expanding towns and arable fields in its periphery, that were prone to flooding depending on the direction of the prevailing wind during storm. The Haarlemmermeer had also some useful functions, as a shipping route between Rotterdam and Amsterdam, and via the Zuiderzee, to international destinations (see Chapter 3). The lake was also of significance for fisheries and it was a place to dump garbage and sewage water. In the 17th and 18th century numerous plans were developed for partial or full reclamation of the lake, but these schemes were technically too ambitious.

But the Haarlemmeer steadily grew. In 1250 it covered 9,000 ha, in 1500 it had increased to *ca.* 11,000 ha, and by 1800 it had grown to nearly 17,000 ha. In 1836 a fierce south-westerly storm drove its waters to the gates of Amsterdam, and a month later, impelled by a north-westerly gale, they threatened the walls of Leiden. Promptly, a governmental commission was appointed to examine the feasibility of draining the lake. Leeghwater had first suggested such a plan in the 17th century, and since then various other schemes had been put forward, but reclamation had to await state intervention and the introduction of steam-power. The commissioners met with considerable opposition from vested interests. The town of Leiden, although menaced by the lake, hesitated to give up the income from the leasing of its fisheries. Haarlem foresaw the pollution of the town canals if drainage into the lake ceased, and the polder board feared the loss of its storage basin into which it emptied its excess water in wet seasons. Last but not least, the boatmen operating the trading barges opposed any scheme which adversely affected their livelihood (Lambert, 1985).

Despite all objections, a detailed plan for draining the Haarlemmermeer was presented in 1838, and 2 years later, work started on the digging of an encircling dyke and canal 60 km long (Fig. 5.6). The dyke was completed in 1845 and the first of three major steam pumps was installed by English engineers. A second followed in 1848, and in 1849 the Cruquius pumping station, now the polder museum of the Royal Netherlands Institute of Engineers, began work. In 1852 the Haarlemmermeer fell dry and 18,000 ha of new land was opened to settlement. The reclamation of the Haarlemmermeer can be seen as a technical apotheosis of water management of those days.

The object of the project was flood protection, not land winning. Once drained, the land was handed over by the government to private enterprise. Farm lots were sold, mostly to well-to-do investors, but since returns from the sale were less than the drainage costs, the authorities built no roads, villages, schools, churches or farmhouses, and the pioneer settlers had a hard struggle to survive in a wilderness of reeds. At first, as on other newly won lands, the farmers practised a robber economy, utilising the accumulated fertility of the newly exposed clay soils of the lake bed. There was no regular cropping system to maintain the fertility of the soil and little expenditure on manures. But the soils were by no means uniform and their drainage was imperfect, so yields began to fall. In addition, cholera epidemics broke out, and despite the proximity of Amsterdam, Haarlem and Leiden, the area was virtually isolated because of the poor roads within the ring-canal. Furthermore, the ribbon pattern of settlement along the ring-dyke was conducive neither to social cohesion nor to farm efficiency. The area threatened to become a social disaster until, in the 1880s, the pioneering phase ended. The land was divided into rectangular blocks of 20 ha and let in relatively large farms of 20–100 ha. Since labour was scarce, machinery was introduced, including steam ploughs and threshing machines, and the area became one of modern large-scale husbandry (De Haan, 1969; Lambert, 1985). In addition, Schiphol, the Dutch national airport has been built on the bottom of this former peat lake, 4.3 m-NAP, some metres below the level of the North Sea.

## 5.8 Water Defence Line

In the 19th century, there was yet no political concern about the deterioration of landscape values. In contrast, the military-inspired policy demanded the maintenance of open space surrounding walled towns. In times of war threat the army needed a free field of fire and the countryside should be available for inundations. Following the Old Holland Water Defence Line (Chapter 4), in 1815 a second water defence line was constructed, the New Holland Water Defence Line (Fig. 4.12). The advantage of this more eastward-situated defence line lay mainly in the fact that a larger part of the Central Delta was now protected, including the town of Utrecht.

The success of the Old Holland Water Defence Line in 1672–1673 had created the idea that such systems were the best to hold the enemy, but considering the advancing war machinery the successes would prove to be incidental (Van de Ven, 2004).

The Goilberdingenwaarden, a floodplain area along the river Lek south of Utrecht (Fig. 4.12), is part of the military strategic landscape of the New Dutch Water Defence Line. These floodplains form together with a couple of adjoining forts, bunkers and water inlets, a connected defence unit, where specific military regulations dictated land use, for example, the field of fire should be empty and flat to 300 m outside the fort. Dykes and quays were designed in such a way that they did not give protection to the enemy. Willows were planted in floodplains that could not be inundated. These trees had the advantage that they could easily be cut or burnt down, while the roots remained in the soil. The presence of the willow roots prevented the enemy to dig foxholes in the floodplain. A row of tall trees camouflaged the side of the fort where an enemy was expected to attack, without obstructing the field of fire (Geldersch Landschap and Geldersche Kasteelen, 2003).

A good example of the great influence of military physical planning on the river landscape is the ‘Stelling’ (fortifications) of Amsterdam, a chain of forts built between 1880 and 1913, and surrounding Amsterdam. The ‘Stelling’ had a length of 135 km and encircled an area of 900 $\text{km}^2$; it was built at a large distance from Amsterdam in order to avoid the city from being attacked by gunfire in a potential war. In order to keep an open field of fire it was not allowed to erect obstacles in the wide surroundings of the town. Nowadays, the forts of the ‘Stelling’ are the only isolated patches of protected nature in a culture landscape. They are surrounded by canals with reed and water plants, and overgrown with trees, excellent breeding places for birds (Van Zanden and Verstegen, 1993).

## 5.9 The IJsselmeerpolders

In 1667 Hendrik Stevin devised a plan for the drainage of the Zuiderzee basin and further such schemes were proposed in the 19th century, but none came to fruition. The stimuli of a great storm-tide, which inundated the Zuiderzee shores in 1916, and the food shortages caused by World War I, were required before Cornelis Lely’s plan for its closure and reclamation was sanctioned in 1918. The scheme had three objectives: the reclamation of 205,000 ha of new farmland (equal to one tenth of the Netherlands’ existing agricultural area) in five great polders, the reduction of the coastline by 300 km, and the provision of a freshwater reservoir of 120,000 ha to supply agriculture and industry and to check infiltration of saltwater into the subsoil.

Encouraging results during some preliminary experiments prompted a start on the Wieringermeerpolder in 1927 (Figs. 5.1 and 5.7). Its encircling dykes were completed in 2 years; pumping began, and in 1930 the polder fell dry. The main canals, dredged while the polder still lay under water, allowed barges carrying men and materials into the area, where the muddy land surface was incapable of supporting vehicles. Ditches, dug at first by hand, then by special ploughs as the polder dried out, were ultimately replaced by deep pipe drainage, which more effectively carried away the salt washed out of the soil by rain. In the meantime, the land was sown with reeds to keep down weeds, and an intensive programme of agricultural research began. Once the ground was firm enough, the state built roads, farms and villages, and provided public services. The polder was wilfully inundated by the German occupying power in April 1945, but by the year's end the dyke breaches were sealed and the land had emerged again. Crops were produced the next year; and by 1950 the reconstruction was complete and new settlements were built.

Surveys had shown that the best line for the Afsluitdijk (Fig. 5.7), the main Zuiderzee closing dyke, ran from the island of Wieringen to Zurich in Friesland. The closing dyke was, meanwhile, being built of boulder clay and sand pumped from the sea bed. Despite furious tidal races through the narrowing gap between the two dyke ends, this gap was sealed in 1932. A solid seawall with two groups of sluices, each with a shipping lock, separated from than on the brackish Wadden Sea from the freshwater IJsselmeer. Subsequent reclamations followed the sequence of operations outlined for the Wieringermeerpolder. Their interest lies in the manner in which they have been modified in the light of experience, changed economic and social conditions, and advances in technology (Lambert, 1985).

Desalinisation became unnecessary once the IJsselmeer (Fig. 5.7) was in being, and the stage of preparation for agriculture has gradually shortened. Plans for the remaining lJsselmeer polders have been much modified. The last scheme for drainage and embankment concerned the Markerwaard (Fig. 5.7), and a ring-dyke separating the potential polder from the IJsselmeer was built in 1976. The role of the Markerwaard, now called Markermeer, a shallow 3–4 m deep freshwater basin, is still undecided. The water household of the IJsselmeerpolders appeared to be more complicated than expected: the drained and subsiding polders subtracted too much groundwater from the mainland surrounding the former Zuiderzee. Moreover, there was an increasing demand for water-recreation facilities, together with the protection of existing ecological values. The potentials of this freshwater lake, e.g. its use for urban overspill, its potentials as a freshwater reservoir and other functions such as the place of settlement for a second major airport, and amenity facilities, are being debated for decades (Rijksdienst voor de IJsselmeerpolders, 1980; Robert et al., 1982).

The original idea was to develop the IJsselmeerpolders exclusively for agricultural purposes, but after World War II these views have changed. Instead of the need of more arable land, there was an increasing demand for housing and recreation facilities. Table 5.1 shows the present land use in the four existing polders, a significant change from agricultural use to nature reserves, built-up areas and infrastructure. The physical planning of the Oostvaardersplassen in Zuidelijk Flevoland (Fig. 5.7) form the apotheosis of these changes. This area was originally intended to be developed as an industrial area, but the views about the destination of this low-lying, marshy area changed in the course of the years. The area was set aside as a nature reserve, and 6,000 ha of reclaimed land has been turned with government assistance into one of Europe's largest conservation experiments.

Originally reed was sown in, as in all polders, to stimulate the ripening of the soil. The Oostvaardersplassen spontaneously developed into reed marshes, willow

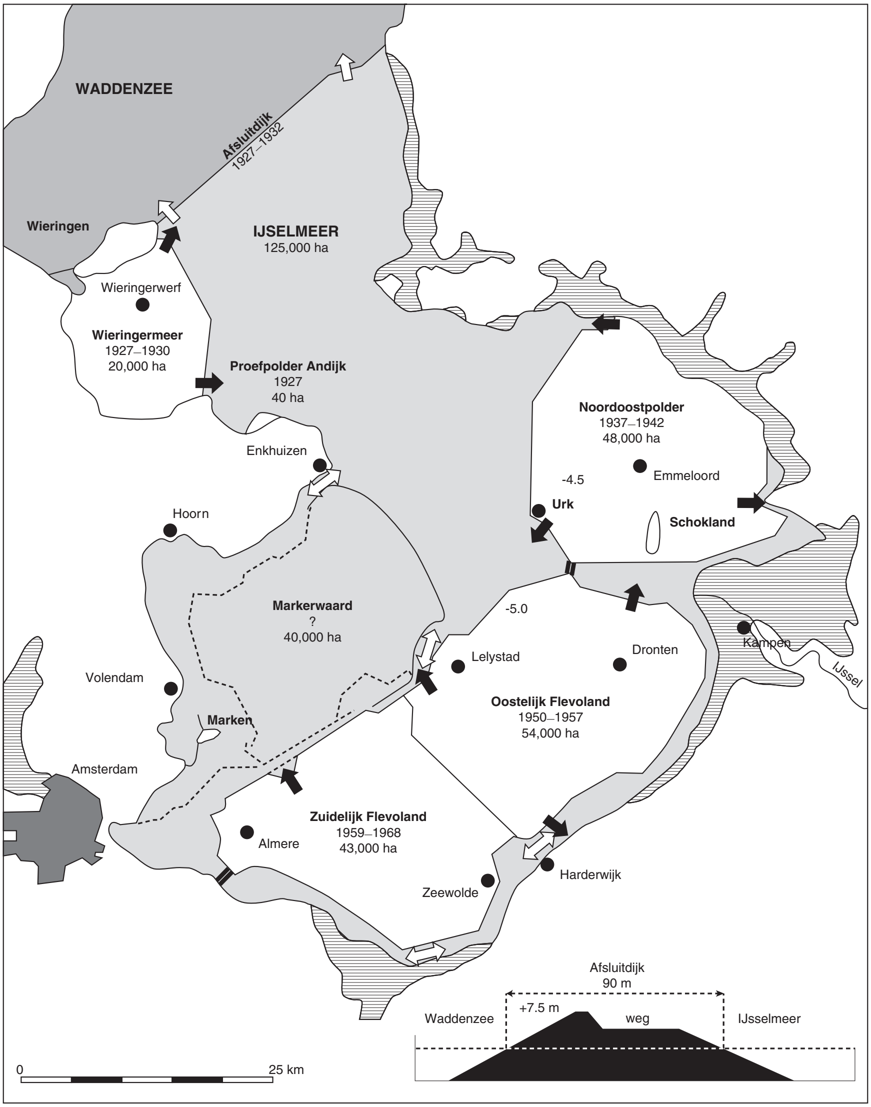

**Fig. 5.7** Reclamation of the polders in the Zuiderzee (since 1932 IJsselmeer) (see inset III, Fig. 5.1). The Wadden Sea (Waddenzee) is a marine-estuarine area, the IJsselmeer is a freshwater basin. Black arrows = pumping stations; white arrows = sluices in Afsluitdijk; double white arrows = fixed bridges and ship-locks (Berendsen, 2000)

forests and open water, but from 1985 onwards the area is managed by an increasing number of red deer and cattle, foreign races such as Heck cattle and Konik horses that keep the woodland open and stimulate the development of grassland. Natural population growth of the large grazers is allowed, which led to a spectacular increase in the number of herbivores, from some tens in the 1980s to almost

**Table 5.1** Land use and changes in land use (in %) of the IJsselmeerpolders (Van Duin et al., 1985)

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Agriculture | 87 | 87 | 75 | 50 |
| Forest and nature | 3 | 5 | 11 | 25 |
| Built up, water | 10 | 8 | 14 | 25 |

(1) = Wieringermeer, reclaimed 1927–1930; (2) = Noordoostpolder, reclaimed 1937–1942; (3) = Oostelijk Flevoland, reclaimed 1950–1957; (4) = Zuidelijk Flevoland, reclaimed 1959–1968

3,000 individuals in 2004, comprising a substantial population of red deer (1,200 individuals in 2004) (www.grazingnetworks.nl). Together with an occasional white-tailed eagle and a large number of breeding birds and migratory birds, the Oostvaardersplassen are supposed to represent a type of Delta landscape 'lost' 1,000 years ago. Notwithstanding its considerable size, however, the reserve is artificially managed: a high groundwater level is maintained, the reserve is isolated from the larger protected areas on the mainland, and surrounded by a 'desert' of arable land and built-up areas, and consequently the migration routes for wandering large mammals (e.g. the red deer) are blocked.

## 5.10 'Dredge, Drain, Reclaim. The Art of a Nation'

The four IJsselmeerpolders, artificially embanked lakes that were subsequently pumped dry, increased the area reclaimed by pumping dry lakes ('droogmakerijen') with 165,000 ha, far out the largest reclamation project in the history of the Delta (Van Duin et al., 1985). Figures 5.8 and 5.9 summarise the surface areas of land gained in the Delta since 1200, divided in areas reclaimed by pumping dry lakes, and areas reclaimed by embanking salt marshes and brackish marshes. In Chapters 2 and 3 it has been shown that in the original raised bogs of the Central Delta, substantial land loss occurred due to peat mining. Peat has been the major fuel of the Dutch economy since the Middle Ages. When the peat moors in the vicinity of the main centres of economy in the mediaeval Delta became either exhausted or were reduced to groundwater level, new sources of peat had to be found. One source was the extraction of peat from below groundwater level. This practice started in the 16th century and soon developed into a booming industry. Nearly 1,000 km$^2$ have been mined in this way, especially in the NW and Central Delta, resulting in the creation of an equally large area of shallow broads and lakes. Many of these lakes have been pumped dry again, a process that started in the 16th century, and this proved to be the start of the reclamation of ever more and ever larger lakes. In the 17th century the windmill technology was applied for reclamation purposes, and in the 19th century, steam engines and still later diesel and electric engines were used to power the pumps. These enabled the large reclamations of Haarlemmermeer in the 19th century and the IJsselmeerpolders in the 20th century.

The extraction of peat for fuel and salt-saturated peat led to an enormous loss of land mainly in the SW Delta but also in the NW Delta, but in the course of centuries

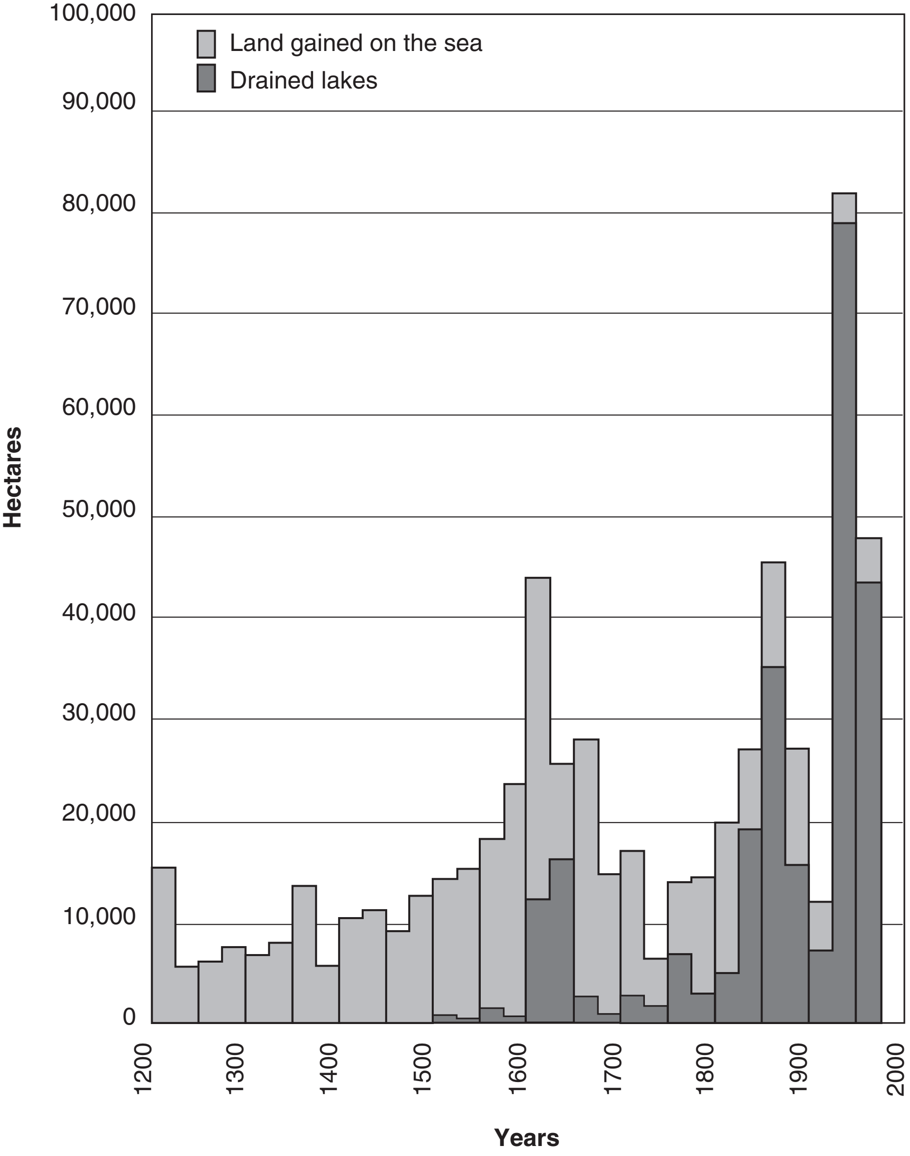

**Fig. 5.8** Reclaimed land in the Delta in the course of time. Land gained on the sea, i.e. areas reclaimed by embanking salt and brackish marshes from 1200 onwards, and drained lakes, i.e. areas reclaimed by pumping dry peat lakes since the 15th century (Derived from Van Veen, 1950; compilation by Rijksdienst voor de IJsselmeerpolders, 1980)

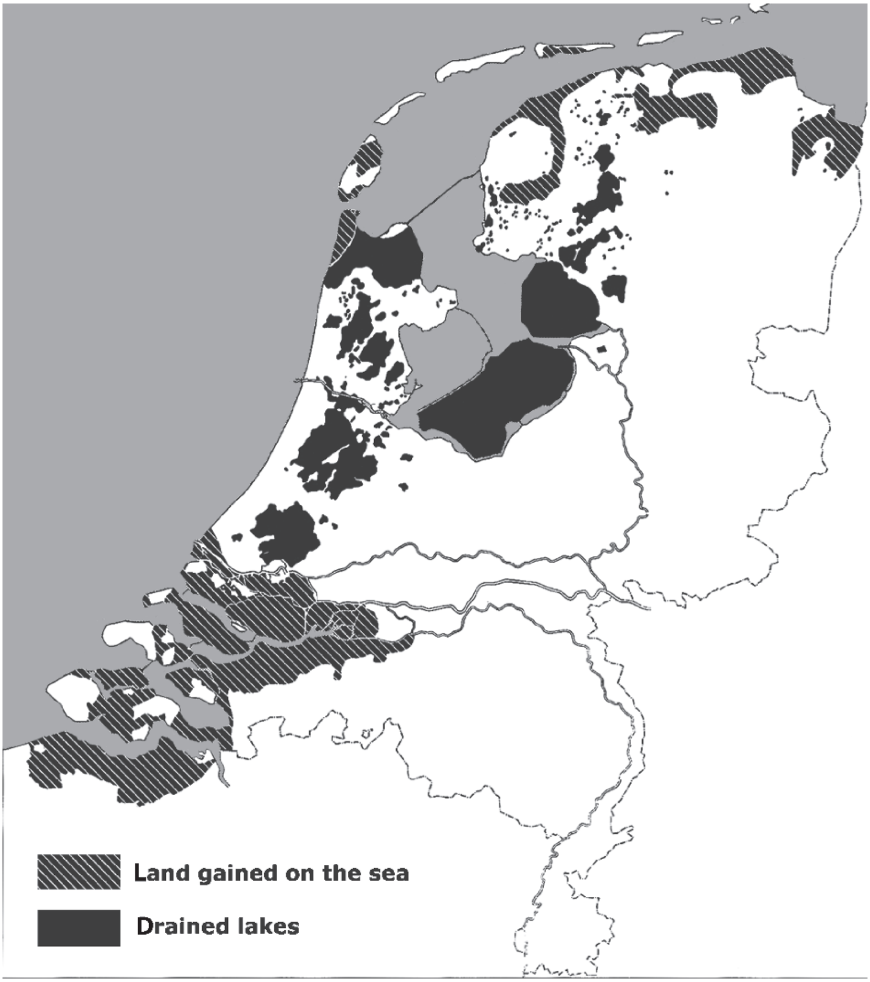

**Fig. 5.9** Land gained on the sea in the Delta, mainly in the SW and NW Delta, and drained lakes in the Central Delta and NW Delta (Derived from Van Veen, 1950; compilation by Rijksdienst voor de IJsselmeerpolders, 1980)

large areas were reclaimed by embanking salt and brackish marshes. Once the existing land had been protected by dykes against flooding by seawater, salt marshes continued to accrete outside the dykes. The inhabitants of the Delta changed their strategy of defensive embankments into an offensive one. Piece by piece, about 4,000 km$^2$ of salt marshes were reclaimed in a process which started immediately after the 12th-century large-scale defensive embankments, and which continued until the second half of the 20th century (Fig. 5.9).

Van Veen (1950), a chief-engineer of 'Rijkswaterstaat' the State Department of Water Management, demonstrated a strong belief in progress and prosperity following the devastating World War II. He gave a portrait of an era with an unshakeable trust in technological advancement, and he stated: ‘The reclamation of the Zuiderzee is one of the greatest works ever carried out by man for the promotion of human welfare (p. 115). The great increase of our population necessitates the gaining of more and more land, and our generation is the greatest of all in making that new land; we have machines infinitely more powerful than the tools of old (p. 65). Holland is not yet finished. It will not be finished before the sea is driven out wholly, not before the country has become a paradise. For this the generations have striven. The present generation is prepared to work for this ideal harder than ever, partly from tradition, (…) and partly from the necessity imposed by the fast-growing population’ (p. 171). And indeed, schemes were published, designed to reclaim parts of the Wadden Sea and the SW Delta, aiming at the reclamation of roughly twice as much land as was to be gained in the IJsselmeerpolders (Van Veen, 1950).

But history adopted another course. A changing attitude towards wetland reclamation awoke in the 1960s, and after 1989 all pending cases of reclamation of parts of the Wadden Sea have ceased. Now, in 2007 the international values of the Wadden Sea have been fully recognised. The governmental policy is dedicated to sustainable protection and development of this unique tidal landscape (www.lnv.nl; www.vrom.nl).

## 5.11 Conclusions

- In the traditional agricultural society of the Delta the Industrial Revolution got under way relatively late, around 1850. Developments in river management in the 19th century were a continuation of a millennia-old strategy: the use, maintenance and improvement of waterways as economic arteries for transport of humans and goods.
- Safety and navigability were important motives for river improvement. Safety against flooding demanded regulated rivers, strong and high dykes, and straight river channels without obstacles, sandbanks, etc., especially to avoid damage through drift ice. Effective transport demanded also a continuous, navigable shipping channel, reliable at low water and at high discharges.
- At the end of the 18th century, after a centuries-long process of river regulation, the embanked, silted-up river channels became unmanageable. Navigability was laborious and unpredictable; regular floods changed the configuration of sandbanks and meanders, and summer droughts revealed silted-up thresholds. Local dredging could not cure that problem; it only meant a displacement of the sedimentation process.
- Rigorous measures were especially taken in the 19th and early 20th century, to ‘normalise’, i.e. completely regulate and canalise the riverbeds of Rhine and Meuse. The removal of numerous meanders and sandbanks, the building of hundreds of groynes to narrow and deepen the channel, the digging of lateral canals and bypasses, and the building of weirs and ship-locks fully canalised the Meuse, and large sections of the Rhine (Nederrijn–Lek). The execution of the

projects was favoured by the improved economical situation in the second half of the 19th century.

- The main rivers Rhine and Meuse were definitely separated in 1904, by the opening of the Bergse Maas, and the closure of the spillways at Heerewaarden. The Beerse Maas, a medieval spillway of the river Meuse was closed in 1943.
- River regulation schemes are part of an endless spiral of civil engineering measures that should necessarily be executed in the future to alleviate the flooding problem and to enhance international shipping.
- The 19th and early 20th centuries is the great age of canal digging, initially by hand with spade and wheelbarrow but increasingly facilitated by steam-power. Hundreds of kilometres of shipping canals were dug, artificial alternatives for the unpredictable, in terms of transport almost useless natural rivers.
- Reclamation of peat lakes continued in the 19th century. Owing to the application of the new steam-pumping station technology the Haarlemmermeer fell dry in 1852 and 18,000 ha of new land was opened to settlement. The aim of the project was flood protection, not land winning.
- The systematic normalisation changed the rivers into tamed and regulated streams. The amputation of the smaller landscape elements is significant: sandbanks and floodplain forests were removed, river branches were cut off, secondary channels became dry land, and natural harbours silted-up. Awaking interests in recreation and nature conservation in the first half of the 20th century did not play any role in the decision-making processes underlying the river normalisations.
- The closure of the Zuiderzee in 1932, and the resulting reclamation of the IJsselmeerpolders between 1927 and 1968 surpassed all other projects before in acreage. This scheme had three objectives: the reclamation of 205,000 ha of new farmland, the reduction of the coastline by 300 km and the provision of a large freshwater reservoir. Recently (1980) a significant change took place from agricultural use to the development of nature reserves (e.g. the Oostvaardersplassen in Zuidelijk Flevoland), built-up areas and infrastructure.

# Part II
# The Legacy of Human Intervention

# Chapter 6
# Changes in the Relation Between Man and Nature

## 6.1 Introduction

The environmental history of the Rhine–Meuse Delta is basically the story of the settlers in the Delta, the draining and exploitation of peat, the cultivation of the raised bogs and the reclamation of fertile river polders, surrounded by dykes followed by technical achievements in river management. Inventions like the windmill technology opened up possibilities for reclamation of lakes, and the reclamation of lost land in the coastal zone. All these aspects have been discussed in Chapters 2, 3, 4 and 5. The basic questions of this book, however, have not been answered satisfactorily. How did the river landscape and wetlands really look like in former centuries, how did plant and animal life change and, in short, how did this legacy of human intervention evolve? Only indirect 'ecological' reconstructions can be made, based on reports of deforestation, use of wood and timber, cultivation and use of agricultural products, vegetables and herbs and the catch and use of fish and game. Nature was the 'free' resource, to be used and exploited by humans. Everything nature provided was used by humans, either as food or for numerous applications in trade and household. Literally every part of plants and animals harvested in nature or kept in husbandry, was used for one purpose or another (timber and wood, hunting, fishing, vegetables, herbs, etc.). Early medieval descriptions and printings of 'nature', often coloured by religious perceptions, give us some biased information on 'ecological' subjects (Van Uytven, 2003).

A survey of the descriptions on nature made by the post-medieval naturalists has to start with some notes on the profound transformations set in motion in Europe by the Scientific Revolution and the Age of Enlightenment (*ca.*1540–1789). This chapter will focus mainly on the most significant Dutch naturalists from the 17th to the 19th centuries. The economic use of everything nature provided was a leading principle until the beginning of the 20th century. From the 17th century onwards, however, a change in attitude towards nature can be recognised. Reliable descriptions and drawings of biota, e.g. higher plants, invertebrates, fish, birds and mammals, made because of their intrinsic and scientific values, became increasingly important. The protection of nature awoke only in the late 19th century, and the professional interest in the ecology of the aquatic and wetland environment only

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started in the early 20th century. The systematic and large-scale collection and reworking of environmental data started a decade or two after World War II. Compared to the situation 40 years ago, a tremendous output is now available comprising numerous data on the quality and quantity of chemical and biological parameters in the Rhine–Meuse Delta.

## 6.2 Medieval Images of Plants and Animals and their Perception

The question about the reliability of historic images of river landscapes can be rephrased: When did man start to publish reliable descriptions of ‘nature’, landscape and biota? Two thousand years ago some educated Romans, city dwellers, gave their subjective view on the ‘inhabitable’ Delta (Chapter 2). After the Romans left, centuries long there was no written information available on the natural environment. Early descriptions and paintings of nature during the later Middle Ages were dominated by religious perceptions. Proper descriptions of nature and landscape were not made in the Middle Ages, and when there was the need to approach nature realistically, the landscape was depicted in a pastoral way, the peaceful life at the countryside. Paintings of nature and landscape functioned as accessory, harmonious boxes around religious and secular images. A well-known example is the Book of Hours of the Brethren van Limburg ‘Les très riches heures du Duc de Berry’ (1413–1416), a number of secular images showing labour at the countryside in the four seasons. They give a lot of information on the daily work of farmers on the fields, the gathering of the harvest, the winter rest with hooded crows and snow-clad beehives, but repeatedly in an idealised construction (Fig. 6.1). Flemish painters like Jan van Eyck (*ca.*1390–1441), Rogier van der Weyden (1399–1464) and Hans Memling (1433–1494) depicted religious images set in Arcadian landscapes, with winding rivers and green meadows. The flowering plants in the front are so naturalistically painted that they can be identified to the species. But the meaning of plants and animals on the paintings is rather symbolic, instead of giving a realistic image of the existing landscape. An early secular source is left by Jacob van Maerlant who wrote his book ‘Der Naturen Bloeme’ (‘The Beauties of Nature’) in *ca.*1270 (as reworked by Van Oostrom, 1996), referring to imaginary and mainly bizarre phenomena supposed to occur in the natural world. Van Maerlant’s descriptions are not realistic, for the greater part not based on his own observations but borrowed from older scholars.

In the Middle Ages, animal stories were immensely popular throughout Europe, and far beyond. The people of the time were, of course, dependent on wild and domestic animals for their survival, and so had an obvious interest in the animals around them. But there is more to it than just a requirement for knowledge of the animals they knew and used; there is a distinctly spiritual and even mystical aspect to the animal lore of the Middle Ages. The bestiary, or ‘book of beasts’, describes a beast and uses that description as a basis for an allegorical teaching. It also includes text from other sources and while not a

**Fig. 6.1** 'February' from the Book of Hours of the Brethren van Limburg (1413–1416). Museum Valkhof, Nijmegen

'zoology textbook', it is not only a religious text, but also a description of the world as it was known in the Middle Ages. In medieval Europe, bestiaries were very popular and respected by all who consulted it. After the Church appropriated it for its own purposes around the 6th century, the bestiary became a book of learning which used examples of animal lore to teach Christian values. Mixing fact and fiction with a dab of moralisation, bestiaries became incarnations of the medieval mind which so preoccupied itself with salvation that it could scarcely look beyond its horizon without seeing it through God-tainted glasses. The bestiary was an odd compilation. It combined observations from nature, zoological commentaries, imaginative illustrations and a good dose of moral and religious lessons to bind it all together. In a time where there was no distinct separation between church and science, it seems almost natural that a book like the bestiary evolved from such an unlikely union.

Some medieval animal lore was not at all religious, though it still sometimes had a moral message. One of the most popular of the fable series was that of Reynard the Fox. Reynard is certainly no example for the proper life; the stories depict him as a schemer, a liar, a thief and a killer, yet in the end he always gets away with his misdeeds, usually at great cost to those around him. The Reynard stories were particularly popular in the Netherlands, Germany and France, where several vernacular versions were produced (Olsen and Houwen, 2001; Everaert, 2004).

## 6.3 The Scientific Revolution and the Age of Enlightenment

Of all the changes that swept over Europe after the Middle Ages, the most widely influential was a profound transformation that is called the Scientific Revolution (*ca.*1540–1700). The year 1543 may be taken as the beginning of the Scientific Revolution, for it was then that Nicolaus Copernicus (1473–1543) published 'The Revolution of the Heavenly Bodies' ('the earth revolves around the sun'). Within a century and a half, man's conception of himself and the universe he inhabited was altered, and the scholastic method of reasoning was replaced by new scientific methods. In fact, the history of natural sciences is strongly written from the perspective of mathematics, physics and technology. The science of physics made great progress in the late 16th and in the 17th century. Among many others, it was Simon Stevin (1548–1620; Box 4.1) who gave an impulse to laws in mechanics; the Italian scientist Galileo Galilei (1564–1642) formulated physical laws and their implications for astronomy. The English philosopher Francis Bacon (1561–1626) advocated the inductive scientific method of reasoning, and stressed the strong connection between natural sciences and technical science. René Descartes (1596–1650) postulated that the physical world is dominated by arithmetical laws; metaphysics are subjective and hence no subject of research in natural sciences. The work of philosophers like Bacon and Descartes created a philosophical and methodological framework for the practice of natural science, challenging scientists to falsify hypotheses raised with concrete empirical observations, measurements and experiments.

In the popular mind, the Scientific Revolution is indeed associated with natural science and technological change, but the revolution was, in reality, a series of changes in the mental attitude of the inhabitants of Europe: systematic doubt, empirical and sensory verification, the abstraction of human knowledge into separate sciences and the view that the world functions like a machine. These changes greatly influenced the human experience of every other aspect of life, from individual life to the life of the group. This modification in world view can also be charted in painting, sculpture and architecture; people of the 17th and 18th centuries started to look at the world in a very different way, compared to the medieval visions on reality (Dijksterhuis and Forbes, 1961).

The Scientific Revolution set the stage for the Enlightenment. It is generally used to describe the period between 1700 and 1789 as the Age of Enlightenment, and it refers to the intellectual movement which stood for rationalist, liberal, humanitarian and scientific trends of thought. The French philosophers Voltaire (1694–1778) and Rousseau (1712–1778) became the most outspoken exponents of this movement. Voltaire became the most vigorous anti-religious advocate of the Enlightenment, the erosion of religion as the only source of authority, in which the church was seen the centre for intolerance and superstition.

Next to the changing visions on nature that characterised the age of the Scientific Revolution, there (still) existed a very strong religious tradition. Christians believed that God had revealed not one but two books, the Bible and the Book of Nature. Nature was not a combined action of laws of nature, but a system of references to God. These thoughts appeared to be very influential among Dutch theologians and naturalists during the 17th century. Among the intellectuals of that time the biblical perspective was more important than the mathematical reality. According to Jorink (2004) the high-pitched and for a layman not to follow exclamations of leading scientists (e.g. Galilei: 'the Book of Nature is written in mathematical language'), placed these scientists outside the discussions in society. And the attractive side of the Book of Nature was indeed that it was accessible for the layman, because the objects to be studied were around them, concrete touchable and observable. Looking through the spectacles of the Book of Nature a different image arises of the intellectual culture in the Golden Age. Various clergymen, humanists and naturalists joined each other in practicing natural history, without endless quarrels about right or wrong. Starting from the shared opinion on the doctrine of the Book of Nature, it was an unblemished terrain, not dictated by sermons, but by observations and descriptions. Natural history was far less burdened than nature philosophy, including its intellectual clashes and the godless thinking about nature as a machine (Descartes) (Jorink, 2004).

The naturalists did not accept gratuitously each word in the Bible. It was the age of journeys of discovery, and collections of curiosities, and they increasingly discovered creatures that were not described in the Bible. The Book of Nature became more and more an independent entity at the end of the 17th century, indeed illustrating the creative powers of God Almighty, but disconnected from the Bible, and solely based on observations in nature. This is precisely the focus we need to consider the papers of the Dutch naturalists in the 17th and 18th centuries. They did not belong to the revolutionaries that formed the high mountains of the Scientific Revolution or Enlightenment, but they were respected, though curious civilians who exclaimed their astonishment for the Book of Nature, connected to their detailed observations and descriptions of natural phenomena.

## 6.4 Dutch Naturalists in the 16th and 17th Centuries

It is impossible to answer the question about the composition of the flora and fauna of the river landscape in detail before the end of the 19th century. Before the 17th century, simply no reliable descriptions of wild plants and animals existed. Publications on plants were herbals dealing only with the useful plants, and very seldom comprising the exact localities were the pant was to be found. A well-known example is the ‘Cruydt-Boeck’ of Rembert Dodoens (Fig. 6.2), written in Latin, which appeared in 1554 (Schierbeek, 1954). It described 1,060 plants, among which 109 were new to the flora. After a superficial description of the plant follows a long paragraph on the ‘strength and the efficacy’ in herbal medicine. The oldest collection of higher plants available in the Netherlands is the Petrus Cadé herbarium made in 1566. The book contains 171 dried plants, collected because of their medicinal properties, presumably from a garden of a cloister in Noord–Brabant. The plants are ordered roughly according to the ‘Cruydt-Boeck’ of Rembert Dodoens (www.bio.uu.nl).

**Fig. 6.2** Rembert Dodoens (Rombertus Dodonaeus), author of the ‘Cruydt-Boeck’, a herbal that appeared in 1554 as one of the first comprehensive books on wild and cultivated plants (Schierbeek, 1954)

Adriaen Coenen (1514–1587) produced his ‘Vis boec’, a book on marine life of invertebrates, fish, and mammals in 1577–1580. It is a handwritten, nicely illustrated manuscript, one of the oldest Dutch publications on marine life (Fig. 6.3) (www.kb.nl/visboek). Coenen was a fisherman, auctioneer and wreck-master, and in those trades he was able to collect and describe many creatures living in the sea. He was a self-taught man; learned people provided him with information and consulted his large collection (Egmond, 2005).

Although birds are conspicuous elements in the landscape, it was common use to ‘observe’ birds with a gun, instead as with binoculars (already used in 1608 by Jacob Adriaansz in Haarlem). Hunting documents contain rather detailed information about local bird-life. Many birds were mentioned in the literature as useful creatures, because they produced eggs or could be eaten; also birds harmful to agriculture and forestry were worth mentioning. One of the oldest books on birds is written in Latin in 1660 by Martinus Schoock, ‘De Ciconiis Tractatus’ (as mentioned in During and Schreurs, 1995). Schoockii was professor in logic and physics at Groningen University, but that did not refrain him from writing a treatise on the life of the stork. Besides an extensive description of the bird, he published several personal field observations, like the breeding behaviour of storks in urban centres.

Anthonie van Leeuwenhoeck (1632–1723) was a tradesman, a textile salesman and scientist from Delft, the Netherlands. He was introduced to microscopy by Christiaan Huygens (1629–1695) a mathematician and physicist – acclaimed as the greatest Dutch scientist ever – to observe the quality of the fabrics that he sold. The invention of the microscope presumably dates back to the first decades of the 17th century. Van Leeuwenhoeck is best known for his contribution to the improvement

**Fig. 6.3** Adriaen Coenen (1514–1587) produced his ‘Vis boec’, a book on marine life of invertebrates, fish and mammals in 1577–1580. It is a handwritten, nicely illustrated manuscript, one of the oldest Dutch publications on marine life. The picture shows a stranded whale in the Westerschelde near Antwerpen, July 2, 1577 (www.kb.nl)

of the microscope and his share in the development of cell biology. He is known as 'the Father of Microbiology', although he was not a teacher and left no followers in the town. He built simple microscopes consisting of a single lens, and those instruments that survived the years are able to magnify up to 270 times. In the field of microscopy, Huygens was surpassed by van Leeuwenhoeck because of his exceptional powers of observation. Using his handcrafted microscopes he was the first to observe micro-organisms, like bacteria and infusoria (multi-celled freshwater ciliates) (Dijksterhuis and Forbes, 1961; www.museumboerhaave.nl).

Jan Swammerdam (1637–1680), a 17th-century Dutch microscopist, made major discoveries in medicine and anatomy. However, his greatest contribution to biology was his understanding of insect development and his demonstration that the same organism persists through its various stages. Using meticulous dissections and careful experimentation, he showed the errors of spontaneous generation and laid the basis of the modern understanding of morphogenesis. Mayflies (Ephemeroptera) have attracted man's attention for a long time and one of the oldest accounts of mayflies in biology was published by Swammerdam in 1675. The mayflies have a light colour and they fly preferably at night. They appeared during a short time in enormous numbers, consequently showing a ghostly spectre, and this of course attracted the attention of riverains (During and Schreurs, 1995).

According to Cobb (2000), even a cursory reading of his work reveals that Swammerdam was driven by two powerful and contradictory motivations. On the one hand, he openly embraced what he called 'experimental philosophy', the Baconian principle that favoured empirical observation and experimentation above hearsay, 'authority' and pure reason. As a result, both the form and content of his research have a distinctly contemporary feel for today's scientists. On the other hand, virtually every page of his main publications contains pantheistic exhortations to praise the 'Supreme Architect' God, and uses the wonders revealed by the microscope and the dissecting instruments as proof of the glory of the Creator. Amazed by the beauty and order he discovered in the organisms he observed and dissected under the microscope, Swammerdam could only draw one conclusion: order could not be a product of chance, it must, therefore, be divine. This view was hardly unusual at the time, and only Darwinism would free biology of such reasoning. Of all the natural historians of the 17th century, Swammerdam probably contributed most to the key debates of the time, by demonstrating that insects were just as complex as larger creatures and by showing that no example of 'spontaneous generation' could resist investigation. Overworked, and under the influence of a zealous friend, he refused to publish his opus magnum. However, Boerhaave (1668–1738; famous physician, medical practitioner, chemist and botanist) managed to get hold of the manuscript, wrote a foreword, and published it in 1737, under the title 'Bybel der nature of historie der insecten', that is 'Bible of nature, or history of insects'. This publication was followed by an English translation in 1758, under the mistranslated title 'The Book of Nature', by which it is generally known today (Cobb, 2000; www.janswammerdam.nl).

## 6.5 Dutch Naturalists in the 18th and 19th Centuries

### *6.5.1 The Expansion of Linnaean Taxonomy*

Although Carolus Linnaeus (1707–1778) is not a Dutch scientist by birth, he spent some significant years of his career in the Delta. Linnaeus was a Swedish botanist who laid the foundation for the modern system of scientific classification of plants and animals, during the great 18th century expansion of knowledge of natural history. Linnaeus chose to take his medical doctor's degree at the university of Harderwijk in the Netherlands. He remained in the Netherlands from 1735 to 1738. He completed some manuscript, initially prepared in Sweden, and published them with Dutch publishers. In 1735 he published his 'Systema Naturae', in 1736 his 'Fundamenta Botanica', and in 1738 his 'Bibliotheca Botanica'. Linnaeus himself coined the phrase: 'God created, Linnaeus classified' (www.linnaeus.uu.se).

In the years that followed, voluminous works were published in the Netherlands, which comprised descriptions of organisms according to Linnaeus' taxonomy. An example is the book of Jan Christiaan Sepp (*ca.*1720–1775) who described butterflies, their habits, and where they are to be found. The author also created handsome illustrations of his discoveries. His son founded a publishing house and printing shop and published these works in 1830. The title of his book is revealing and typical of that time: 'Beschouwing der wonderen Gods, in de minstgeachte schepzelen of Nederlandsche insecten'. That is 'Dissertation on the wonders of God, exemplified in the highly depreciated creatures of Dutch insects' (www.library.tudelft.nl). The naturalists Job Baster (1711–1775) and Martinus Slabber (1740–1835) have published descriptions of numerous marine organisms (a.o. seaweeds, coelenterates, worms, arthropods, molluscs and echinoderms) occurring in the estuarine waters of the SW Delta. Research into marine life was still in its infancy in the second half of the18th century, and therefore their work is of great significance. Well-known are the 'Natuurkundige uitspanningen' (1759) of Baster and the 'Natuurkundige Verlustigingen' (1769–1778) of Slabber (www.museumboerhaave.nl). Linnaeus frequently referred to the Gronovius fish collection, a survey on the Dutch fish fauna from the mid-18th century, in later editions of his 'Systema Naturae' (www.nhm.ac.uk). In 1757, Cornelis Nozeman translated the works of father (J.F.) and son (L.T.) Gronovius from Latin in Dutch. In total 87 fish species have been described, and quite a lot of information is given on fish migration and localities of occurrence (Nijssen and De Groot, 1987).

Birds have always attracted human interest. It was in the course of the 18th and 19th century that people like Cornelis Nozeman (1721–1786) and J.F. Martinet (1729–1795) turned out to be real ornithologists. Remarkably, the first real birdwatchers like Nozeman and Martinet were clergymen. They lived in their quiet vicarages, walked through the fields to visit their faithful, and had ample time to observe flora and fauna. The observations of birds gave them inspiration to communicate the wonders of Gods creation to their flock. That birds were quite inspiring for writers and illustrators alike, is perfectly illustrated by the five volumes of

Cornelis Nozeman, ‘Nederlandsche Vogelen’, published between 1770 and 1829. The first volume appeared in 1770; the text was from Cornelis Nozeman, and the book was splendidly illustrated by Christiaan Sepp, draughtsman, engraver and cartographer, and as well interested in biology (Fig. 6.4). The book was published

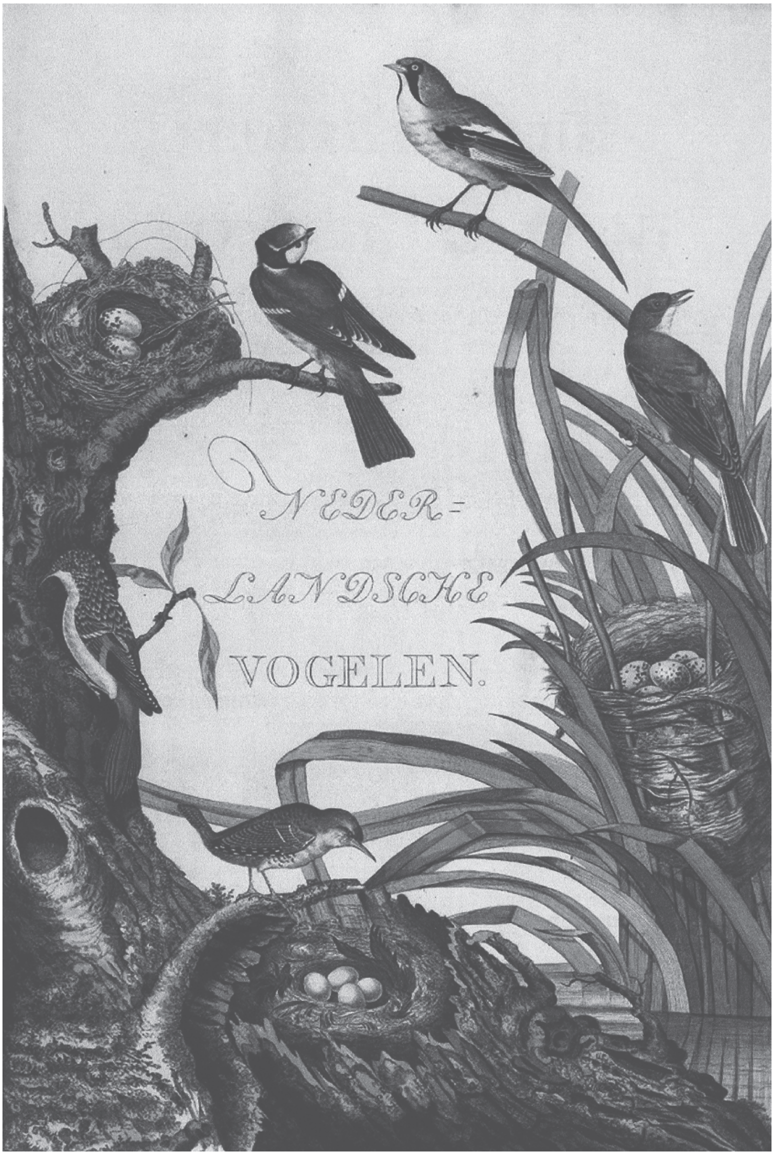

**Fig. 6.4** ‘Nederlandsche Vogelen’ (Dutch Birds) written by Cornelis Nozeman (1721–1786), illustrated by Christiaan Sepp, and published by his son Jan Christiaan Sepp in 1770 (www.kb.nl)

by Sepp's son Jan Christiaan, also devoted to natural history. Nozeman died in 1786, and his enterprise was finished in 1829 by the Sepp family, supported by a number of experts (www.kb.nl).

A few more words on the interest in plants. The flora of Oudemans (written between 1859 and 1862) outlined according to the Linnaean binomial system, comprised the first inventory of almost all wild and semi-wild higher plants living in the Delta. Many botanists have improved and supplemented his work, but the beautiful engravings and detailed drawings are unique. Quite a number of regional floras appeared in the 18th and 19th century, dependent on the activities of a local amateur-botanist. An example is the flora of Van Hoven (1848) on the town of 's-Hertogenbosch and its wide wetland surroundings, composed by an army officer. In the 19th century some books were published, which could be regarded as landscape-ecological studies 'avant la lettre', and it is only at the end of the 19th century that more systematic studies were undertaken, gradually leading to the detailed information we have at our disposal nowadays (During and Schreurs, 1995).

The 18th and the early decades of the 19th centuries are the great age of world travellers who collected on their many journeys overseas whatever they could lay hands on, such as minerals, fossils, plants, animals and objects of folk art. These collections of curiosities sometimes expanded into complete museums, adhering as much as possible to Linnaean nomenclature. The oldest public museum of natural history in the Delta was managed by the Dutch Society of Sciences, erected in 1752 (Sliggers and Besselink, 2002).

### *6.5.2 Johannes Florentinus Martinet (1729–1795)*

J.F. Martinet studied natural sciences, philosophy and theology at the University of Leiden. He defended his Ph.D. on the respiration of insects in 1753, and he finally became a doctor in philosophy and vicar in Zutphen. He published his 'Katechismus der Natuur' (Catechism of Nature) in 1777–1779, four books comprising dialogues between a master and his pupil, in the form of questions and answers, just like the Heidelberger Catechism (Martinet, 1777–1779). His catechism became a very influential work. It covered the entire Creation, viz. all natural phenomena known in those days, from biology, to geology, physics, meteorology, astrology and also philosophy, theology and psychology. Martinet did not become famous because of his innovative research, but rather because of his attitude to popularise science. He was a moralist with a teleological belief in final causes. He refuted new theories about the existence of the universe (Copernicus), but he preached the appropriateness of nature, answering its purpose fully in favour of man. Two examples: a deer is created to give man the pleasures of hunting, and to serve as excellent venison. Plants are green because black is too sombre, and other colours are too variegated and too fatiguing for the human eyes, etc. This way of reasoning was still common coin in the 18th century. In 1779 he wrote his 'Kleine Catechismus voor Kinderen' (Martinet, 1779), a work that has been translated in various languages. In 1791 his translation 'The Catechism of Nature for the Use of Children' was well received in North America, and reached several reprints (Paasman, 1971).

I will now discuss a few examples (two mammals and some birds), just to sketch the changes in attitude over the past 250 years with regard to wildlife protection. Chapter 19 will go deeper into this subject. The otter (*Lutra lutra*) was until 1900 rather common in wetlands of the Delta. It was hunted because of its fur and because the animal was considered as a competitor of fishermen. In 1942, when there were only *ca*. 300 individuals left in the Delta, the hunt for otters was closed; in 1988 the otter became extinct. In 2002, after 14 years of absence, a few otter have been reintroduced in the wetlands of the IJssel delta (www.vzz.nl; see Chapter 19). More than 200 years ago Martinets' (1777–1779) vision on the otter leaves no doubt about the usefulness of a live or dead individual. I will give a summarised translation of his long-winding text in the 'Catechismus': 'With all its tricks the otter is depriving our waters of clean and tasty fish. You can change this disadvantageous behaviour into an advantage, by training the otter, and learn him to fetch and carry fish, just like hunting dogs do. But if you do not succeed in training the otter, just kill the animal, and apply the useful fur to line your winter clothes, and to make muffs and caps'.

The beaver (*Castor fiber*) used to be a common species in the Netherlands, in particular along the rivers (Van Wijngaarden, 1966). The animal, however, was rigorously over-hunted throughout its range, in demand because of its fur, meat and odour glands. In Martinet's time the beaver was already a rare phenomenon. He mentioned occasional observations along the river Waal and IJssel. Martinet (1777–1779) described how 'the last beaver' was shot in 1770 at Hedel along the river Maas, 'that destroyed a lot of green and young wood'. The pupil in Martinet's catechism stated: 'Lucky we are released of these harmful animals'. The master answers: 'The beaver is indeed harmful, but it has also advantages, it delivers precious fur and castor, used as an excellent medicine'. Around 1800 the species was still observed, however, along the river IJssel; the last 'official' beaver in the Netherlands was killed in 1826 (Stoltenkamp, 1986). Thijsse (1938) gave full attention to Martinet's 'last beaver' in the Delta, and therefore this animal became the icon of many extinguished animals. The beaver was reintroduced in the Delta in 1988 (Chapter 19).

Ducks and geese were also intriguing animals to Martinet (1777–1779). In his days these birds were ruthlessly hunted (Table 6.1). Martinet: 'They provide my table in winter with roast, they give large eggs, and their breast-down is excellent for the making of feather beds; their feathers and flight-feathers are well suited to do the most detailed writing and drawing, and the goose-quills are well suited for the writing work of school children and civil servants'. We have to realise that he is talking about ducks and geese, of which most species have a highly protected status in the Delta AD 2007 (see Chapter 19).

From the correspondence of Martinet with a number of medical practitioners, kept in the Martinet archive (R. Loenen Martinet in Wageningen), I took some interesting observations. A medicine man in the area of the river IJssel described the quality of soil, water and air in the district around 1775. The doctor considered

**Table 6.1** Numbers of killed 'harmful vermin' during the period 1852–1857 for which the government of the Netherlands paid premiums (Wttewaal, 1859, in Van Zanden and Verstegen, 1993)

| | | | |
|---|---|---|---|
| Eagles | 219 | Sparrow hawks | 16,626 |
| Buzzards | 1,474 | Stone-martens | 974 |
| Polecats | 26,711 | Falcons | 2,787 |
| Hawks | 2,828 | Foxes | 5,861 |
| Ermines | 1,245 | Weasels | 88,449 |
| Martens | 675 | 'Kites' | 5,017 |

the province, where the river IJssel and tributaries flow through, as one of the most healthy areas of the entire country. The water quality of the IJssel is 'clear, excellent and unsurpassable'. Most attention goes to the quality of the air. The doctor noticed a relation between the 'bad vapours' and 'exhalations' of waters, and the occurrence of diseases among humans. The closer people lived to marshy and coastal areas (Zuiderzee; surroundings of river IJssel), the more diseases were noticed, such as pneumonia, tuberculosis, rheumatoid diseases and angina. Several diseases were indeed attributed to damp and moist living circumstances. This image is corroborated by a medical practitioner in Nijmegen on the river Waal, who described the relation between 'exhalations' and moist living circumstances and the occurrence of diseases in downtown Nijmegen. The closer people lived to the river the more unhealthy the living circumstances were. The town of Nijmegen is situated on an ice-pushed glacial ridge, and during showers the rainwater, mixed with garbage and faeces, runs from the upper town down to the river, where part of it stagnates in the narrow streets and alleys. Consequently, this leads to damp and moist houses, where 'bad vapours', connected to 'exhalations' from the river, create rather nasty living circumstances. The 18th-century fear for living close to marshes, wetlands and rivers with their damp 'exhalations' is in violent contrast to the 21st-century experience where living close to water is fashionable and trendy (cf. Chapter 21).

### 6.5.3 *Walking Vicars*

It is remarkable that some of the 18th- and 19th-century naturalists were vicars of wide reading (e.g. Nozeman and Martinet). Obviously they had ample time next to their daily duties, and they had the abilities to write down their experiences. A specific 'kind' are the 'walking vicars' who published extensive travel-stories of their rambles along the country roads. Hanewinkel (1766–1856) was a vicar of a small parish in Noord–Brabant on the river Maas. Obviously, he had ample time and he liked to walk along the countryside, and that was not altogether without danger ('for protection I carried a couple of pocket-pistols'). He presented his travel-stories in the format of letters to a 'dearest friend' (Hanewinkel, 1798–1799, 1803). On a few of his rambles he touched upon the rivers Maas and Dommel (see Chapter 11).

He describes the landscape in colourful language, but he is not burdened with detailed knowledge of plants and animals. Hence, most stories got stuck in exclamations about ‘beautiful meadows and corn fields’ and ‘numerous birds singing their morning song’ of course always ‘to the glory of God’. These books are interesting to read, but the level of ecological information is low; an additional list with the names of a number of common plants and animals is obviously borrowed from Martinet. In contrast, the historic, geographic and ethnographic values are more substantial. Every village gets a separate paragraph. The better parts of these books comprise meticulous descriptions about influential inhabitants, such as clergymen and magistrates, descriptions of the main buildings in town, and which disasters have struck the village in the course of time, such as floods and fires.

Craandijk (1834–1914) was another walking vicar, with a great interest in history and the beauties of the landscape. He was more ambitious than Hanewinkel; his wanders are spread over a wide area of the southern Delta, and published in seven issues between 1875 and 1888. His walk along the river Maas (Craandijk, 1883) is interesting, and contains, next to a lot of historic facts, some detailed semi-landscape-ecological descriptions. Figure 6.5 shows the stretch of Craandijk’s wanderings in an old region, rich in cultural-historic traces, inhabited before the Roman era, and embanked step by step from the 10th century onwards. The river polders in Craandijk’s time were dominated by orchards, arable fields, meadows and here and there small woods and tickets. Numerous human settlements tell the

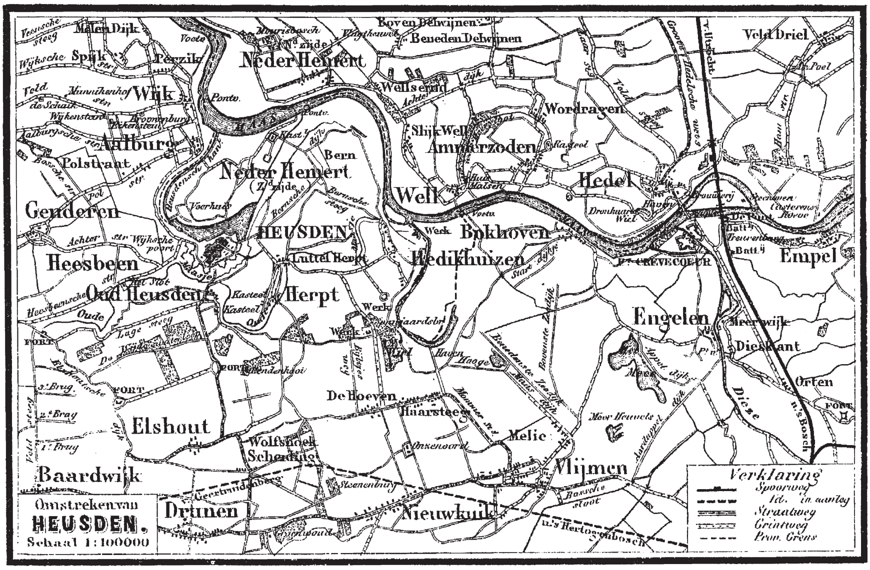

**Fig. 6.5** Craandijks’ (1883) walk along the river Maas from Hedel to Woudrichem. The map, taken from his book, shows the section of the river Maas between ‘s-Hertogenbosch (Empel) and Wijk en Aalburg, the present Afgedamde Maas (cf. Fig. 5.5)

story of civilisation, religious and secular wars, prosperity and poverty alike: the ruins of castles and abbeys, in some cases dating back to the 9th century, with a few mighty strongholds left (castles of Ammerzoden and Nederhemert), the numerous small villages, each with their characteristic church steeple rising above the trees.

Craandijk walked in the summer of 1883 along the river Maas from Hedel to Woudrichem (Fig. 6.5), as the crow flies a distance of 20 km. Better than other historic narrators I have consulted, Craandijk lively sketched the outline of the river landscape in 1883, which allows a comparison with the present situation in 2007. The changes over the past 130 years are very significant. In Craandijk's time the Maas was not yet regulated and canalised by the digging of the Bergse Maas; this project was finished in 1904 when the Maas branch from Hedel to Woudrichem, the Afgedamde Maas, was cut off from the mainstream of the Maas, with a dam and locks (compare Fig. 5.5). We have to realise that the step from Craandijk's observations to 'modern times' is only the final phase in a changing landscape, fixed on a macro-scale in the late Middle Ages (cf. Chapter 3), but continuously adapted on a mesoscale and microscale; e.g. some large meanders were already cut off in the 15th century. In 1880 transport of humans, cattle and goods took place via the main waterways, several ferries frequently crossed the river, the floodplains close to the larger villages were characterised by numerous human activities concentrated around small businesses; the floodplain landscape was speckled with trees and thickets.

Craandijk started his walk at the railway station of Hedel (Fig. 6.5). He mentioned the modern railway bridge, built in 1870, crossing the Maas and the long floating bridge in the 'main road' (poorly metalled, narrow road, PN) between Utrecht and 's-Hertogenbosch, used by pedestrians, carts and carriages. He walked along an open, gravelled road (*ca.* 6 km) to Ammerzoden, and from there he took the local ferry to the other side of the Maas, to Bokhoven. In the surroundings of that village he observed lots of trees and wood on the dykes, fertile hops fields and rich orchards. He memorised also clearly visible traces of the river flood of 1880 (Chapter 9), deteriorated dykes, and dilapidated houses unfit for habitation. In Bokhoven he joined a steamship from 's-Hertogenbosch to Rotterdam. He got off at Nederhemert, took the ferry to Heusden, stayed overnight in that town, and the next morning he joined a steamer again. That boat sailed from the Oude Maasje in Heusden, an insignificant rivulet, 'narrow and shallow, bordered by reed and rushes, more a ditch than a river', via the narrow Heusdensch Kanaal, to the wider waters of the river Maas, bordered by dykes lined with trees and underwood, to the still wider and rather bare floodplains were Maas and Rijn flow together, and where the clear Maas water mixed with the 'turbid, grey-green fluid discharged by the Waal'.

Waiting in Bokhoven on the river Maas for the arrival of the steamship Craandijk gave a vivid description of the surrounding landscape, which I will summarise. 'Bokhoven: the winding river dyke, willow groves and coppice, numerous small boats moored along the dyke, the ferry-dam where diverse cargo for the steamboat has been brought together, the loaded carts with their horses in colourful caparisons, the floodplains with grazing cattle and patches of rushes, the sandy foreshore, the piles of brushwood and wattles, the small boats and steamships sailing with the stream; on the landside of the dyke the haystacks and farms with moss-grown thatched roofs, the old lime-trees, on the other side of the river the white ferry-house of Ammerzoden, and in the background the high walls of the castle, to the right the long railway bridge and the floating bridge spanning the river and farther away the dominant cathedral of ‘s-Hertogenbosch. And to the west and south in a wider view numerous church steeples, and the dense wood hiding the town of Heusden – altogether a landscape, quiet and simple but rich in colours, structures and variety’.

Now in 2007 the river is completely canalised, with a fixed width between the groynes, the steamships have disappeared forever, the dykes bear no trees or underwood, large infrastructural works are characterising the landscape, straight highways and large bridges overarching the floodplains; the expansion of urban sprawl of ‘s-Hertogenbosch dominates the skyline (see Chapter 11).

## 6.6 Nature Protection – Late 19th, Early 20th Century

The expanding industrialisation, that stimulated the nature conservation movements in the United Kingdom and Germany, gained momentum rather late in the Delta, and the same accounted for the practicing of field biology. The Netherlands were no front runner in these international developments. Next to the retarded growth of industrialisation, the second half of the 19th century is characterised by a strong increase in the human population, leading to an acceleration in the process of urbanisation. The area of wasteland decreased dramatically, and the building of infrastructural works changed the face of the countryside considerably: canals, railway and tramway connections were built at quite a large scale. Another factor of economic growth is the development of agriculture, after the crisis of 1875–1895, again induced by the industrialisation, such as the enlargements of farms and fields for agricultural production, and the spectacular increase in the use of artificial fertiliser. Particularly the ‘wastelands’ on the Pleistocene higher grounds underwent a severe transition process. The developments in the flora and fauna in the 19th century are not documented in proper detail, but it is for sure that in that era the last beaver, and the last wolf disappeared from the Delta, and that several biotic communities (a.o. the last lot of natural forest) were lost for good in this process of rationalisation (Van der Windt, 1995; see also Chapter 19).

Nature conservation driven by ethical, esthetical and scientific motives, dates back to the end of the 19th century. F.W. van Eeden (1829–1901) may be considered as an important forerunner of the nature conservation movement in the Netherlands. He published his opinions in the journal ‘Album der Natuur’, that appeared in the second half of the 19th century. Mainly based on his romantic feelings for the (lost) Arcadian landscape, Van Eeden interpreted his displeasure about the developments of society, particularly the negative effects of agricultural developments on the flora and fauna. In 1886 Van Eeden published his booklet ‘Onkruid, botanische wandelingen’ (‘Weeds, botanical rambles’), indicating (presumably) the first thoughts on nature conservation in the Netherlands (Van Eeden, 1886).

Two outstanding men in the gallery of persons that greatly stimulated the interest in field biology and education were Jac. P. Thijsse (1865–1945) and E. Heimans (1861–1914), pioneers of the organised nature conservation movement in the Delta. At the end of the 19th century, inspired by Van Eedens' ideas, they wrote a series of popular books on field biology. 'In sloot en plas' (1895) and 'Door het rietland' (1896) contain a lot of information on landscape, flora and fauna of lowland rivers and wetlands in the Delta. In order to get a picture of the changes in biodiversity in the 19th century, however, books of this calibre are insufficient. I consulted the sixth print of 'In sloot and plas' (English: In ditch and pond) (Heimans and Thijsse, 1928). The authors are encouraging young people to arrange a freshwater aquarium (Fig. 6.6). The book contains careful observations of morphology and behaviour of commonly occurring water insects. Most information is anecdotic, e.g. about the flying capabilities of large water beetles, like *Dytiscus marginalis* and *Hydrophilus piceus*. These insects were obviously far more common than nowadays. Heimans and Thijsse (1928) described how the streets of Amsterdam '…were swarming with flying water beetles. During the dry summer of 1892 the pedestrians in the Utrechtsestraat in Amsterdan (a busy street in the centre of Amsterdam) were repeatedly startled at warm summer nights, and hit out a buzzing water beetle'. Interesting is the survey of *Elodea canadensis*, the 'waterpest', at the end of the 19th century a very common water plant clogging up canals and ditches. Nowadays, this water plant has only a modest appearance (see Chapter 17).

In 1896, Heimans and Thijsse founded the first Dutch popular journal 'De Levende Natuur (English: The Living Nature) dedicated to field biology, and aiming at more contact between people with common interests who were concerned about the deterioration of the (semi-) natural landscape and nature in the Delta. The protection of the Naardermeer southeast of Amsterdam, is a successful and early example of their nature conservation strategy. From the 17th century onwards that area has been wholly or partially reclaimed on three occasions, but it proved difficult to keep the polder dry (cf. Section 5.6). Large areas of water, reed beds, wetland woods and scattered meadows characterised the polder, but there was more fishing and duck shooting than there was farming activity. Because of the negative influence of brackish seepage water it was decided to abandon the attempts to drain the Naardermeer in 1886. In 1904, a number of nature conservationists, including Thijsse and Heimans, protested against the intention of the city of Amsterdam to use the polder as a dump for household refuse. In 1905 they founded 'Natuurmonumenten', the Dutch society for nature protection, and with the acquisition of the Naardermeer as its first feat it announced the dawn of non-governmental preservation of nature. The society is now one of the most important opinion-makers in the field of spatial planning. For more than 70 years, Natuurmonumenten's chief objective was to preserve the Naardermeer in the state in which they encountered it in 1905. The old polder layout could still be recognised in the landscape, but the biological succession did not stop, and gradually the lake changed into a forested marshland. In the late 1970s, nature conservation changed: from pure 'preservation' it slowly shifted via 'more intensive management' and 'restoration' to 'development' of nature (Beintema, 2005) (see for details Chapters 20 and 21).

**Fig. 6.6** Observing the catch in a freshwater aquarium (Heimans and Thijsse, 1928); drawing by E. Heimans in 1895. Note the attributes for fieldwork under the table, botanical case and dip-net

The best known publications of Thijsse are his 'Verkade albums', popularly written books on landscapes, flora and fauna of the Delta, illustrated with beautiful watercolours, e.g. by J. Voerman. 'De IJsel' (Thijsse, 1916) and 'Onze Groote Rivieren' (Thijsse, 1938; Fig. 6.7) are fully dedicated to landscape and biota of the Large Rivers IJssel, Rijn and Maas. Thijsse was a charismatic writer and narrator. He wrote the text for his albums 'to stimulate a sense of well-being and love of one's country'. 'Onze Groote Rivieren' is an ode to the beauty of the large rivers, comprising a pragmatic, almost opportunistic approach to the technological 'water works' that dominated the first decades of the 20th century. The radical Maas normalisation works were on their way in 1938, including the large-scale removal and cutting-off of meanders, and the straightening of the riverbed to regulate the erratic discharge of water and ice. Extremely drastic changes in the river landscape were evoked by the building of weirs and sluices in the river Meuse, and the digging of a canal, the Julianakanaal, parallel to the capricious riverbed for reasons of navigation (cf. Chapter 5). This all happened during Thijsse's lifetime; it is remarkable that in a period of significantly negative, large-scale changes in the river landscape, Thijsse sketched a romantic environment, in which all technologic interventions are considered light-heartedly and in a non-critical mood. And there really were more facts to be concerned about during Thijsse's life: in between 1865 and 1945, the human population of the Netherlands increased from almost 5 million to more than 10 million people; the area of 'wasteland' decreased from 900,000 to 200,000 ha (Zonderwijk and Van Bohemen, 1970).

ONZE GROOTE
RIVIEREN
DOOR DR. JAC. P. THIJSSE

TE ILLUSTREEREN MET VERKADE'S
PLATEN, NAAR AQUARELLEN VAN
C. ROL, J. VOERMAN JR. EN H. ROL
BANDVERSIERING EN ZWART-WIT
TEEKENINGEN VAN C. ROL. PLATEN IN
OFFSET VAN L. VAN LEER & CO.
DRUK- EN BINDWERK VAN
BLIKMAN & SARTORIUS

1938
UITGAVE VERKADE'S FABRIEKEN N.V., ZAANDAM

**Fig. 6.7** The frontispiece of Jac. P. Thijsse's album 'Onze Groote Rivieren' (Our Large Rivers), published in 1938

A good example of Thijsse's positive state of mind is the way he judged the new weirs in the Meuse basin. 'These weirs form a completely new element in the river landscape. I like them these structures. Their lifting towers are completely different from church and castle towers, but they are nonetheless doing their useful and beneficial work. The towers have no pretensions, nor superfluous structures, they are just doing what they are meant for' (Thijsse, 1938, p. 34). To my opinion these weirs are massive, ugly structures of steel and concrete, tens of metres high, and detonating in the flat river landscape. There is no disputing about tastes, but I think that when Thijsse had lived in the 21st century he should have liked the 'Betuwelijn', a much contested modern railway connection between Rotterdam and Germany, almost parallel to the river Merwede–Waal, rigorously splitting the flat and 1,000-year-old Betuwe landscape lengthways in two parts. My impression fits into the picture that has been drawn by Thijsse's biographer (Dijkhuizen, 2005): Thijsse had indeed a positive, opportunistic way of thinking, preferably stressing the romantic aspects of nature.

Victor Westhoff (1916–2001) was the most influential nature conservationist in the Netherlands after 1945. He was a researcher and conservationist, and one of his major merits is that he bridged the gap in the debate concerning the supposed 'natural landscapes' and 'cultural landscapes' occurring in the Delta. He introduced the term 'semi-nature', in contrast to 'real nature', i.e. gated nature preferably without human influence. In fact, it is a rhetoric question: what is nature in the Delta? Westhoff stressed that the man-made Delta for the greater part comprises only man-made landscapes, and to allow these semi-natural landscapes to persist, they should be preserved and managed by human actions. Due to his numerous publications, lectures, and above all his vision, he became the symbol of the Dutch nature and landscape conservation movement, and from then on nature management got a firm scientific underpinning (Westhoff, 1999). P.G. van Tienhoven, one of the founding fathers of 'Natuurmonumenten' should have sighed when Westhoff entered the arena after World War II 'Eventually, a biologist orientated towards practical solutions' (Van der Windt, 1995).

## 6.7 The Development of the Aquatic Sciences and Water Management

In this section I will dwell a little bit into the rise of the aquatic sciences and ecological developments in water management in the Delta. My bias in favour of the aquatic and semi-aquatic environment instead of the terrestrial environment is decided by the scope of the book. The man-made river landscape comprising numerous water masses, marshes and wetlands is drastically differing from the older Pleistocene landscape were forests and 'wasteland' were for a long time considered as 'real nature' in the Delta.

In 1901 the 'Nederlandsche Natuurhistorische Vereeniging' was founded, a society of Dutch amateurs and professional biologists, soon thereafter followed by the erection of botanical, zoological and ornithological societies (Van der Windt, 1995). The history of scientific hydrobiology, or as it is presently narrowed to 'aquatic ecology', dates back to the late 19th century. Pioneers like P.P.C. Hoek (1851–1914), ('An eminent researcher and manager; you will not find his peer up to the present'; De Groot, 1988), M. Weber (1852–1937), G. Romijn (1868–1930), H.C. Redeke (1873–1945), N.L. Wibaut-Isebree Moens (1884–1965), A.G. Vorstman (1895–1963), Th.G.N Dresscher (1902–1985) and A.A. van de Werff (1903–1991), have paved the way for the modern approaches. M. Weber was a professor of zoology in Amsterdam; Redeke was one of his Ph.D. students, just as Mrs. N.L. Wibaut, a biologist and engaged in public health service.

Publications containing chemical data go back to the 19th century, including their methodological restrictions; publications comprising systematically sampled biological data are of a more recent date, and moreover, useful data are scarce. The 'Hydrobiologische Club' (English: Hydrobiological Club) was founded in 1921 by Redeke, and some other professionals, trained in chemistry and biology. Professional hydrobiologists did not exist in the early 20th century and the members of the club realised that fundamental knowledge of the aquatic environment was a prerequisite to understand the changes evoked by modern economic and industrial developments. High-level education, of course, was of utmost importance: Redeke gave his lectures in hydrobiology of the Delta from 1916 onwards at the University of Amsterdam (Redeke, 1922a, 1922b, 1932). He decided to write a handbook in Dutch 'Hydrobiologie van Nederland' ('Hydrobiology of the Netherlands'), of which the first part on the freshwater environment appeared posthumously in 1948 (Redeke, 1948), and received a facsimile reprint in 1975. His well-known classification system of brackish waters was published already in 1922 (Redeke, 1922c). His work is an unrivalled milestone in Dutch hydrobiology, and I consider Redeke as the man pre-eminently standing at the dawn of the discipline of aquatic ecology in the Delta (Fig. 6.8).

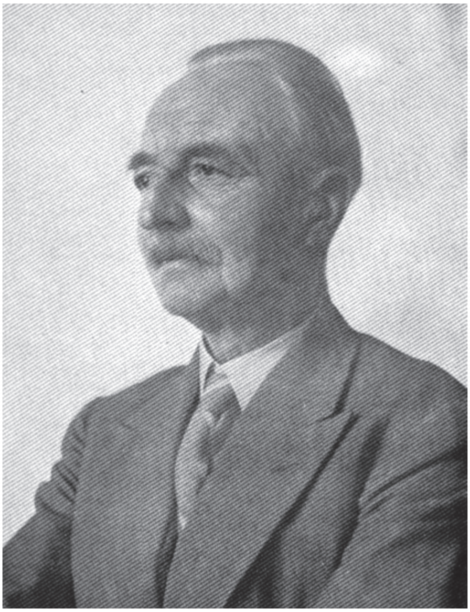

**Fig. 6.8** H.C. Redeke (1873–1945), pioneer of Dutch hydrobiology, author of the handbook 'Hydrobiologie van Nederland' (Hydrobiology of the Netherlands) in 1948 (Photograph in Redeke, 1948)

The closure of the Zuiderzee in 1932, and the consequences of these measures for flora and fauna were one of the main subjects of study of the Hydrobiological Club, from the 1920s onwards. A series of descriptive, systematic studies on flora, invertebrate fauna, plankton and fish appeared in the course of the years (Redeke, 1922c; Redeke and Ten Kate, 1936). The – still existing – international society Societas Internationales Limnologiae (SIL) was founded in 1922, with the aim to unite limnologists all over the world. Redeke was one of the founding fathers of this society and he represented the Netherlands during 20 years.

Already in 1910 G. Romijn, a pharmaceutical chemist and public health officer, made a plea for the foundation of a Netherlands' research institute for fundamental hydrobiological questions (Romijn, 1910). Later on he repeated his statement for the erection of an international hydrobiological institute for the study of aquatic communities (Romijn, 1920). Notwithstanding repeated attempts, the foundation of a scientific institute succeeded only in 1957. The Hydrobiological Institute comprised two affiliations, one in the peat-bog fens in the Central Delta and the area of the Large Rivers, and the other one in the SW Delta. Researchers of the former institute started their work on the composition of the phyto- and zooplankton and the self-purification capacities of the Large Rivers. The latter institute was founded to analyse the changes in the estuarine ecosystems, as a consequence of the closure of the main estuaries after the storm flood disaster of February 1953. Both institutes are still existing, highly qualified departments of the Netherlands Institute of Ecology (Geelen and Leentvaar, 1988; Zevenhuizen et al., 1996).

The Dutch have long cherished the pretension being a frontrunner in the fight against environmental deterioration. The question is whether this pretension is justified. It is undeniable that a wealth of good research has been done (and is done) in Dutch universities and research institutes. But initially universities did not lead the way in the application of academic knowledge for the solution of environmental problems. The Dutch have a strong tradition in following the Anglo-American trends. It was already in 1962 that Rachel Carson wrote her famous book 'Silent Spring' about the devastating effects of pesticides on the functioning of ecosystems. Briejèr wrote a book about the same theme only in 1967 after his retirement (Fig. 6.9). This book got far less attention as the work of Rachel Carson, and it was interpreted as a document from an old scientist fighting his moral dilemma. But Carson is citing work of Briejèr from 1958 about the growing resistance of insects against insecticides, obviously demonstrating the authenticity of Briejèr's anxiety (Nienhuis, 2003).

The same reluctance is to be seen in the aquatic sciences. Golterman and Clymo (1967) organised in 1966 an international symposium in the Netherlands on the fate of nutrients and other chemical compounds in lakes and rivers; the proceedings comprise not a word of concern about present and potential water pollution problems. But water pollution problems were immanent in those years, also in the Delta. Vollenweider, a Swiss limnologist working in Canada, published in 1969 an innovative theory on the causes of eutrophication, the enrichment of our surface waters with plant nutrients. Vallentyne, also a Canadian, wrote in 1974 a dramatic popular scientific book on the causes and the effects of eutrophication, particularly caused by superfluous phosphates drained into the surface waters.

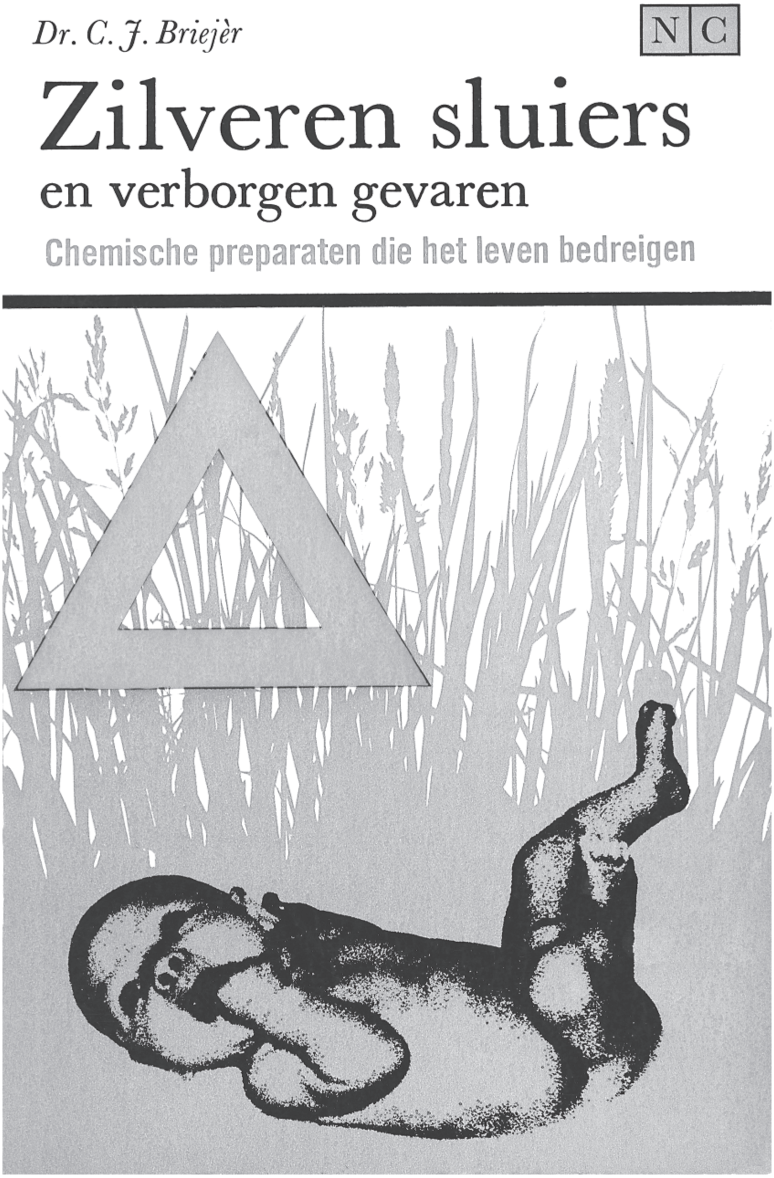

**Fig. 6.9** The frontispiece of Briejèr's (1967) book 'Silver veils and hidden dangers. Chemical compounds that threaten life'

Why were the signals about the accelerating deterioration of the environment in the decades 1950–1960 not perceived in Dutch academic circles? During that time a certain embarrassment prevailed among scientists, not to come down from their ivory towers to solve mundane environmental problems. It is typical that the anxiety of young Ph.D. students in biology about the loss of aquatic ecosystems in the Delta in the 1960s and 1970s, only was ventilated in the non-academic theses, an annex to their main subject: in academia environmental pollution was perceived as a matter of secondary importance (Nienhuis, 2003).

'Ecological restoration' has neither been discovered in the Netherlands. In the proceedings of an international conference on 'Restoration and Recovery of Damaged Ecosystems' in 1975 (Cairns et al., 1977), not a single example from the Rhine–Meuse Delta was reviewed. Rehabilitation of the river Thames, and recovery of lakes in Sweden and the USA, suffering from eutrophication, got ample attention. The Dutch are neither frontrunner in the discussion on the negative impact of dam building on the functioning of estuarine and river ecosystems. In 1977 there was yet a large (German) barrage built at Iffezheim in the river Rhine. The Dutch Delta project started in 1957, and only the past 15 years it is considered to partially reopen the seawalls and to rehabilitate the lost estuarine ecosystems (see Chapter 10 for a more refined analysis). In comparison: in the USA several dams were already removed from smaller rivers in the 1970s and 1980s, because the sustainable ecological values of nature and fisheries were more appreciated then the short-term profits gained by the retention of river water in a reservoir (Shuman, 1995).

The archives of the 'Hydrobiologische Vereniging', the Dutch Hydrobiological Society, later called the Netherlands Society of Aquatic Ecology (deposited in the Municipal Archive of Amsterdam), contain numerous unpublished items, and uncountable detailed measurements and observations on water quality, phytoplankton and zooplankton organisms, spread over numerous localities, going back to the early decades of the 20th century. This documentation, left behind by the pioneers, is a gold mine for researchers (e.g., a Ph.D. student) interested in the recent history of the science of hydrobiology, and ecological changes in Delta waters in the 20th century. The recent ecological history of the Rhine–Meuse Delta, regarding both the scientific and the applied aspects, is only fragmentary documented (e.g. Roijackers, 1988; Zevenhuizen et al., 1996; Wolff, 1997; Flik et al., 1997; Nienhuis, 2003), and the real meaning in an international context remains to be evaluated.

The systematic and large-scale collection and reworking of data started after World War II, initially with hesitation, but gradually in a more comprehensive way. Compared to the situation of 40 years ago, a tremendous output is now available regarding research on the quality and quantity of water and biota parameters in the Netherlands. A suit of parties is engaged now in water research: scientific institutions, water quality management agencies, water boards responsible for the maintenance of a good water quality and private bureaus engaged in water quality monitoring. Sometimes monitoring became a goal in itself, and one might ask the (rhetoric) question whether effective use is made of all the knowledge gained. In 2000 the European Framework Directive Water came into operation, obliging all the member states to implement in 2015 'a good ecological quality' for all natural waters (paradise regained?). European legislation is providing an extra stimulus for intercalibration of methods used, and the development of countrywide monitoring networks. Useful data sets are provided by www.riza.nl, www.rikz.nl and www.riwa.org.

The most complete data collection in this framework is the Limnodata Neerlandica of STOWA (www.stowa.nl), covering the entire Delta, comprising water quality data, and data on the distribution of aquatic plants and animals, connected to a geographic information system (GIS) system. The database goes back to 1980, a time horizon too close by for an historic environmentalist, for whom the lack of reference data from the remote past can only lead to guesswork and subjective reconstructions of past aquatic and wetland ecosystems.

## 6.8 Conclusions

- Early descriptions and paintings of nature during the late Middle Ages were dominated by religious perceptions.
- Profound transformations in the way of thinking were set in motion in Europe by the Scientific Revolution (*ca.*1540–1700) and the Age of Enlightenment (1700–1789), starting with the revolutionary developments in physics and astronomy.
- Practicing of natural history got momentum in the late 16th and 17th centuries (Van Leeuwenhoeck, Swammerdam, Linnaeus and others); the ‘Book of Nature’ was often the source of inspiration for scientific explorations.
- From the 16th up to and including the 19th centuries the knowledge of biology in the Delta greatly improved, and important systematic works on higher plants, birds, fish and invertebrates were published.
- Influential naturalists in the 18th century were professional clergymen (Nozeman, Martinet) with a great interest in natural history. ‘Walking vicars’ in the 19th century made rather detailed descriptions of their wanders, before the age of photography.
- The economic use of everything nature provides was a dominant principle until the beginning of the 20th century. Literally everything, all parts of animals and plants, were used, not only as food but for a wide variety of applications.
- The accurateness of many descriptions of single biota, made by the 17th- to 19th-century Dutch naturalists can be falsified by present-day research. Descriptions of ecosystems and landscapes, however, cannot be falsified, because most of the images sketched have completely vanished, or have substantially changed.
- Indirect reconstructions of landscapes and waterscapes can be made, based on reports on the use of land and water for husbandry and fishery purposes, and on the use of wood and timber in forestry and other trades.
- Descriptions of landscapes were subjective, and coloured from considerations of religion and utility (Martinet), of a naïve, positive sense of history (Craandijk), or of romantic opportunism (Thijsse).
- The organised protection of nature awoke in the late 19th century, with as figureheads Jac. P. Thijsse and E. Heimans. The first milestone in 1905 was the protection of a peat lake, the Naardermeer, in the floodplain of the river Vecht, meant to function as a garbage dump for the city of Amsterdam.

- Professional interest in the integrated knowledge of the aquatic environment only started in the early 20th century, with H.C. Redeke as a principal exponent.
- The history of scientific hydrobiology, c.q. aquatic ecology, in the Delta dates back to the late 19th century. Water quality parameters were quantified from roughly 1870 onwards, systematically sampled biological data are of a more recent date. The systematic and large-scale collection and reworking of data started after World War II.
- Interest in the ecological consequences of river engineering and in the need to minimise damage to the natural environment did not arise until the1970s, when the restoration of the Rhine became an important issue.
- The history of hydrobiology in the Delta, both the scientific and the applied aspects, is only fragmentary documented, and the real meaning in an international context remains to be evaluated.

# Chapter 7
# Land Use: Agriculture and Use of Wood

## 7.1 Introduction

The history of the green Delta is the litany of the production of food, feed and fuel as the bare necessities of life. In this chapter the history of agriculture and the use of wood and timber will be treated. In contrast with the lack of documented information on the history of the natural environment (the subject of this book), a tremendous amount of information is written about applied sciences, such as agriculture and forestry. In 1918 a Dutch Agricultural University was erected in Wageningen, and many other schools and courses on the practice of husbandry are available in the Delta. The Society for the History of Agriculture produces reprints of historic documents on agriculture (e.g. Roessingh and Schaars, 1996), and regularly Ph.D. theses appear on detailed subjects (e.g. Van Den Bergh, 2004). The prime publication of Slicher van Bath (1960) on the history of agriculture in Western Europe offers little specific information on the Delta. Bieleman's (1992) handbook on the history of Dutch agriculture is a valuable source of information, however. The publication of books on the past and future of husbandry continues (e.g. Hendrikx, 1999; Reijnders, 2002), and much agricultural history is also wrapped up in historic geography and cultural history (e.g. Haartsen et al., 1989; Barends et al., 1995). Nowadays specialised publishers have prepared for the 'retro-trend' and bring nicely illustrated regional studies on the (agricultural) history of the Dutch landscape to the market (e.g. Matrijs publishers in Utrecht and Waanders publishers in Zwolle – 'History of the farmers' life'). Which image should we foster of the farmer of the past centuries, the romantic one, the pastoral worker surrounded by his cattle and poultry (Fig. 7.1) or the laborious, scanty one, the farmer who had to cope with continuous flooding of his fields (Fig. 7.2)?

It is not my intention to rewrite, or even summarise, the historic role of agriculture in the environmental history of the Delta. The farmers' history until 1900 is closely interwoven with the origin and the development of the fertile Delta, and details are given in the cultural-historic context of Chapters 2–5. The aim of this chapter is to highlight some aspects of the history of agriculture in the Delta with emphasis on the 19th and the 20th centuries. A survey

P.H. Nienhuis, *Environmental History of the Rhine—Meuse Delta,*

**Fig. 7.1** The romantic, pastoral farmer (etching by Luiken, 1694)

will be given of the changes in the cultivation of crops, such as hemp, hops, madder and others, and the rise of dairy farming over time, which changed the face of the Delta. Ample attention will be given to the changes in significance and use of the 'small landscape elements', particularly related to wetland and woodland management, such as willow coppices, reed and bulrush marshes, hedges, poplar groves, ridge-and-furrow systems, duck decoys and more. Both toilsome and prosperous farming in the 19th and 20th century will get ample attention, culminating in land consolidation and re-allotment measures after World War II.

The contrast between agricultural use versus ecological values of the embanked floodplain basins and river forelands will be treated. Now in the 21st century the future of farming is pressing, and new destinations for the green Delta, such as 'nature development', and nature management of the countryside on an agricultural basis (e.g. Melman, 2003) are explored and brought into practice on a small scale.

**Fig. 7.2** The laborious, scanty farmer (Photograph in Zeldzame Mensen, T. Michiels Kempen Uitgevers)

## 7.2 Agriculture from Prehistoric Times until 1900 in a Nutshell

The prehistoric hunters, fishermen and gatherers were succeeded by settlers that started agricultural practice in the fertile Delta. The history of agriculture coincides with the draining of accreted land, the building of dykes and the reclamation of the polders. The first inhabitants of the Large River basins settled on the natural levees

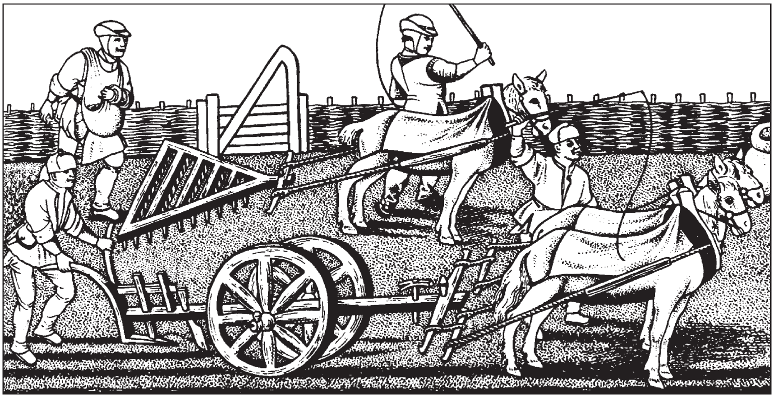

**Fig. 7.3** Ploughing, harrowing and sowing of a field, fenced by wattle-work, in the late Middle Ages, as depicted in a Flemish translation of Vergilius Georgica from 1473 (From Singer (Ed.) (1979). History of technology 2. Oxford: Clarendon Press, in Bitter, 1991a)

and the channel belts bordering the meandering river branches, consisting of sandy loam and clay. The natural marshes in the Delta were overgrown with wood and timber, and these useful resources became exhausted already in the late Middle Ages. On the fertile soil of the channel belts small arable fields were laid out, where wheat, barley, oats, beans, peas and rape were cultivated, and hay fields and meadows were exploited in the transition zone to the swampy flood basins (Fig. 7.3). The low-lying flood basins in between the elevated levees, where the finest silt particles deposited during flooding, consisted of heavy clay, poor in calcium. These grounds have been uninhabited during centuries; the compacted clay was very difficult to drain, and consequently the fields were inundated during a large part of the year. Forced drainage by steam engines in the 19th century, and later on by re-allotment measures have greatly improved the living conditions of the farmers. At present grassland dominates the landscape, elevated channel belts carry arable fields and orchards.

In prehistoric times water from the Large Rivers stagnated in the Central Delta, and extensive peat layers were built-up from the decomposing remains of the luxurious vegetation of water plants and marsh overgrowth. Every now and then the rivers braiding and meandering through this landscape overflowed their banks, and a thin layer of clay was deposited on top of the peat. From Roman times onwards these peatlands and clay-on-peatlands were developed. The raised bogs were drained, the peat was used as fuel and small arable fields were exploited (Chapter 2). Systematic cultivation followed from the 10th century onwards (cope-exploitation) (Chapter 3). The drained peat layers, however, oxidized and subsided. Initially the small fields were raised, and locally a ridge-and-furrow system was developed, but the wet soil conditions did not allow the cultivation of winter-corn anymore. Summer-corn like oats and barley could stand the deteriorating soil conditions for a longer period.

But the water nuisance remained, and already in the late Middle Ages the farmers were forced to change their working method from arable farming to dairy farming, which gave better perspectives. Hundreds of small dairy farms developed, with often no more than 10–12 cattle, and already in the 15th century considerable quantities of butter and cheese were exported to foreign countries. Land subsidence and counteracting sea-level rise continued, and with the aid of windmills, and later on with steam engines and drainage-pipes the land was forced to remain situated just above the level of the surface water. Large parts of the Central Delta, prone to flooding, are now situated below NAP, that is, 2–3 m lower than 1,000 years ago. In the course of the centuries the peat deposits in the SW and NW Delta were severely attacked and torn apart by the rising sea. Subsequently, the lost land was reclaimed by embanking salt- and brackish marshes, and fertile marine clay landscapes were created, until the present day used as arable land (Bieleman, 1992).

## 7.3 Cultivated Crops from the Past

The river clay deposits of the 'waarden, and the river forelands of the Large Rivers, and the clay-on-peat and peat deposits of the Central Delta are nowadays dominated by grassland (70%). Arable fields, horticulture and fruit farming (20%) and built-up areas (10%), comprise the remaining land (roughly estimated based on data from www.cbs.nl). This picture has changed significantly over the centuries, and in this section some crops will be dealt with that dominated the agricultural scene in the past.

### *7.3.1 Hemp*

The clay-on-peat soils of the flood basins in the transition zone from the Large River basins to the Central Delta (a.o. Lopikerwaard, Krimpenerwaard, Alblasserwaard; Fig. 3.9) were exploited already in the Middle Ages, following the cope-cultivation pattern. From the 16th century onwards the cultivation of hemp (*Cannabis sativa*) has been a characteristic trade for the low-lying parts of these river polders. Just like flax, hemp provides high-quality fibrous material that was used for various purposes, and it produced oil-containing seeds, that were used for the preparation of paints, dyes, varnishes and soft soap. In the 17th century the cultivation of hemp became a large-scale enterprise, and many cattle breeders started to grow this plant, in combination with dairy farming. Hemp needed to be fertilised intensively, and cattle manure and additional sludge dredged from the ditches provided the hemp cultures with the necessary nutrients. Hemp products were in great demand during the Golden Age, in connection with the weal and woe of the sailing fleet. Martinet's (1777–1779) ode to the hemp is revealing: 'Our country owes it greatness to the hemp. If we had not manufactured sails and cables from hemp, how could we have conquered the Spaniards, and brought home the treasures from the Occident and the Orient? Hemp is a remarkable and useful plant, by which God has made great our fatherland.'

Hemp growing and manufacturing was a labour-intensive trade, surrounded by various industrial activities. The harvested hemp stems were retted in polder ditches, a break-down process during which pectin that kept the fibrous material together was mineralised by bacteria and fungi. This process was a burden for the surface water system: it demanded a lot of water, and that became anaerobic, leading to significant fish mortality. The deterioration of the water quality was so severe that the polder board of the Alblasserwaard decided in 1646 that hemp retting was only allowed in specific ditches that formed a closed system (www.histkringnieuwpoort.nl).

The retted stems were subsequently dried in the field and heated above a small fire in a brake-hut, quite a distance removed from the farm because of the fire risk. During the process of braking the bone-dry stems were crushed manually with a hammer or hackled over a sort of iron comb, thus separating the fibre bundles from the woody parts of the stem. The farmers delivered the raw fibrous material to tradesmen or directly to weaving-mills and ropeyards along the Hollandse IJssel and the Lek (Fig. 3.9), where the material was manufactured for the production of sail cloth and various kinds of rope and cord, and fishing nets. In the 18th century the decline of the hemp manufacturing industry set in, because of the import of cheap hemp from the Baltic states and also because of series of devastating floods that ruined the hemp harvest. Alternative products came on the markets, like sisal and synthetic material, and in the 19th century the production of hemp gradually ceased. More and more farmers changed from the cultivation of hemp to the production of dairy products, particularly cheese (Lambert, 1985). Nowadays, in the 21st century dairy and cheese production are still important regional products from the Central Delta.

### 7.3.2 Potato

At the end of the 16th century the potato (*Solanum tuberosum*) was imported from South America into Europe. The tubers were introduced in the Delta in early 17th century, and the cultivation of potatoes spread vastly throughout the Delta. In some river polders (Bommelerwaard, Tielerwaard; Fig. 3.9) the potato crop replaced the declining hop cultures. Potatoes were cheaper than corn, and hence the crops expanded to the detriment of corn-growing, and developed into popular food for the common man. In the Bommelerwaard where 60% of the area of arable fields was planted with potatoes, farmers became socially and economically fully dependent on the potato harvest. But the benefits of these harvests led to a dangerous inflexibility in the food system, because the majority of food energy was being provided from a single crop. That alone is not unusual, and is still the case today for many subsistence farmers around the world. Although the exact causes are still unclear, in 1845 a potato blight caused by the mould *Phytophthora infestans* struck across

Europe, turning potatoes into a soggy and inedible mess. Not only in Ireland, as the best known historic example, the mould-infestation led to a catastrophe. In parts of the Large River basins, e.g. in the Bommelerwaard, the potato blight had devastating consequences, resulting in famine and many human casualties. It is suggested that the fact that only four types of potato were brought from the Americas was a fundamental cause of the famine, as the lack of genetic diversity made it possible for a single fungus-strain to have much more devastating consequences than it might otherwise have had (Bieleman, 1992).

### *7.3.3 Hops, Tobacco, Flax and Madder*

In the Middle Ages the consumption of beer was a reliable alternative for the drinking of water. Hops, the dried female flowers of *Humulus lupulus*, was used by beer brewers as a raw material, improving the taste and the preservation of beer, so that it could be better traded and transported over long distances. For a long time in the past a lot of hops was cultivated in the Land van Heusden en Altena, and later also in the Bommelerwaard and the Tielerwaard (Fig. 3.9). The first half of the 17th century was the heyday of the hop crops in the river area, but thereafter beer was gradually replaced by products imported from overseas, such as cacao, coffee and tea (Bieleman, 1992).

An exotic, tobacco (*Nicotiana tabacum*) was introduced from North America in the Delta in the 17th century, and rather soon the cultivation of this new crop spread over the eastern part of the river area (e.g. Betuwe, and Land van Maas en Waal; Fig. 3.9). The planting, growing, harvesting and drying of tobacco was a labour-intensive job, in which entire families were involved. Already in the second half of the 18th century the conditions for a profitable tobacco crop ceased, because of the import of better quality tobaccos from abroad.

On the fertile marine clay in the SW Delta one of the primary crops was wheat, but also considerable amounts of flax (*Linum usitatissimum*) were produced, just like hemp used for many purposes, such as the production of linseed oil and fibres for linen fabrics (Bieleman, 1992).

From the late Middle Ages on madder (*Rubia tinctorum*) was a specific crop in the SW Delta, a perennial plant, of which the long roots were harvested after 2–3 years. The harvested madder was kept in sheds (‘meestoven’), dried and pulverised to powder (‘racine’), and delivered to staple markets and exported to foreign countries (England, France). Madder powder was treated chemically with water and sulphuric acid to distract the concentrated pigment (‘garancine’). The pressure on the environment was substantial: the disposed sulphuric acid was discharged directly on the surface water system, resulting in severe water pollution and connected foul smell. ‘Garancine’ was a resource used for the production of a red-brown pigment for the painting of textiles and leather. At the end of the 16th century the madder production underwent considerable expansion owing to the expanding cloth industry in the Delta and abroad. Until 1875 the madder sheds and the ‘garancine’ factories remained profitable enterprises, but soon thereafter the production ceased because of the production of synthetic paints (Wiskerke, 1952).

### 7.3.4 Sugar Beet

For centuries Dutch traders were involved in the cultivation of sugar cane and the production of sugar, mainly in South-American countries. In the early 19th century, during the French occupation an import ban on cane sugar was declared, and supplies came to a halt. Inventive farmers started to grow sugar beets (*Beta vulgaris*), and around 1860 the production of sugar from the roots of beet became an unparalleled success in the Delta. The draining of the Haarlemmermeer (Fig. 5.6), a lake southwest of Amsterdam, made it possible to cultivate sugar beet on a large scale near to the city. A new sugar factory was built close to the sugar beet in the fields (Bieleman, 1992). Cane sugar and beet sugar are currently in the spotlight in Europe. The sugar industry is involved in the developments concerning the abolition of subsidies on European sugar beet.

## 7.4 Small Landscape Elements

### 7.4.1 Woodland Management

Rackham (1986) described the normal practice of woodmanship over most of England, where almost all woods have been managed, often intensively, for centuries (Fig. 7.4). There is no reason to believe that this practice is principally differing from the habits in the Delta. Woodmen traditionally make use of the self-renewing power of trees. Some trees such as pines can be got rid of by cutting them down, but nearly all native species grow again either from the stump or from the root system. Ash and elm, for instance, form coppice, underwood trees which are cut to near ground level every few years; the stump sends up shoots and becomes a stool from which an indefinite succession of crops of poles can be cut at intervals of years. Aspen, cherry and most elms sucker: the stump normally dies but the root system remains alive indefinitely and sends up successive crops of poles, forming a patch of genetically identical trees called a clone. Osiers are willow stands coppiced at 1–3 year’s growth, an ancient cultivated crop. They may either be of low-growing species (*Salix viminalis* and S. *purpurea*) or of tree willows grown as osiers.

Coppicing and suckering (Fig. 7.4) are efficient and reliable ways of getting a new crop. Sallow can grow at 5 cm a day, reaching more then 3 m high in the first season after felling; even oak can stand 2 m high and 3 cm thick after one summer’s

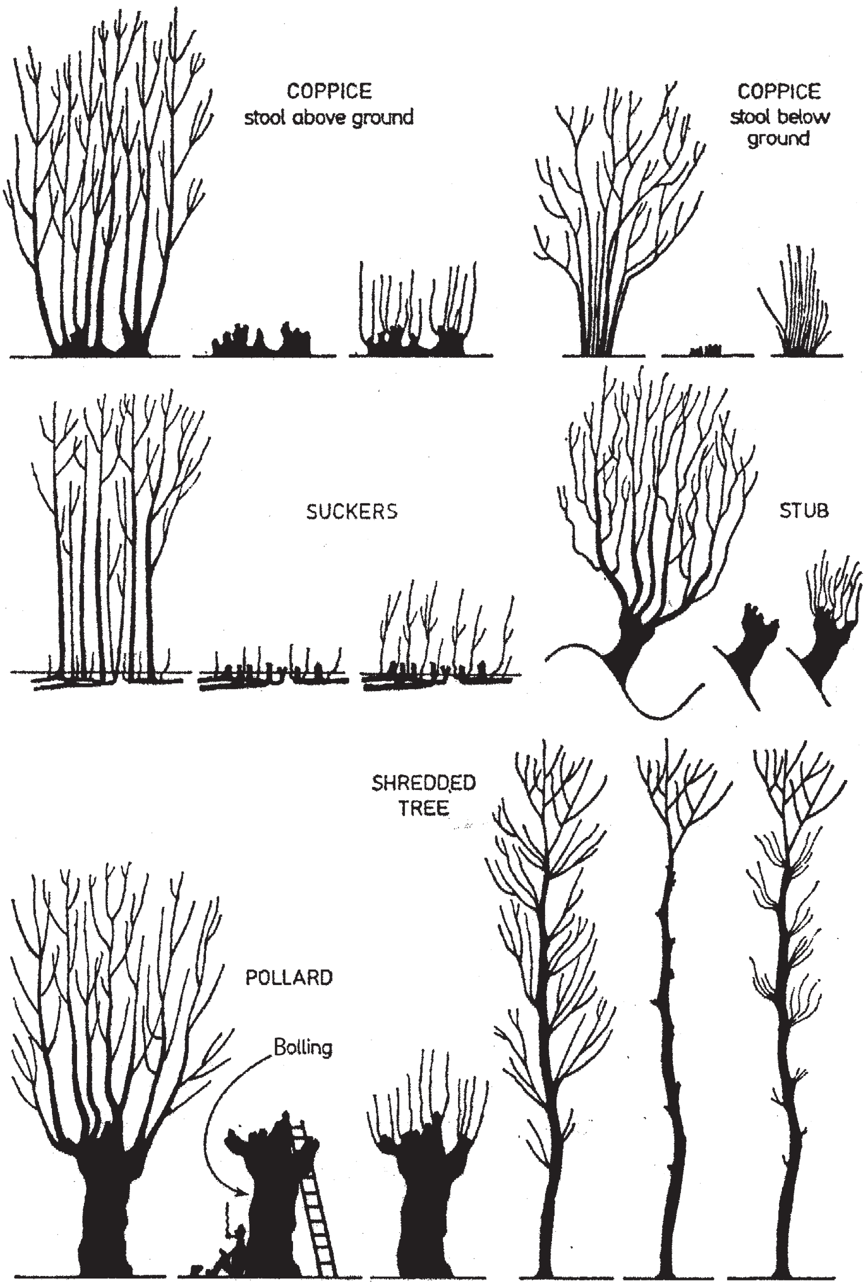

**Fig. 7.4** Ways of managing wood-producing trees. For each method the tree, or group of trees, is shown just before cutting, just after cutting, and 1 year after cutting. All drawn to the same scale (Rackham, 1986)

growth. Such shoots, though largely immune from rabbits and hares which destroy slower-growing seedlings, are a favourite food of cattle, sheep and deer; and in places where these animals could not be fenced out it was the practice instead to pollard trees in order to get a crop. Pollards are cut at 2.5–4 m above the ground and allowed to grow again to produce successive crops of wood. Cut pollards are leaving a permanent trunk called a bolling, which sprouts in the same way as a coppice stool but out of reach of livestock. Pollarding is much more laborious than coppicing, and is typical of wood-pasture and some non-woodland trees but not of the interiors of woods. According to Rackham (1986) pollards may be antiquities; even a quite small bolling can be a couple of hundred years old. The medieval practice of shredding – cropping the side-branches of a tree leaving a tuft at the top – vanished from the Delta long ago. The painting of Meindert Hobbema (1689), ‘the alley of Middelharnis’, shows a good example of trees that were shredded.

The trees of a wood are divided into timber trees (a minority) and underwood. Every so often an area of underwood is felled and allowed to grow again by coppicing or suckering. Scattered among the underwood are the timber trees, which are allowed to stand for several cycles of regrowth and are felled when full-grown. Timber trees are usually replaced by seedlings. The whole wood may be demarcated from its surroundings by an earthwork called a wooded bank with a ditch on its outer side, traditionally set with a hedge to keep out livestock (Rackham, 1986). In the Delta a wooded bank is a thrown-up, low earthen wall, planted with trees, mainly occurring on the higher Pleistocene sandy grounds, or in the transition areas from the lower Delta to the higher grounds. A specific type of wooded bank is the wooded embankment (‘houtkade’) that occurred only in the peatland areas in the transition between the Large Rivers and the Central Delta. In the Middle Ages embankments were built, and subsequently afforested, between two adjoining areas of cope-allotments (cf. Chapter 3). Wooded embankments functioned also as levees for the drained and cultivated land, in use as pastures and hay fields, against flooding from the not cultivated bog-peat area. The embankments were planted with trees that were used as multi-purpose wood (Burm and Haartsen, 2003).

The wood therefore yields two products, timber from the trunks of the trees, and wood from coppice stools or suckers (plus the branches of felled timber trees). Timber and wood had different uses and are not to be confused. Wood is rods, poles and logs, used for fencing, wattle-work (see Fig. 7.3), and many specialised purposes but in large quantities for fuel. Timber is the stuff of beams and planks and is too valuable (and too big) to burn. Underwood was normally the more important product; woods were traditionally regarded as sources of energy. Rackham (1986) stated that popular writers suppose that a wood gets ‘exhausted’ as if it were a coal-mine or a pine plantation. Not so: a wood is self-renewing, and is no more destroyed by being cut down than a meadow is destroyed by cutting a crop of hay. Woods do not cease to exist through being felled. Woods cease to exist through being deliberately destroyed, in order to use the land for something else, through misuse (especially long-continued grazing), or occasionally through natural encroachment of sand-dunes or blanket-peat.

In the past the small farmer’s lots were separated by ditches, hedges or wattlework. Often a shallow trench was dug and the soil was used to throw up a low bank;

**Table 7.1** Surface area of ‘wasteland’ (i.e. not cultivated land) and forests in the Netherlands, in hectares × 1,000, in the period 1833–1968 (Burm and Haartsen, 2003)

| | 1833 | 1927 | 1968 |
|---|---|---|---|
| Wasteland and forests | 1076 | 666 | 422 |
| Heath-land, sand drifts | 907 | 416 | 143 |
| Forest | 169 | 250 | 279 |
| Deciduous forest | 20 | 14 | 53 |
| Coniferous forest | 30 | 145 | 196 |
| Coppice | 117 | 78 | 26 |
| Osier-beds | 2 | 13 | 4 |

on this bank alder or oak brakes were planted, consisting of bands of trees and brushwood. These stands of wood functioned mainly as cattle fence, at the same time fencing out small and big game (‘wildgraaf’). The wooded boundaries were also used as coppice, i.e. that the wood was regularly cut and used for various purposes. The fertile marine clay and river clay and loam did not satisfy the ever-increasing demand for food production. This is mirrored (Table 7.1) in the dramatic decrease of the area of ‘wasteland’, i.e. not cultivated land in favour of agricultural land in the 19th century.

Table 7.1 shows also the switch from (oak-)coppice to coniferous forest at the end of the 19th century. Oak-coppice and scrub were much appreciated as raw material for the tanning industry; after processing, ground oak-bark was used for the tanning of leather. Brush-wood of oak was also used for the production of fuel wood, and faggots for the baker’s ovens, and for charcoal burning. Oak-coppice occurred mainly on Pleistocene sandy grounds, and many tanneries were established in the border area between the sandy grounds and the adjoining clayish and peaty soils of river catchments, in the transition area between two resources, oak and cattle, in favour of the tanner and the leather-dresser. When the gaining of this resource was no longer necessary, owing to the application of artificial tannins, large forest areas were pulled up and replanted with Scots pine (*Pinus sylvestris*). The demand for pine-wood, particularly mine-timber, increased considerably at the end of the 19th century (Dirkx, 1998).

### *7.4.2 Willow-Coppice*

Osiers are willow stands that were periodically coppiced. There were two types of osiers, the osiers where the shoots of the pollard willows were cut annually (‘snijgrienden’), and these that were cut once every 3–4 years (‘hakgrienden’). As far as is known, the first osiers were planted in the Biesbosch (Fig. 5.5) and in the forelands of the Large Rivers in the 16th century. These willow stands were useful, enhancing the deposition of silt, but mainly for the production of shoots and branches. Willow shoots were mainly used for basket-making, and in the course of the centuries millions of them have been fabricated (see Section 7.5.3.). The thicker branches served many purposes. They were used as multiple-purpose wood for farmers ('boerengeriefhout'), e.g. to make fences of wattle-work, or wattle-and-daub, plaited walls for barns and houses impregnated with clay. Cattle hides in the open meadows were often built of wattle-work. Casks were used for everything that was fluid, but also for herring and butter. Innumerable numbers of willow branches have been used to make hoops for barrels. Although nylon mats are preferred, until the present-day willow-matting is used in hydraulic engineering projects, for example, the 32 km long Afsluitdijk closed in 1932 between the Zuiderzee (now IJselmeer) and the Wadden Sea, has entirely been covered with mattresses of willow shoots.

The heyday of the osier culture was between 1900 and 1930, when the total surface area of willow plantations amounted to 13,000 ha (see also Chapter 18). Large areas of the Biesbosch and forelands along the great rivers, were covered with coppice: Central Delta, Oude Maas, Biesbosch, Hollands Diep, Nieuwe Merwede, upper Merwede, Bergse Maas (Fig. 5.5), Vijfheerenlanden, Tielerwaard (Fig. 3.9), and small osiers along the IJssel. Osiers thrived well in the freshwater tidal area of the Large Rivers, and consequently their surface area decreased eastwards. Osiers were also exploited at the most marshy spots of a river polder. Permanent inundation of the willow trees, however, was detrimental to their growth, and therefore ridge-and-furrow systems ('rabatten') were thrown up to grow coppice. Isolated, small osiers surrounded by ditches were exploited in the peat-pasture area of the Central Delta. Next to their main function as producer of wood, these osiers were meant to protect cattle and milkmaids exposed to all sorts of weather. Near country seats osiers were sometimes exploited, except for the wood, to provide shelter for game; consequently, these stands had an important function for game hunting.

After the tidal influence had mainly ceased in the SW Delta in 1970, riverside willow-woods as we see them nowadays have grown out of neglected osier plantations. These abandoned pollard willows of fens and river-banks appear seldom to be of great age, but continue an ancient tradition and are specially important for the variety of wildlife that lives on them. Plants such as briars and even sizeable ash and holly trees, and other willows, live in their crowns; as with other pollards, lichens grow on their old bark (see Fig. 18.8), many species of insect are specific to their mouldering interiors, and birds and bats roost inside them (Burm and Haartsen, 2003).

### *7.4.3 Reed Marshes*

Reed is growing in reed marshes, and along water courses, ditches, rivers, canals and lakes, the marshy border area, too wet for grassland. Reed was mown every year, and it had numerous applications. The most significant use of reed was for thatching the roofs of farms and houses. In the Middle Ages most houses were built of timber and wood, and the roofs were thatched. Owing to the considerable fire danger houses in the towns were gradually built of stone with tiled roofs, but at the countryside reed remained for a very long time the preferred roofing. Reed had many other applications, such as for the construction of screens for partition walls, as isolation material, e.g. as a roof cover underneath the tiles. In the Alblasserwaard the walls of the cowsheds were isolated at the inner side with straw or reed. In the peat areas of the Central Delta reed was used as litter in cowsheds; hay was too costly, and straw was not available in that area. The decoy-man used reed to build his screens along the pipes of his decoy. Reed was used as a fixation layer for ceiling and wall plaster until far in the 20th century. Large reed marshes were known from the freshwater tidal areas in the SW Delta (Biesbosch), but good-quality reed was also growing in the peat lakes in the northeast of the Central Delta. These lakes were created by peat digging, gradually grew solid and changed into reed marshes, with predominantly sandy bottoms, low in nutrients and provided with slightly brackish groundwater (Van der Toorn, 1972).

Between 1950 and 2000 the reed area in the Delta declined from 12,000 to 6,000 ha. The reed quality declined also, owing to eutrophication, the cease of brackish water influx (Hollands Diep) and the unnatural, artificial water table (high in summer and low in winter). Reed land is a succession stage in between shallow open water and marshy wood (Chapter 18). Reed was preferably mown in winter when the water was frozen. In the IJssel delta and in the Vijfheerenlanden professional reed cutters did their work, but in most cases cutting reed was a small extra earning for farmers during wintertime. The historic information on reed cutting is rather scarce. The Roman Plinius the Elder who visited the Delta in the 1st century AD mentioned the use of reed as roofing. From old archives, such as the bookkeeping of toll-collectors in the area of the Large Rivers in the second half of the 14th century, it is evident that reed was an important trade product (Burm and Haartsen, 2003).

### *7.4.4 Bulrush Marshes*

Bulrush, or mat-rush (*Schoenoplectus lacustris* and *S. tabernaemontani*), is an emergent plant with underground wintering rhizomes, and up to 2 m tall round and flexible stems. Bulrush is a pioneer species of shallow areas, along lakes, rivers and canals. In 1932 the Zuiderzee was dammed and is now called IJsselmeer (Fig. 5.7). The tides ceased completely and the lake gradually became a freshwater body. The bulrush stands which had been planted near the mouths of the IJssel for centuries, declined significantly. In the (formerly) estuarine and freshwater tidal areas in the SW Delta bulrush overgrew extensive areas. In the framework of the Delta project (Chapter 10), the Haringvliet was dammed in 1970, and tidal influences were largely reduced. The extensive bulrush stands in the Haringvliet, Hollandsch Diep and Biesbosch (Fig. 5.5), disappeared almost completely within 15 years. Along the river Oude Maas (Fig. 4.4), where a minor reduction of the intertidal zone took place, the bulrush zone was less affected. Among the processes that probably accelerated the local decline of bulrushes are changes in sedimentation pattern, strongly increased bank erosion, concentrated wave action as a result of reduced tidal amplitude, water and sediment pollution, increased grazing by waterfowl, and withdrawal of bulrush culture from several areas.

Traditionally, bulrush stems have been harvested and dried for use in the handicraft industry. Products were, for example, floor mats and chair seats; bulrushes have long been used by coopers to close off the casks. At the turn of the 18th century, there was a brisk trade in bulrushes, in which the town of Genemuiden, near Kampen in the IJssel delta (Fig. 5.7), played a central role. Sedimentation of tidal flats and land reclamation were accelerated by the planting of bulrushes. Large areas in the IJssel delta and in the Biesbosch have been reclaimed in this way. The processing of and trade in bulrushes led to relative local prosperity. In the 1920s and 1930s, the bulrush trade was affected by the rise of coconut-straw and sisal mats. Planting of bulrush fields diminished for that reason. Today only a small fraction of the former bulrush wetlands is left. Nature conservation groups and local authorities are now increasingly concerned with the conservation and restoration of bulrush stands. At present the bulrush is cultured in some parts of the IJsselmeer and along the river Oude Maas. The small demand for mat-plaited chairs has remained constant over the last few decades (Smit and Coops, 1991).

### *7.4.5 Hedges*

Hedges were planted along fields and pastures. Hawthorn is the dominant bush of the hedge, often intermingled with ash, elm and elder scrub, and particularly with thorny blackthorn and blackberry, enhancing the qualities as a fence. The hedges were known for their rich flora and fauna of breeding birds. Hawthorn prefers nutrient-rich, not too dry soil, but it can stand a period of complete inundation, which makes the bush very suitable for planting in floodplains, where they also enhanced the sedimentation of silt during flooding (Burm and Haartsen, 2003).

Hawthorn was the barbed wire of the past, and a well-trimmed hedge was a perfect cattle fence. The thick, thorny brushwood was also often used for military purposes, as defensive works for fortifications and entrenchments. In the course of the centuries farmers have bordered their pastures and arable fields with a dense network of hedges and wooded banks. The hedges marked the borders between private properties; they fenced in the cattle, but they also fenced out big and small game. The branches were trimmed every 4–5 years, and, for example, used as faggots in bakers' ovens. Around 1900 this green, fine-meshed cultural landscape reached its climax, particularly owing to the far-reaching splitting up of property rights. Many ecologists consider the then richness of nature values as a most important reference situation.

Around 1900 it went wrong. The continuous modernisation and scaling-up of agricultural practice led to significant changes. Meandering rivulets and brooks were straightened, and rigorous re-allotment measures turned the landscape into an efficient green geometrical pattern. After World War II this process was continued, systematically and accelerated. Altogether, approximately 200,000 km of hedges and wooded banks in the Delta became a prey to the rationalisation of agriculture. Barbed wire, invented in 1880, replaced the green network (Burm and Haartsen, 2003).

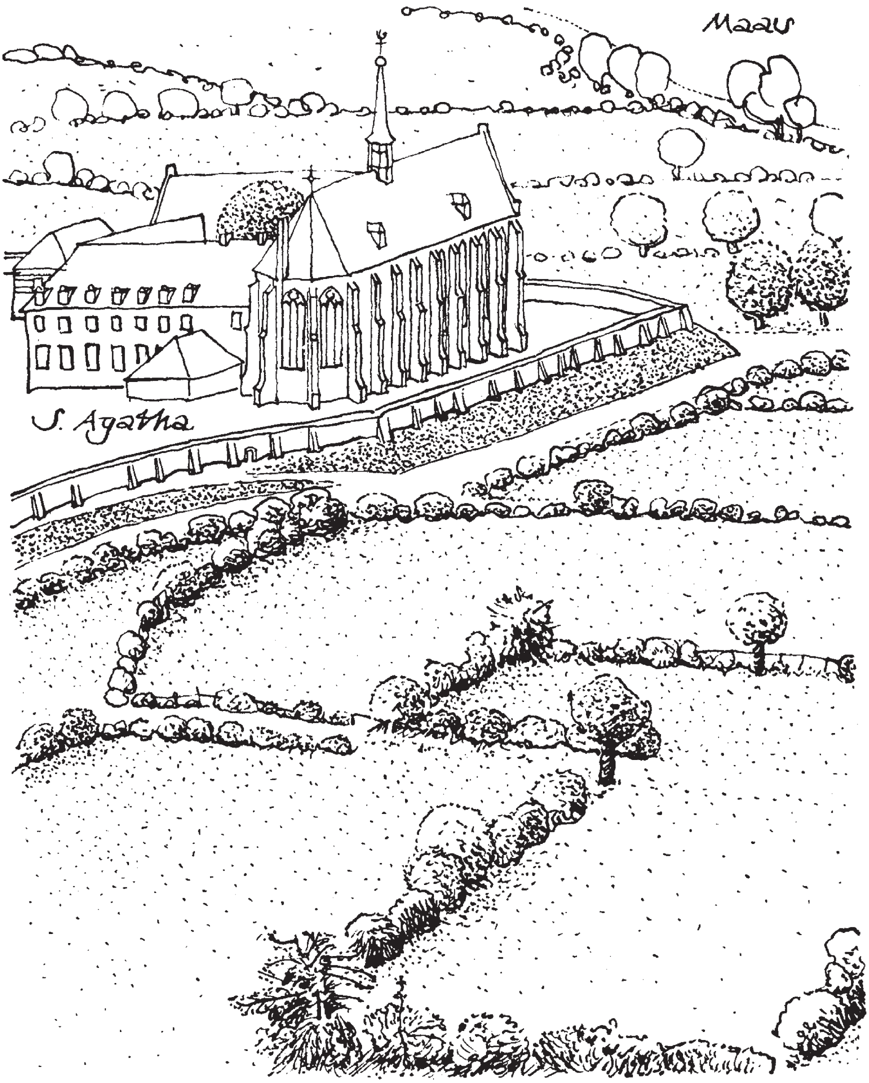

**Fig. 7.5** River foreland of the Maas with a characteristic pattern of hedges. On the mound in the background the monastery of St. Agatha, dating back to the 14th century. In the remote background the river Maas (de Vrieze, 1979)

Of all hedges and wooded banks in the Delta more than 90% was lost in only a couple of decades, and in some small areas only a reflection of the former richness remained. The majority of the hedges in the Meuse floodplains have been lost, but the last remnants have been protected just in time, some 30 years ago, at the 'hedges nature reserve' at Vierlingsbeek (Fig. 7.5). Before some tens of years this reserve was part of a large floodplain area dominated by hedges, on both sides of the upper section of the 'gestuwde' Maas, over a distance of *ca*. 60 km (Fig. 5.1, close to Mook). And even in the nature reserve along the Maas, the density of hedges is smaller than in 1920, and the labour-intensive maintenance is often far below standards (De Vrieze, 1979).

Hedges and wooded banks have besides a great ecological and landscape value, also a large historic and cultural value. Along the rivers IJssel and Maas hedges of wattle-work occurred: thinner branches were braided around thicker branches creating an impenetrable hedge. The history of wattle-work hedges goes at least back to Roman times (it is said that Julius Cesar mentioned the wattle-work hedges in his war diary 'De Bello Gallico'), and is strongly connected with the agricultural exploitation of the Delta (see e.g. Fig. 7.3). The technique to construct wattle-work hedges is lost. Hawthorn hedges particularly occur in floodplains along the great rivers, and in the SW Delta. It is estimated that from the remaining hedges and wooded banks ca. 85% dates back to the 19th century, and a considerable number of hedges is older than 150 years. Recently there is a turn in the public opinion regarding the values of hedges and wood-banks, and in several 'nature development' projects new hedges are planted and maintained (Derckx and Van Slobbe, 2000).

### *7.4.6 Orchards of Tall Growth*

In former centuries standard orchards comprised apple and pear trees of tall growth ('hoogstamboomgaarden'). The Romans have introduced a number of trees into the Delta: e.g. apple, pear, prune, walnut and chestnut. After the Romans left the Delta the cultivation of fruit was mainly continued in cloister gardens and on noble estates. Only in the late Middle Ages archives mentioned the cultivation of fruit trees at farmyards. In the course of the centuries fruit trees got a fixed position at a farmstead, sometimes as a number of solitary trees, more often as an extensive orchard. In the 17th century the Betuwe (Fig. 3.9) was called the 'apple cellar' of the towns in the Central Delta. Particularly at the end of the 19th century the cultivation of fruit was intensified, but the exploitation of standard orchards almost completely ceased after 1960, owing to a changed agricultural policy. It takes a tall grown fruit tree several years before the first harvest, and besides that it is seen as inefficient and time-consuming to pick fruits from an 'old-fashioned' tree.

Old maps show the orchards as girdles around villages, often in combination with pastures where young cattle was tended. The area of the Large Rivers shows a concentration of orchards, and they are all situated on natural levees and channel belts, consisting of sandy or loamy channel deposit; the soil is not too heavy, and not too wet, and rich in calcium. More westwards in the transition area between the Large Rivers basins and the Central Delta, orchards are often situated on sandy deposits originated after a dyke breach. Standard orchards are becoming very rare nowadays, and fragments are maintained because of their cultural and historic values (Burm and Haartsen, 2003).

### *7.4.7 'Stinzen' Groves*

'Stinzen' plants is a collective name for a number of introduced exotics, mainly bulbous or tuberous flowering plants. A 'stins' (plural: 'stinzen') is a fortified stone house. The first 'stinzen' plants were introduced in the Delta in the 15th century (*Leucojum vernum*, *Galanthus nivalis*, *Narcissus pseudonarcissus*), and most of them entered the Delta in the 16th and 17th century (*Corydalis solida*, *C. cava*, *Ornithogalum nutans* and *Arum italicum*), among many other introduced ornamental and medicinal plants, and later on in the 19th century during the construction of parks and gardens in the English landscape style. Most species were deliberately introduced because of their beautiful flowers. The majority of the 'stinzen' plants have their original habitat in the Mediterranean area or in Central Europe.

The preferred biotopes of 'stinzen' plants are composed of well-drained nutrient-rich soil with a loose structure, rich in calcium, at relatively warm spots. Such soils are often occurring around centuries-old living places, fortifications ringed in by canals or country seats and estates at the border of peat extractions, or along river branches. A well-known example is that during the period of the peat trade the barges transported turfs to the towns, and they returned loaded with city garbage. This material was used to prepare small arable fields in the drained peat marshes; it contained minerals, manure as fertiliser and material to elevate the low-lying peat-extraction areas, thus forming potential habitats for the 'stinzen' flora. 'Stinzen' groves and other biotopes for 'stinzen' plants have been created by human activities, and as a small landscape element they represent a great cultural and historic value up to the present day (Bakker and Boeve, 1985; Jansen and Van Benthem, 2005).

### *7.4.8 Poplar Groves and Plague Proves*

Poplar groves were a characteristic landscape element in marshy brook valleys and in the low-lying flood basins of the 'waarden'. In thinly planted groves grass for feeding cattle was grown underneath the trees, and on the dryer spots flax or hops were cultivated. Poplar wood was mainly used for the fabrication of wooden shoes, but also to make wooden utensils, the branches were used for all kinds of utility purposes. Poplar timber was a cheap alternative for oak timber, that already became rare in the late Middle Ages. In the Dommel basin, a tributary of the river Maas, the making of wooden shoes reached its summit at the end of the 19th century; in those days there were more than 700 clog-makers in the area (see Chapter 11). In the past poplars were often planted along roads and along the borders of arable fields, based on the rights of a group of people or an individual to raise poplars on common grounds. From the 17th century onwards the farmers in the Dommel valley had the duty to set aside small parts of their arable land for the cultivation of trees, particularly oaks and beeches, but also poplars. Poplar groves and lanes (narrow country roads) are still rather common in the 'waarden' of the Large Rivers, but they are disappearing quickly, and in almost all cases an obligation to replant trees is lacking. This means another cultural-historic impoverishment. The black poplar (*Populus nigra*) holds a special position in river-land, because this species has its natural area of distribution along the large rivers. Consequently, nowadays old and solitary individuals are managed with care (Burm and Haarsten, 2003).

Contagious diseases among cattle are from all times. ‘Rinderpest’ (cattle plague) was mainly manifest during the 18th century, during several repetitive outbreaks. To avoid the spread of ‘rinderpest’ the government declared several measures, but repeated obstruction of the farmers made the disease not easy to have in hand. The farmers considered the plague as the punishing hand of God, rather than that they could envisage an epidemic. When a contagious disease was discovered, the farmers were obliged to destroy all the animals from their infected stables. The animals had to be buried, whether or not burnt, under quicklime or carbolic acid at a remote lot, in the middle of an open area of pastures, to prevent contamination of other stables. The grave had to be watched during the first weeks after the burial, to prevent the theft of fells and meat. The lots were planted with trees and bushes so that the farmer had at least some benefits from his land. These isolated groves, often surrounded by a ditch, were later called plague groves. In case the cattle were hit by anthrax, a very contagious disease, of which the spores could be active for hundreds of years, the groves were called anthrax groves. Plague groves are often situated in the middle of an open area of meadows and pastures, at the end of a parcel of land, and surrounded by ditches. They are mainly known from the peat-bog areas in the Central Delta. However, not all solitary groves are plague groves; they may also be normal spinneys. To be sure soil research should show traces of carrion. In the past the plague groves were managed as coppice. The trees and bushes were regularly cut, and the wood was removed and used as firewood, poles for fences, beanpoles, building material and tool-shafts.

Groves, and also the plague groves, are vital to the flat landscape, and play a key role as an ecological transition between pastures and meadows and remote closed forest. It is not known how many plague groves have existed in the Delta. What is known is that in the 1980s the number of timber groves in the Delta had declined by 65% compared to the situation in 1945. The original use became obsolete during the agricultural modernisation process. The groves still present are often strongly neglected. Besides, small spinney are vulnerable to external influences, such as the lowering of the groundwater table, the input of atmospheric N-composites, and the blowing in of fertiliser and pesticides from the neighbouring pastures (Jansen and Van Benthem, 2005).

### *7.4.9 Ridge-and-Furrow System*

The burden of flooding was a dominant problem in the low Delta. Indeed, willow, alder (brake), birch and poplar, did grow on waterlogged or flooded soil, but for other trees it was often far too wet. Particularly when the prices of oak-bark rose, because of the great demand on tannins extracted from the bark, it became profitable to drain the temporarily inundated areas. Oak is growing on diverse types of soil, but it cannot stand permanent waterlogged situations. That is the reason why ridge-and-furrow systems were laid out, a sequence of trenches and ridges, parallel to each other. Trenches were dug, and the soil was used to throw up narrow strips of ground, narrow fields (‘rabatten’, sometimes called ‘spekdammen’). The more flooded the areas were, the more trenches were cut. The trenches drained the superfluous water, and on the higher ridges trees were planted, mainly oak wood (oak scrub) and ash brake. In the Delta tens of thousands of hectares of ‘rabatten’ were laid out, particularly from the 18th to the 20th century, in marshy areas on the higher Pleistocene grounds were groundwater and rainwater stagnated, but also in the Delta proper, particularly in river floodplains.

‘Rabatten’ were all cut and thrown up by hand and they demanded quite a lot of care in order to maintain the drainage function of the ditches: the sides of the ditches had to be kept in proper shape and washed in sand, branches and leaves of trees had to be removed regularly. Nowadays most ridge-and-furrow systems are no longer kept in proper shape, the maintenance costs are high and the profits are low, and particularly at inland sites the rigorously lowered groundwater table has set the water courses dry. This means that a characteristic cultural historic landscape element in the Delta is fading away (Jansen and Van Benthem, 2005; Wolf et al., 2001).

### *7.4.10 Duck Decoys*

A duck decoy might be called a typical Rhine–Meuse Delta landscape element, only a few can be found in other countries. It is a device for catching wild ducks and teals, consisting of a duck pond, connected to one or more narrow ditches, the ‘pipes’ where the ducks are lured to an enclosure and eventually caught (Fig. 7.6). The pipes are curved in shape and tapering from their mouths to a point. Preferably, there should be four pipes for use in different directions of wind. In use they are roofed over with netting on hoops and surrounded by screens of reeds with peep-holes for observation. A flock of wild ducks alights on the lake and is decoyed into the mouth of one of the pipes: they will follow either tame ducks trained for the purpose or a trained dog. Once they are safe inside the pipe the decoy-man is showing up behind them, and in panic they crowd into the little end of the pipe, where they are caught. The pond and the ditches are surrounded by a thicket of trees and brushwood that forms characteristic wooded areas in the flat polder landscape. The history of duck decoys dates back at least 700 years, and the business of the decoy-man is a form of enticement with a marked cultural-historic tradition. In the past thousands of decoys have been exploited in the Delta, but most of them have disappeared; only 118 registered decoys are left in the Delta, spread over the coastal area of the NW and SW Delta, the peat area of the Central Delta and along the Large Rivers, areas traditionally rich in bird life. Nowadays decoys function as small nature reserves, where ducks are only caught to be ringed (Rackham, 1986; Burm and Haartsen, 2003).

**Fig. 7.6** A duck decoy is a device for catching wild ducks and teals, consisting of a duck pond, connected to one or more narrow ditches, the pipes where the ducks are lured to an enclosure and eventually caught. The pipes are curved in shape and tapering from their mouths to a point. In use they are roofed over with netting on hoops and surrounded by screens of reeds with peep-holes for observation. The decoy-man in the foreground is feeding his tame ducks, and his trained dogs, In the background the 'kooibos', a thicket of trees and brushwood, that forms characteristic wooded areas in the flat polder landscape. In the centre a willow coppice and sheaved reeds are to be seen (Painting by Hans Zantinge in 2003; Biesbosch Museum Werkendam)

## 7.5 Agriculture in the 19th and 20th Centuries

### *7.5.1 The Farmers' Life in the 19th Century*

The successive large-scale cultivation of a variety of crops from the late Middle Ages onwards, demonstrates the flexibility of the farmers in the Delta to adapt to changing circumstances. The farmers were, however, at the mercy of the vagaries of the weather, and many diseases and plagues stroke the growth of arable products, without that countermeasures could be taken. Next to the erratic consequences of the weather and the changing climate, the farmers had to cope with continuous seepage problems, and the abundant occurrence of unwanted weeds. A corn field in the Betuwe in 1850 was described as 'a flower garden with poppies, cornflowers, camomile, and charlocks but not an arable field' (Bieleman, 1992).

Dairy farmers were fully dependant on one crop, grass, and lack of hay during winter was fatal for the livestock. A wet and cold summer could be disastrous for the hay harvest, just like very dry summers with little rain. Particularly when a fitful winter was followed by a dry summer, in short time the corn harvest could be decimated by the common vole. In 'mice years' not only the corn crop was destroyed but also the pastures were ruined because the voles were digging numerous holes in the ground. Not only crops were continuously threatened, but the stock of cattle was also at permanent risk of getting incurable diseases. In 1713 Dutch merchandisers introduced cattle from the Baltic states into the Delta, infected with the cattle plague. Cattle plague is an Asiatic malady, at times carried into Europe. It is one of the most infectious and fatal diseases of ruminants, a virulent eruptive fever, infecting the intestinal system, which runs its course so rapidly and attacks such a large percentage of ruminants when it is introduced into a country, that from the earliest times it has excited terror and dismay. The cattle plague annihilated a large part of the livestock in the Delta during three periods in the 18th century, 1713–1720, 1744–1756 and 1768–1786 (Lambert, 1985).

In the pre-industrial life of a farmer only a narrow margin existed between prosperity and poverty, between life and death. Death was always close by, and his entire conduct of business was subject to enormous risks, that are nowadays hardly imaginable. The farmers survived through the building up of their collective experiences and traditions, and the passing on of their professional skills from father to son (Fig. 7.7). Until the invention of artificial fertiliser at the end of the 19th century, the farmers manured their fields with animal dung. Manure was scarce and very much needed. Dung and dirt from the streets of Amsterdam was, for example, brought to the infertile sandy fields on the Veluwe. Transport was a problem, and the Commission for Agriculture for the wider Veluwe region sighed in 1826 'that the digging of canals and waterways would greatly improve the supply of this dung'. The more fertile clay soils of the river polders were manured once in every 4 or 5 years, the year in which the land lay fallow. In that year the field had to be ploughed at least four times in order to get rid of the deep-rooting weeds. The hay fields were mown every year, and they were only seldom manured. The best hay fields were situated in the river forelands that were inundated particularly during winter resulting in the deposition of a thin layer of silt; the addition of fertile soil allowed the farmers to hay the fields twice a year. The inland hay fields were far less profitable, and from the common grounds, low-lying fields were water stagnated, only poor, 'acid' grass could be harvested. The nutrient-poor meadows allowed only a very low density of livestock of one cow or ox per hectare, while in the river forelands two animals per hectare could be grazed (Roessingh and Schaars, 1996).

The more the river polders subsided, the more the seepage of river water through the dyke body became a problem. In winter the ditches in the 'waard' overflowed and inundated the fields that had no further possibilities for drainage. Consequently, even winter-wheat that could stand inundation quite well, rotted away, and the fields could not be ploughed in springtime. Under these conditions only the unwanted weeds flourished abundantly. Until mid-19th century a simple causal relation existed between precipitation and the annual harvest in the river polders: a very wet autumn and winter period almost inevitably resulted in a bad harvest in the following year. In the course of the second half of the 19th century some technical means became available, and these allowed the farmers step by step to regulate the water level of their fields. Two inventions were of utmost importance in this

**Fig. 7.7** Farmstead in Brakel, Bommelerwaard where from 1550 onwards generations of farmers have worked and lived (Photograph by Cas Oorthuijs, winter 1963; in Van Vossen-van Soest and Ruiter, 2003)

context, in the first place an efficient drainage system. The earliest experiments to drain agricultural land effectively were done in the early 19th century, using deep ditches filled with willow shoots and covered with soil (Kops, 1808). This was a toilsome and expensive method, and the English development of machine-made earthenware pipes (1845) accelerated the building of drainage systems all over the country. The second invention to drain the fields was the steam-pumping station. Contrary to the traditional windmills, steam-pumping engines were able to discharge large amounts of water, independent of the vagaries of the weather. One of the early plants was the experimental design in 1846 of a small steam-pumping station near Dreumel in the Land van Maas en Waal (Fijnje, 1847). The results were rather convincing: owing to the lower groundwater table the production (of grass) increased and soggy land ran dry (Van Zanden, 1990; Van der Woud, 2004).

Notwithstanding the improved drainage methods, the floodplain basins of the river polders remained backward areas. These basins were large treeless plains of heavy clay and exploited as grasslands of bad quality, inundated during wintertime, and during summer dry and cracked. Scattered osier fields, decoys and small poplar stands were conspicuous elements in the landscape. Owing to the small size of the farms, due to the system of the landlords and their tenants, and owing to the bad state of the water economy, the prosperity of the local inhabitants was low. In the early decades of the 20th century these areas belonged to the poorest parts of the country. The villages suffered from 'double isolation': the large rivers formed a barrier (compare the situation in the past: Chapters 3 and 4), and at the same time the villages were isolated from each other, only connected by narrow, winding dykes (Fig. 7.8A). The few metalled roads that opened up the basins ended in the middle of nowhere (Fig. 7.8B). The bad physical structure and permeability of the basin-clay was another source of disturbance. The marsh horsetail (*Equisetum fluviatile*) was growing here luxuriously, but this plant is toxic for cattle. Re-allotment was considered as an important means to restructure the land physically, and, moreover, to structure the social life of the inhabitants of the basins (Van Heiningen, 1965, 1971).

### 7.5.2 Land Consolidation in the 20th Century

During the late 1800s and early 1900s, circumstances in the rural part of the Rhine–Meuse Delta were alarming, most farmers had numerous plots of land, often lying scattered far apart, and the hydrological situation and infrastructure of their land left a lot to be desired. The re-allotment of land, land consolidation ('ruilverkaveling'), an instrument used during the better part of the 20th century to modernise Dutch agriculture, was designed to improve the economic situation of small farm holders, and to stimulate farmers to produce their goods more efficiently. It goes without saying that the process of land consolidation also changed over the years. This was caused by changing economic, social and political circumstances, as well as by technical innovations in agriculture. During the economic crisis in the 1930s, the export market for agricultural products shrank, and many farmers experienced financial trouble, only aggravated by the outbreak of the World War II. By the 1950s, prizes started to rise at increasing rates, and the income level in the agricultural sector could not keep up with this. The problem was that too many people were trying to make a living as a farmer. Policy became more and more aimed at reducing the number of farms and farmers, because increasing farm size and reducing the people that made a living in the agricultural sector was seen as the solution.

At the same time that farming intensified, the rural parts of the country were increasingly occupied by 'new' functions. From the early 20th century onwards nature conservationists expressed their worries about the changing countryside (cf. Chapter 6). Not much later, from the late 1940s on, industries were looking for cheaper locations, towns and villages expanded, commuters bought their houses in

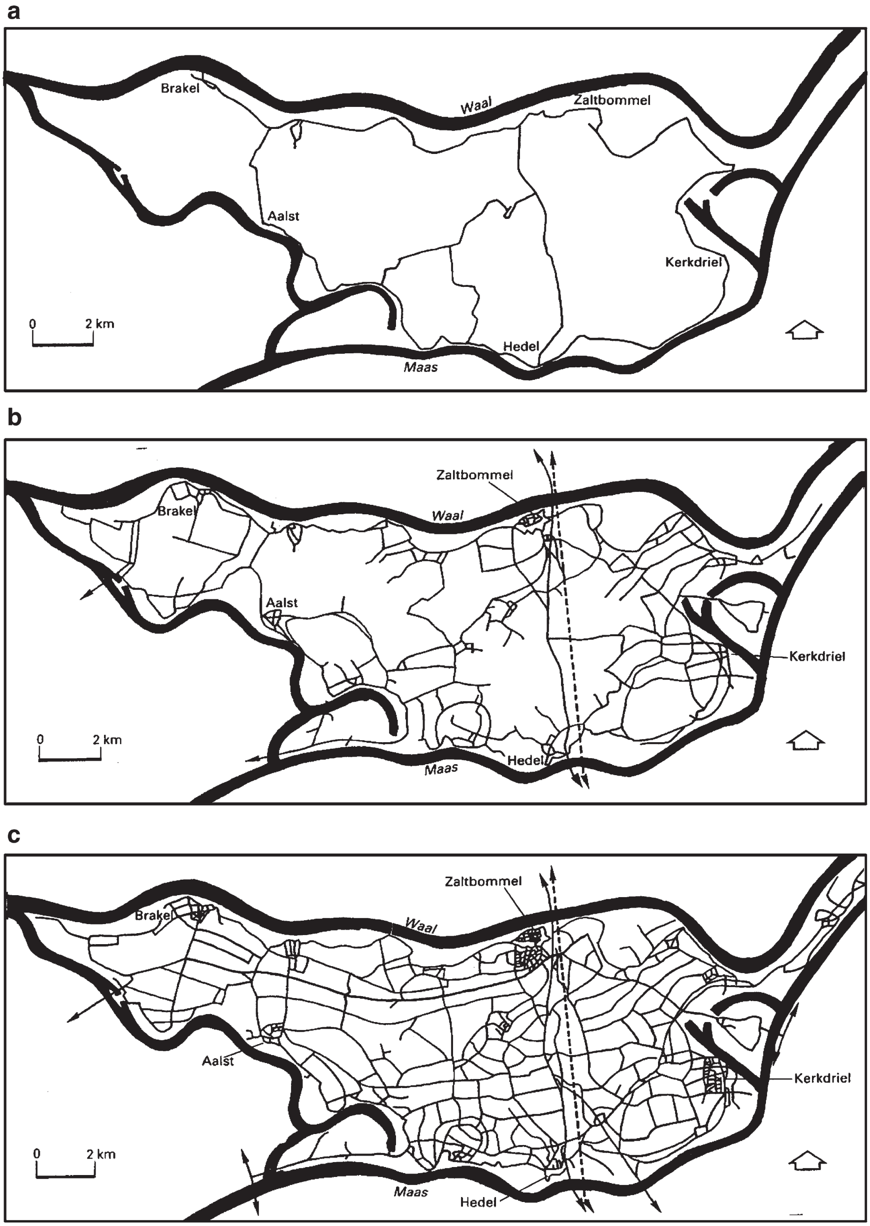

**Fig. 7.8** Metalled roads in the river polder Bommelerwaard in 1840 (A), 1935 (B) and 1985 (C) (Berendsen, 1986)

rural towns and villages, and tourism and recreation also made a claim on the 'green' space. Gradually, the traditional configuration of the countryside had changed: while in the past agriculture was the only important interest at the countryside, this pattern changed dramatically during the 20th century in favour of many other parties concerned (Van den Bergh, 2004).

The history of land consolidation can be set against the context sketched above. In 1924 the first Land Consolidation Act was implemented, solely meant to improve the conduct of business for farmers, and other functions and interests were not taken into account. Initially, land consolidation was aimed at improving the conditions for every farmer. As time progressed, and small farms were hardly able to earn any income at all, as happened during the economic crisis of the 1930s, this attitude slowly changed. Land consolidation was more and more aiming at improving rural, but still agricultural, economies. This meant that no longer all farmers were supposed to benefit from the plans. Old farmers without successors were encouraged to stop their business, and to sell their land, in favour of the enlargement of other farms. As the interpretation of the Land Consolidation Act was increasingly stretched, it got more and more criticism from all actors in the countryside. Farmers were opposed to the idea that the Land Consolidation Act was used for other than agricultural purposes, while representatives of the 'new' functions were reluctant against the fact that their interests were only served by a purely agricultural law. As time progressed improvisation and reinterpretation of the existing legislation had to be used to match agricultural, conservationist, industrial and all other interests. As the importance of agriculture lessened, in 1985 a new Act with broader, more integral aims for physical planning was adopted, the Land Reconstruction Act ('Landinrichtingswet'), and from then on a more balanced distribution of interests was made in the physical planning of the countryside. River forelands not occupied by recreation facilities, since decades seen as unprofitable meadows prone to flooding, were entirely dedicated to function as nature reserves (Van den Bergh, 2004), as part of the so-called Ecological Main Structure (see Chapters 20 and 21).

### *7.5.3 Land Use in the Bommelerwaard in 1825 and 2000*

In this section land use in 1825 will be compared with land use in 2000 in more detail. The Bommelerwaard is chosen as an example representing the agricultural conditions of the river polders in the Rhine–Meuse Delta. When in the 14th century the ring-dyke around the Bommelerwaard was closed, the 'landside' of the dyke (the river polder proper) was eventually separated from the 'waterside' of the dyke (the riverbed and river forelands). Figure 7.9 shows the landscape around the village of Brakel in 1830 (for location see Fig. 5.5). Most farms and houses are situated on the ring-dyke. The village is surrounded by orchards and vegetable gardens. Hardly any roads are leading into the polder that is characterised by numerous very small lots of land, grassland and arable fields. It is known that the floodplain forests in the river forelands were gradually changed by farmers into grassland or osiers; multi-purpose wood from coppice and osier-beds was applied for many objects. On the 1830 map the river floodplains are dominated by grassland and osiers. Large sandbanks are showing up in the channel of the river Waal.

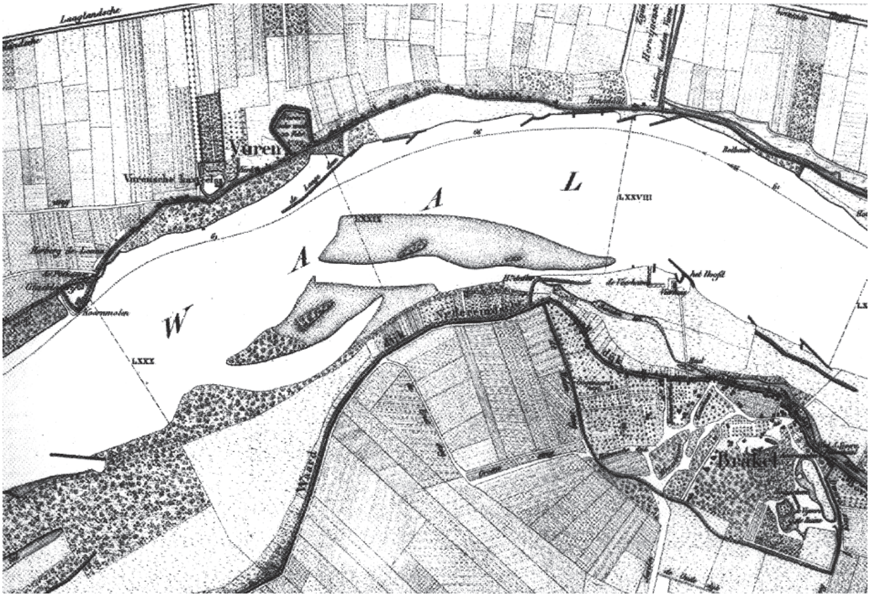

**Fig. 7.9** River Waal at Brakel in 1830 showing a variety of landscape characteristics. For explanation see text (From Schoor and Sorber, 1998)

During the agricultural crisis around 1880, when the prices for corn and hops slumped owing to the import of cheap foreign products, the making of baskets was seen as an alternative to gain some income. In Kerkdriel the number of basket-makers increased from 7 in 1870 to 143 in 1910, and in Ammerzoden and Well in the same period from 30 to 290 (see Fig. 5.5 for topographic position). In Kerkdriel a school for ‘wood- and reed-weaving and basket-work’ was founded in 1913, where boys were trained as basket-maker (the school was closed in 1938). During those decades both villages, having altogether a few thousands of inhabitants, were characterised by highly stacked stocks of baskets, ready to be shipped to the towns in the Delta, or to be exported, e.g. to the United Kingdom. Large faggots of osiers and willow-twigs, pretreated and steeped in ditches or water basins, completed the image. This trade vanished after World War II when baskets made of synthetic material appeared on the market (Schipper, 2001).

Table 7.2 shows a comparison of land use in the Bommelerwaard in *ca.*1825 (Roessingh and Schaars, 1996) and *ca.*2000 (www.statline.cbs.nl). A large area of land was occupied by farmers in 1825: at least 80% of the land was used for agricultural purposes. The remainder was water, used for fisheries purposes, and less than 5% was built-up area. Nowadays, roughly 55% of the land has an agricultural destination. The remainder is built-up area, and occupied by infrastructure works and nature reserves. In 1825 the Bommelerwaard had twice as much grassland as arable land. The better meadows were situated in the river forelands along Waal en Maas, were the regular flooding by river water provided the fields with the necessary

**Table 7.2** Land use and numbers of cattle in the Bommelerwaard in *ca.*1825 (derived from Roessingh and Schaars, 1996) and in *ca.*2000 (derived from www.statline.cbs.nl, Publicatie Lanbouwtellingen regional 1980–2003)

| Year | 1825 | 2000 |
|---|---|---|
| Total land surface (ha) | 16,000* | 16,455 |
| Arable land (ha) | 3,081 | 1,564 |
| Grassland (ha) | 7,921 | 6,244 |
| Orchards (ha) | 458 | 581 |
| Horticulture (ha) | X | 394 |
| Coppice (ha) | 394 | – |
| Osiers (ha) | 1,073 | – |
| Production forest (ha) | 32 | 11 |
| Fallow land (ha) | X | 141 |
| Wasteland (ha) | 71 | – |
| Nature reserves (ha) | – | 1,250 |
| Horses (N) | 1,839 | 1,009 |
| Cattle (N) | 5,143 | 7,799 |
| Sheep (N) | 2,472 | *ca.* 3,400 |
| Pigs (N) | 811 | *ca.* 20,000 |

* = Approximate surface area, exact data not known; X = presumably negligible; – = not existing. The partitioning in land-use units in 1825 differs from the one in 2000, and the data presented should be interpreted as an approximation

nutrients. The lowest-situated fields in the basins on the landside of the dykes, suffered from chronic flooding and seepage, notwithstanding the obligatory cleaning of ditches. These lands were used as hay fields or pastures.

The land-use picture of 1825 as sketched in Table 7.2 has existed for centuries. A considerable variety of agricultural products were grown in the Bommelerwaard in the course of time: flax, hemp, hops and potatoes, next to a variety of corn races. Potatoes were introduced in the early 17th century, and became popular food for the common people; they were rather cheap, compared to very expensive corn. The potato blight (*Phytophtora infestans*) catastrophe in 1845–1848 hit the Bommelerwaard in particular. The blight led to acute famine, a high death-toll and great poverty (Brusse, 2002; see Section 7.3.2.). Nowadays the area of arable land has roughly been halved compared to the land use in 1825. The area of grassland was 1.3 times larger in 1825 than nowadays, but the intensity of grassland use has greatly increased (re-allotment; fertiliser). The number of cattle (average $2\,\mathrm{ha}^{-1}$) and sheep increased with a factor of *ca.* 1.5. The number of pigs showed the largest increase, 25 times; the land use, however, is relatively small, the animals are kept in large pig-breeding farms. The number of horses was 1.8 times larger in 1825 than in 2000. Next to riding-animals, in 1825 horses were the most important pack- and draught-animals, and large numbers were bred for the cavalry. The village of Hedel in the Bommelerwaard still has one of the largest horse-fairs in the Netherlands, a trade going back to the times when horse-power was the most important propeller for the transport of humans and their goods. Nowadays the riding-horse has become part of the life of luxury; of the present-day horses 544 are luxury horses, and 465 are ponies that are also kept for fun.

Comparing 1825 and 2000, the area of orchards has increased, situated on the fertile soil of the former channel belt and natural levees. A contested feature of the present-day landscape are the 260 ha of greenhouses, an important share of the total area occupied by horticulture. In 1825 'horticulture' was presumably negligible, and covered mainly the vegetable gardens on the farmyards. In 1825 a considerable area of coppice, osiers and planted production forest provided wood and timber, a most necessary resource in those days. There were 25 decoys in the Bommelerwaard alone. Nowadays osiers and decoys are no longer exploited, and there are only two remnants of decoys left. The present-day landscape is touched up with small scattered poplar plantations, planted with an economic motive, to be harvested after 30 or 40 years. In 1825 grass verges of roads and the commons were considered as 'wasteland', that could be farmed out, but in most cases these spots were left to indigent persons who were allowed to graze their cattle there. Nature conservation did not exist in 1825; in 2000 *ca*. 8% is nature reserve, and this percentage will steadily increase (Ecological Main Structure; Roessingh and Schaars, 1996; Van Balken et al., 1978; Jansma and Schroor, 1987; www.statline.cbs.nl).

## 7.6 Grassland: The Dilemma Ecology Versus Agriculture

### *7.6.1 Ecological Values of Grassland*

During many centuries the arable fields close to the human settlements in the river polders were fertilised and exploited. Animal manure was scarce, and consequently the hay fields farther away from the farms were not fertilised; they comprised grasslands rich in slowly growing flowering plants, that were harvested only once, late in the season in July. The hay fields thus provided quiet breeding biotopes for birds like ruff (*Philomachus pugnax*), corn crake (*Crex crex*), and yellow wagtail (*Motacilla flava*). After the harvest the hay was transported to the farms; there it was fed to the cattle, and their dung was used to fertilise the arable fields. This habit, maintained over the centuries, intensified the spatial ecological gradient from the remote, poor soils to the enriched fields close to the farm, and from the clear and clean nutrient-poor surface water in the ditches separating the meadows, to the eutrophicated surroundings of the farm. The introduction of artificial fertiliser at the end of the 19th century has abruptly changed this situation; it stimulated the growth of grass and the flowering plants were suffocated, a process often completed with chemical destruction of the unwanted weeds. Mowing is fixed at an earlier date, in the middle of the breeding season. A network of metalled roads has opened the countryside, and consequently the former tranquillity has disappeared (Fig. 7.8). The spatial variation in habitat types has declined, and intensified land use resulting in eutrophication is still one of the major problems of pollution. These changes in agricultural habits are considered as major negative impacts on the semi-natural landscape of the 19th century (Westhoff et al., 1970, 1971).

The low-lying grasslands in the basins of the ‘waarden’ had a very erratic water household: dry in summer and flooded during winter. The poorest soil consisted of compacted clay, acid and poor in lime, were *Juncus effusus* and *Ranunculus flammula* dominated. The less compacted hay fields were rich in higher plants, with *Cirsium palustre*, *Ophioglossum vulgatum*, *Orchis morio*, *Leucanthemum vulgare*, *Achillea ptarmica*, *Angelica sylvestris*, *Equisetum palustre*, *Thalictrum flavum*, *Rhinanthus angustifolius*, *Rhinanthus minor*, *Pedicularis palustris*, *Jacobaea paludosa*, and *Jacobaea aquatica*. Much of these hay fields rich in flowers has disappeared after World War II, owing to re-allotment measures, drainage and fertilisation. Only small remnants of these vegetations have survived, thanks to specific management measures, such as an artificial water table, and inlet of nutrient-poor surface water.

The meadows-on-peat in the Central Delta harboured once thousands of hectares of un-fertilised nutrient-poor hay fields with a great diversity of flowering plants. This habitat already became rare in the 1930s. Just as in the meadow-on-clay of the ‘waarden’ these hay fields functioned as the very basis of the dairy cattle farms. At specific spots the soil was so poor in available nutrients, that its vegetation was comparable to the vegetation of a heath field. In late summer *Gentiana pneumonanthe*, a characteristic plant of heath-lands coloured the fields and the grass verges of roads in the Central Delta dark blue, whereas in springtime the orchid *Orchus morio* was one of the dominant higher plants in the hay fields. According to Westhoff et al. (1971) this colourful plant growth in an oligotrophic landscape ‘is for us incredible and hardly to believe’. On an area of less than 1 ha close to the Hollandse IJssel 12 species of orchids flourished, together with many other nowadays rare plants. These un-fertilised blue-grasslands were considered as botanical jewels, dull blue- or grey-green in colour, in contrast to the shining yellow–dark green colour of fertile grasslands (De Vries, 1974). The quickest way to get rid of the blue-grasslands is providing them with fertiliser. Although many areas have escaped from re-allotment practice, intensification of the dairy farming, using large quantities of artificial fertiliser, has been the fatal blow for the ecological values of grassland and adjoining wetlands in the 20th century. Blue-grass fields have almost all disappeared and only remnants have survived. For example, in the Krimpenerwaard (Fig. 3.9) the area of blue-grasslands decreased from 10,000 ha in the 19th century to 3 ha in 1953 (Van Zanden and Verstegen, 1993). In AD 2007 only *ca.* 50 ha of well-developed blue-grassland is left in the entire Delta (www.natuurmonumenten.nl).

The grasslands in the river forelands, the so-called river corridor vegetations (‘stroomdalgraslanden’), provided the best hay; they were frequently re-fertilised by the deposition of river silt during floods. The ‘outer hay’, from the floodplains, had a better quality than the ‘inner hay’, harvested from the fields on the landside of the dyke. The hay from the floodplains with its higher lime and nutrient content was dominated by lime-preferring grasses (a.o. *Arrhenatherum elatius*). Grasslands on the dryer and warmer, river dunes were very rich in species. These habitats were lower in nutrients, but rich in lime. One of the dominant grasses is *Festuca rubra*. The nowadays highly appreciated flowering plants like *Salvia pratensis*, *Ononis spinosa* and *Chrysanthemum leucanthemum* and many others, were in the 19th century seen as ‘weeds’, i.e. unwanted herbs (Roessingh and Schaars, 1996; Maes and Caspers, 2001; Westhoff et al., 1970, 1971).

### *7.6.2 Agricultural Misery of Grassland*

Botanically the blue-grasslands might be considered as jewels, economically they were considered as land sank into poverty. De Jonge (1954) wrote a sensational book on this economic problem. I will quote a few parables from his book:

> The low-lying flood basins, tundra’s in winter, as hard as nails in summer. The grasslands were very deficient in phosphates, and economically seen these fields were so badly managed that only heavy applications of fertilizers and liming (lime offal of beet sugar factories was very suitable for that purpose) will not result in satisfactory improvements. Drainage of the soil, in order to allow a year round control of the water table is also seen as a necessary measure. The farmers in the river-clay regions were mainly small-holders. The prospects of progress in the past have been very poor. Unfavourable conditions in tenancy and losses of property and stock due to dike breaches and flooding, kept the small-holders poor. The large re-allotment projects designed after World War II were aiming at the improvement of the means of subsistence and the raising of the standard of living of the population in the area between the large rivers. The economic significance of this development work, both for the population themselves and the national prosperity, should not be underrated. An area of some 100,000 hectares is involved. It is estimated that, with modest investment, an average production increase of some 50% may be achieved, and in the poorest parts even of 100%. It is intended, in a period from 10 to 20 years, starting in the early 1950s, to build 500 new farms, to reclaim and reallocate thousands of hectares of basin soils. The modernisation of these backward areas will require an tremendous investment. In the Bommelerwaard and in the Brabant Maas border area, work will be started in 1954 on the reclamation of basin soils and the building of new farm-houses. Social-cultural and education work has been started, to prepare the population mentally for the often drastic changes in the existing living-conditions. The conversion of an old, inefficient farm into a modern one means quite a lot to the farmer. The old way of living will have to be replaced by a somewhat more expensive and more modem style of living. The struggle for life of the basin soil farmers has been so hard and bitter that they hardly take an interest in general development, technical training, education to organized cooperation and association. Thus the population themselves present a problem, which needs solution as much as technical and economic problems do. Anyone who realizes the intricacy of the problems, knows that what has grown in the course of the ages, cannot be changed within a few years. (End quote De Jonge, 1954)

Now in 2007, the re-allotment schemes of the 1950s–1970s can be judged as very beneficial for the local farmers, but at the same time as disastrous for the regional ecology. The rigorous draining of the land, the use of an overdose of artificial fertiliser, the clearing of wild shoots and wood (hawthorn hedges were replaced by barbed wire), the enlargement of the farmers’ lots, and replacement of the farms in the framework of the re-allotment schemes, are nowadays seen as a severe devaluation of the cultural landscape. The cynical side of this development is that since the physical planning schemes were realised, the agricultural significance of the countryside is only decreasing year after year (owing to a complex of factors; see Chapters 20 and 21), and ‘nature development’ is stimulated.

## 7.7 Brickworks

Already in Roman times brickworks existed in the Delta, but when the Romans left around AD 400 the use of bricks fell into disuse. For centuries it became customary to build wooden houses, with wattle-and-daub walls, and thatched roofs. The first churches built in the Delta, from the 8th century onwards, were built of wood or tuff stone imported from Germany and Belgium, sailed in by ships along the Rhine and Meuse. In the 12th century monks, connected to specific monastic orders, started their brickyards in the Delta; they made the large *ca.* 10-cm thick medieval bricks, the 'kloostermoppen'. Around 1700 quite a lot of brickworks were founded in the Large River area, not without a reason, because their resource, river-clay, was plentiful available.

As an example we will discuss the developments in the Bommelerwaard. The first documents proving the existence of brickworks in or close to this river polder date back to *ca.*1600. Around 1730 three brickworks were counted in the Bommelerwaard, increasing to a number of ten in 1925. At the end of the 19th century field-ovens were replaced by more efficient ring-ovens or tunnel-ovens with their characteristic tall, brick chimneys. Now, in 2007 only two big plants are left in the 'waard'. Brickworks were built on a mound in the river floodplain, close to their resource, but also close to the waterfront were the supply of fuel for the ovens, and the conveyance of the bricks took place. This habit changed only in the 20th century. Most brickworks now use natural gas, and the transport of bricks is done by heavy goods vehicles.

Of old, the processing of bricks and tiles was labour-intensive handwork, where next to men, also women and children were employed. Digging the brick-clay ('tichelen') with a spade was man's work (spade and wheelbarrow were the universal tools of the navvy until the 20th century). The clay was mixed, moulded in wooden boxes and the pre-formed blocks of clay were laid out on the drying fields. Turning the drying bricks and stacking up the bricks in the storehouses was the work of women and children. After a few weeks of drying in the open air, the bricks were put in the brick-oven for their final processing. Entire families were employed by the owner of a brickyard. Data for the brickyard at Hurwenen in 1860 shed sharp light on the then working conditions: men had to work 12 h per day, women 7 h, boys (age 14–18 years) 12 h, girls (14–18 years) 10 h and children (8–14 years) 7 h (Hollander, 2007). For children and women this meant a meagre seasonal income from April to mid-September. The men continued their work until the floodplains became inundated, or until the soil was frozen. It was hard labour, in summer from four o'clock in the morning until nine o'clock at night, and one brickyard provided hundreds of poor people with a most welcome income (Van Balken et al., 1978; Groenendijk, 1998).

In the 20th century the gaining of brick-clay was gradually taken over by machines that could dig deeper into the floodplain down to the sand layer. All over the river forelands large clay-pits have originated, now seen as a characteristic feature of the floodplains. Nowadays, next to clay, sand and gravel are also highly valued resources, mainly used as building material. Sand is excavated by suction-dredgers, transported via long pipelines, and used for raising building sites and foundations of roads. Many of these sand- and clay-pits are so deep (20–30 m) that the water mass is permanently stratified (see Fig. 13.3), a very unnatural situation in the low-lying Delta where natural deep lakes do not exist.

## 7.8 Conclusions

- The well-documented history of agriculture is closely interwoven with the physical and cultural-historic development of the fertile Delta.
- Flooding is a continuum. In the late Middle Ages the farmers of the Central Delta were forced to change their conduct of business from arable farming to dairy farming. The more the ‘waarden’ subsided, the more the seepage of river water became a problem. The introduction of steam engines in the 19th century did only slightly alleviate this problem.
- The farmers were subjected to erratic weather conditions, and repetitive disasters stroke both cattle and crops: seepage and flooding, cattle plague, infectious diseases, crop failure, harmful weeds, etc.
- The successive large-scale cultivation of hemp, hops, madder, potatoes, tobacco and sugar beets from the late Middle Ages onwards, demonstrates the flexibility of the farmers in the Delta to adapt to changing circumstances. Especially the 17th century Golden Age meant a stimulus for many-sided husbandry.
- From the Middle Ages onwards the wane of an agricultural produce was, for example, decided by import from foreign countries (flax, hemp, hops, buckwheat, tobacco), and later by the introduction of artificial alternatives (hemp, madder). Dairy farming on peat and river clay, and the culture of potatoes (on various soils) and sugar beets on marine clay remained.
- Woodmen and farmers traditionally made use of the self-renewing power of trees. Coppicing and suckering were efficient and reliable ways of getting a new crop.
- For many centuries numerous small wooded landscape elements characterised the semi-aquatic and terrestrial ecosystems of the Delta: duck decoys, hedges, wooded banks, osiers, timber and wood groves, ridge-and-furrow with underwood.
- Timber and wood had numerous applications: building material, firewood, faggots in bakers ovens, multi-purpose wood for farmers, poles for fences and toolshafts, beanpoles, etc.
- Wetlands were characterised by osiers, reed marshes and bulrush marshes, which delivered indispensable resources for numerous tradesmen. Decline in area and use started in the course of the 20th century, owing to the cease of tidal movements, deterioration of the environment and availability of artificial alternatives.
- Coppiced willow shoots were used for basket-making, for the production of hoops for barrels and casks, as multiple-purpose wood for farmers, e.g. to make

fences and cattle hides of wattle-work, and sheds and barns of wattle-and-daub. Willow shoots are still needed for the production of willow-matting for hydraulic engineering projects.

- The large-scale river normalisation in the 19th and early 20th centuries had significant consequences for habitat structure and concomitant agricultural practice in river forelands. Small landscape elements were annihilated: meanders, secondary channels, marshes, groves and osiers.
- Although the normalisation of the great rivers in the 19th century brought considerable deterioration to the river landscape, it is generally believed that around 1880–1900 the green, fine-meshed cultural landscape of the Delta, comprising numerous small landscape elements, reached its climax.
- Hedges (particularly hawthorn) were the cattle (and game) fences of the past. Barbed wire, invented in 1880, replaced this green network. Hundreds of thousands of kilometres of linear landscape elements have been removed in the course of the 20th century.
- Until the end of the 19th century, the farmers manured their fields with animal dung. Manure was scarce. The introduction of artificial fertiliser around 1900 meant a revolution in Dutch agriculture.
- From approximately the 18th century onwards grassland dominates the landscape of the Large Rivers and the Central Delta (50–70%). In the 20th century the semi-natural meadows and hay fields, however, made completely room for intensively fertilised and (over)grazed pastures.
- The rigorous draining of the land, the use of an overdose of artificial fertiliser, the clearing of wild shoots and wood, the enlargement of the farmers’ lots and replacement of the farms in the framework of the re-allotment schemes, are nowadays seen as a severe devaluation of the cultural landscape.
- The un-fertilised blue-grasslands in the embanked floodplain basins were considered as botanical jewels, poor in nutrients and lime, sometimes acid. The quickest way to get rid of the blue-grasslands is providing them with fertiliser, and consequently far out the majority of these vegetations have disappeared.
- The re-allotment schemes of the 1950s–1970s and later decades can be judged now as very beneficial for the local farmers, but at the same time as disastrous for the regional ecology. The cynical side of this development is that since the physical planning schemes were realised, the agricultural significance of the countryside is gradually decreasing, in favour of ‘nature development’.
- The ecological values of the embanked flood basins and the river forelands changed mainly in the second half of the 20th century. Osiers and decoys were no longer exploited and gradually disappeared, ‘wasteland’ changed into nature reserves, dynamic wetland transitions between water and land became sharp borders between dry land and water.
- In the 20th century the ground rule of agriculture, to enhance the productivity per hectare, has led to systematic manipulation of biological and chemical processes, and increasing discrepancy between the natural environment and agricultural practice.

# Chapter 8
# River Fisheries Through the Ages

## 8.1 Introduction

From the oldest times onwards fish has always been an important part of the human diet, in the Delta of Rhine and Meuse. That is not surprising in a country with many rich fishing-waters, and numerous inhabitants strongly oriented on the waterside. Owing to the fact that the spectacular marine fisheries draw full attention both from contemporaries as well as from historians, the freshwater fisheries remain strongly underexposed. This is fully unjustified, according to De Vries and Van der Woude (2005). There are indications that until far in the 16th and early 17th century, the consumption of freshwater fish was even more important than salt herring and other sea fish. Inland fishing was an important sector of economic life in the Middle Ages, in particular in wetlands along coasts such as those in the Delta. Although eel fishing dates back at least to the early Middle Ages, and archaeologists have unearthed traces of its existence considerably further back in time, its marine counterpart, in particular herring fishery, is much better known. How should this be explained? Obviously, inland fishing has never captured the imagination of historians as have the marine fisheries. In older historical surveys the image of the Dutch fisheries was dominated by the rapid rise of the herring fisheries, a trade that expanded exponentially after 1400, exploiting the seemingly endless oceans. Local inland fisheries were apparently much less prominent (Van Dam, 2003a).

The aim of this chapter is to give a concise review of river fisheries through the ages in the Delta. The past and present status of a number of anadromous fish species in the Delta water will be discussed: sturgeon, eel, allis shad, twaite shad, smelt, some coregonids, sea trout and salmon. Nowadays, most of these species are rare or endangered, and some became virtually extinct. Of the 'big three', sturgeon, allis shad and salmon, the salmon came on the first place, all year through a regular customer in the rivers, except during a short period in winter. In the 19th century, or perhaps far more earlier, a major decline in catches set in, for some species earlier than for others. A complex of causes thought to be responsible for the dramatic decrease of fish stocks in the Large Rivers will be dealt with in this chapter. Most of these causes are related to the river regulation and normalisation works, as discussed in previous chapters. Habitat loss ranks among the most important factors, and severe water pollution might be considered as the death-blow to some species.

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Major impact on stock sizes was evoked by the closure of the Zuiderzee in 1932 and the damming off of the estuaries in the SW Delta at the end of the 1960s.

The importance of river fisheries in the past, a ‘passed away pride’, can convincingly be illustrated by an inventory of literally thousands of (hardly translatable) terms in Dutch and in Dutch dialects, regarding aspects of river fish and fisheries, of ships and types of fishing gear, not in use anymore. Nowadays the interest of sport fisheries far exceeds the economic importance of professional inland fisheries. Finally, some notes will be made on the question whether restocking attempts of rare or extinct fish species will lead to the possible reintroduction of a viable population. The introduction of tens of non-indigenous fish species in the Delta waters in relation to the indigenous fish stocks and habitat quality will be discussed.

## 8.2 Inland Fisheries in the Past

Hoffmann (1996) has shown that for Europe as a whole, from the early Middle Ages onwards, freshwater fish underwent drastic changes, and in many cases existing stocks were destroyed, far more early as assumed in classic historical treatises. Humans interfered with aquatic habitats by diverting and canalising streams, building dams and watermills, and altering water quality by adding nutrients to the water, either of agricultural or industrial origin. According to Van Dam (2003a) the Delta version of this process of environmental change consisted of several phases. The destruction of habitats for freshwater fish began with the reclamation of the large coastal peat bogs in the west; the techniques used included canalisation and dam building, especially after 1200. A pause in this process followed the economic decline of the 14th century. Between 1400 and 1600 large lakes came into existence in the peat bogs due mainly to activities such as the commercial mining of peat for fuel (Chapter 3). The new lakes must have increased the size of the habitat for freshwater fish, in particular for eels, although data are only scarcely available. Archaeological findings indicate an increasing number of remnants of carp and carp-like fish in cesspits and garbage heaps. In the 17th century, Golden Age, the process of habitat destruction intensified, as lakes were drained and reclaimed for agricultural purposes (Chapter 4).

Fish has always been a subject of great interest in the Rhine–Meuse Delta, a country rich in water. It was mainly the economic usefulness of fish that caught attention. Fish is food, and food is money. From the later Middle Ages onwards, fish was supplied and sold in fish markets. A rich source of information on fish is formed by the documents about disputes and restrictions on the catching of fish. And there was plenty of fish in the Dutch surface waters, like salmon and eel. Between 1235 and 1864 roughly 2,000 regulations dealing with fish and fisheries have been issued by the government. These restrictions pointed to the rights of the owners of the fish-waters, to the fish quota, to the periods in which fish might be caught, to the size and mesh width of the nets to be used, etc. The orders both mentioned the fish species and the locations were the fish was to be caught, hence offering a valuable source of information on the fish stocks in earlier centuries (During and Schreurs, 1995).

It is most likely that the relative consumption of fish in the Middle Ages was far more important than it is nowadays. Fish was a prominent source of proteins for the common man. A significant impulse for the consumption of fish from the Middle Ages onwards, was the weekly fasting-day, ordained by the church ('Friday, fish-day'). That the marine herring was the fasting-fish pre-eminently, particularly in the coastal provinces, is commonplace among cultural historians. But there was also a considerable supply of freshwater fish, like salmon, eel and carp (Van Dam, 2003b). Of course, there were differences in appreciation and depreciation of specific fish species. Small freshwater fish like the ruffe (*Gymnocephalus cernua*), not appreciated by present-day anglers, was popular food in the Middle Ages (Burema, 1953). The allis shad was also an appreciated fish; considering its taste and structure of the flesh, it held the third position after salmon and sturgeon.

From the later Middle Ages till far into the 19th century thousands of fishermen from villages and towns along the rivers practised their trade (Fig. 8.1). They

**Fig. 8.1** The fisherman (etching by J. and C. Luiken, 1694), set in an imaginary landscape, certainly not the flat Rhine–Meuse Delta

followed the seasonal cycles of the migratory fish, and fished on the rhythm of the tides. Their catch consisted of salmon, sturgeon and allis shad, completed with eel, twaite shad, houting, river lamprey, flounder and smelt, all popular fish species. The fishermen made their own gear, only their boats were constructed in a shipyard somewhere else. They tarred their boats, made their baskets, and knitted, mended and tanned their nets, particularly during winter when the river was frozen or pack ice hindered their job. Until the 20th century the making of baskets, weaved from willow twigs, was an important trade where whole families were involved in (cf. Chapter 7). Tanning of the nets was done in a tanner's kettle containing boiling water with oak-bark or willow-bark, a by-product of basket-making. Creosote was used for the first time in the early 20th century, particularly for conserving fish-traps.

No doubt, river fishery was an important trade until the 20th century. Each town along the major rivers had its own fish market or auction. But as Verhagen (1998) pointed out, in former centuries most people had a sober life, and they scraped along on their income, collecting everything that could be eaten. They were roaming along the waterside, trying to catch some fish as additional (and cheap) meat or as main food, using all kinds of simple fishing gear. Eel was caught with eel-spears, by sniggling with earthworms or with baskets hung in the water filled with straw and bait, such as animal refuse or carrions. Self-made angling gear, lines with hooks, and of course several small nets, often with local names ('gebbe, haam, hoepelnet, fuik, schepnet, geel, trommel', etc.), were used to catch all kinds of other fish. Old paintings often show those fishing gear in detail, for example, a painting of Pieter Stevens from Antwerp, around 1600 (Fig. 8.2) depicts the various fishing gear to be recognised on the painting, as drawn by Verhagen (1998).

The importance of inland fishery is stressed here, but it cannot be denied that from the late Middle Ages on, and particularly in the 17th century, on the peak of the Dutch herring fisheries, this trade got legendary proportions (Fig. 8.3). It is said that the gutting and curing of herrings (removing the guts and glands; 'haringkaken') was invented by a Dutchman in the 14th century, but recent archaeological finds question that fact (Lauwerier and Laarman, 2006). Anyway, this processing meant that the perishable herring could be 'gutted' and salted at high sea, and hence was preserved for a longer period. In the mid-17th century roughly 500 herring-boats ('buizen') meant a living for 6,000–7,000 fishermen, and from 1660 onwards the whale fisheries comprised another 200 boats. Next to the fisheries tens of thousands of people were employed in shipbuilding, weaving-mills for sailcloth, net-makers, herring-packing, try-houses and not to forget the salt-works and cooperies. In the fishery trade half a million of casks and barrels were used on an annual basis. Considering the fact that each herring barrel needed 35 kg of salt, an annual catch of 240,000 barrels of herring asked for 8,400 t of salt. When the herring fishery was at its peak, a theoretical production of 6 million baskets of peat was necessary, in order to boil the demanded amount of salt. However, the preferred salt for preserving the herring was sea-salt. Large amounts of raw salt were imported from Portugal and southwestern France, and this resource was treated in the Dutch salt-works. These examples show clearly how the different trades were interconnected, and offered

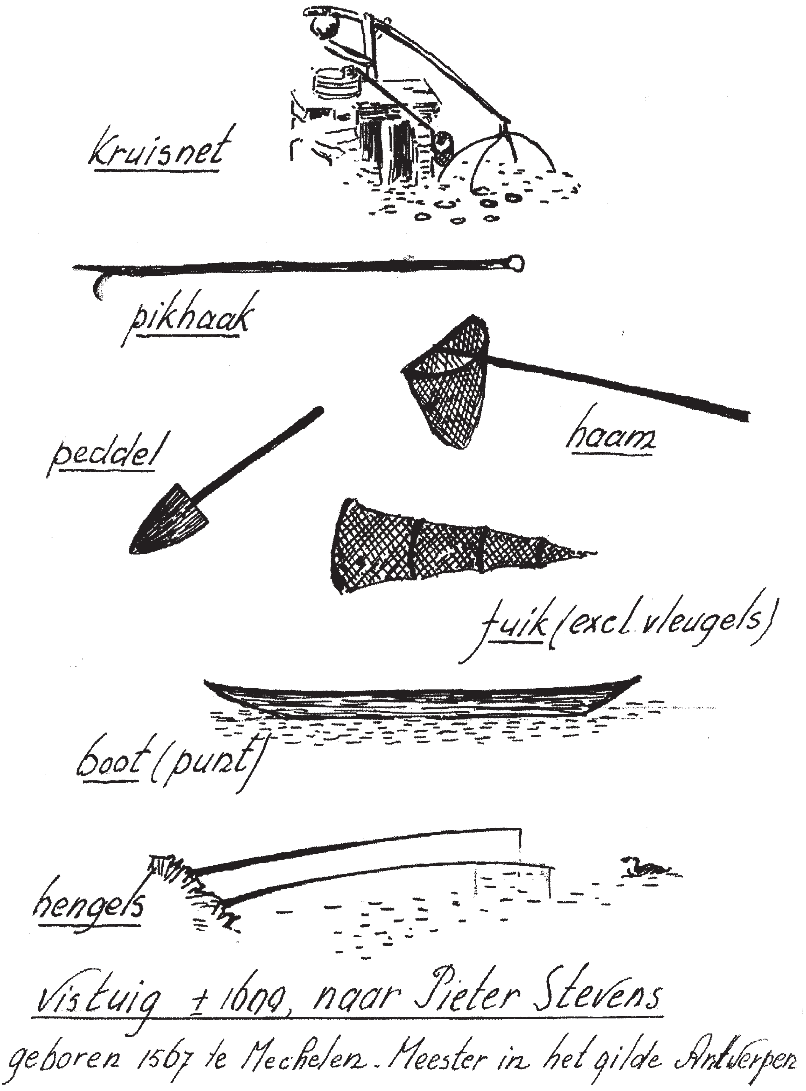

**Fig. 8.2** Fishing gear depicted on a painting of Pieter Stevens (*ca.*1600), as drawn by Verhagen (1998)

employment to tens of thousands of people (Kranenburg, 1946; De Vries and Van de Woude, 2005). Further treatment of the marine fishery is beyond the scope of this book, but herring-barrels and peat extraction have a direct relation with the ecological history of the Delta rivers.

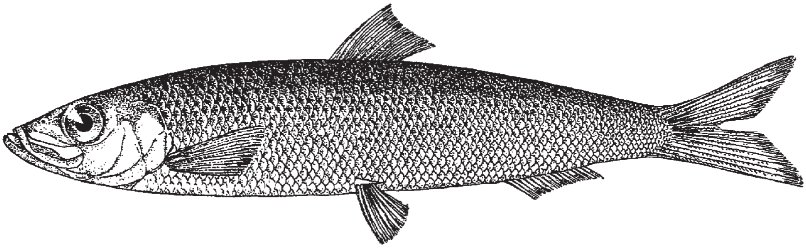

**Fig. 8.3** Herring (*Clupea harengus*), *ca.* 40 cm (Nijssen and De Groot, 1980)

## 8.3 The Catches of the River Fishermen

River fishery is ‘passed away pride’ (www.visplanner.nl). This is clearly demonstrated by a review of the past and present status of a number of anadromous fish species in Delta rivers that were commercially important in the past. Most of these species are probably extinct now, according to the Red List of De Nie (1996), except sea trout, and eel which are ‘vulnerable’. The smelt is at the moment ‘not endangered’ (see Table 15.1). Most data in this review have been borrowed from De Groot (2002)

### *8.3.1 Sturgeon (Acipenser sturio)*

It is known that the sturgeon (Fig. 15.1) inhabited Dutch waters in the New Stone Age. Fragments of dermal plates were found in the hunting camp, excavated at Berschenhoek, dating back 6,000 years BP (for details see Box 2.1). Findings from the Iron Age and Roman times suggest that during pre- and protohistoric times the sturgeon regularly occurred in the Rhine–Meuse Delta (Brinkhuizen, 1989). It is suggested that the decline of the sturgeon population was already noticeable in the later Middle Ages, when man intensified the cultivation and draining of floodplains, and built small dams and dykes cutting off the inland waters from the sea. The extinction of the sturgeon in the river IJssel around 1300 is presumably to be blamed to the embankments of vast areas of floodplain in river meanders (Van Dam, 1999). Boddeke (1971) stated it apodictically: the best spawning ground for the sturgeon were eventually taken by cows. Kinzelbach (1987) carried out a reconstruction of the now extinct population of the sturgeon in the river Rhine-system. He based his study on records from the 15th century. Sturgeons were common in the Delta and in the lower Rhine until about 1910, becoming extinct as a breeding species in 1942. About two thirds of the sturgeon population stayed in the lower Rhine and Delta Rhine and about one third swam up to the middle and upper Rhine (up to 850 km upstream) and their tributaries.

Spawning of sturgeon has never been observed in the Delta waters. It is unknown where sturgeon nurseries existed in the river Rhine. After spawning the adults migrate rapidly to the sea, where they remain before returning to spawn again. The juveniles leave the freshwater area and move into the estuary. They may migrate for a while into the sea and then return to the estuary. The fact that sturgeon males require about 8 years to reach sexual maturity, and females even 14 years, makes them especially vulnerable to fishing. After a strong decline of river-caught sturgeon, sea catches exceeded the river catches during a short period, but after 1960 no river catches of sturgeon in the lower Rhine were reported anymore. After 1992, however, juvenile sturgeons have been reported occasionally from the lower Rhine and adjacent waters, but some of the individuals proved to be hybrids between other sturgeon species. According to De Groot (2002) the reported revival of the sturgeon in the Rhine cannot be taken seriously, as the specimens collected are likely originating from accidental releases of aquarium fish.

What are the causes of the decline and ultimate extinction of the sturgeon in the Rhine? Kinzelbach (1987), assuming that the fisheries took about 30% of the sturgeons in the Rhine, calculated that around the turn of the 19th century the stock of Rhine was only several thousands of individuals. He concluded that the decline of the sturgeon started in the mid-19th century and that the species became extinct in the 1930s. The most likely cause was the overfishing, and the destruction of spawning grounds, due to canalisation and the construction of dams and weirs. Increased fishing pressure proved to be as destructive as the deterioration of the spawning areas. The river fisheries caught far too many adult specimens, the sea fisheries finished off the immature and remaining adults.

### 8.3.2 Eel (*Anguilla anguilla*)

In the Middle Ages, eel fishing was carried out wherever eels were found: in the large freshwater lakes and the numerous rivers, streams, drainage canals and ditches that existed both in the western peat bogs and the higher sandy grounds in the eastern Pleistocene parts of the Delta (Fig. 8.4; cf. Box 8.1). Specific locations, however, offered particularly favourable opportunities for catching the migratory eels: the river dams. By 1300 dozens of dams closed off water outlets. These dams were originally built of wood and earth and grew larger over time. The dams contained sluices for the necessary draining of the hinterland, small closed culverts or larger open sluices with gates. With their sluice tunnels acting as funnels, the dams offered excellent fishing opportunities. No wonder that sluice fishing rights came into existence that were attached to the right of property or the obligation to maintain the sluice. At the end of the 15th century, eel fishing at the sluices was carried out with all sorts of equipment. Weirs, large complexes of hundreds of metres of wattle-screens that led the eels into dozens of eel-traps and baskets, were used during the entire season. During the eel migration in the autumn, up to 80 baskets were used per sluice gate. During that period more capital-intensive gear was also utilised, including trawl nets ('kuilen'). In deep waters the trawl was drawn by a ship, but on land specialised servant-fishermen called 'kuilers' manipulated smaller versions, sometimes on foot or in small rowing boats (see Section 8.4). By 1550 special gear was attached to the sluice to seal the opening of the gates (Van Dam, 2003a).

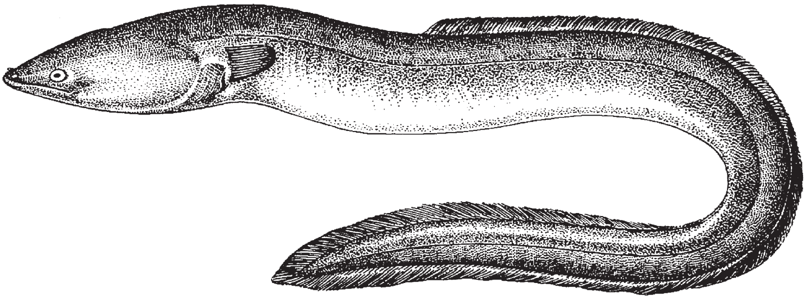

**Fig. 8.4** Eel (*Anguilla anguilla*), *ca.* 50–100 cm (Nijssen and De Groot, 1980)

**Box 8.1** Eel tales (Lobregt and Van Os, 1977)

Eel has always been a desired fish. The Romans were great lovers of eel, a dish for gentlemen. It is said that they kept their eel in ponds, in which the fish was fattened on the flesh of slaves sentenced to death. Already around 1400 Dutch eel was exported to England and Germany. In Holland baked eel was consumed, offered in popular fish-stalls along streets and markets. Smoked eel became customary in the 19th century. The eel held a prominent place in popular medicine and in public amusement. A stripped-off skin of an eel around the lumbar region was a good remedy against backache; an eel skin wrapped around the leg dispelled rheumatism. 'Skinning' of eel was a widely spread popular amusement. The people in the Jordaan, a working-class quarter of Amsterdam, had their own variation of this 'game'. Live eels were attached to a rope that was stretched across the canal several metres above the water level. Notwithstanding a police regulation that forbade this 'game', everyone was allowed to use a small boat and to pull an extremely slippery and twisting eel from the rope, naturally in most cases without success. On July 25, 1886 the 'eel pulling' contest was running, but when the armed police arrived, the game got under way even more intensely. The heated minds of the people did not tolerate police interference in their centuries-old and 'harmless' public amusement. The government, on her term, suspected the resistance of the 'eel pullers', and interpreted this rebellion as the subversive attitude of slumbering socialism. Police force and drummed-up soldiers needed 2 days to beat down the riot. The 'eel rebellion' caused loss of life to 26 persons, more than 100 wounded and tens of arrests.

From the mid-14th through the 16th century toll and customs records throughout the Central Delta mentioned the marketing of eel. The town of Purmerend north of Amsterdam had a special privilege to export eels to London. Dutch ships containing perforated compartments, that allowed the continuous replenishment of water, carrying live eel were a common feature on the London fish market until the early 20th century at their fixed anchorage near London Bridge. By then, however, the fishmongers' cry of 'Dutch eels' had lost its meaning, since the drainage of most lakes in the 17th century had forced Dutch traders to turn to Denmark for eels that swam during autumn in huge quantities through the Sont. Indeed, in the 17th century the centre of the eel-export business had shifted from Purmerend to other places along the Zuiderzee coasts of the NW Delta, where eels were stored before being assembled for London (Van Dam, 2003a). The last Dutch eel boat arrived in London in 1938 (Ypma, 1962).

The numbers of freshwater fish have fluctuated over time, and some species have become extinct. Until recently, the eel has escaped this fate since it migrates between the deep oceans, where it spawns, and the continental wetlands. Thus, for a long time man was unable to interfere with its reproduction. Since 1980s, however, the eel has become a threatened fish in the Delta waters. The eel population has dramatically declined (more than 90%) during the past decennia, not only in Dutch waters but along large stretches of the European coastline. Before World War II eel was a popular food for the average citizen, and nowadays the fish is luxury food, 20 times more expensive than 50 years ago. European eel is listed as 'susceptible' and 'vulnerable' (Table 15.1).

An analysis of the population dynamics of the eel, one of the few cases exhaustedly investigated, led Dekker (2004) to the conclusion that no unequivocal explanation can be given for the current decline. The European eel has its (assumed) spawning grounds in the Sargossa Sea near the Bermuda islands. The 90% decline suggests at least that the reproduction success is disrupted. Climate change might be coined as one of the causes, changing circulation patterns in the Atlantic Ocean. Another large-scale threat is industrial overfishing of elver ('glasaal') on the Spanish and French coasts, but this cannot be considered as a limiting factor for the migration of elver into Delta waters. The regional factors comprise the 'closed gates' (weirs, dams, Afsluitdijk, Delta works; Chapter 5 and 10) where elvers try to enter the Delta surface waters. In the past lock-keepers (e.g. from the river Vecht to the Zuiderzee) partially opened the sluices when elver stock was observed in front of the doors. Nowadays the sluice regimes, and the connected polder regimes, are fully artificial without any connection with migrating fish. The polders are in fact isolated 'bath tubs', with a closed circuit of water management. Lastly, water quality (mainly PCBs), although improved, might still be a problem for the maintenance of a viable eel population (Dekker, 2004).

### 8.3.3 Allis Shad (*Alosa alosa*) and Twaite Shad (*A. fallax*)

The allis shad and the twaite shad (Fig. 15.1) both belong to the riverine Clupeidae, and supported considerable commercial fisheries in the past. Historically, the catches of the allis shad were rather important, but the twaite shad has gained some significance concurrently with the disappearance of allis shad.

#### 8.3.3.1 Allis Shad

Before 1910 adult allis shad was commonly caught by the Delta Rhine fishermen from March to June. Actual spawning was from May to June, but this never took place in Delta waters, but rather in the higher reaches of the Rhine, near Koblenz, and in the Mosel, and in the Neckar (Chapter 12). Vertical diurnal activity, rhythmically synchronised with the rising and falling tides, permits the fish to remain in the estuary for over 1 year. In good years, the catch made up about 20% of the annual income for the local fishermen, and salmon comprised the remaining 80%. The decline in allis shad over the years is striking. Nationally as well as internationally, protective fishery measures were difficult to agree upon. According to De Groot (2002) the reasons were simple: restricting allis shad fishing from March to June would also have had repercussions on salmon fishing. Hence the main reason for the sharp decline in stocks was probably overfishing. Next to overfishing, destruction of spawning habitat can be considered as a main factor that has led to (near) extinction in the Rhine–Meuse Delta. River alterations (e.g. deepening, barrages) have negatively affected the spawning areas of allis shad. Pollution combined with physical difficulties for anadromous fish species to enter into the Rhine–Meuse estuary will certainly hamper future reintroduction efforts. In the past the lower reaches of the river Rhine acted as a nursery, but due to the construction of large flood defence works (Delta works), juvenile fish of both allis and twaite shad can no longer thrive throughout the year in the lower river reaches (De Groot, 2002).

On June 16, 2004 the catch of three allis shad in the Large River section of Rhine and Meuse was announced. Newspapers published this message on the front page, indicating the still existing interest in these former river inhabitants. Publications on the assumed ‘return’ of the allis shad are premature, however. The building of fish traps, the digging of secondary channels, the ‘Room for the river’ projects, and the partial reopening of the Haringvliet sluices (Chapter 10) offer indeed new changes for migratory fish, but great doubts exists whether the allis shad will ever return. The allis shad needs for spawning pebble banks near the main stream of the river, located stream upwards, and this habitat is simply non-existent in the Netherlands. The twaite shad, in contrast, can perhaps make it in the near future; this species is still present in considerable numbers off the coast, and spawns more stream downwards (www.biesbosch.nl).

#### 8.3.3.2 Twaite Shad

Spawning of twaite shad occurs under conditions comparable to those of the allis shad. However, the twaite shad stayed in the freshwater tidal zone, and spawning took place mainly in the Delta part of the Rhine River, whereas the allis shad moved further upstream. Because the twaite shad had a shorter distance to move upstream, the entry period and the length of the stay of the adult fish in the area were much shorter than that of the allis shad. April and May were the months of river entry and spawning, with actual spawning occurring over 3 weeks. Well-known spawning areas were in the Merwede (near Woudrichem) and in the Bergse Maas, but actual spawning sites were never identified. After spawning, the adult twaite shad left the river but the juveniles remained in the lower reaches together with young allis shad (De Groot, 2002).

As twaite shad were considered commercially inferior during the days when allis shad were numerous, no catch data were kept. Only when allis shad catches were declining the twaite shad did become of interest, leading to a fishery between 1933 and 1944. In 1950 catches increased to some extent, but since the late 1960s when Hollands Diep and Haringvliet were virtually cut off from the sea by the Delta works, catches dropped to zero in the lower Rhine River reaches. Twaite shad are currently found in very small numbers in several locations close to the coast of the Netherlands. Observations in lake IJsselmeer do not coincide with the spawning period, and justified the assumption that the fish enter lake IJsselmeer unintentionally or only for a short period of time (Hartgers et al., 1998).

The decline of the twaite shad in the Rhine was probably caused by several factors, not only overfishing. River regulation works destroyed several spawning habitats, and although twaite shad seems to be more tolerant to low oxygen concentrations and water pollution (Nijssen and De Groot, 1975), pollution and silting-up may also have played a role in the stock depletion. Closing off of the river, thereby changing the freshwater tidal system in the estuary into a river with a one-way flow, has likely been the fatal blow for the population. However, the introduction of a new sluicing regime in the Haringvliet is being reconsidered, to allow partial recovery of the former tidal movement, and this may lead to a restricted partial build-up of the twaite shad population in the SW Delta (De Groot, 2002).

### *8.3.4 Smelt (Osmerus eperlanus)*

Smelt in the Delta waters are present in both migratory (anadromous) and landlocked (non-migratory) forms. The migratory form is known from the estuaries, the Wadden Sea and the lower reaches of the Large Rivers. Migratory smelt have essentially vanished from the coastal waters of the Delta, owing to the construction of the large Delta works project, particularly the Haringvlietdam. An additional cause of the decline is the deposition of enormous amounts of river borne silt, following the closure of the Haringvliet estuary (Chapter 10). Silt-covered and heavily polluted river bottoms are unsuitable for egg survival (De Groot, 2002). Redeke (1914) indicated that migratory smelt spawned in the lower reaches of the Rhine and in the freshwater tidal areas of Hollands Diep, between Moerdijk and Willemstad. In the upper Rhine reaches of the Delta, near Arnhem and Nijmegen, the migratory smelt has always been rare in the past (Van den Ende, 1847).

The non-migratory smelt spawns as well in lakes as in rivers from February to April; the eggs adhere to stones, gravel or water plants, but never to silt bottoms. The non-migratory form is found in large quantities in the lake IJsselmeer; the annual landings vary between several hundreds of thousands and several million kilograms. The fish is also caught in the lakes in the NW Delta and the Central Delta.

### *8.3.5 Coregonids*

According to De Groot (2002), depending upon the taxonomic system selected, either two or three anadromous coregonid species inhabit, or have inhabited the Rhine: *Coregonus lavaretus* (whitefish or schelly), *C. oxyrhynchus* (houting) and *C. albula* (vendace). Vendace have been caught only a few times in the Rhine (the last time in 1927), but it is most likely that the fish were simply incorrectly identified when caught. At the turn of the 20th century, whitefish were caught in all large rivers such as the Rhine, IJssel and Meuse, and houting was very common in the Wadden Sea (Redeke, 1934).

Coregonid fishing occurred from August to November. Until 1910 houting migrated in considerable numbers upriver to spawn, and until 1927 the fish was observed in the river IJssel and Meuse (Nijssen and De Groot, 1975). Prior to 1910, catch data are difficult to trace because fish were sold directly by the fishermen at local markets. Although the fishery was never large, there is an obvious decline between 1916 and 1920. In 1917 the catch was still around 5,000 kg: the decline was therefore far quicker than that observed for salmon (De Groot, 1992). The dramatic downward trend and near-extinction of the species was reason for great concern by government authorities. Artificial rearing was tried, for the first time in 1907, and a restocking programme was initiated, and continued between 1907 and 1939, however, there were no increases in abundance. It is assumed that the present increase of houting in the Rhine, as well as in the Dutch lake IJsselmeer, must originate from Danish–German restocking attempts (De Groot and Nijssen, 1997).

Coregonid populations have not recovered in Delta inland waters, because migratory forms of coregonids are unable to enter the inland waters owing to the disappearance of suitable tidal inlets. The return of houting for spawning in the Large Rivers could be a possibility, coupled to the reopening of enclosure dams in the SW Delta and the IJsselmeer. In 2007 ‘the return of a viable population of houting’ in the Rhine–Meuse Delta was heralded (www.wageningenimares.wur.nl) but the taxonomic status of this *Coregonus* population is questioned (Freyhof and Schöter, 2005).

### *8.3.6 Sea Trout (Salmo trutta trutta)*

The sea trout became rare in Delta freshwater streams in the 1960s. In the past the fish migrated in large numbers stream upward for spawning. The brown trout, *Salmo trutta fario*, a non-migrating subspecies of the trout, has disappeared from the Delta since approximately 1945, caused particularly by water pollution. Brown trout are regularly planted in the river Geul, a tributary of the Meuse and in smaller brooks, and this blurs the picture of the natural occurrence of the subspecies (Nijssen and De Groot, 1975)

The life cycle of the sea trout resembles that of other anadromous fish such as the salmon. However, an important difference is that both sexually mature and immature trout ascend the river together in autumn on their return from the sea. Trout can reproduce several times over their lifespan, with the eggs being laid in gravel beds in the upper reaches of the river. Sea trout hybridise with brown trout and are rarely found in rivers with currents in excess of 60 cm $s^{-1}$. In contrast to salmon, sea trout generally remain closer to the coast; most of the trout leaving Delta waters head northwards and stay within 100–350 km of the coast. Compared with salmon catches, the numbers of sea trout caught in the river Rhine were relatively small (De Groot, 2002).

Annual trout catches over the period 1886–1986 varied considerably, but no evidence can be found to suggest that there has been a systematic decline in numbers. Reports from professional fishermen are too infrequent to allow firm conclusions to be drawn about trout stocks, but they do provide an indication of the continuing presence of trout in the river. The action that has most affected the sea trout and other migratory fish in the Rhine is the closure of the estuaries in the SW Delta. The presence of sea trout in the IJsselmeer could be due to trout entering via the rivers Rhine and IJssel. However, it is also plausible that sea trout enter via the sluices in the Afsluitdijk. The fact that trout are mainly caught in the lake and not in the rivers is not sufficient justification for assuming that trout are only present in large numbers in lake IJsselmeer, and that this lake serves as a catchment area for trout. These fish could equally well originate from brown trout populations and have been forced to leave their environment because of insufficient food supplies or inadequate conditions. Similarly, the presence of sea trout in the lower reaches of the rivers Meuse, Lek, Merwede or in the Rhine–Meuse–Scheldt estuary in the SW Delta cannot be viewed as conclusive evidence that these fish are intending to ascend the river. In contrast to the behaviour of the salmon, young sea trout often undertake what are known as ‘dummy runs’. Sexually immature trout that inhabit coastal waters often accompany their sexually mature counterparts a short distance up the river before returning to the sea. Although it is generally agreed that trout enter Dutch rivers from the sea, the volume of this phenomenon is difficult to establish (De Groot, 2002).

## *8.3.7 Salmon (Salmo salar)*

### 8.3.7.1 History and Fall of a Famous Fishery

Prehistoric human occupation of the Delta is connected with salmon catches. In archaeological findings from human settlements around 6,000 years BP remnants of salmon could be identified (Louwe Kooijmans, 1985).The first written evidence to suggest that salmon were being caught in reasonable numbers dates back to 1100. However, proper statistics describing the number of salmon caught in the Rhine–Meuse Delta at that time are not available. Similarly, few details are to be found about domestic consumption or export. Due to the lack of data, it is impossible to give precise estimates of the number of salmon caught in the Dutch, German, French and Swiss sections of the Rhine basin on an annual basis. The most detailed historical records (1863–1957) that were kept concern the salmon caught in the Dutch part of the Rhine (Fig. 8.6).

According to Verhagen (1998) we can hardly imagine the importance of river fisheries in the late Middle Ages and the centuries thereafter, until the early 20th century. The rivers contained far more fish than nowadays. Of the ‘big three’ the sturgeon, the salmon and the allis shad, the salmon came on the first place. The sturgeon has always been rare, and an incidental catch made the day of the fisherman, but could not be considered as a regular income. The catches of allis shad were rather uncertain too. Generally, between March and the end of May tremendous numbers of allis shed swam upriver, but one could never be certain about the intensity of the migration: there were bad and good years. The salmon (Fig. 8.5), however, was all year through a regular customer in the rivers. The fish was most numerous in spring and early summer, and during a short winter period it was absent. Salmon was known as ‘winter salmon’, large and small ‘summer salmon’ and ‘Jacob salmon’ (small, young salmon caught midsummer). The salmon was so important that river fishery became almost identical with salmon fishery.

At several places salmon was accepted as legal tender. Since 1104 the fishermen from Heerewaarden could pay their toll at Koblenz (Middle Rhine in Germany) with a well-sized salmon (Lobregt and Van Os, 1977). Restaurants, pubs, market places, guildhalls, etc., proudly carried (and still carry) the name of the salmon. Many town and municipal arms, carrying one or two, or sometimes three salmon, remain the imposing witnesses of the importance of the salmon fishery (e.g. Almkerk, Andel, Brakel, Capelle aan de IJssel, Giessen, Werkendam, Woudrichem). As Verhagen (1998) noticed, only a few humans have been honoured as the salmon has been. The salmon was an esteemed fish, and there were, of course, many anecdotes in circulation. Van Doorn (1971) mentioned that until the early 18th century the supply of

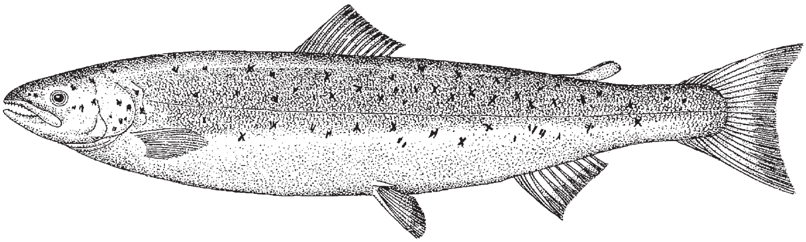

**Fig. 8.5** Salmon (*Salmo salar*), *ca.* 100 cm (Nijssen and De Groot, 1980)

salmon was so numerous that inhabitants of Lekkerkerk called it ‘cat feed’. In Dordrecht salmon was so abundant the maidservants only accepted a job under the condition that they were not obliged to eat salmon more than twice a week. Lenders et al. (2007) made some amendments to this ‘maidservants anecdote’ in the light of the assumed declining stocks of salmon in the 17th century. The anecdote may have been meant to let foreigners know that people in the Central Delta were so rich that even household personnel was served salmon in large quantities. Seen in this context, the anecdote should have ascribed exactly the opposite meaning as later was imputed to it: salmon was not cheap and abundant, but costly and rare.

The annotated legendary salmon catches date back to approximately 1650–1750. In those days fish was plentifully available, but it had one disadvantage, viz. it was very perishable. Around 1100 the salting of fish, particularly herring, must have been a known procedure. Later, in the 15th to the 18th century stocks of salted and dried salmon were recorded, sold to foreign markets, but freshwater fish was preferably brought to the market in fresh state and sold on the same day. In the years when the rivers teemed with salmon, the catches did not yield much money for the fishermen in the Central Delta and Large Rivers area because of the dictatorial attitude of the leaseholder. The more fishermen he could get, the better he liked it, as it meant bigger catches, but for the salmon-fisher it resulted in smaller wages. Between 1750 and 1850 salmon stocks drastically declined. It is suggested that one of the causes for this phenomenon was overfishing, but the death-blow was given by river pollution ands river regulation, of which the signs became immanent at the second half of the 19th century. The salmon treaty in 1886 between the Netherlands and Germany did not result in the improvement of the salmon stock which the governments of the two countries had expected. After 1886 the catches gradually declined (Fig. 8.6). The salmon-fishers on the upper reaches of the Delta rivers were even worse off on account of the intensive catching of salmon on the lower reaches. The decline in salmon fishing was probably one of the main causes that gave rise to poaching (Verhagen, 1998).

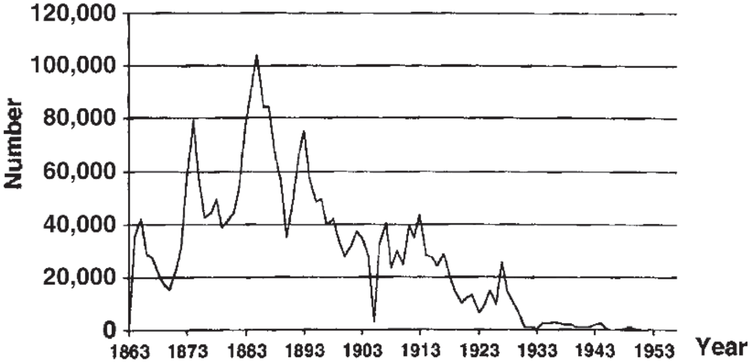

**Fig. 8.6** Dutch salmon catches 1863–1957, based on RIVO-data (De Groot, 2002)

The end of the 1920s witnessed a major decline in salmon catches in the Rhine (Fig. 8.6). In subsequent years, the numbers of salmon landed in the Delta was stabilised at about 1,000–2,000 fish per year, up to 1944. However, these figures would probably have been higher, had organised salmon fishing not ceased in Dutch waters in 1933. To rehabilitate the Rhine salmon population, experiments began as early as 1861 releasing salmon fry which had been reared under controlled conditions. These activities assumed greater importance after the ratification of the Salmon Convention in 1886. Enormous numbers of fry and parr were released into the Rhine at the end of the 19th and the beginning of the 20th centuries. Throughout the period that serious restocking operations were carried out, most observers were convinced of the positive effect of this policy. It was felt that without such action the decline in salmon numbers would have been even more rapid. However, in 1947, a report on the effect of restocking operations on salmon catches concluded that no clear statistical evidence could be found to support such a link from the available data (De Groot, 1992).

A number of factors is held responsible for the disappearance of the once important salmon fishery from the coastal area of the Delta and the Large Rivers (De Groot, 2002): (1) canalisation, flood control and loss of habitats; (2) sand and gravel extraction; (3) waste water discharges; and (4) the impact of the fishing industry (see also Chapters 4, 5 and 14).

1. Canalisation, flood control and loss of habitats. It is not only the presence of locks and weirs along the Rhine that are preventing the return of salmon. The condition of the many streams and rivulets that traditionally formed the spawning grounds for these fish has also changed by human intervention. Moreover, simply restoring a few tributaries of the Rhine – which is suggested by certain parties as a potential solution – would not guarantee the return of the salmon on a permanent basis, as a variety of habitats would be required. Since the construction of the Afsluitdijk in 1932, which closed off the Zuiderzee, salmon have been hampered from using their once traditional route to re-enter the Rhine via the river IJssel. Sluices are not forming an absolute barrier, and a few salmon succeeded in entering the freshwater bodies via the sluices in the Afsluitdijk and those of the North Sea Canal (IJmuiden) (Larsson, 1984). At present, the Nieuwe Waterweg offers the only open link between the Delta and the North Sea, but the intensity of shipping along this route could severely discourage salmon migration.
2. Sand and gravel extraction. Sand and gravel banks in the main channel of the river Rhine were important to salmon, probably not as spawning sites but as resting sites during their journey to their spawning biotopes. It is questioned, however, whether sand and gravel extraction activities in the Rhine–Meuse Delta have had a serious impact on salmon stocks. Sand and gravel extraction operations in the smaller German rivers and streams will have had a much more dramatic effect on the salmon population, since these areas were historically used as spawning grounds. The increase in silt levels in the river and subsequent sedimentation on the spawning grounds made these spots unsuitable for reproduction purposes.

3. Waste water discharges. As early as the end of the 19th century, discharges of polluted waste water were identified as one of the possible reasons for the decline in the salmon population in the Rhine (Hoek, 1916a, b). Already after 1887 ‘carbolic acid salmon’ were caught, fish with a ‘hospital flavour’ of phenols and carbolic acid, disinfectants, resources for synthetic resins (bakelite), paint, etc. (Lobregt and Van Os, 1977). Some 10 years later, the domestic and industrial waste waters were considered to pose a far greater threat to the fish population than had been thought possible years before. The number of fish kills had increased dramatically in 1927, but it was often difficult or even impossible to give detailed causes for such events. An exception is the effect of acidity on smolt development. It has been shown that acid (and acid plus aluminium) exposures that have little effect on survival and growth of parr or smolts in freshwater, completely destroy the function of the salmon-gill in saltwater (Staurnes et al., 1996). The smolt inhabits the main stream of rivers and estuaries, which are more heavily impacted by pollutants then high-elevation tributaries where fry and parr live. Pollutants may also, intervene with the development of olfactory imprinting (Bardach et al., 1965; Holl et al., 1970).
4. The impact of the fishing industry on salmon stocks. With the advantage of hindsight it can clearly be said that the fishing industry has had a negative effect on salmon stocks in the Rhine. However, in the final analysis, economic forces dictate that the fishing industry often cannot fish a particular species to extinction. The loss of income as the size of the catch declines can bring such activities to a natural end, as was the case with the Rhine. The Dutch salmon fishing industry effectively ceased to exist after 1933 and that of the Germans after 1950 (De Groot, 2002).

#### 8.3.7.2 Feasibility of Restocking Operations for Salmon

At present, salmon catches in the entire North Atlantic are declining, and many fisheries, both commercial and recreational, have already been closed. Fishing seasons are shortened, and more and more anglers are returning their caught fish to the river. The situation is quite serious. Even though a number of excellent salmon rivers are still to be found in countries around or near the North Sea, salmon catches in these rivers are on the decline as well. Salmon cultures, however, e.g. in Norway and Scotland, are flourishing. If attempts to halt the natural decline will be successful, the purity of the original species will have been affected by interbreeding with non-indigenous or cultivated salmon. It is therefore obvious that restocking the tributaries of the Rhine will be a slow and arduous process (De Groot, 2002).

Migration behaviour of stocked fish may also be impaired. It is not clear whether certain smells that are characteristic of the spawning grounds are still discernible to salmon that have passed through rivers rich in detergents (Holl, 1965; Holl et al., 1970). Presumably, stress by detergents does not play a role anymore in the Rhine basin. A further complication is that none of the rivers in the vicinity of the Rhine can serve as alternative entry points for salmon returning from sea.

Rivers such as the Ems, Weser and Elbe, which once had relatively small salmon populations, now cannot be regarded as true salmon rivers. The latter also applies to the Meuse and river Scheldt. Consequently, factors such as straying and infiltration, which play an important role in populating remote rivers, are likely to be of little significance in the Rhine basin.

It should be possible, however, for river systems along the main stream of the Rhine to be re-colonised by salmon, and hence to increase the size of the spawning grounds. It is therefore essential that a wealth of spawning streams be made available for salmon in the Rhine. However, creating the right conditions is no guarantee of success. Salmon interbreed with trout (Refstie and Gjedrem, 1975), and this may considerably endanger restocking programmes. According to the Groot (2002), a natural hesitation exists to kill the trout in a river system before implementing restocking with salmon. However this would be the best solution, as trout also prey on salmon. Only when a salmon stock has established itself, trout should be allowed to return.

The success of establishing spawning stocks in German tributaries of the river Rhine-system by simply releasing fry obtained from all over Europe (Norway, Scotland) is limited. This can be concluded from the work of Youngson and McLaren (1998), who demonstrated that restocking a river with naturally spawned salmonid ova resulted in a far better survival ratio than using fry from hatchery-reared salmonids. If the Rhine is to be rehabilitated as a salmon river, it is essential that the water quality of the river should meet the requirements for salmon rivers as laid down in the relevant EC Directives. Finally, it can be concluded that establishing a natural population of salmon in the Rhine without outside help will certainly not be realised within the foreseeable future (10–20 years). After all, the Rhine is still a considerably polluted river, and it suffers from the added disadvantages that it contains a large number of locks and weirs that restrict fish access to traditional habitats (De Groot, 2002).

The Rhine border states have an agreement about the passage of migratory fish; in the near future these fishes may not be hindered anymore by obstacles like sluices and weirs. In the past 10 years several salmon and trout adults have been observed in front of the weir at Hagestein. At the end of 2004 the fish passages at the weirs of Hagestein and Amerongen in the Nederrijn–Lek were opened. At the weir at Driel a fish passage was already installed in 2001 (www.rijkswaterstaat.nl). Experiments are done in the river Maas to improve the migratory route of salmon. A small transmitter is implanted in the belly of adult salmon and trout. Detection lines were installed at several places on the bottom of the river, electronically signalling the passage of a transmitting fish. At Cuijk, between the weir complexes of Grave and Sambeek in the river Maas regular plantings of salmon and trout took place, in order to study the 'natural' migratory behaviour of these fish. The idea is to test whether the fish passage that has been built in the weir of Sambeek some years ago functions properly. The majority of the fish passed the upstream weir within 24 h, indicating that the running experiments are successful. In the near future, fish passages will be built at Grave and Borgharen in the river Maas (Organisatie Verbetering Binnenvisserij; Brabants Dagblad 10–02–05).

## 8.4 Fishermen and Fishing Gear

Van Doorn (1971) aimed at giving a more or less complete inventory of the terminology of the river-fishermen in the Netherlands between roughly 1900 and 1960. He catalogued more than 2,500 (two thousand five hundred!) terms in Dutch and in dialects, on river fish and fisheries alone, most of them untranslatable in English. This wealth of detailed terms indicates the importance of the trade. The fishermen's main freshwater catches were migratory fish by means of the 'zegen' (seine or drag-net without a bag), and eel by means of an 'ankerkuil', which is a bag-shaped net fastened to a frame or to two masts (Fig. 8.7). A not unimportant trade on a small scale which was, or is still exercised on all rivers uses 'korven' (baskets), 'fuiken' (fish-traps or fykes), 'repen' (long lines) and 'dobbers' (hand lines). Eel was caught in eel-baskets, plaited from willow twigs, used by the river fishers long after the fish-trap plaited from twined threads were in use. Often the fish-traps were baited with fish refuse or earthworms. Fishing with fish-traps is a very old custom, known from archaeological findings of more than 6,000 years ago (Chapter 2). In the Middle Ages combinations of fish-traps were used, connected to wattle-work or fish weirs, in order to maximise the catches. The remaining catches, e.g. of smelt, carp and flounder, were of some importance in specific waters only. This also goes for fishing by means of the 'kornet' (trawl-net), the 'schrobnet (double stick net) and the 'bezaan', a seine with small boards attached to a line which serve to drive the fish into the net.

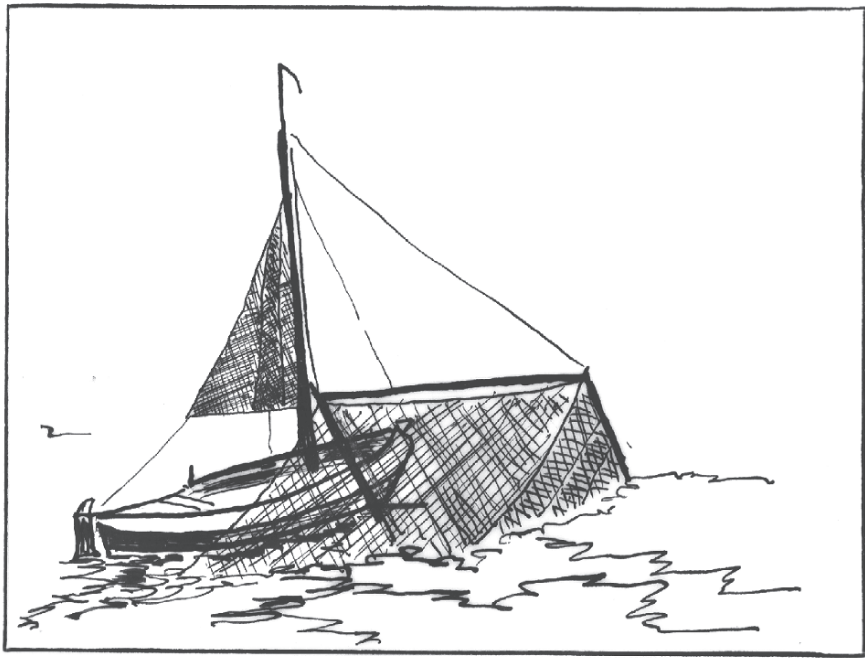

**Fig. 8.7** 'Ankerkuil' (bag-shaped net fastened to a frame) partly lifted from the water, attached to a 'schokker' (fishing-boat) on a joint anchor (Drawn after Verhagen, 1998)

The fishing-tackles used on the Delta rivers for migratory fish, sturgeon excepted, were the ‘zegen’, the ‘drijfnet’ (drift net), the ‘steek’ (hoop-net) and the ‘zalmkruisnet’, the salmon bait-net. The ‘zegen’ (seine) was a frequently used type of net to catch salmon. The fishermen in the Rhine–Meuse Delta had already learnt in Roman times how to use a small seine net, which can be easily handled in the river currents. Effective fishery was possible when reasonably priced yarn, suited for knitting strong nets, became available in the 13th century. The small ‘handzegen’, a seine operated by hand, could be handled by a few fishermen (Fig. 8.8). Handling large seines, that were set over almost the full width of the river, was skilled labour, practiced by the State Fisheries enterprise, and by private fishermen. The heavy work was hauling in the net, dragging the net filled with fish on land with manpower, or using hand-driven or horse-driven windlasses mounted to an anchored raft or fixed to the bank of the river. The big salmon fisheries can be considered as large-scale enterprises where intensive differentiation and organisation of labour was practiced. In 1907 the State Commission for the Salmon Problem registered more than 1,600 persons working in the salmon fishery, mainly in the hand-seine fishery (Van Doorn, 1971).

A drift net was a long net that hung from the surface approximately 2 m deep into the water. Salmon fishery with the drift nets was mainly night-work; and this had two advantages. It did not hinder navigation on the river, and because salmons have a sharp sight, at night the fish could not avoid the net. The seine was far more efficient than the drift net that could in fact only be operated during night. The seine was also a hindrance for river navigation, and the fishermen used special ‘zinkboten’, small vessels, always painted white to make them as conspicuous as possible, that

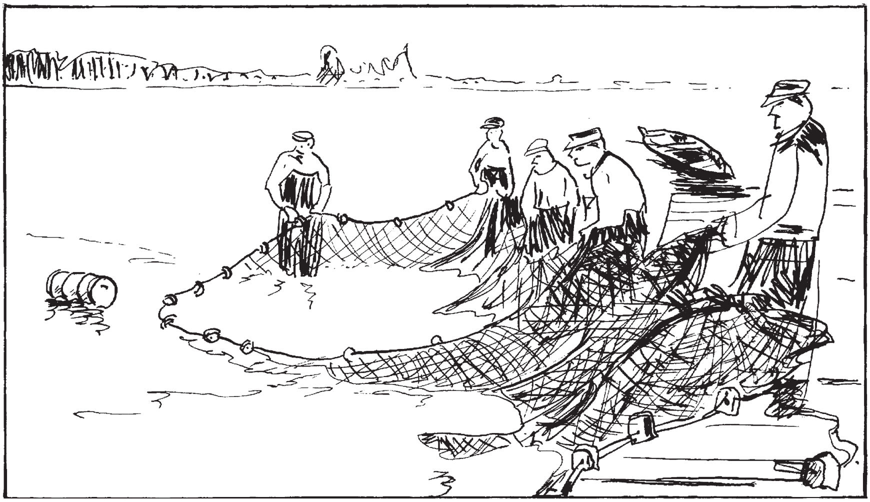

**Fig. 8.8** Netting in the ‘handzegen’ (seine operated by hand), an important dragnet to catch salmon (Drawn after Lobrecht and Van Os, 1977)

temporarily attached sinkers to the net, lead or stone weights to keep it under water, in order to let the ships pass (Lobregt and Van Os, 1977).

During their migration to the spawning grounds salmons are able to jump several metres high out of the water, to overcome waterfalls and rapids. One of the oldest and lucrative fishing techniques in the late Middle Ages is based on this ability, the 'steek' fishery. The 'steek' is an osier revetment, a fence of sometimes more than 100 m long, perpendicular to the main stream of the river, and strengthened with poles The fence stretches from the bottom of the river to above the water level. The stream upwards swimming salmon touches the screen, jumps up, or swims around, and lands in one of the fish-trap, connected on both sides to the 'steek' (Fig. 8.9).

The turn of the 20th century witnessed the rather sudden emergence of the stow net on an anchor, a development out of the swing net on an anchor, which is apparent from the various names of this fishing-tackle, such as 'kleine kuil' or 'ankerkuil'. The regulation of the rivers caused the speed of the current to increase, and moreover navigation on the river with large vessels increased. It became too risky, concerning the ever-increasing river navigation, to use seines that were set over almost the full width of the river. And besides that, the salmon fishery was not lucrative anymore. Consequently, the fishermen were forced to adapt their fishing-tackle to the changed circumstances. Thus the 'ankerkuil' or 'schokkerkuil' for catching eel replaced the swing net on an anchor. The stow net on an anchor with two stakes ('ankerkuil met

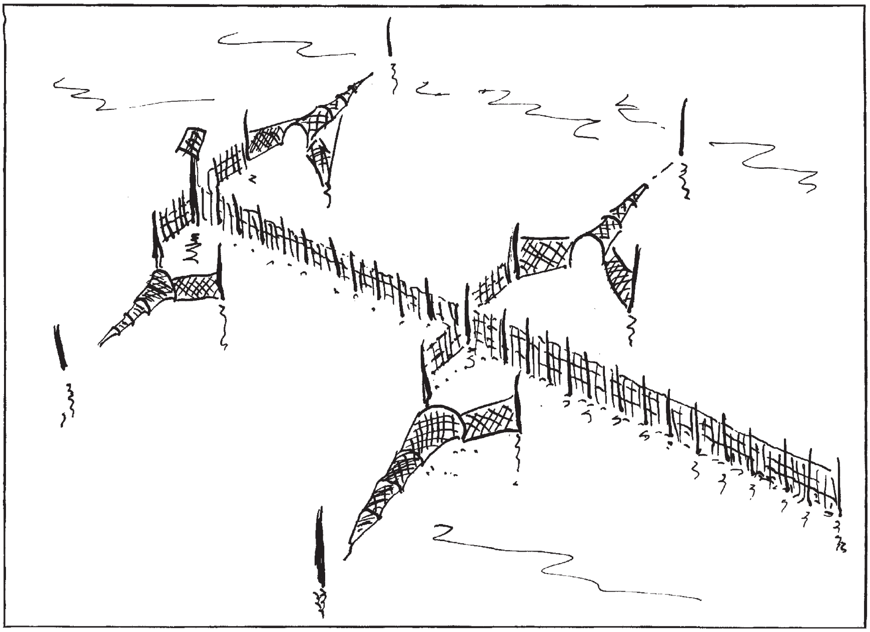

**Fig. 8.9** 'Steeknet' (hoop-net) wattle-work, a fence made of osiers connected to ebb and flood fish-traps (bow-nets), mainly for catching salmon (Drawn after Verhagen, 1998)

twee houten'), developed out of the stow net with an iron frame. The fishermen from Heerewaarden adopted this way of fishing in imitation of the fishermen from Moerdijk. From Heerewaarden the use of the stow net on an anchor spread upstream, because the fishermen were familiar with the swing net on an anchor. Through Dutch fishermen the use of the stow net on an anchor, which was a typically Dutch way of fishing, spread to Germany and France (Van Doorn, 1971).

## 8.5 Inland Fisheries in the 20th Century

### *8.5.1 Changes from Saltwater to Freshwater*

At the end of the 19th century the Netherlands were one of the first countries with a keen eye on the emerging problems around the management of marine fish stocks. This awareness meant the start of the official fisheries research in 1888, and, in fact, also the birth of fisheries biology as a separate branch of biology (De Groot, 1988). The interest of sea fisheries has always been far more important than the interests of the inland fisheries.

The closure of the Zuiderzee on May 28, 1932, meant a complete stop of the tidal rhythm in this part of the North Sea. Gradually 3,000 km of saline water changed within a few years into the freshwater lake IJsselmeer (Table 8.1). Following the closure, anchovy and herring disappeared completely, and the flounder fishery gradually declined. The fishery on eel increased considerably, but nowadays the catch of eel is far more lower than the pre-1932 level (405 t in 2002; www.visplanner.nl). The smelt fishery decreased dramatically, but it restored, and is nowadays approaching the level before 1932 (catch of 850 t in 2002; www.visplanner.nl). The gradual change into a freshwater basin is reflected in the catches of typical freshwater fish, of which the pikeperch is the most important one (De Groot, 1988).

**Table 8.1** Official catches of fish before and after the closure of the Zuiderzee on May 28, 1932 (approximate amounts in kilogram × 1,000), averaged and rounded off over the periods mentioned, derived from De Groot (1988), based on data of B. Havinga, who described the biological changes from Zuiderzee to IJsselmeer ('De biologie van de Zuiderzee tijdens haar drooglegging')

| | 1922–1926 | 1927–1931 | 1932–1936 | 1937–1941 |
|---|---|---|---|---|
| Anchovy | 1,040 | 1,970 | – | – |
| Herring | 7,780 | 11,140 | – | – |
| Flounder | 1,120 | 1,850 | 790 | 40 |
| Eel | 675 | 780 | 2,040 | 3,210 |
| Smelt | 1,110 | 1,070 | 370 | 90 |
| Zander | – | – | <10 | 960 |
| Perch | – | – | 10 | 100 |
| Bream | – | – | <10 | 150 |
| Roach | – | <10 | 10 | 130 |
| Carp | – | – | <10 | <10 |

With regard to fish communities, the enclosure of estuaries in the SW Delta and the consequent changes into river-fed freshwater lakes, triggered comparable colonisation strategies. More than 40 years after the closure of the Zuiderzee, comparable changes took place in the Haringvliet–Hollands Diep, an estuary closed off in 1970 (Wiegerinck, 1988), and 16 years later in the Volkerak–Zoommeer, a lake closed off from the Oosterschelde estuary in autumn 1986 (Oesterdam) and spring 1987 (Philipsdam) (see Chapter 10). The tidal estuary changed into a stagnant freshwater lake, filled with water from Rhine and Meuse. The lake was quickly colonised by freshwater fish, constituting a community in which initially predatory fish, like perch and pikeperch dominated, and the share of whitefish was limited. After a few years roach, carp and particularly bream started to dominate (Ligtvoet, 1993).The biomass of the bream population in lake Volkerakmeer increased from about 1 kg $ha^{-1}$ in 1988 to 140 kg $ha^{-1}$ in 1998. As bream became the dominant species in the lake, the water transparency decreased from a maximum of 3 m in 1990 to approximately 1 m in 1998. Concomitantly, the chlorophyll-a concentration increased from a minimum of 5 μg $l^{-1}$ to a maximum of 45 μg $l^{-1}$. Aquatic vegetation stands initially increased to a maximum of 20% cover of the total lake area in 1992, but subsequently decreased to 10% when water transparency was reduced (Lammens et al., 2002).

### *8.5.2 Future Perspectives of the Professional Inland Fisheries*

In 2002 the inland fisheries counted 240 trades, of which 70 fished on the IJsselmeer and 170 on other inland waters. In total 475 persons worked in these trades, which means that the average business is a one-man or two-men trade. In 2002 the professional inland fishermen caught roughly 1,000 t of eel, of which 405 t came from the IJsselmeer. Of the total revenues from the inland fisheries 70% came from the eel fisheries. The main other catch was smelt. Hardly any data are known from the small inland fishermen, because their catches are not offered on the official fish auctions. Often their catch goes directly to fish-processing industries, fishmongers and restaurants. The decreasing market position of the eel forces many small fishermen to stop their trade. The professional inland fishery has hardly any future in the Netherlands (www.visplanner.nl). The economic importance of sport fisheries, angling, is several tens of times as important as the professional inland fisheries. The number of anglers has exploded since World War II. In 1970 there were 600,000 anglers in the Netherlands, and in 2002 this number had already grown to 1.7 million. Internet sites (o.a. www.totalfishing.nl) provide professional information on the best beats, fishing gear, etc.

The total revenues of the Dutch high sea and coastal fishing industry as a whole is roughly 40 times higher than the revenues of the inland fisheries, based on the volume of landings to Dutch fish auctions The statistics of 2003 indicate that the North Sea cutter fleet accounted for almost 53% of the total revenues. The large-scale high-sea fishing fleet achieved an increasing total gross revenue of 30%. The Dutch cockle, mussel and oyster cultures, although specific, are of minor economic importance. More than 50% of the catches of the cutter fleet are flatfish (sole, plaice and other species); herring, mackerel, scad, cod and whiting comprise roughly 20%; the remainder is shrimps and other species. The high-sea fishing fleet preferably sails to remote fishing grounds, e.g. the African coast (Taal et al., 2004).

## 8.6 Introduced Fish and Stocked Surface Waters

The rearing of fish is a rather old trade in the Delta. The successful introduction of the carp in the Middle Ages, is the best known example. The carp is originally indigenous in Central Asia, and spread into the Danube basin in Eastern Europe. Already the Romans cultivated the carp, and had it on their menu. In the Middle Ages the consumption of carp spread over Western Europe, because the fish was cultivated to serve as adequate food during the fasting days. The fish species is now considered as indigenous in the Delta. Several carp races have been introduced in the course of time, and these races interbreed successfully. The carp is a common fish in many freshwater bodies, mainly owing to the frequent and massive stocking of waters in favour of the anglers. Like other Cyprinidae, the carp may stir up the bottom sediments while searching for food, enhancing the turbidity of the water.

At the end of the 19th and in the early 20th century the introduction of non-indigenous fish species in the Netherlands has been accelerated. At least 25 species were introduced since then, and stocked in specially designed fish ponds, or planted in Dutch surface waters. The introduction of non-native fish species has had serious drawbacks for the native fauna, far more intensive as was initially foreseen. The most conspicuous group consisted of Salmonidae, in order to compensate for the decline of the commercially important salmon (*Salmo salar*) in the Rhine catchments. Over the decades many attempts have been undertaken, but none of these introductions was successful. Therefore attempts were made to plant American salmonid species, having a comparable life cycle, like the Chinook (*Oncorhynchus tschawytscha*), the American houting (*C. clupeaformis*), and the rainbow trout (*Salmo gairdneri*). None of these displacements was successful, i.e. that none of the species was able to reproduce successfully, and hence could not maintain a viable population. The main reason for these principal failures was that fish managers realised too late that the environment had changed almost irreversibly (habitat loss; water pollution; see Chapter 14), and had become unsuitable for Salmonidae (Nijssen and De Groot, 1987).

Of all attempts to introduce a salmon-like fish, only the rainbow trout became a commercial success. The fish is not able to reproduce in Dutch waters, and annually the surface waters are stocked with roughly 30,000 t of small rainbow trout, in favour of restaurant keepers and anglers. Consequently, rainbow trout is rather common now in river deltas, and brackish water lakes. Its competitive behaviour as a predator, however, has changed the food-web dynamics in several water bodies.

A successful introduction was the pikeperch. This species cannot really be called a non-indigenous species, because it is known from fossil records before the last ice age. At the end of the 19th century pikeperch has been introduced from the Danube basin into the Rhine. From 1901 onwards several lakes and river systems were stocked with numerous young pikeperch individuals, and these plantings continue to this day. Pikeperch is now one of the most important commercial fish species in Dutch waters (IJsselmeer).

There are two other introduced carp-like species that should be mentioned here, the grass carp (*Ctenopharyngodon idella*) and the silver carp (*Hypophthalmichthys molitrix*) (Van der Zweerde, 1990). The grass carp is indigenous in China, and it has been introduced in 1966 from Eastern Europe. The fish spawns at water temperatures of 27–29°C, which is seldom or for too short a period reached in Dutch surface waters. The herbivorous grass carp has been introduced to remove water plants and algae from eutrophicated water bodies, as an alternative for the (expensive) mechanical removal of weeds. In the Netherlands various studies have been carried out on the ecological side effects of grass carp. There are few or no negative effects, provided that 10–25% of the surface area of a water body remains covered with plants. In many instances, it appeared that conditions for a large number of organisms improved after the introduction of grass carp. In the western part of the Delta, for example, many watercourses are covered during the summer period by a blanket of filamentous algae or a thick layer of duckweeds (Lemnaceae) and/or water ferns (*Azolla* spp.). As these small floating plants do not markedly obstruct the water flow and mechanical removal of these plants is rather difficult, they are generally not controlled. Grass carp, however, preferentially consume these water plants and after stocking with grass carp, these plants usually disappear, which improves the oxygen regime in the water. According to Van der Zweerde (1990) grass carp can be used with no greater risk to the aquatic environment than any other weed control measure and, in many cases, the fish are much to be preferred to alternative measures because of their general lack of ecosystem side effects, provided that the fish population is managed in the right way.

The silver carp has roughly the same distribution area as the grass carp; the fish is a plankton consumer, introduced in 1966. The idea behind this introduction was that the faeces of the weed-consuming grass carp would cause massive plankton blooms that could then be consumed by the silver carp. This theory did not work out in practice, and the experiments have been ended. Another three exotics from North America have been introduced in Dutch waters, the brown bullhead, the pumpkinseed and the mud-minnow. The brown bullhead, *Ictalurus nebulosus*, lives in slowly flowing and stagnant, eutrophicated waters. The pumpkinseed, *Lepomis gibbosus*, occurs mainly in small brooks with a rich vegetation of water plants, presumably introduced via fish-culture, or via dumped aquarium fishes. The mud-minnow, *Umbra pygmaea*, occurs preferably in rather polluted water with a low pH (around 4).Commercially, these species are of no importance (Nijssen and De Groot, 1987).

## 8.7 Conclusions

- The destruction of habitats for freshwater fish in the Central Delta started in the Middle Ages with the reclamation of the large peat bogs, and connected canalisation and dam building.
- From the late Middle Ages till far into the 19th century thousands of fishermen along the Large Rivers practised their trade. The rivers contained far more fish than nowadays. Of the ‘big three’ the sturgeon, the salmon and the allis shad, the salmon came on the first place.
- The importance of river fisheries in the past can convincingly be illustrated by an inventory of thousands of (hardly translatable) terms in Dutch and in Dutch dialects, regarding aspects of river fish and fisheries, of ships and types of fishing gear, not in use anymore.
- At the end of the 19th century the freshwater fisheries on the Large Rivers were declining rapidly. The decline in catches of salmon and allis shad became the reason for great concern, but so did the declining catches of far less important species such as sea trout, and the coregonids (houting and whitefish), sturgeon, twaite shad and smelt.
- The reasons for the decline of these species are to be found in the river regulation works, the construction of numerous barrages and sluice systems to improve shipping on the rivers, the dredging of the gravel spawning beds, increasing turbidity and the impact of chemical pollutants, and changes in oxygen content and temperature.
- In the early 20th century it was thought that mass releases of fertilised eggs or juvenile stages of fish would counteract the negative effects of river regulation. This was unsuccessful in all cases for the salmonids. Restocking the waters with eggs of the allis shad was abandoned after a few experiments. It was never tried to restock the sturgeon in the river Rhine.
- At the end of the 19th and in the early 20th century at least 25 non-indigenous fish species have been introduced in the Delta, and only some of them appeared to be successful (rainbow trout, pikeperch) owing to continuous restocking of surface waters.
- Following the closure of the Zuiderzee in 1932, anchovy and herring disappeared completely. The fishery on eel increased considerably, but nowadays the catch of eel is far more lower than the pre-1932 level. The smelt fishery is approaching the level before 1932, and the catches of a typical freshwater fish, pikeperch, are important now.
- The closure of the estuaries in the SW Delta has led to drastic changes in fish stocks. Lake Volkerak was gradually colonised by roach, carp and particularly bream. The biomass of the bream population exploded in the 1990s, with consequent eutrophication phenomena.
- The population of eels in the Delta has dramatically declined (more than 90%) during the period 1980–2000. Among other factors, remote disrupted reproduction processes and local factors are coined as causative. Nowadays the sluice and

polder regimes are fully automatic, without any connection with migrating fish.
- The professional inland fishery has hardly any future in the Netherlands. Nowadays the economic importance of sport fisheries, angling, is several tens of times as important as the professional inland fisheries. The number of anglers has exploded since World War II; in 2002 *ca.* 1.7 million anglers were counted in the Netherlands.

# Chapter 9
# Floods and Flood Protection

## 9.1 Introduction

The history of 'floods and flood protection' in the Delta is a story of great misery and at the same time great prosperity, the story of the self-created 'enemy', storm floods from the west and river floods from the east, that had to be 'fought' with ever-improved technological means: ever-higher and ever-stronger sea walls and river dykes. But the problem of flooding aggravated, accordingly as the sea level rose, and concurrently the embanked land subsided by forced draining. Straightforward technological solutions have always been the preferred strategy to cope with flooding problems. Already in the 16th century, however, there were far-seeing persons like Andries Vierlingh, a dykemaster, and much concerned with the building and maintenance of sea dykes in the SW Delta. In 1570 he wrote a book on the construction of dykes, dams and sluices. According to him the only way to conquer the tidal forces was not with blunt technology, but with delicate, simple and intelligent designs. 'Water will not be compelled by force', he wrote, 'or it will return that force unto you' (Van Veen, 1950).

In this chapter the history of floods that stroke the Delta will be reviewed. I try to answer a number of questions in this context: How reliable are the historic data? What is told about floods in the course of history? What is the relation between storm surges, river floods and climate change? What is the relation between ice forming and river floods? There have been literally hundreds of storm floods and river floods in the course of history. The causes and effects of a few notorious floods will be discussed, in order to distract some lessons for future scenarios of flood defence.

The toilsome history of flood protection will be reviewed, together with the construction of river dykes and sea walls through the ages. A case study of a floodplain transformation into an enclosed river polder will be elaborated. The river polder, embanked in the Middle Ages, gradually subsided while the river silted-up. The polder was unwittingly transformed into a 'bathtub': the chance that the present-day massive ring-dyke will be overtopped or will breach under the forces of an extreme river flood is very small, but the devastating effects of a flood would be disastrous.

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The construction of the ‘strong dykes’ of the 20th century is the answer between times to the threats of flooding. But are these levees strong enough to withstand future storm floods and river floods? Now in the 21st century the Large Rivers are completely regulated, constrained by massive dykes. The Rijn branches have been embanked along their entire length, and the lower stretches of the Maas have also been protected by solid embankments. The prosperous and very densely populated Delta harbours a society living below sea level and below the high water level of the Large Rivers. This chapter will end with a discussion on recent changes in the perception and acceptance of floods. The standards set, that is, the acceptance of being flooded, have changed drastically, but the risks have changed too.

## 9.2 The History of Floods

### *9.2.1 Floods Through the Ages*

#### 9.2.1.1 Availability and Reliability of Data

Gottschalk (1971, 1975, 1977) published an extensive compilation of the historic data on storm floods and river floods in the Delta, from the 6th century onwards. Although various earlier storm surges are mentioned in the literature, she has left them out of consideration because statements on proto-historic floods are completely without foundation. Even the first few centuries following AD 500 are historically elusive in relation to storm floods. Information about river floods in the Delta up to the mid-14th century is very scarce, and for the most part the documentation on river floods of the Delta is a reflection of those in the neighbouring countries. Gottschalk’s data clearly reflect the increase in information proportional to the passage of time. This factor must always be taken into account, and it is impossible to apply a correction factor to the earlier periods: anyone asking for quantitative data about the Middle Ages is making impossible demands. For the period before 1400 there obviously exists no illustration material in the form of maps and figures. No measurements were carried out at that time and, if figures are quoted, these can only be rough estimates, to which hardly any value can be attached. The literature is still by no means reliable as far as floods in the 15th and 16th centuries are concerned. Even where an author can be regarded as authoritative it is still necessary to test reports of floods against the authentic data.

Based on historic data from the Middle Ages Bakker (1958) supposed a correlation between periods with mild winters and a high storm surge frequency on the one hand, and periods with hard winters and a low storm surge frequency, on the other hand. According to De Vries and Van der Woude (2005), this hypothesis is generally believed, and several scientists hold the marine transgressions, concomitant with accelerated sea-level rise, responsible for the outbreak of storm surges and dyke breaches in the 15th and early 16th centuries. The succeeding ‘Little Ice Age’ would have created a more favourable situation for the gaining of land and hence for the building of defences against flooding. Gottschalk (1977) has contested this view. Figure 9.1 shows that the number of actual storm surges steeply increased after 1250 until a maximum of 29 serious floods in the period 1550–1600. Thereafter, until 1700, the number of damaging storm surges decreased and remained almost constant, 20 in the period 1600–1650 and 18 in 1650–1700. The available technique and the willingness to invest in building stronger dykes seems to be the important causal factor explaining the decrease, but it is impossible to decide what is most significant, the climate change (cold winters, low storm flood frequency) or the economy (stronger dykes).

It is very difficult to decide whether the number of serious storm surges increased or decreased in the course of time. A storm flood is subjectively defined as a situation with strong winds and extremely high water, and above all severe damage to human lives and properties. It may be assumed that the medieval inhabitants of the Delta had developed a high tolerance for the nuisance caused by water in general, and particularly for the devastation caused by floods. They were certainly fully depending on the height and the strength of their dykes and seawalls, and these

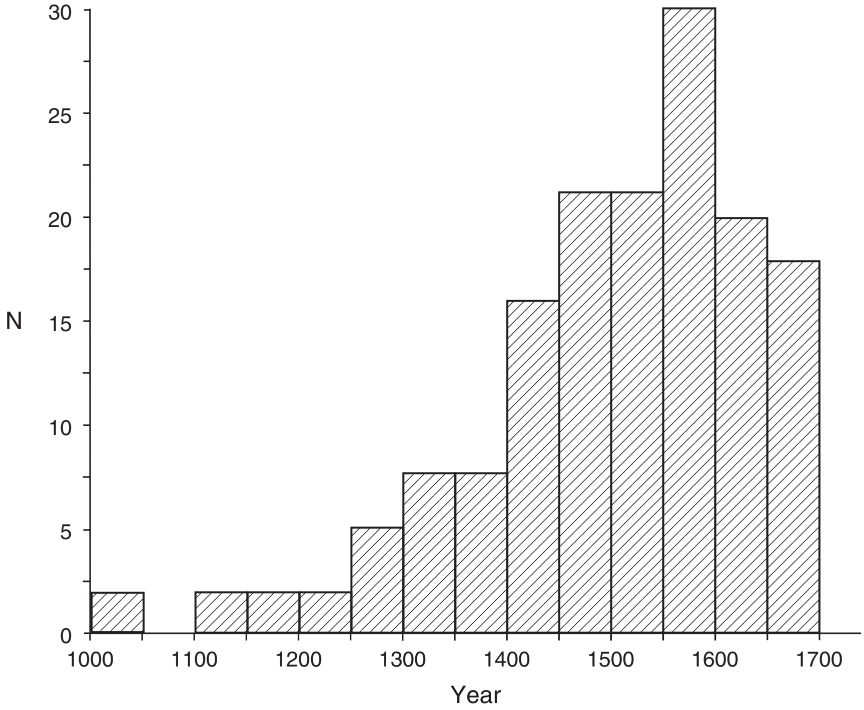

**Fig. 9.1** Numbers (N) of documented storm floods including doubtful floods (i.e. not reliably documented) over the period 1000–1700, on the coasts of the SW, Central and NW Delta; the floods that exclusively hit the N Delta have been omitted from the picture. (Derived from Gottschalk, 1971, 1973, 1975)

structures had to be strengthened again and again. Only since an ordnance level (NAP) has been introduced at the end of the 19th century, one is able to measure the height of storm surges more or less objectively. But even now we have the NAP datum, it is not possible to judge the negative impact of a river flood or storm flood properly: the strength of a dyke may fail for other reasons, and it is not always springtide when a storm flood strikes (e.g. neap tide in 1421, see Section 9.2.4.1). And above that, the size of the damage done by a flood is also depending on wind direction, and concurring river and marine floods.

#### 9.2.1.2 What is Told About Floods?

In the course of history there have been literally hundreds of dyke bursts and consequent flooding, both caused by storm surges from the sea as well as by the melting ice and superfluous rain flowing down the rivers, and causing river floods. The Internet site www.home.zonnet.nl/rampenpublicaties/watersnood gives an overview of 642 publicly accessible publications (books, reports, pamphlets, etc.) compiled by the Netherlands Central Catalogue (NCC) dealing with storm floods and river floods between 1500 and 2000. These data differ partially from the sources used by Gottschalk; she consulted besides the official literature, official charters, accounts, chronicles, and inventories and governmental archives, and hence her data (Figs. 9.1 and 9.2; Gottschalk, 1971, 1975, 1977) give a more objective overview of floods in the course of time, distracted from officially written documents. Figure 9.3 presents an overview of the public interest in floods, distracted from the NCC data base. I made an arbitrary choice from the documents, I left out publications on the northern part of the Delta, beyond the direct influence of the rivers, but I included publications on the NW Delta, including the Zuiderzee, the Central Delta, the SW Delta and the Large River basins.

Until 1650 there is very little public interest in flood events, followed by a steady increase. After 1700 quite some attention is shown, both for storm surges as for river floods. The hits for storm floods show an erratic picture. The storm surge of 26 January 1682, during a northwesterly gale, inundating 161 coastal polders, is the first big flood described in details in annals (see Section 9.2.4.4). The storm flood of 1717 attracted ample attention. This flood struck the Zuiderzee region, and the northern part of the Delta. The 1717 flood claimed thousands of human casualties. It is reported that the seawater stood more than half a metre high in the centre of the town of Groningen. Publications that exclusively pertain to this disaster in the Wadden Sea area have been left out of Fig. 9.3.

The enumeration of distress is endless. The storm flood of January 15, 1808 hit the SW Delta, the flood of 1825 hit the northern Delta and the Zuiderzee region most severely, and claimed hundreds of casualties. The flood of March 12, 1906 led to another general round of dyke enforcements; the characteristic Muralt walls (named after the designer R.R.L. de Muralt), solid walls from reinforced concrete of *ca*. 0.75 m high, were placed on top of the existing sea dykes over a distance of hundreds of kilometres. The flood of January 13 and 14, 1916 caused great damage

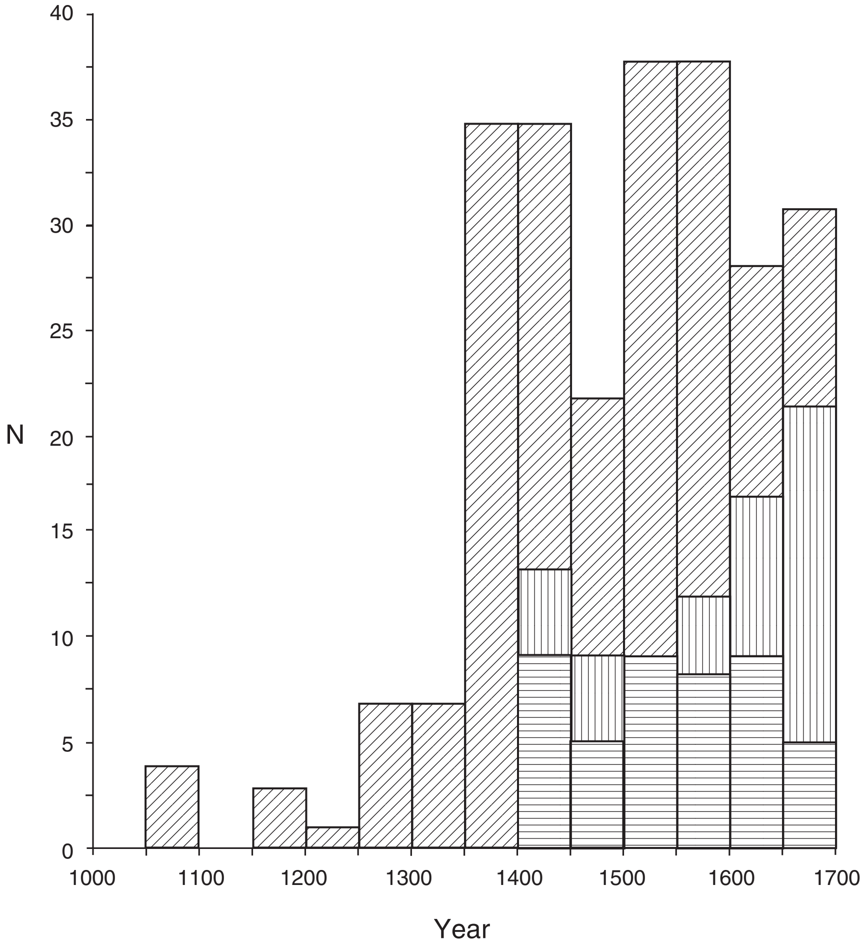

**Fig. 9.2** Numbers (N) of documented river floods over the period 1000–1700 in the Large River basins and the Central Delta; the data include doubtful floods (i.e. not reliably documented) and deliberate war inundations. The serious floods (i.e. floods with heavy damage and many casualties) (combined horizontally and vertically hatched), and the floods with heavy ice drift in the rivers (vertically hatched) over the period 1400 to 1700 are also indicated (Derived from Gottschalk, 1971, 1973, 1975)

around the Zuiderzee, and eventually motivated the closure of the Zuiderzee in 1932 (Chapter 5). The inundations in 1944 and 1945 during World War II were partly executed by the German occupants and partly by the liberators. The storm flood of February 1, 1953, called ‘The Disaster’ (‘de Ramp’ in Dutch), took a toll of 1,835 casualties, and prompted the Delta project (Chapter 10).

The same distress counts for the river floods. Until 1700 river floods hardly drew attention in the public media. Although ice jams had caused numerous floods

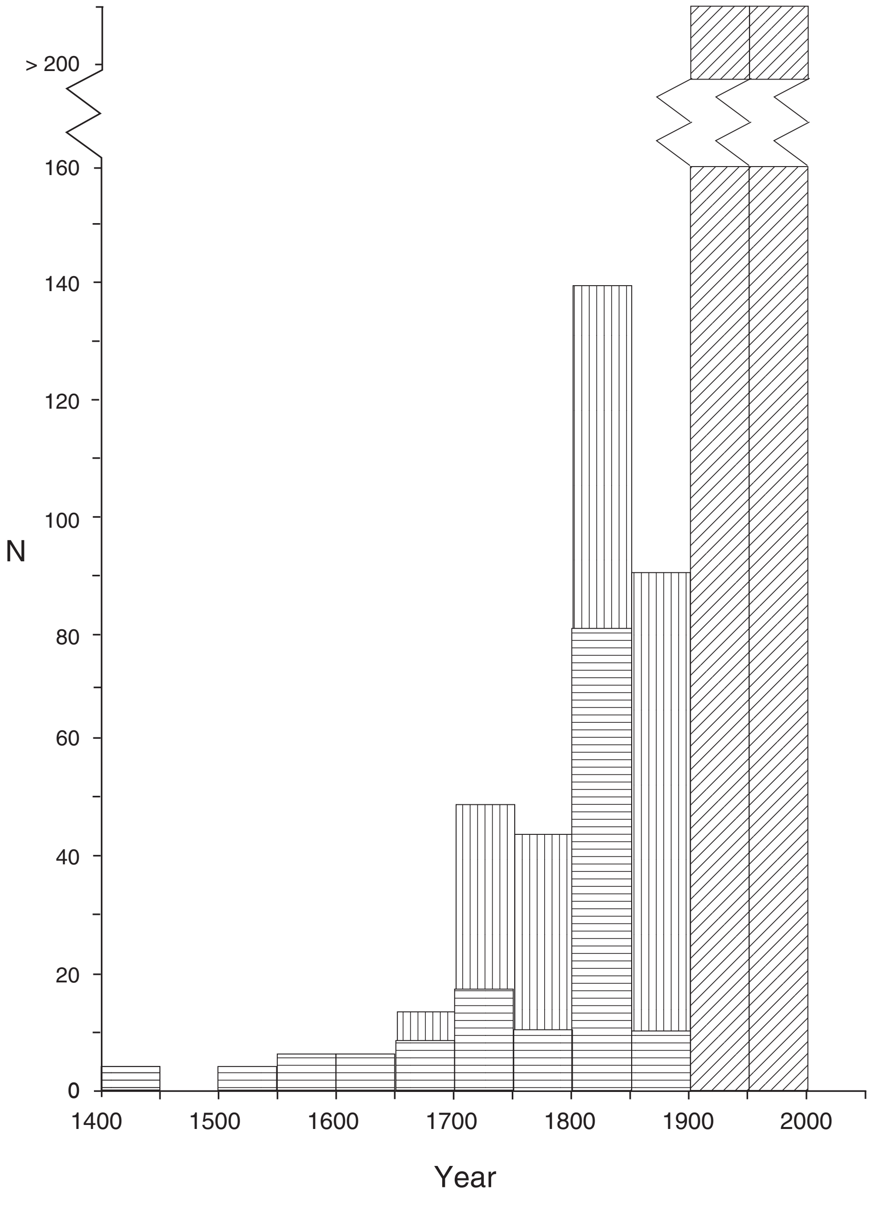

**Fig. 9.3** Numbers (N) of publications in the free press, documented by the Netherlands Central Catalogue on storm floods (horizontally hatched) and river floods (vertically hatched) occurring in the Delta (excluding the N Delta) from 1400 to 1900, as foreshadowing of the public interest. The number of publications over the period 1900–1950 and 1950–2000 is a wild guess, in any case far more than in previous centuries. For further explanation see text

during the 15th to the 18th century, only from 1726 onwards public mention is made of drift ice blocking river courses, giving rise to dyke breaches and floods. The river floods of 1740–1741 evoked much attention, they ravaged large parts of the western river areas. The period 1750–1800 is characterised by numerous river floods spread all over the Rijn–IJssel–Maas river area. The flood of 1809 took much attention. The hits in the literature for river floods steadily increased to 82 in the period 1850–1900, caused by two big floods, in 1855 and 1861. The floods in the 20th century attracted most public attention: 1926 (Land van Maas en Waal) and 1953, and the near-river floods of 1993 and 1995 (Fig. 9.3), which induced the 'Room for the river' policy (Chapters 20 and 21).

Since a great part of the Delta lies only slightly above sea level and the country is dissected by a large number of rivers, its social and economic life were often sorely affected by the numerous floods. The farms frequently suffered a sad fate not only because of the acute excess of water but also because sea-borne floods caused the soil to become saline, so that the fields yielded low returns for a number of years. After dyke breaches the inhabitants of the countryside were faced with increased dyke dues, which often weighed heavily on their enterprises. More than once major floods led to migration. People moved away from the affected areas in order to escape the increasing burdens. It was usually precisely those best able to pay who left their homes, so that the burden became even heavier for the less well-to-do, possibly resulting in pauperisation. The value of the land encumbered with dyke dues declined dramatically. Examples are known where the land could no longer be sold and people were ready to pay in order to be relieved of the exorbitantly high obligations appertaining to the dykes.

The authorities were also faced with considerable problems at times of major disasters. The population was repeatedly unable to pay for the dyke repairs from its own resources, so that subsidies had to be paid. On the other hand, the taxes due could sometimes not be paid during a series of years and the treasury suffered a great loss of income. It is obvious that flood disasters have had serious consequences for the regional and national economy. The total or partial disappearance of settlements, the losses of land through floods and coastal erosion, increasingly followed by the victory when land was gained elsewhere have had great impact (Gottschalk, 1977).

After 1950 in general terms 'water nuisance' became an important item in publicly accessible publications and newspapers. Heavy rain inundating low-lying polders, and flooded parts of towns metres below NAP, is increasingly drawing public attention. This is not to say that the nuisance increased objectively, compared to the 19th and early 20th centuries, but that the tolerance of people for flooding events has decreased. What before 1950 was accepted as 'normal', belonging to the all day life – fields under water during winter and after heavy rain – has led to complaints and annoyance in recent decades.

Recently the buzzword is 'climate change' in relation to sea-level rise, and hence storm surges, and river floods. In popular publications everything is lumped together: the changing climate is coupled to an increasing incidence of storm floods and river floods. However, the changes in climate over the past thousands of years are erratic, and not unequivocally connected with a continuous rise in temperature. The sea level is undoubtedly rising, as it did for the past 15,000 years (cf. Kroonenberg, 2006). The least I will notice here is that it is the interaction between climate and society that matters. An assumed increase in river floods and storm surges is not so much related to changes in climate but to the building of dykes that could be damaged or overtopped, which will consequently result in flooding. I will further analyse the relation between storm surges, river floods and climate change in Section 9.2.2 and Chapter 21.

### *9.2.2 Relation Between Storm Surges, River Floods and Climate Change*

Past transgressions and regressions of the sea have been associated with the occurrence and the intensity of storm floods. Bakker (1958) and others distinguished an early medieval and a late medieval transgression phase separated by a regression phase of the sea, mainly based on the records of storm surges. Edelman (1953) defined a transgression as 'a general occurrence of incursions (of the sea) during which continental deposits are covered by marine deposits over a wide area'. Based on this literal definition, Gottschalk (1975) is opposing Bakker's point of view. According to her there are too few reliable sources to assume a heightened storm surge frequency during the 5th to the 7th century and certainly not a transgression phase.

Starting with the first man-made levees in pre- and proto-historic times, it is generally believed that the systematic construction of sea dykes around the North Sea began in at the end of the 10th century. The oldest embankments were undoubtedly only weak constructions, which did not offer much more protection then against normal tides and ordinary spring tides. But in the course of time the seawalls were strengthened and heightened, and around 1,200 large parts of the Delta were protected by dykes. How primitive these dykes may have been initially, the fact that defensive measures were being taken against the sea will nevertheless have had a great effect on the behaviour of the inhabitants of the coastlands in relation to storm surges. In earlier times the flooded land was abandoned to the free play of ebb and flood, as a result of which channels and creek systems were scoured out, which eventually silted-up again. Once dyke building began, however, it became normal after a storm surge, once the sea had calmed down and the land partly fell dry again at low tide, to make new and stronger dykes in order to drive back the sea. Dyke building was of far-reaching significance, even though the desired security was by no means always achieved.

Historically, there is a fundamental difference between the periods before and after the construction of the dykes. According to Gottschalk (1977) 'transgression' is a valuable concept for the period for which there are no written sources, but that it lost its significance when written documentation started. Storm surges are isolated events, however great their consequences may have been. The 'late mediaeval transgression phase' was dated by Bakker (1957) to between *ca* 1200 and 1500.

Gottschalk's (1975) researches have shown that a number of major and minor storm surges struck sometimes here, sometimes there, and sometimes affected the whole of the Delta North Sea coast. Each century had one or more storm surges which resulted in the loss of considerable areas of land for a long period. A number of notorious storm surges occurred respectively in 1170, the origin of the Zuiderzee, in 1421 the destruction of the Grote Waard, and in 1530–1532 the disappearance of large parts of the SW Delta.

The land losses, however, were amply compensated by land gains elsewhere, so that the sea cannot be said to have gained over the land. Dekker (1971) succeeded in drawing up a quantitative balance of land losses and gains for the island of Zuid–Beveland in the SW Delta for the period between 1250 and 1570 (Table 9.1), and his data are very illustrative in this respect. In spite of the great losses in the wake of the storm surges of 1530, 1532 and 1552, there was a gain on Zuid–Beveland of some 8,100 ha. This example contradicts the idea of accelerated sea-level rise, along the Western European coasts dominated by land loss. It is true that, generally over the whole period before 1600, a rising line can be observed in the frequency of the storm surges in the Delta, reaching its culmination in the 16th century (Fig. 9.1). The rise in sea level is obviously climatically determined but there is no proof, however, in the historical material of the occurrence of marine transgressions, in the sense of a universally occurring phenomenon over a wide area; at most there is question of prolonged, regional inundations, caused by isolated storm surges at very different points of time and under widely varying circumstances. Consequently, Gottschalk (1977) rejects the idea of the coupling between sea-level oscillations and the occurrence of storm surges in the period *ca.*1200–1600. Gottschallk's ideas are supported by Augustyn (1992) who studied the relation between sea-level rise, transgression phases and storm surges to the end of the 16th century in the SW Delta.

Gottschalk (1975, 1977) analysed further possible parallels between the movements of Alpine glaciers and the occurrence of storm surges, river floods and severe winters, but there is very little that can be directly correlated. However, an increase in the number of severe winters during the 17th century is clear, i.e. more frequent freezing over of the Large Rivers in the Delta and a slight reduction in the number of storm surges at this time (see Section 9.2.1.1, however, for public perception). Apart from this relation she was not able to match the storm surges with the periods of retreat of the Alpine glaciers. The storm surges occurred at very irregular intervals during the course of the centuries. The majority of great river floods in the Delta were a result of the formation of ice dams in the rivers, the accumulation of the

**Table 9.1** Land loss and land gain at Zuid–Beveland (SW Delta) in the period 1250–1570 (Dekker, 1971) remodelled by Gottschalk (1975): data have been rounded off; 50-year periods have been combined into whole centuries

| | |
|---|---|
| 1250–1350: no loss of land | Gain *ca.* 4,560 ha |
| 1350–1450: land loss *ca.* 670 ha | Gain *ca.* 6,300 ha |
| 1450–1570: land loss *ca.* 5,100 ha | Gain *ca.* 3,000 ha |
| 1250–1570: total loss *ca.* 5,770 ha | Total gain *ca.* 13,860 ha |

meltwater and damage to the dykes by ice-floes. The situation was often aggravated by the fact that the mouths of the rivers had not yet thawed while masses of meltwater were already being discharged from the more southerly areas upstream, where temperatures were higher. Such floods, therefore, did not always have a parallel in the surrounding countries. On the other hand, it repeatedly happened that the rivers did not flood after a severe frost, i.e. if the thaw set in from the west, facilitating a ready discharge of the meltwater. Gottschalk (1977) could not discover any relationship between storm surges and river floods, nor could she find a direct relationship between storm surges and milder, ice-free winters. In her view the theory of marine transgression and regression phases during the historical period, linked to the frequency of storm surges and river floods, is invalid. Tol and Langen (2000) reviewed the history of river floods in the Delta, and they concluded along the same line of thinking that the influence of climate changes on changes in flood hazards should indeed be considered with proper nuances. The relation was either indirect, virtually absent or confounded with social dynamics.

In general, Fig. 9.1 shows that the number of storm surges continually increased and that an unmistakable maximum in the frequency can be observed in the 16th century. It might be suggested that this is due to more plentiful information derived from the increasingly voluminous source material, but when the latter becomes still more copious in the 17th century, there nevertheless proved to have been fewer catastrophes than during the 16th century. It is further remarkable that, after 1570, the SW Delta suffered no further major storm surges for more than a century (until 1682), in contrast to the period before 1570, when this region was ravaged much more frequently. The storm surge activity seems to have been temporarily displaced somewhat farther to the north. According to Gottschalk (1977), the question as to how far this phenomenon was related to changes in the atmospheric circulation is far more complicated than the simplistic explanation given in the recent past, i.e. as the climate became colder, the cyclonic activity decreased and eastern winds prevailed in the Delta.

From the data of Gottschalk (Fig. 9.2) running from 1000 to 1700, it appears that the number of river floods reported is low until 1250 (0–4 per 50 years). Thereafter the number increases (7 over 50 years in the period 1250–1350), followed by a sharp increase to 35 floods in the period 1350–1400. Thereafter, the number of river floods reported varied between 22 and 37 over a 50-year period, with no significant increase or decrease over the time span 1400–1700. The increase during 1350–1400 concurs with the closure of the ring-dykes around the ‘waarden’, and the consequent narrowing of the river basins. Obviously, the harnessing of the rivers led to a significant increase in the number of river floods. In the period 1400–1700 five to nine serious floods per 50 years were reported, with heavy material damage and many casualties. In many cases ice drift, and consequent breaching or overtopping of the dyke, is mentioned as the primary cause of the flood: 8–17 times per 50 years. After 1600 a gradual increase in the number of severe winters with frozen rivers and estuaries can be demonstrated for the Delta. In the first half of the 15th century 14 winters with pronounced ice formation have been recorded; less than 10 between 1450–1500 and 1500–1550, respectively, and thereafter an increasing

**Table 9.2** Storm floods and river floods in the Alblasserwaard, 1470–1744. Originally published in 1749, by Isaak Tirion, bookseller in Amsterdam, and strongly adapted by Postma (1963). Until the 17th century sea-borne storm floods dominated in devastation, thereafter most damage was caused by river floods

| Year | Date | Cause and consequences |
|---|---|---|
| 1470 | 1 November | First documented flood |
| 1530 | 5 November | St. Felix-flood |
| 1532 | 1–2 November | Storm flood |
| 1552 | 13–14 January | Storm flood |
| 1570 | 1 November | Allerheiligen flood, very severe |
| 1573 | January | River flood, breach in Lek dyke; |
| 1573 | | Military inundation |
| 1577 | | Polder still inundated; emigration and great poverty |
| 1595 | | River flood |
| 1599 | | River flood |
| 1653 | | River flood |
| 1655 | | River flood breach in Merwede dike |
| 1658 | 30 December | Ice drift; inundation until March 1659;hemp harvest lost |
| 1663 | 20 January | Ice drift, breach in Merwede dike |
| 1663 | 11 March | river flood |
| 1709 | 18–19 March | River flood; inundation lasted until autumn; no harvest |
| 1726 | 7–8 February | Ice drift and heavy rainfall, breach |
| 1741 | 3 January | |
| 1744 | 20 March | Zouwe dike; inundation until autumn, no hemp harvest |

number, with a maximum of 23 winters with serious ice problems in the period 1650–1700.

The river polders in the border area between the Central Delta and the Large River basins suffered both from marine storm floods and river floods. The Alblasserwaard is enclosed by the river Lek in the north and river Merwede in the south and west; the cross-dyke Zouwendijk was the borderline between the Alblasserwaard and the Vijfheerenlanden in the east (Fig. 3.9). Postma (1963) reported 19 floods (storm floods and after 1570 only river floods) over the period 1470 to 1744, i.e. on average one flood per 14 years (Table 9.2). During that period the Alblasserwaard was repeatedly partly or completely inundated, often to 2.4–3 m water depth, and at the lowest places to 4.8 m water depth, frequently lasting for several months and sometimes for years before the farmlands were dry enough to be cultivated. The floods often led to human casualties, and the drowning of many cattle; they brought great damage to human settlements, farms and windmills, leading to bad harvests, famine and great poverty.

### 9.2.3 Relation Between Ice Forming and River Floods

In their review of the air temperature records in the Delta for the recent past (from *ca.*1850 onwards) Wijbenga et al. (1993) could not find evidence of a statistically significant change that would indicate that the winter period is getting warmer or colder. Less detailed records are available for years as far back as AD 1200. These records do show that the time from 1200 to 1850 could have been slightly colder than the recent past, but the difference is small and may be due to differences in temperature measurement techniques. Using daily temperature data, in order to classify frost periods during winter, IJnsen (in Wijbenga et al. 1993) calculated a 'frost number' V, following the relation:

$$V = 0.00275n^2 + 0.667y + 1.111z$$

where $n$ is equal to the number of days where the minimum temperature is below 0°C, $y$ the number of days where the maximum is below 0°C and $z$ the number of days where the minimum is below −10°C. IJnsen took available temperature records – assumed to be reliable – from the period 1634 to 1849 to calculate his 'frost number'. The frost numbers were averaged for each 10-year period beginning in 1634 (Fig. 9.4). It is obvious from the 10-year averages that there has been little or no climatic change over the period indicated. The suggested, subtle temperature fall of 1°C during the 'Little Ice Age' can certainly not be derived from Fig. 9.4.

The frost number of IJnsen is a way to classify the severity of a winter. Based on a record of the daily mean temperature for the years from 1850 to 1990 Wijbenga et al. (1993) presented a more detailed method to indicate the severity of a winter, in relation to the ice drift in the rivers. The severity can be determined by accumulating the number of degrees that the average mean temperature for each day was below 0°C. For example, −4°C would be equal to a d° of 4 and −13°C would be 13. Their sum would be 17. The summation continues until the temperatures become

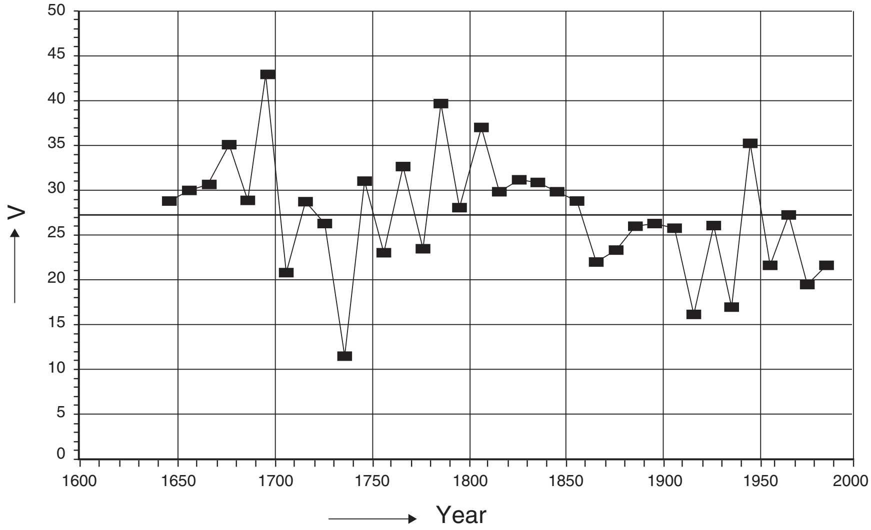

**Fig. 9.4** IJnsen values (V) over the period 1640–1990. Explanation see text (Wijbenga et al., 1993)

positive. If the temperatures are positive for less than 5 days their value will be subtracted from the total. After 5 days one can assume that the ice has left the main channel of the river. In the event of another cold period the summation process will start again. It is therefore possible, and this has happened in the past, that more than one ice period has occurred during a winter period. The difference between V and d° is that one can have a considerable value for V and yet have little or no ice while a high d° value, greater than 50, will always produce ice. Figure 9.5 shows the d° values over the period 1850–1990 for the river Waal; no ice jams occurred when d° was under 100. Irregularly ice jams occurred in the river Waal during severe winters, but these did not result in dyke breaches and flooding anymore after the flood of 1861. The only recorded ice thickness measurements in the past were 14 cm for the Waal and 40 cm for the IJsselmeer. This means that ice jams can be removed relatively quickly by mechanical means, such as ice breaking vessels, dredges or blasting. Before 1861 the authorities lacked an early warning system for ice problems, and they were obviously surprised by the sudden accumulation of drift ice in the river, and above all they lacked the proper means to alleviate the problem in time (Wijbenga et al., 1993).

Next to Gottschalk's (1971, 1975, 1977) survey, other data are available on the relation between river floods and ice dams. Glimmerveen (1856) added data on the floods until 1856. Van der Toorn (1867) listed the floods that struck the Bommelerwaard between 1595 and 1861, i.e. on average once per 17 years. Driessen (1994) gave a detailed survey of the river floods in the Land van Maas en Waal from 1750–1820. From these surveys taken together it can be concluded that the formation of ice dams in the river has caused numerous dyke breaches, but also that not every ice dam has necessarily led to a breach in the dyke.

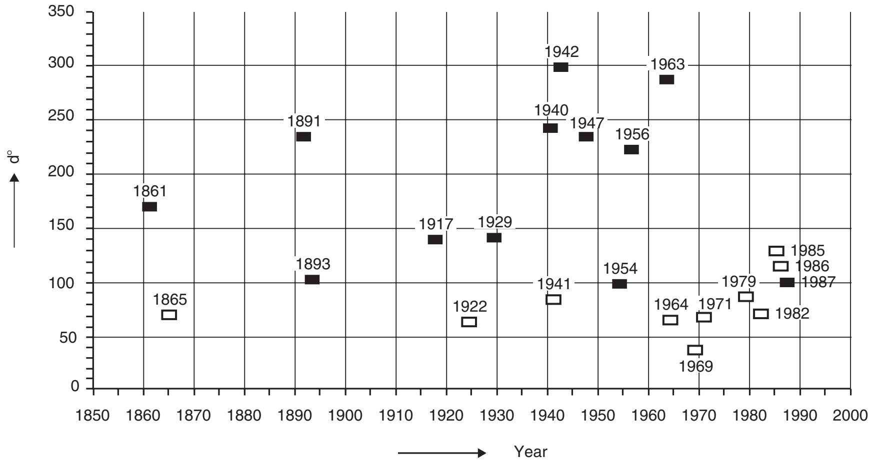

**Fig. 9.5** Values of d° over the period 1850–1990 for the river Waal. Black box = ice jam; white box = no ice jam. Explanation see text (Wijbenga et al., 1993)

Serious breaches in river dykes in the 19th and 20th century occurred in 1809, 1855, 1861, 1876, 1880, 1881, 1920 and 1926. The floods of 1881, 1920 and 1926 were caused by extremely high water levels, the breaches in the remaining years were caused by the forming of ice dams in the rivers. After 1880 no dyke breaches have occurred caused by ice dams. During the period 1850–1890 the large rivers in the Delta have been ‘normalised’, including the closure of secondary channels, the streamlining of a single main channel of specified minimum depth, the reduction of floodplain vegetation, and removal of sandy islands and sand banks, guaranteeing an improved discharge of ice and water. The non-occurrence of dyke breaches caused by ice dams does not mean that ice dams did no longer occur after 1880. The ice dams formed after 1880 have without exception been of the ‘freeze-up’ type, instead of the ‘break-up’ type that often occurred before 1880. The thickness of the layers of ice formed during the freeze-up ice dams is smaller compared to the break-up type, and hence the ice dams formed are less stable, and can be easily removed by ice breakers. The emission of cooling water has significantly decreased the formation of ice in the rivers. It takes more time before ice is formed, and the degeneration of the ice flow starts earlier. During the very severe winter of 1962–1963 all Large Rivers, including the river Waal, and the IJsselmeer were frozen over. Ice dams might have been formed in the rivers, but the river dykes were considerably higher and stronger than the dykes in 1880 (Wijbenga et al., 1993).

The rise in temperature of the Rhine water is significant. As development continued, the cities along the river increased in population which resulted in an increase in river activities. Industry settled along the river because of transportation and used the water in their processes. Power plants were also being located along the river where they used the water for cooling and then return the warmer water to the river. In the late 1960’s the cities along the river constructed waste water treatment plants which also placed their warm treated water into the river. All of this added water has resulted in a +3°C increase in the water temperature in the German section of the Rhine, too high to form ice of any significant magnitude. This increase has also affected the water temperature of the river Waal, the rise in temperature at the border of the Delta is approximately 1.8°C. The channel improvements that have been undertaken in both Germany and the Netherlands has also been a major factor in the reduction of major ice jam occurrences, especially of the break-up type (Wijbenga et al., 1993).

### *9.2.4 Notorious Storm Floods and River Floods*

From time immemorial storm floods and river floods formed an essential part of the lives of the inhabitants of the Delta. Hundreds of floods have been recorded in the course of time (cf. Figs. 9.1 and 9.2). In this section I will discuss a few historic, disastrous floods that stroke the Delta until 1700, on the basis of the thorough work of Gottschalk (1971, 1975, 1977). Both storm floods and river floods show repetitive patterns, and the answer always has been to build higher and stronger dykes, but obviously not high and strong enough (Section 9.3). The great storm flood of 1953 and the near-river floods of 1993 and 1995, of course, run through this book like a continuous thread. The records on the forces of the waves battering the dykes, and the water levels reached during the devastating storm floods of 1570 and 1682, allow a prudent comparison between these historic floods and the recent disaster of 1953. The once-in-a-100-years flood of 1953 was not an exception, and the dykes in the SW Delta, with their 1/50 years safety standard, were obviously not designed for the forces unchained in 1953. In Sections 9.3.3 and 9.4 relevant details on these recent floods will be given, which are still part of the collective memory of many inhabitants of the Delta.

#### 9.2.4.1 St. Elizabeth's Flood (1421)

In Chapter 3 a section has been devoted to the downfall of the Grote Waard (Fig. 3.9). Nowhere can the dangers of human interference with the natural order be better illustrated than in the case of the Grote Waard, and therefore I will extend on this subject in this chapter. During the Middle Ages the Grote Waard had developed into a prosperous polder, but the great problem was, however, that its dykes had never been satisfactory. Great lengths were built on weak and unconsolidated peat; there was much subsoil seepage, and, if the embankments were raised too high, they were liable to collapse under their own weight. The dykes were thus inherently inadequate and were, moreover, in an especially vulnerable situation, for the Grote Waard lay where floods could come upon it from two sides: from the sea and down the Large Rivers. On the one hand, the Waal was bringing down the bulk of the water from the Rhine basin, but the narrow channel past Dordrecht was scarcely able to cope with this flow, let alone the diverted waters of the Maas as well. Major floods were inevitable when one or other of the streams was in spate. Disaster came when there was high water in both Maas and Waal, accompanied by westerly gales that drove the tides up the narrowing estuaries (Lambert, 1985).

The Grote Waard had experienced serious and widespread flooding in 1287, 1288, 1374, 1376, 1394 and 1396, but on all these occasions the flooded areas had dried out and the dyke breaches had been sealed. From written records it is known that the Grote Waard was a prosperous polder, with vast corn fields, provided with a drainage system propelled by wind-watermills. The larger villages had a corn-mill and several houses and a church built of brick, next to the majority of reed-thatched dwellings made of wood. Then, in the early 15th century, the work of the polder board was disorganised by internal dispute over a dyking scheme, and this disorganisation was aggravated by political quarrels. Thus the Grote Waard, its polder administration disrupted, its dykes inadequate or weakened by peat digging and neglect, and perilously exposed to river and sea floods, had to face the catastrophic inundation of St. Elizabeth's flood in 1421. On the night of 18–19 November a storm surge attacked and breached the dykes in the southwest, spreading its saline waters widely over the lands within. At the same time the Maas and Waal burst through the dyke of the Waal–Merwede in the north and ultimately swept away all this dyke over a large distance. These breaches on both sides of the polder sealed the fate of the embanked area. After the flood villages and cloisters were abandoned; the number of settlements is not exactly known. About 28 villages drowned and an unknown number of people lost their lives. Subsequent storm floods tore apart the remnants of the polder, and the inhabitants realised that it was impossible to regain their land. After 50 years of attempts to repair the levees, they gave up their polder. Foreign tradesmen visiting Dordrecht around 1500 mentioned in their travel records the drowned land with the church steeples rising above the water level. Re-embankment was attempted in due course but progress was slow. In addition, wars and neglect prevented recovery, and for a considerable period open water occupied the area where the Grote Waard had once stood. At the end of the 15th century the eastern part of the Grote Waard was again protected from tidal floods by the building of a dyke; the area was embanked again in the 17th century, and is now called the Land van Heusden en Altena. The western part of the Grote Waard was abandoned to the sea and the rivers; this area is now called the Biesbosch (Fig. 5.5), until 1970 the largest freshwater tidal area of Europe (Chapter 10) (Lambert, 1985; Van de Ven, 2004; Van der Ham, 2003).

The calamity in the Grote Waard made a great impression both in the Delta and beyond. The chronicles do not record what else was destroyed by the storm surge, and the many charters which were issued in connection with this storm surge scarcely give any direct information about what happened. It is usually only indirectly that any deductions can be made. In general, charters were issued only when dyke restoration was encountering difficulties and the authorities were compelled to intervene, such as when the population were unwilling and recalcitrant, when there was serious disagreement, money and manpower were lacking, etc. To the extent that such difficulties did not arise, we have no information about the damage done. Consequently, the charters by no means give us complete information about the effects of the storm surge. Numerous authors have been tempted into all kinds of speculations, theories and even fantasies on the basis of the insufficiently available data. In general, attention has been directed much too exclusively to the Grote Waard, neglecting what happened elsewhere along the coasts of the Delta. By contrast, it was taken for granted that the northern part of the Delta was equally badly affected by the storm surge, although absolutely nothing is known of such damage. Added emphasis is given to this by the fact that nowhere is there any mention of floods along the German North Sea coast in 1421 (Gottschalk, 1975).

According to Gottschalk (1975) some authors take as a matter of course that the St. Elisabeth's Flood of 1421 occurred during a springtide. In fact, the opposite was true: it was then almost neap tide. The force of the storm, on the other hand, must have been very great. The knowledge that the Grote Waard's destruction occurred during neap tide, throws another light on the events in 1421. The downfall of the embanked polder has now been visualised as a gradual process, in which one village after another was made uninhabitable by flooding because of the failure to restore the dykes. The St. Elizabeth's flood was only the finishing stroke for the once prosperous polder.

#### 9.2.4.2 The Early 16th Century – St. Felix Quade Saterdagh Flood (1530)

A serious storm surge occurred on November 5, 1530, which inflicted severe damage, particularly in the SW Delta, the ‘waarden’ of the Central Delta, as well as the English counties of Essex and Kent on either side of the Thames estuary. Contemporary sources speak of a spring tide coinciding with a full moon. The numerous dyke breaches and very extensive floods caused panic everywhere. In the SW Delta, not a single island was spared by the surge, a process that would soon be carried further by the storm surge of 1532. It may well be true that the inspection and maintenance of the dykes in this and certain other areas, during the period preceding the storm surge of 1530, left something to be desired, but whether the disasters could have been prevented is an open question. In eastern Zuid–Beveland (Fig. 4.4) the core of the submerged land consisted of an area of peat, which probably formed a shallow basin as a result of peat digging over a long period, and must have filled with water after the dyke breaches.

Far less known than the storm flood of 1530 is the one of 1532, and in contrast with 1530, no official reports are known of the storm surge of 1532. The great storm surge of November 2, 1532 did not, like that of 1530, coincide with springtide, but with neap tide. This is a phenomenon that has already been observed with the major surges in 1421. The effects were no less catastrophic than with surges which coincided with springtides. The whole archipelago of the SW Delta was particularly severely affected. Everything that had been restored after the storm surge of 1530 was destroyed again in one blow, and what had been spared in 1530 was damaged in 1532. In the SW Delta, the great storm surges generally hit the eastern parts of the estuaries more severely than the islands situated closer to the North Sea. This was also the case in 1530 and 1532. This is explained by the great driving up of the water eastwards when gales were blowing from between southwest and northwest. The great storm surges of 1509, 1530 and 1532 were each accompanied by land losses, which were particularly extensive in the SW Delta. The storm surges of the 16th century repeatedly gave rise to emigration from the affected areas. The population moved elsewhere, where less danger threatened and where they were not obliged to pay ruinous dyke dues. The migration resulted in a great shortage of labour for dyke repairs and was an additional reason for the lengthy postponement of certain reclamations.

Although the phenomenon of the sudden collapse of a dyke is not related directly to the storm surges, it is nevertheless striking that the falls increased alarmingly in number and frequency after 1530–1532. Landslips and dyke falls were by no means rare in the SW Delta before 1530, but thereafter there was evidently an accelerated and more intensive crumbling of the coasts. Contemporaries attributed this process to the changing regime of the tidal currents in the estuaries where vast areas of land remained submerged, which must have had a disastrous effect on the isolated islands (Gottschalk, 1975; Lambert, 1985).

In the Central Delta, the area north of the Oude Rijn suffered severely during the floods in the early 16th century (Fig. 5.6). As a result of breaches in the Spaarndam dyke caused by the storm surges of 1508, 1509, 1514 and 1532, the entire peat district extending southwards from the IJ was repeatedly put under water. The results were disastrous for the population, since peat digging was the chief form of livelihood in the countryside. The existing water bodies, such as the Haarlemmermeer, will undoubtedly have been extended, and presumably many people left their homes and sought their salvation elsewhere (Lambert, 1985).

### 9.2.4.3 Allerheiligen Flood (1570)

The year 1570 has become notorious because of the 'Allerheiligen' (All Saints) flood of November 1 (Fig. 9.6), one of the great storm surges, a southwesterly gale during springtide, which has acquired a legendary fame. Its effects were felt along the whole North Sea coast of the European mainland from France to Denmark. The Allerheiligen flood was a real catastrophe for the Delta and received attention in the contemporary literature. Practically no attention was paid, however, to the dyke

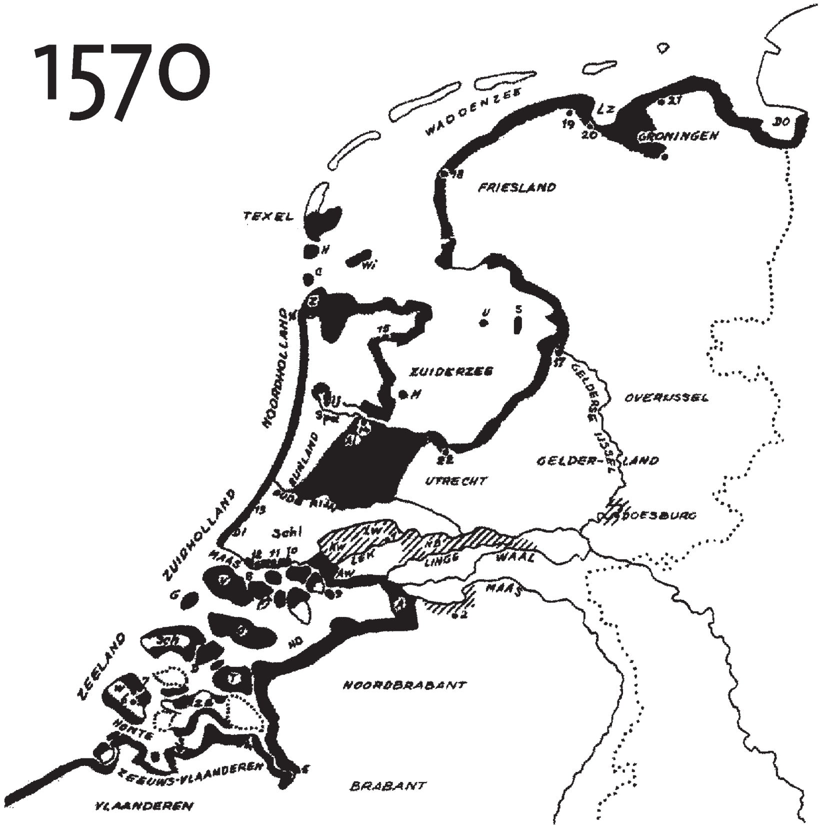

Fig. 9.6 Dimension of the Allerheiligen flood of 1570; black = marine flood; hatched = river flood (Gotschalk, 1975)

breaches and river floods that preceded and followed this disaster. At the end of January 1570, nearly all the Large Rivers in the Delta overflowed their banks (Fig. 9.6). Floating ice caused the Lek to breach the dyke at the Lopikerwaard, thereby setting this ‘waard’ and the more westerly Krimpenerwaard under water. Dyke breaches along the Waal and the Linge caused the inundation of the lower Betuwe (see geographic position in Fig. 3.9). The Maas caused damage in the neighbourhood of ‘s-Hertogenbosch. There was very probably also flooding at this time along the IJssel.

The largest numbers of victims of drowning during the Allerheiligen flood were obviously to be found where the floods occurred during the night, and the people were overwhelmed in their sleep by the rising waters. Thousands of human casualties were counted, particularly in the northern part of the Delta. In general, it must be concluded that the Allerheiligen flood of 1570 did a great deal of damage in the SW Delta, but that the destruction caused by the storm surges of 1530 and 1532 was considerably greater. In the northern part of the SW Delta and in the Central Delta, the balance seems to have swung the other way. The islands of Goeree, Overflakkee, Voorne, Putten and their surrounding were largely submerged. The damage was enormous. The Krimpenerwaard, the Alblasserwaard and the Land van Heusden en Altena (see geographic position in Fig. 3.9) were all affected by serious dyke breaches and floods. The Central Delta was very badly affected. The Spaarne dyke remained intact, but the dykes along the IJssel and the Zuiderzee east of Amsterdam gave way, and large areas north of the Oude Rijn were inundated (Fig. 9.6; geographic position in Fig. 5.6), just as in 1508, 1509, 1514 and 1532 (Gottschalk, 1975; Lambert, 1985).

It is tempting to compare the impact of the storm surge of 1570 with the effects of the storm surge of 1953. Gottschalk (1975) attempted to compare the maximum height of the storm surges in 1570 and 1953, respectively, relative to NAP. In 1570 the NAP datum level did not exist, but reliable measurements of the height of the water level (e.g. in centimetres above the stone floor of still existing churches) allow a conversion to the 1953 data. In Rotterdam in1570 the seawater stood at a maximum height of NAP + 3.60 m; in 1953 this was NAP + 3.75 m. Data for Scheveningen (near ‘s-Gravenhage on the coast) in 1570 indicate NAP + 4.15 m, and for 1953 NAP + 3.90 m. A preliminary conclusion is that the storm floods of 1570 and 1953 reached comparable water levels. In case, however, a conservative scenario of 0.15 m relative sea-level rise per century (Wind, 1987) should have been taken into account, the maximum height of the storm surge should have been *ca.* 60 cm higher in 1953 than in 1570. This tentative calculation classifies the 1570 storm flood as unprecedented.

#### 9.2.4.4 River Floods (1624) and Storm Floods (1682)

The river floods in January and March 1624 affected the Delta seriously. Many rivers in Western Europe had frozen over in December 1623, and during thaw voluminous discharges of meltwater occurred in early January, affecting the Rhine among other rivers. Since the Large Rivers in the Delta, such as the Waal and the Lek, had been blocked by ice jams, the large flow of water from the upstream areas could not be discharged into the sea. A catastrophic breach occurred in the Lek dyke south of the city of Utrecht on the night of 10th–11th January. Extensive flooding was caused not only in vast areas of the Large Rivers basins, but also in a very large part of the central Delta; even Amsterdam was affected by flooding (see Fig. 9.7). Floating ice also occurred on the Waal, Meuse, IJssel and Linge, where dyke breaches were caused. The disastrous floods were followed by a second period of frost, which probably lasted from end of January to end of February. Where the polders were still flooded, the situation must have been terrible. The misery was made still worse because the repaired Lek dyke gave way again on March 6, causing

**Fig. 9.7** Dimension of the river floods of 1624 (horizontally hatched) (Gottschalk, 1977)

further flooding that extended far into the Central Delta. This time, however, the water levels were perhaps not as high as in January (Gottschalk, 1977).

The 1570 storm surge was preceded and followed by many other floods. A remarkable one was the flood that hit the SW Delta and the neighbouring areas of Belgium on January 26, 1682, during a severe storm surge associated with a springtide and a northwesterly gale (Fig. 9.8). Simultaneously with the sea-borne storm, high water levels on the rivers aggravated still further the damage in the estuaries. The damage was described in detail by a few contemporary authors. This is the first time in history that extensive and detailed data have been made available, polder by polder. In general it is noteworthy that some parts of the SW Delta which are situated closest to the North Sea coast, suffered less from flooding than areas

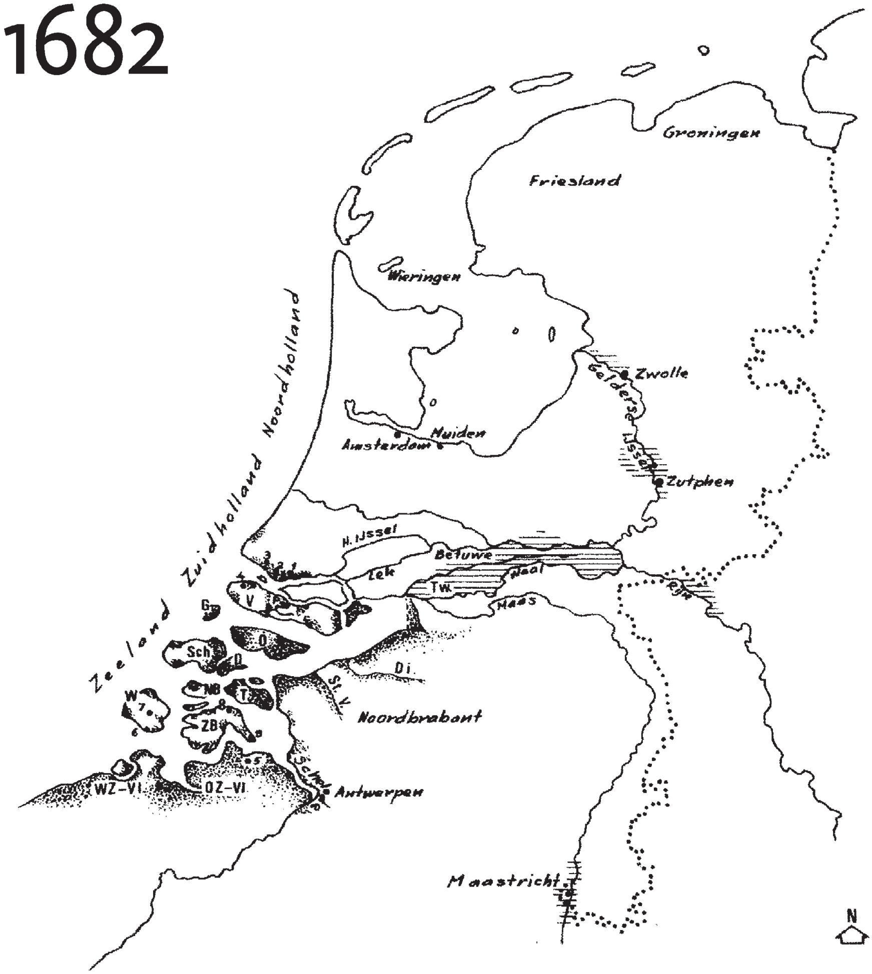

**Fig. 9.8** Dimension of the storm flood and river floods of 1682; grey = marine flood; horizontally hatched = river floods (Gottschalk, 1977)

farther east. On the individual islands too, the storm surge damage was generally greater on the east side than on the west side. Consequently, the effect of the storm surge extended far inland, and the higher driving up of the water in the eastern sections of the various estuaries undoubtedly contributed to this. Attempt to compare the damage of the flood of 1570 with that of 1682 is a precarious enterprise. The Allerheiligen flood of 1570 was, in any event, a much greater catastrophe as far as the extent of the disaster and the toll off human lives are concerned. Regarding the maximum height of the water level, some memorial stones erected in inundated towns in 1682 indicate higher levels than in 1570, particularly at the most land inward places, other datum levels indicate slightly lower water levels (Gottschalk, 1977).

#### 9.2.4.5 River Floods in the 19th and Early 20th Century

Floods were part of everyday life. As stated before, each generation living in the Delta has experienced during its lifespan at least three to four major floods. In this section I will focus again on the Bommelerwaard (Fig. 5.5), being a representative river polder in the area of the Large Rivers. Until the end of the 18th century the Bommelerwaard was a rather prosperous agricultural area but from that time onwards the ‘waard’ fell behind socially and economically, mainly owing to a number of disastrous floods and insufficient draining of the basins. Particularly the western, lowest part of the river polder suffered greatly from floods. In between 1750 and 1861 five major dyke breaches resulted in massive flooding, which led to great misery among the population. From the end of the 19th century until mid-20th century the Bommelerwaard together with adjoining river polders were counted among the poorest regions of the Delta. This explains why the large-scale and rigorous re-allotment measures after World War II were very much welcomed by the local farmers (cf. Chapter 7).

A severe river flood that hit large parts of the area of the Large Rivers, and the most recent one that ravaged the Bommelerwaard, took place in January 1861. As most preceding floods, it was caused by drift ice in the river. In December the rivers froze over; around January the thaw set in, breaking the ice mass, and starting the ice drift. An ice dam was formed in the river Waal, and the level of the down-flowing water mass behind the dam steadily rose, and this became fatal: on January 6 the dyke of the Bommelerwaard broke at several places, and water and ice rapidly filled the ‘bathtub’, up to 2–4 m above the surface level, overtopping the southern dyke along the Meuse. Within 3 days the water mass reached the higher situated eastern part of the ‘waard’. The main town Zaltbommel succeeded in keeping the flood outside its ramparts by barricading the town gates. The town took over 1,400 refugees that found a safe haven within the town walls. In the course of January the frost set in again, changing the polder into a grim frozen lake. Early February the inhabitants could start filling the dyke breaches, and in May the ring-dyke was closed again, but the low basins remained inaccessible, and suffered the entire year from stagnating groundwater.

The disastrous flood of 1861 induced several emergency measures in the Bommelerwaard. The southern Maas dyke was provided with an overflow, a lowered part of the dyke, where in case of flooding from the river Waal, the water could flow into the Maas. Soon after the flood small mounds were thrown up in the villages situated in the central parts of the Bommelerwaard, were farmers and their livestock could take refuge in case of a spate. It was supposed that the inhabitants of the other villages, situated on or close to the ring-dyke, could take refuge on the dyke, in case of a flood. It is characteristic for the mentality of the people living in these villages that the mounds still exist. Notwithstanding the high safety standards in the year 2007 (see Section 9.4), the fear for flooding is anchored in the genes of the autochthonous inhabitants (Moorman van Kappen et al., 1977; Driessen, 2001).

The flood of 1861 accelerated the execution of several civil engineering works along the Waal and the Maas, such as the further canalisation, and the building of groynes (see Chapter 5). Between 1883 and 1904 the separation of Rhine and Meuse took its definite shape, namely the construction of the bypass of the river Maas, the Bergsche Maas in 1904 and the separation dyke at Heerewaarden in the same year (see Chapter 5).

The most recent flooding disaster that hit the area of the Large Rivers took place in January 1926. Unprecedented discharges of the rivers Rhine and Meuse, in combination with strong seepage weakened extensive stretches of the river dykes. In 1926 the Rhine had the highest discharge ever recorded of $12{,}600\,\mathrm{m}^3\,\mathrm{s}^{-1}$, which is equivalent to a once per 150-year flood (records run from the late 19th century onwards). The overflow areas (a.o. Beerse Overlaat and Spijkse Overlaat) were, of course, the first polders to be filled with river water. But notwithstanding, this overflow capacity the river dykes broke at several places and large polders along the rivers IJssel and Maas (Land van Maas en Waal) were flooded (Driessen and Van de Ven, 2004). After the flood of 1926 continuing measures were taken to improve the discharge of Waal and Maas. The canalisation of the Maas was continued energetically: ten sharp meanders were cut off (Fig. 5.4), the summer-bed of the river was widened and deepened, and the floodplains were excavated.

## 9.3 The History of Flood Protection

### *9.3.1 The Construction of Dykes Through the Ages*

From prehistoric times onwards the building of levees has always been the first measure to fight flooding (Chapters 2 and 3). The early water defences built around the beginning of our era were low, not very watertight embankments of tamped earth. Such dykes had to face up to a wide variety of conditions. Whereas sea defences have to contend with the beating of the surf and tidal currents, river dykes need to be able to withstand seepage during prolonged periods of high water. For river dykes a steep riverward face poses few problems, since it does not have to meet the sudden attack of the waves. The main essential is a lining of clay to prevent percolation, a gentle landward slope to resist the pressure of the water and a gravel-filled ditch at its foot to catch the seepage. Simple earthen embankments long served as sea defences, in the later Middle Ages a new type of mud-dyke was introduced into the NW Delta. Outside the earthen dyke proper (Fig. 9.9) turves or clods of sticky clay were piled to form a steep seaward face, which was soon overgrown with seaweed. A steep slope was, in fact, not the most suitable for breaking the waves' attack, but the paucity of material largely dictated this method of construction.

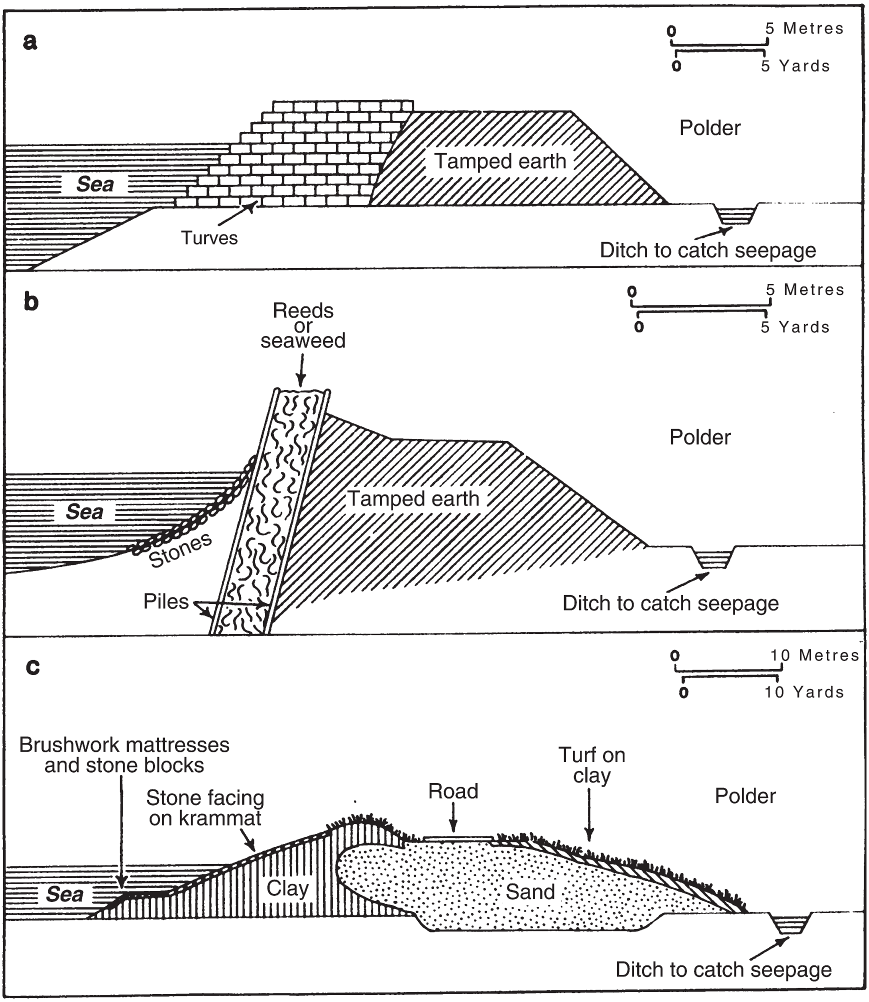

**Fig. 9.9** Types of sea dyke employed in the Delta from the Middle Ages to the modern time. (a) Medieval mud dike; (b) medieval seaweed (mainly eelgrass) or reed dike; (c) modern dike of sand and clay with stone facing (Lambert, 1985)

Modifications of the mud-dyke came into use in the 15th century. In the weed-dyke (Fig. 9.9) the earthen embankment was strengthened on its seaward face by a mattress of eelgrass retained by a palisade and, where possible, reinforced by stones or bricks at its foot (cf. Chapter 16). The pile of weed sometimes reached a height of 5 m, always overtopping the dyke proper, and since it had the property of clinging together firmly under its own weight and through a process of mineralisation, it formed an elastic cushion resisting the impact of the waves. In reed-dykes bundles of reeds stowed against the earthen dykes replaced the eelgrass, but they were less durable, having to be renewed every 5–6 years. Both weed- and reed-dykes were reinforced by piles on either side and in front of the reed and seaweed beds. In the late Middle Ages true pile-dykes were constructed, made of several metres long piles set close together, a type which remained in use until the 19th century. Pile-dykes occurred along the coast of the Wadden Sea, the SW Delta area and along the lower courses of the Large Rivers; particularly the southern shorelines of the Zuiderzee were protected by pile-constructions (Lambert, 1985).

During the building of medieval dykes a lot of wood and timber was used. Fascines and wattle-work were in common use when a breach in an existing dyke should be repaired or when a new dyke had to be erected. Fascines are long faggots of flexible willow branches, which were bundled with osier twigs. They had a diameter of *ca.* 50 cm and could vary in length from a few metres up to 30 m. By using fascines a fascine-dam could be made to close off a tidal breach or an erosion pit in a river dyke. Fascines were also used in mats to serve as foundation for sluices, in the construction of groynes and for the protection of dyke slopes. Wattle-work was also frequently used; it consisted of vertical hurdles of braided osier twigs and poles, reinforced with fascines. Underwater wattle-work constructions had a very long lifetime, but above water they would rot and they needed to be replaced every 2 or 3 years. Apart from osier, rush or straw was also used for dyke protection, attached to the dyke slopes with clamps of straw (Van de Ven, 2004). The application of all these techniques can be seen on a picture from 1624, the repair of a breach in the Lek dyke south of Utrecht (Fig. 9.10).

Wooden ramparts proved adequate until in 1731 the shipworm (*Teredo navalis*) made its first appearance. As the shipworm invasion spread, the piles of the sea walls crumbled and the protective beds of seaweeds and reeds were washed away (see Section 9.3.2.). The successful countermeasure consisted of gently sloping stone revetments (Fig. 9.9), an angle of 1 in 2.5 or 3 being preferred, extending from the dyke foot to a metre or more above the average high water level at springtides. At the same time, masonry began to be used in the framework of locks and sluices. The high cost of the imported stone was compensated by its greater durability. At first irregular boulders were used; at the seaward side of the dyke the brushwork mattresses were covered with stone blocks, and higher up in the littoral zone with a stone facing on a several centimetres thick bed of straw, designed to serve both as a shock absorber and as a protection against percolation and erosion. At the end of the 18th century the holes between the boulders were filled with rubble, and subsequently it became almost universal for the entire lower sea-dyke slope to be given a continuous revetment of stone resting on the straw beds (Lambert,

**Fig. 9.10** Repair of the breached dyke of the river Lek after the ice jam of January 10, 1624. Dyke workers are engaged in closing off the breach by means of a 'vingerling'. To the left a part of the old dike with wattle-work is reinforced with faggots. In the centre a new curved stretch of dyke is built ('vingerling') in which numerous fascines are used; on top of the new dyke charts pulled by horses (Drawing by the contemporary artist Esyas van den Velde)

1985). River embankments were also greatly improved and heightened in the course of centuries. The low, disorderly built levees with numerous small ferries and landing stages (Fig. 9.11) were gradually changed into the smooth embankments as we know them nowadays, the strong dykes, with their slightly inclining inner and outer slope, and with a very broad foot (Fig. 9.12). Houses built on top of the embankment in the 18th century can be located now roughly 2 m below the top of the dyke, as a result of a number of dyke reinforcements (Fig. 9.13).

The body of the sea dykes were preferably constructed from clay that was dug close to the dyke from the accreted salt marshes, a method that was developed in the SW Delta, and that was applied until the 20th century. If sand was used this material had to be covered with a clay layer of several feet. As long as the soil was still wet and weak, transport of clay and sand was done with wheelbarrows. As soon as the ground was dry enough and could carry carts and horses, they had to be used because the thrown earth was compacted by the pressure of the cartwheels and the horses' hooves. The dyke had to be built up layer by layer, which had to be tamped down by the carts and horses each time. As soon as a dyke lot had been inspected and approved, the contractor was allowed to cover the slope with grass sods, or if no grass sods were available, fascine work made from rush or straw would suffice. The new dyke had to be 1 ft higher than the dyke of the adjacent polder, to which it was

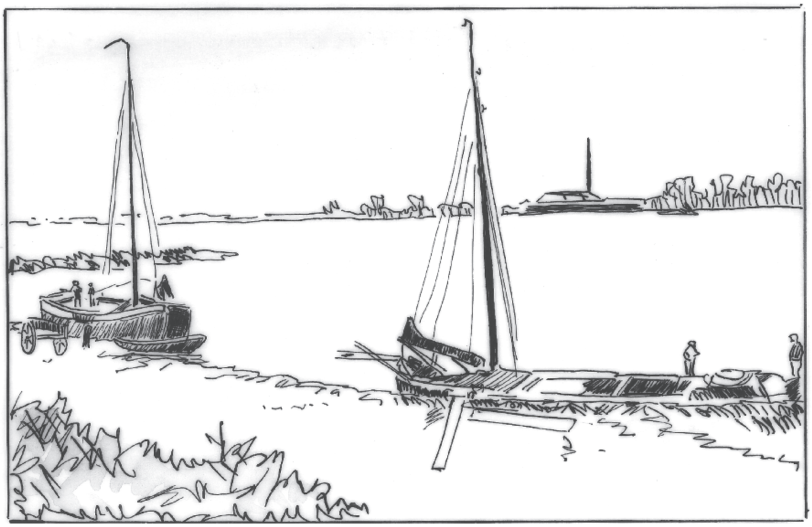

**Fig. 9.11** Upper panel. The river Lek at Elshout *ca.*1850, drawing after a painting by Johannes Weissenbruch (1822–1880) in Teylers Museum Haarlem. The picture shows a small ferry boat for persons, sailing barges, landing stages in the floodplain, and houses and large trees on the embankment. Nowadays the river dyke is much higher and massive than 150 years ago, large trees and houses are not allowed on the crown of the dyke, sailing barges and small 'wild' mooring sites have disappeared; jetties and mooring sites have been concentrated in yachting harbours.
Lower panel. A landing stage for sailing barges at Rossum, on the river Waal, in *ca.*1920; in the background the chimney of a brickwork. The image of loading and unloading of sailing barges along the river forelands is completely lost (Redrawn after Verhagen, 1998)

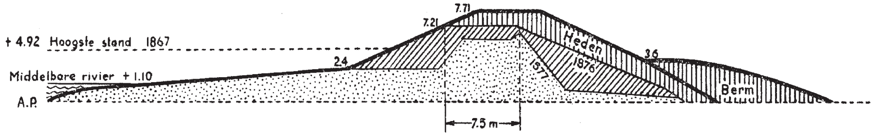

**Fig. 9.12** Development of the river dyke of the river Lek at Vreeswijk (south of Utrecht) from the 16th to the 20th century. AP = Amsterdams Peil (ordnance datum); 'middelbare rivier' = average discharge; 'hoogste stand 1867' = highest flood level 1867 (Cools, 1948)

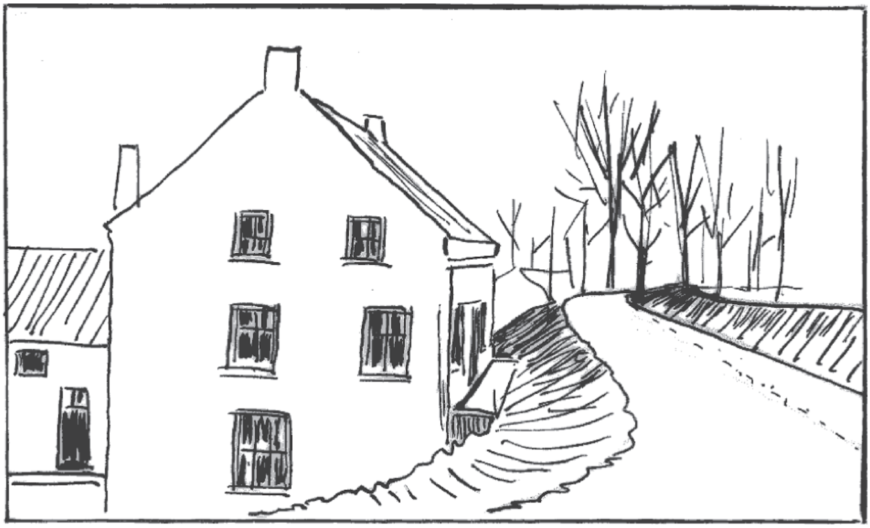

**Fig. 9.13** The result of a number of dike-reinforcements at the Waal ring-dyke in Rossum, Bommelerwaard. The house was built in the late 18th century. The front door of the house was situated on the crown of the dyke before 1861. After the flood of 1861 the dyke has been raised *ca.* 1 m; the road is on top of the dyke. After the narrow escape from the flood of 1995 the dykes have been heightened again with *ca.* 0.7 m, which shows on the right (Drawing P.H. Nienhuis)

attached. The idea was that the new dyke would subside 1 ft in the course of time and would become the same height as the old one. In general, river dykes were built as grass dykes, comprising a body of sand and clay covered with grass sods. They were considerably weaker than sea dykes, and only at exposed spots where scouring currents attacked the dyke, it was reinforced with a stone facing (Van de Ven, 2004).

### *9.3.2 The Shipworm Invasion*

The Golden Age had its drawbacks: it was certainly a prosperous time for the wealthy merchants and investors, but surely not for the common man ('acts of God'). The great shipworm was introduced in the Delta during the period, 1713–1720 with wooden ships which came in from Asia. The great shipworm, *Teredo navalis*, is a small fragile bivalve, of which the shell encloses only a small part of the vulnerable body. The shipworm is an occupant of driftwood or burrowing in floating timber, groynes and wooden boats. In the Delta it bored holes not only in the wooden ships, but also in the wooden piles reinforcing the river dykes and sea defences. Towards the end of the 17th century, the shipworm was already detected in Delta waters, but it was recognised as a disaster in 1731–1732. It turned out, for example, that 47 km of the sheet-piling of the sea wall in the NW Delta had been destroyed by the boring bivalve. Particularly the dykes along the Zuiderzee, which had wooden sheet-pilings into the sublittoral zone, were threatened by the shipworm. A dyke protected by a weakened wooden revetment could more easily being attacked by a storm surge. The shipworm ruined in a short period of time most dyke revetments along the coast of the Delta, causing numerous dyke breaches and flooding (De Vries and Van der Woude, 2005). Many measures were quickly taken. On Walcheren in the SW Delta, between 1732 and 1790, all the exposed dyke timbers were covered with iron or copper plates and nails at enormous cost. Elsewhere tropical hardwoods were used and arsenical solutions or impregnations in creosote oil applied. The inhabitants of the NW Delta, whose Zuiderzee dykes were faced with wood, foresaw an impending calamity and hastened to strengthen their inland secondary dykes.

But the solutions were not sufficient, and this meant the end of the then applied system of building dykes and sheet-pilings. It finally became clear that the only answer lay in a complete change in the mode of dyke construction. The vulnerable vertical sheet-pilings were more and more replaced by gently inclining dykes, in order to break the force of the waves. The use of stones was the only conclusive measure, and by 1755 most sheet-pilings were replaced by an underwater protection of rubble. Below mean tide level the eelgrass dykes, in common use in the NW Delta, were also protected with rubble and stones; the upper part of the eelgrass belt could be kept in place by pilings. Initially, boulders from the Pleistocene areas of the Delta broken to pieces were used for rubble, later on natural stones from Scandinavia was imported for this purpose (Van de Ven, 2004).

### *9.3.3 History of Embankment of the Bommelerwaard, a Case Study*

Figure 9.14 shows an imaginary map of the Bommelerwaard in Roman times (*ca.* AD 200), in *ca.*1400, and in *ca.*2000. The oldest traces of human settlements in the Bommelerwaard date back to the New Stone Age, based on archaeological finds in river dunes, slightly elevated above the floodplain. During the Roman period (approximately from 2000 to 1700 BP) the human occupation increased considerably, as witnessed by at least 80 locations where remnants of human occupation have been excavated (Reuselaars, 2001; see Fig. 2.7). These small settlements were, without exception, located on a channel belt or on a natural levee. In Roman times the area was a large natural floodplain with braiding and meandering river courses, building up extensive channel belt deposits. Active river channels incised into the older peat (or sand) formations, and gradually filled themselves with coarse and fine sand. The finer sediments – silt and clay – were deposited in the natural floodplain. The elevated sandy channel belts were the first places were humans erected their settlements. The channel belts were dangerous but fertile places, relatively dry during average high water, but at extreme high water the settlements were flooded.

A palaeogeographic reconstruction of the river floodplains on the location now called the Bommelerwaard shows channel belts with existing river channels, and presumed (eroded) river courses, and flooded or partly flooded natural floodplains (derived from Weerts and Berendsen, 1995; Berendsen, 2001). The cross-dykes, small earthen dykes, thrown up almost perpendicular to the prevailing river currents, to protect small areas from excessive flooding, presumably date back to 800–1000. Gradually the embankments surrounding a settlement and adjoining fields were closed. These ‘village-polders’, areas of land, surrounded by low embankments, drained by ditches and wider water courses, were presumably finished around 1100. Gradually the system of village-polders grew, and the outer embankments bordering the main rivers Waal and Maas were reinforced and heightened, and developed into the ring-dyke surrounding the entire ‘waard’. The ring-dyke around the Bommelerwaard was closed in *ca.*1324 (Fig. 9.14B, derived from Bervaes and Van Tussenbroek, 2000). Until the 19th century the rivers followed their irregular pattern, and sandy islands and shallows were a common feature (cf. Fig. 7.9). Figure 9.14C shows the present-day outline of the Bommelerwaard. The rivers Waal and Maas have been straightened and regulated, and many meanders and islands have been removed. The connection between the rivers at Heerewaarden is closed by ship locks. The development of the built-up areas, towns, villages and industrial occupations is significant. In 1600 the Bommelerwaard had *ca.* 6,000 inhabitants; in 2005 *ca.* 45,000 humans live in the polder.

Figure 9.15 shows an imaginary cross section through the Bommelerwaard, following the same time sequence as in Fig. 9.14, in *ca.* AD 200 before dykes were thrown up, in *ca.*1400, with cross-dykes and village-polders, and in *ca.*2000, with the strong heightened ring-dyke surrounding the river polder. During the Roman era the entire area could be considered as floodplain: during extreme floods even the most elevated sandy outcrops were almost totally flooded. During the late Middle Ages the floodplains were gradually constricted by local cross-dykes, and finally by the ring-dyke which gave the ‘waard’ its basic outline. During the past centuries, however, the ‘waard’ was still prone to frequent flooding. The present-day outline was only reached at the end of the 20th century, after the dyke reinforcements, following the near-flood of 1995. Because the ‘waard’ was centuries ago deprived of the process of regular silting-up by the river, the difference in height between the silted-up forelands and the subsiding ‘waard’ has increased to *ca.* 2.5 m (Berendsen, 2001). Another result of the ever-increasing constrictions of the riverbed was that the difference in height between extreme high water level and low water level in the river has dramatically increased, from an estimated 1–2 m in Roman times to

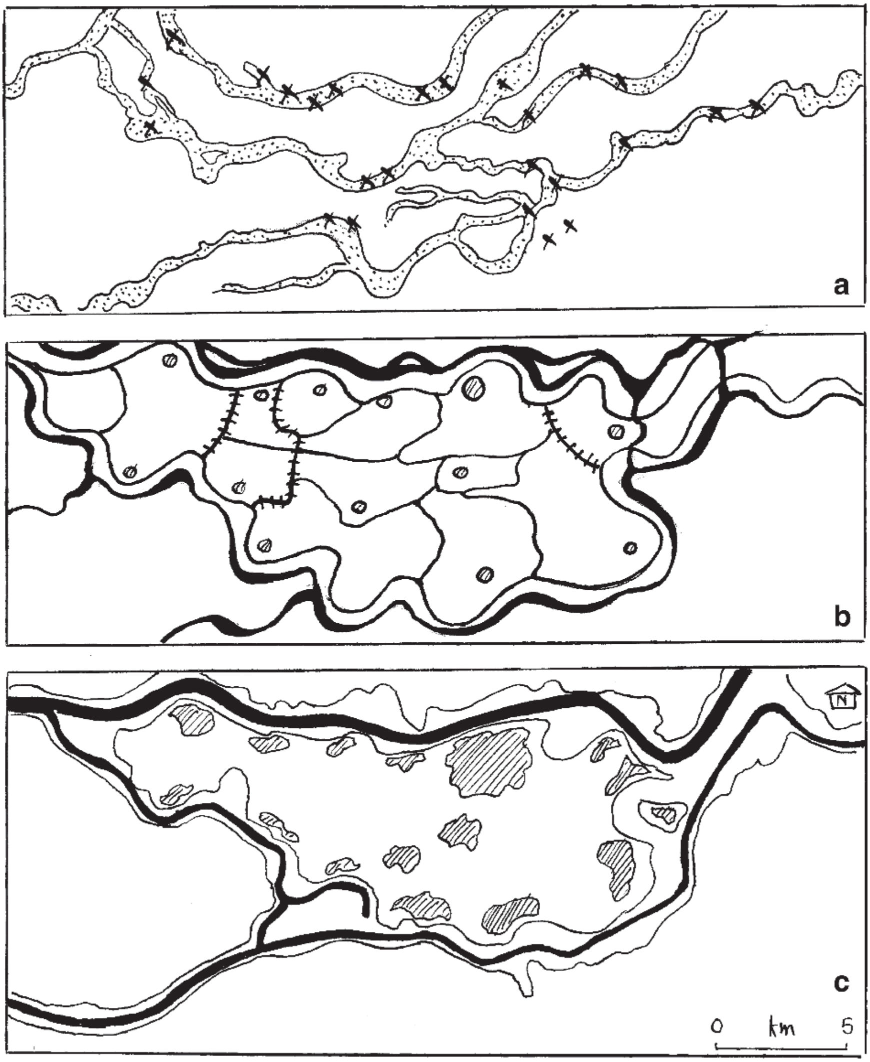

**Fig. 9.14** An imaginary map of the Bommelerwaard (**A**) in Roman times (*ca.*AD 200 AD), (**B**) in *ca.*1400 and (**C**) in *ca.*2000. (**A**) A simplified palaeogeographic reconstruction of the river floodplains of the location now called the Bommelerwaard shows natural levees and channel belts (dotted), and existing river channels, and flooded or partly flooded natural floodplains (white) (modified after Weerts and Berendsen, 1995). A number of excavations dating back to the Roman era, have been indicated with a cross (derived from Reuselaars, 2001). (**B**) Three cross-dykes ('zijdewendes') are indicated (hatched lines), presumably dating back to 800–1000. Gradually the embankments surrounding a settlement and adjoining fields ('dorpspolder'), were closed (not interrupted lines surrounding a settlement), a system presumably finished around 1100. Gradually the system of 'dorpspolders' grew, and the outer embankments bordering the main rivers Waal and Maas were reinforced and heightened and developed into the ring-dyke ('bandijk') surrounding the entire river polder ('waard'). The ring-dyke around the Bommelerwaard was closed in *ca.*1324 (derived from Bervaes and Tussenbroek, 2000). Thick black lines: meandering, interconnected rivers. Hatched: small settlements. (**C**) The present-day outline of the Bommelerwaard. Black: the regulated rivers Waal (upper river) and Maas (lower river). Hatched: built-up areas, towns, villages and industrial occupations

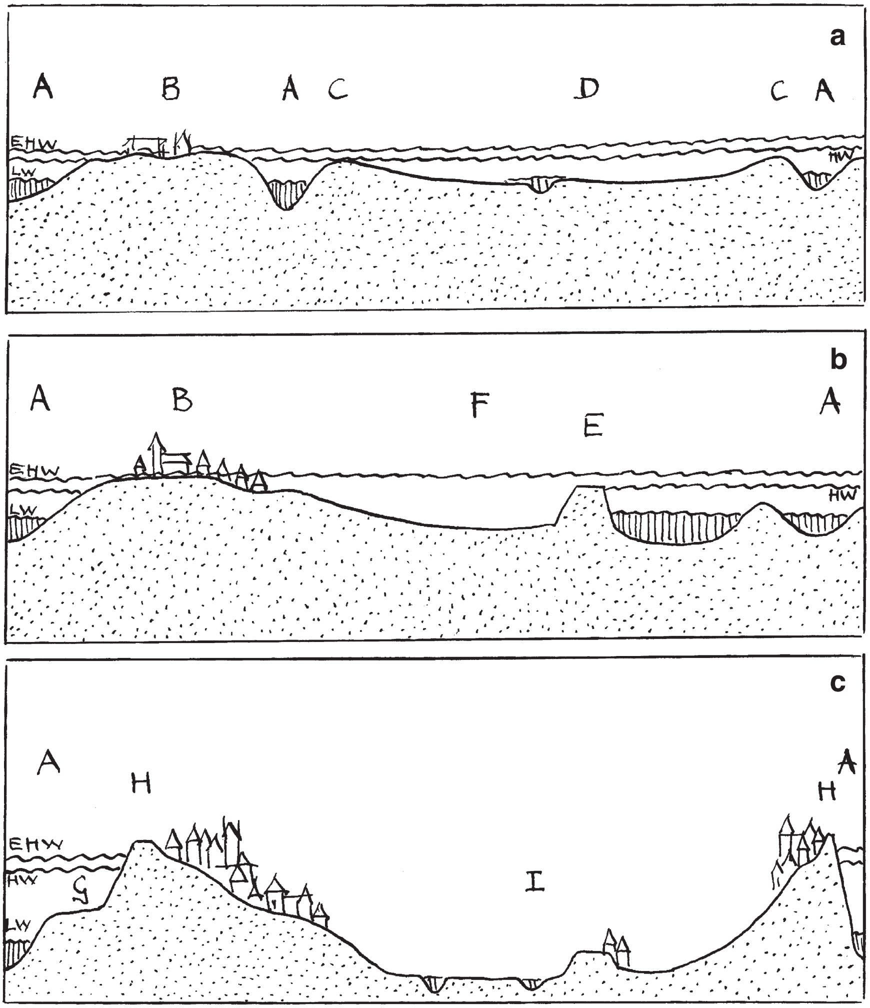

**Fig. 9.15** An imaginary cross section through the Bommelerwaard, following the same time sequence as in Fig. 9.14. (**A**) Circa AD 200 before dykes were thrown up; (**B**) *ca.*1400, when cross dykes and dikes surrounding a settlement were thrown up; (**C**) *ca.*2000, with strong heightened dykes; difference in height between the silted-up floodplains and the subsided river polder is roughly 2.5 m (Berendsen, 2001) A = active river channel; B = channel belt; C = natural levee; D = natural floodplain; E = cross-dyke; F = flood basin; G = not embanked river foreland; H = ring-dyke ('bandijk'); I = river polder ('waard'). EHW = extreme high water level; HW = average high water level; LW = low water level. The difference in height between EHW and LW has drastically increased over time. The river Waal (A) is on the left, the river Meuse (A) is on the right

9–11 m nowadays (Knaapen and Rademakers, 1990). Nowadays the 'waard' has been transformed into a 'bathtub': the chance of a dyke-breach is very small, but the effects of flooding will be disastrous.

### *9.3.4 Strong Dykes in the 20th Century*

The stone slopes of the sea dykes, as we know them nowadays, are of a rather recent date. Not before 1827 the first revetment of Vilvordian limestone was constructed in the SW Delta. Basalt was used for the first time in 1858, and in the beginning of the 20th century the first concrete slope was built. After 1953 dyke-revetment of asphalt came into use in the Delta, and this method became the usual practice in recent years (Wilderom, 1964). Owing to these variegated methods of constructing dykes, it is possible to find on one slope different kinds of substratum, connected to each other, and influenced by exactly the same ecological conditions. In such a case the substratum is the only primarily variable environmental factor, comprising a number of derived factors, such as moisture, texture and temperature. Centuries ago marine epilithic growth on the coasts of the Delta, was only possible on shells of molluscs, peat-banks and – as regards epiphytes – the leaves of seagrasses and other water plants. Epilithic biota made their proper entrance not before man began to protect the mainland against the sea by seawalls, reinforced with palisades and particularly boulders. In this way a great number of marine plants and animals could settle on the artificially constructed rocky shores of the Delta (Nienhuis, 1969; see Chapter 10).

In contrast to the sea dykes, river dykes have in living memory been intensely inhabited. These were in fact the safest places to settle in former centuries, and consequently the built-up stretches have high historic and cultural values. Small dyke houses and larger farms were often partly built in the body of the dyke, connected to drives for vehicles and stairs for persons. Backyards and front yards spread all over the slopes of the dykes, with orchards, nut trees and gardens. Dykes were used as pastures or hay fields, and industrial expansions such as brick factories and shipyards were allowed at many places. Undoubtedly, all these constructions have weakened the strength and the stability of the river dykes. Particularly in the 19th and the early 20th centuries many river dykes have been reinforced and heightened again and again, but often on the cheap. The rights of the landowners were strong and they were hardly prepared to allow the building of a new dyke on their properties; moreover, suitable clay was scarce. At many places the dykes that resulted from these actions had an acceptable height, but their profiles were too steep, their foundation was weakened by the digging of clay pits too close to the dyke, and consequently they were not strong enough to resist the pressure of ice drift or extremely high water (B. de Bruijn, oral communication).

The storm flood of 1953 prompted extensive fundamental discussions on the risk of flooding in the Rhine and Meuse basins. Instead of the trial and error approach until then, the way of reasoning was completely turned around. The level of safety demanded by society became the starting-point. On the basis of an analysis of registered river discharges and concurring water levels over a long period, possible

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Design discharge – a theoretical calculated discharge of the river, acting as a standard for the height of the main dykes along the river, guaranteeing the legally accepted degree of protection against flooding (1/1250 per year calculated for the year 2000).

future water levels and corresponding wind forces were extrapolated. From these models the ‘design discharge’ (see Note 1) for the river Rhine at Lobith, where the Rhine enters the Delta, was calculated, and derived from that data the ‘design water levels’ were decided for all stretches of dyke. All existing dykes, sea dykes and river dykes, appeared to be too low and too weak. Not a single stretch of dyke did meet the new standards, and therefore an extensive programme was developed to improve the quality of the embankments. The existing dykes were too low, often 0.5–1 m, and they were far too narrow. In most cases it was not the height of the dyke that gave problems during the execution phase, but the space demanded to construct the appropriate width. The base of an old river dyke was often only 25–30 m in width, and the new standards demanded a base width of 60–90 m (cf. Fig. 9.12). The water boards, alarmed by the negative experiences in the past, aimed at maximum safety for the population, using technological solutions: high and strong dykes, preferably as straight as possible, without buildings or trees, slightly sloping and covered with basalt, concrete or an asphalt revetment. Thousands of historic dyke houses had to be broken down, in order to execute these plans.

Following the decision to heighten the dykes along the main rivers, priority was given to the dyke reinforcement at Brakel in the Bommelerwaard (Fig. 5.5), because that dyke section of *ca.* 7 km was not reinforced after the flood of 1926. Already in 1967 it was reported that the dyke at Brakel was one of the weakest in the entire Delta Rhine basin. A consequence of the dyke reinforcement would be that 25% of all the houses in the village would be demolished (140 houses). Public participation was out of order, it were the higher authorities that decided. The dyke had to be completely rebuilt, broadened and heightened 0.5–1 m, in order to guarantee the safety standard of 1/3000 per year. The dyke improvement works were executed in the period 1972–1978, almost according to schedule. The dyke reinforcement at Brakel was nevertheless very disputed, and a wave of societal protest, against the severe degradation of this nice and historic village, heralded a change in mentality, a culture shock. The Brakel syndrome induced the erection of two state commissions on future dyke reinforcement programmes that reported respectively in 1977 and in 1993. In the meantime the execution of the Delta project in the SW Delta had the highest priority, and the dyke improvement schemes along the Large Rivers were considerably delayed. The works progressed slowly, and the societal resistance to the rigorous dyke improvement projects increased. It became more and more accepted in society that, next to the claims for safety, the natural and cultural values of the river landscape had to be taken into account also. Eventually, the rigorous standard of 1/3000 per year was abandoned, dyke reinforcements along the river Rhine with a design discharge corresponding with a flooding risk of 1/1250 per year, would be sufficient for the near future (Driessen, 2001; Driessen and Van de Ven, 2004).

From 1978 onwards these recommendations for sophisticated designs were also applied to the dykes along the river Maas, i.e. corresponding with a design discharge of 3,650 $m^3 s^{-1}$ at Borgharen (Maastricht). Flood control along the section of the river Maas without dykes, however, demanded separate solutions. The undyked section of the Maas valley is in intensive use, and contains a considerable number of towns and villages. Consequently, even moderate discharges frequently have caused damage and inconvenience to the human settlements in the riverbed. Following the severe flooding of 1995, low ring-dykes were built around the main settlements along this stretch of river. Within these defences, the risk of flooding in any given year is 1 in 50. Thus, although the ring-dykes offer much less protection than ordinary river dykes, they can substantially reduce the damage caused by moderate flood (Middelkoop and Van Haselen, 1999; cf. Chapter 5).

## 9.4 Changing Standards, Changing Risks

When dealing with a flood-prone area, the concept of risk is a central notion. Risk is defined as the probability of the occurrence of an (unwanted) event multiplied by the consequences of that event: Risk = Probability × Effect. Standards are designed by man, and they may change gradually over time, because new points of view and new technical developments may throw another light on existing 'values'. The change in accepted standards, fuelled by ecological motives, will be illustrated by the recent environmental history of the SW Delta of Rhine and Meuse. In 1953 a devastating storm flood struck the estuarine area and the tidal part of the lowland rivers: the toll was 1835 human casualties and gigantic economic damage (see Chapter 10). In 1953 the Delta was defended by dykes and seawalls that had the likely risk of being overtopped by extreme high water from the sea of 1/50 year$^{-1}$. The most recent severe storm flood that hit the SW Delta, preceding the one in 1953, was in 1906, and a cynic comment could be made that the 1953 flood was statistically in time.

The prime objective of the policy makers after the 1953 flood was to guarantee safety for the human population in 1978 at a risk level of 1/4000 year$^{-1}$ in the rural SW Delta, and 1/10,000 year$^{-1}$ in the densely populated and economically paramount Central delta (Delta Act 1957). The objective remained unchanged until the end of the project, but the final year to reach this target was shifted 10 years, to 1987, mainly induced by ecological motives. The original solution to the continuous threats from the North Sea was to close the estuaries from the sea by high seawalls, which led consequently to the change of the saline estuaries into basins filled with – then extremely polluted – river water from the Rhine and Meuse. In the course of the project additional ecological objectives, dealing with the preservation of ecological values, especially the integrity of the 'unique' (as far as the Delta was concerned) features of the tidal estuarine ecosystems, were introduced, followed later by arguments to change non-profitable agricultural land into nature reserves ('nature development'). The closing scheme was changed several times, and finally not the three originally envisaged freshwater basins were executed, but one freshwater basin, filled with polluted water from the Rhine–Meuse, one saline water basin and one regulated tidal estuary, to be closed by a storm surge barrier at the incidence of extreme high water levels. Roughly until 25 years after the storm flood of 1953 the risk of being flooded by the sea remained at 1/50 year$^{-1}$. Partial reinforcement of the dykes around the estuaries in the 1970s decreased the risk to 1/500 year$^{-1}$. The original objective for the SW Delta was finally reached in 1987: safety for human beings at a risk of flooding of 1/4,000 year$^{-1}$. The legally agreed safety standard for the Central Delta, a flood risk of 1/10,000 year$^{-1}$, was jeopardised for another 10 years: the coping-stone of the Delta project the Maeslantkering in the Nieuwe Waterweg came only into use in 1997. In between 1978 and 1996 the standards set by the Delta Act of 1957 have been violated and, moreover, the objectives changed, induced by the growing public awareness with regard to the safeguarding of the natural environment.

The Delta Act of 1957, following the severe storm flood of 1953, was meant to protect the human population and their goods in the Delta against flooding from the sea. Not only marine storm floods caused problems, but irregular river floods called for ever-higher dykes. Two river floods that reached a comparable level (*ca.* 12,000 $m^3 s^{-1}$) to the one in 1926 occurred on the Rhine basin in the years 1993 and 1995. In January–February 1995 prohibitive evacuation took place of 250,000 people, living in the Rhine basin at places where the risk of being flooded was still 1/50 year$^{-1}$. Stimulated by a sense of urgency, already in April 1995 the Delta Act Large Rivers passed parliament. The objective was to guarantee safety for the Large River's population in 2000 at a risk of being flooded of 1/1,250 year$^{-1}$, without jeopardising the ecological values. In the period 1996–2000 roughly 450 km of river dykes have been reinforced and heightened from a safety level of 1/50–1/500 year$^{-1}$ to a safety level of 1/1,250 year$^{-1}$. The towns and villages on the non-embanked parts of the Maas were provided with levees, mainly small walls of brickwork, guaranteeing a safety standard of 1/50–1/250 year$^{-1}$. In 2000 the project was finished: the larger part of the 'waarden' obey the 1/1,250 year$^{-1}$ safety standard now, some smaller parts have a standard of 1/500 year$^{-1}$ or lower. This illustrates again changing standards over time: not only were secondary, ecological objectives added, but also was the primary objective, safety for human beings at a flooding risk of initially 1/3,000 year$^{-1}$ – later changed to 1/1,250 year$^{-1}$ – violated for several decades.

There is more. The near-floods of 1993 and 1995 have biased the existing models on which the Delta Act Large Rivers was based: the 'design discharge' calculated for the year 2000, had to be raised from 15,000 $m^3 s^{-1}$ to 16,000 $m^3 s^{-1}$, heralding another round of flood alleviating measures. But the process of heightening and strengthening of the dykes cannot be continued forever. The risk of being flooded behind the massive river-embankments, separating the low-lying, ever-subsiding and compacting inhabited 'waarden' from the higher situated silted-up river forelands, although small, is nevertheless a reality. And this counts even more for the polders in the SW Delta. Risk calculations for 1953 compared to those for 2005 indicate that the probability of a disaster has declined indeed, but that the potential effects have increased dramatically: more people and infrastructure than in the past will now be damaged by a major river flood or storm flood (Smits et al., 2006).

## 9.5 Conclusions

- The story of ‘floods and dykes’ is a story of endless misery. Literally hundreds of storm surges and river floods have ravaged the Delta in the course of the centuries, but the inhabitants did not give up, and eventually succeeded in greatly expanding their country, while ‘keeping their feet dry’.
- Floods before 1400 have inadequately been documented. The literature is still by no means reliable as far as floods in the 15th and 16th centuries are concerned.
- Only since an ordnance level (NAP) has been introduced at the end of the 19th century, the height of storm surges can be measured more or less objectively. But high water levels are not conclusive in case a flood strikes; the strength of a dyke may fail for other reasons (e.g. piping), and it is not always springtide during a disastrous storm flood.
- Historically, there is a fundamental difference between the periods before and after the construction of the dykes. ‘Transgression of the sea’ is a valuable concept for the period for which there are no written sources, but it loses its significance when dykes were built, and written documentation had started.
- There is no evidence for the repeatedly postulated relationship between storm surges and river floods, or between storm surges and milder, ice-free winters.
- In the SW Delta, the great storm surges generally hit the eastern parts of the estuaries more severely than the islands situated closer to the North Sea. This is explained by the great driving up of the water eastwards when gales were blowing from between southwest and northwest.
- The damage caused by the storm flood of 1682 was described in detail by contemporary authors. This is the first time in history that extensive and detailed data have been published, polder by polder.
- In the 1730s the exotic shipworm ruined in short time most wooden dyke revetments along the coast of the Delta, causing numerous dyke breaches and flooding. The vulnerable vertical sheet-pilings were replaced by gently inclining dykes, in order to break the force of the waves.
- The majority of great river floods in the Delta were a result of the formation of ice dams in the rivers, were meltwater could accumulate and damage to the dykes was done by ice-floes.
- After 1880 no dyke breaches caused by ice dams have occurred. After 1850 the large rivers in the Delta have been ‘normalised’, guaranteeing an improved discharge of ice and water.
- The documentation about the storm floods of 1570 and 1682, allows a prudent comparison between these historic floods and the recent disaster of 1953. The once-in-a-100-years flood of 1953 was not an exception, and the dykes in the SW Delta, with their 1/50 years safety standard, were obviously not designed for the forces unchained in 1953.
- The storm flood of 1953 prompted extensive discussions on the risk of flooding in the Rhine and Meuse basins. Instead of the trial and error approach until then, the level of safety demanded by society became the starting-point. From then on the theoretically calculated design discharge was used.

- The most recent reinforcement of the river dykes, following the near-floods of 1993 and 1995, enhanced the safety level of 1/50–1/500 year$^{-1}$ to a safety level of 1/1,250 year$^{-1}$. The non-embanked Maas was provided with levees, guaranteeing a safety standard of 1/50–1/250 year$^{-1}$. Next to the primary objective, safety for human beings, secondary, ecological objectives were obeyed.

# Chapter 10
# Human Intervention in the SW Delta

## 10.1 Introduction

The flooding disaster of 1953 induced the Delta Plan. Under the motto ‘this never again’ (1,835 human casualties; uncountable damage to human goods and chattels) the inlets of the estuaries in the southwestern Netherlands had to be closed by massive sea walls. The Delta Act was already implemented in 1957, and the estuaries were closed, one by one in the 1960s and in the 1970s. In 1986 the construction of the storm surge barrier in the mouth of Oosterschelde estuary was finished. It is recognised that the decision, following the flood of 1953, to build a large, solid and inflexible ‘wall against the sea’, when placed in the cultural context of the time, was understandable. Ecological motives did not play any role in the original decision-making process, and from the very beginning numerous long-term environmental problems asked for mitigating solutions. The Delta project revealed a paradox: on the one hand it greatly improved the accessibility of the former isolated islands, and led to a booming development of water sports and water-related recreation facilities. On the other hand the unique estuarine gradients and ecological zoning patterns were annihilated, and changed into non-resilient marine and freshwater compartments sealed off by large sea walls and locks.

The aim of this chapter is to cover some aspects of the recent environmental history of the SW Delta. The main accent is on the ecological changes induced by the Delta project after the storm flood of 1953. The closures of the estuarine inlets have also greatly influenced the hydrological and ecological processes in the rivers proper. This paper will start with a reconstruction of the characteristic tidal gradients (horizontal) and zoning patterns (vertical) recognisable in the early decades of the 20th century. The well-studied distribution of hundreds of benthic macro-algae will be used as an example.

The environmental history of estuarine and marine ecosystems (North Sea, Wadden Sea, SW Delta) should be the objective of a separate book. An initiative in 2004, a workshop on the ‘Ecological history of the Wadden Sea: 2,000 years of human-induced change in a unique coastal ecosystem’, was a good start (Lotze and Reise, 2005). The organisers made the statement that a vision of ‘what was natural in the Wadden Sea’ is completely lost in the living memory’ (www.awi-bremerhaven.de).

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I am sure the same counts for the SW Delta. Just as in the Central Delta and Large River basins the landscape and the flora and fauna have been exploited intensively. Numerous waterfowl were caught in decoys and under nets. Fowling, seal hunting (more than 10,000 seals lived in the SW Delta around 1900) and intensive fishing with various gear and nets was common use. Wild mussels and periwinkles were sampled, glasswort and leaves of sea aster were cut as vegetables, large seaweeds and other organic debris washed ashore were used as fertiliser on the fields. The picking up of eggs was lucrative, and specific occupations existed such as the management of artificial breeding places for terns, with the aim to collect as many eggs as possible (see Chapter 19) (Beijersbergen et al., 1980).

A separate section will deal with the river Scheldt, not shared under the central focus of this book. In the SW Delta the waters of Rhine, Meuse and Scheldt have flown together since times immemorial (Chapters 2 and 3). And, moreover, the Westerschelde is the only complete estuary left in the SW Delta, though severely manipulated and polluted.

## 10.2 Estuarine Gradients and Zoning Before 1950

From prehistoric times onwards land use in the SW Delta was connected with the exploitation of the raised bog resources, the cultivation of gained land, and the subsequent loss during storm floods. Since the Middle Ages man reclaimed salt-marsh areas and transformed those into agricultural land. From times immemorial embankments to protect lives and properties were thrown up. These earthen constructions were gradually reshaped and adapted. But irregularly occurring storm floods broke the man-built sea walls and recaptured parts of the gained land. The ancient stone revetments were sloppy constructions, consisting of irregularly piled up blocks of stone, with holes in between the boulders. A large variation of natural stone was used, together with wooden poles and palisades. Breakwaters and groynes were built at vulnerable places, the remainders of old dilapidated dykes were left to their fate, and under their lee small salt marshes developed. Along the coastline many small harbours with wooden jetties were built. In short, a large variation of small landscape elements, and microhabitats developed in the course of some hundreds of years (Wilderom, 1964).

### *10.2.1 Gradients and Zoning in the SW Delta*

The typical geomorphology of the SW Delta system between 1900 and 1950 is shown in Fig. 10.1. The area of roughly 100 by 100 $\text{km}^2$ was characterised by a considerable number of small and larger islands and peninsulas, deep and shallow tidal channels, extensive intertidal sand- and mudflats reaching up to 20 km off the coast, vegetated coastal plains, salt marshes and brackish marshes above mean high

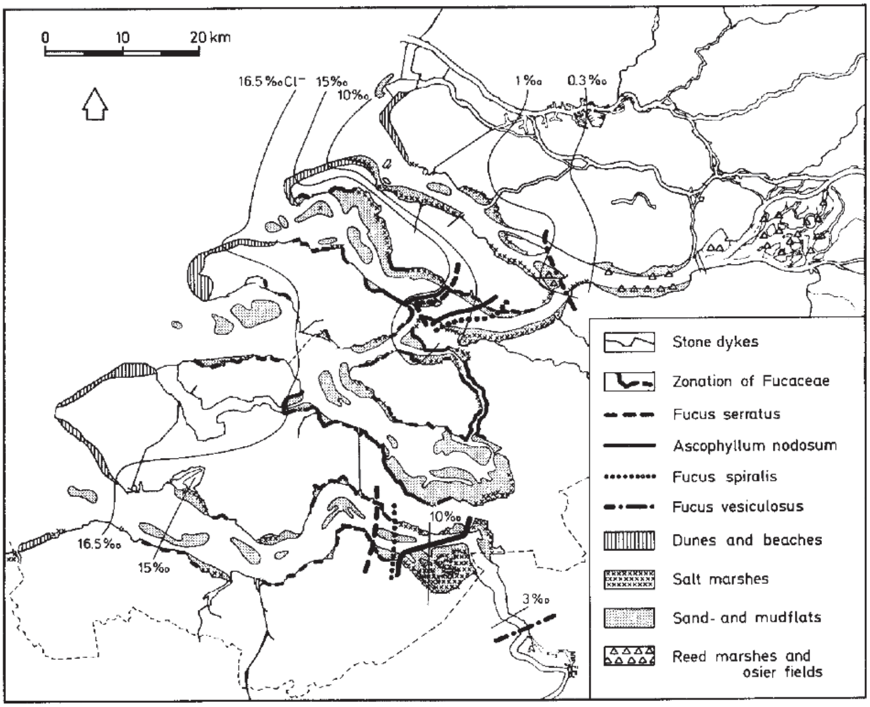


**Fig. 10.1** Hard and soft substrates in the SW Delta of the rivers Rhine, Meuse and Scheldt between *ca.*1900 and 1970, and the distribution limits of dominant Fucaceae. Isohalines at midtide, at average river discharge are indicated; these isohalines relate to the period 1964–1967 and were derived from Peelen (1967) (Nienhuis, 1975, 1980)

water. The most land inwards parts of the estuaries, where the rivers Rhine, Meuse and Scheldt enter the delta, were characterised by freshwater tidal marshes and willow coppice.

To illustrate the large habitat diversification and the distribution of species in the estuarine SW Delta before 1950, some ecological gradients and zonation patterns that existed along these estuaries will be highlighted. My case study deals with the distribution and ecology of benthic macro-algae. Centuries ago benthic algal growth in the SW estuaries was only possible on mudflats and salt marshes, while the only solid substrata consisted of shells of molluscs, peat-banks and – as regards epiphytes – the leaves of sea grasses. The epilithic algal vegetation made its entrance not before man began to protect the mainland against the sea by sea walls, reinforced with palisades and boulders. In this way a great number of algae could settle on the artificially constructed rocky shore. Systematically collected data from the 19th century and before are scarce (e.g. Van den Bosch, 1846, 1851). I will use data collected by myself between 1966 and 1975 in the framework of my Ph.D. study (Nienhuis, 1975, 1980). Quantitative sampling was done all over the Delta area of Rhine, Meuse and Scheldt, randomly spread over the year, both from tidal and inland localities (for details see Nienhuis, 1975, 1987). Benthic species of the following taxonomic groups were identified: *Cyanophyta* (= Cyanobacteria), *Rhodophyta*, *Haptophyta*, *Xanthophyceae*, *Phaeophyceae*, *Chlorophyceae* (nomenclature according to Parke and Dixon, 1976). *Bacillariophyceae* (diatoms) were omitted, although they play a significant role among the benthic algae. The delineation of communities of higher plants in salt- and brackish water is according to Beeftink (1966).

In my case study the Venice classification of brackish waters (Anonymous, 1959) will be followed: euhaline zone: 22–16.5‰ $Cl^-$; polyhaline zone 16.5–10‰ $Cl^-$; mesohaline zone 10–3‰ $Cl^-$; oligohaline zone 3–0.3‰ $Cl^-$; limnetic zone (freshwater): < 0.3‰$Cl^-$. Tidal zones will be defined as: supralittoral zone – from upper limit of salt spray to approximately mean high water; eulittoral zone – from approximately mean high water to mean low water at springtides; sublittoral zone – from mean low water at springtides to lowest limit of macro-algal growth.

#### 10.2.1.1 Gradients and Zoning of Benthic Algae on Hard Substrates

Hard substrates in the tidal area comprise the artificial rocky shores formed by dyke revetments, piers, breakwaters, quays and jetties. Exposure to wave action, salinity of the water and the physical nature of the substrate are important ecological factors responsible for the distribution of benthic algae. For practical reasons the tidal waters in the SW Delta have been divided into seven sections (Fig. 10.2). The boundary lines between these sections roughly coincide with the isohalines of

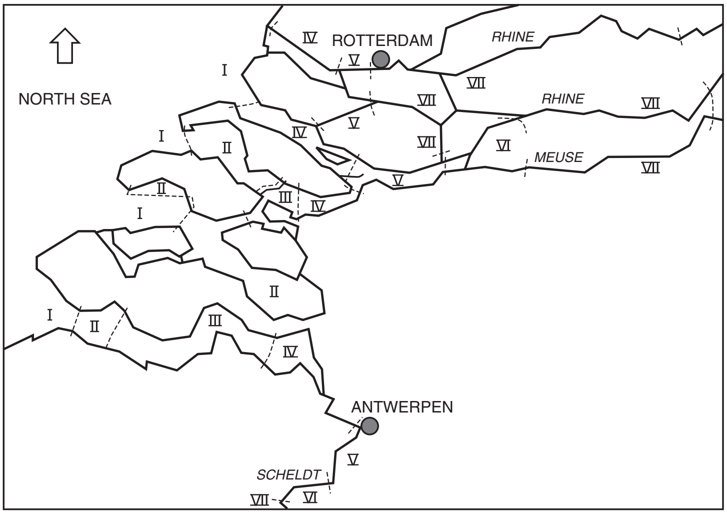


**Fig. 10.2** The seven sections into which the tidal waters in the SW Delta have been divided. For explanation see text (Nienhuis, 1975, 1980)

respectively 15 (between II and III), 10 (between III and IV), 1 (between IV and V) and 0.3‰Cl⁻ (between V and VI–VII). Each section is characterised by its exposure, salinity and the nature of the amount of sediment deposited on the hard substrate. In each of the sections a number of epilithic algal communities have been distinguished; the positions of the dominant species have been depicted in Fig. 10.3.

Section I. Extensive stretches of the North Sea coast of the SW Delta consisted of exposed sandy beaches. At some places dykes covered with stones were present. The inlets of Westerschelde, Oosterschelde and Grevelingen were also bordered by stone dykes. A number of epilithic algal communities dominated by green algae and *Porphyra umbilicalis* could be distinguished. Wooden jetties and rows of palisades along the coast of the North Sea and in the inlets of the sea-arms bore an algal vegetation dominated by green algae and blue-green algae.

Section II. The marine algal vegetation on the dykes along the Oosterschelde and Grevelingen was more diversified than in any other locality in the SW Delta. The water had a high, rather constant salinity. The dyke-slopes were sheltered as regards their exposure to wave action and only little sediment was deposited. About 130 species have been identified in this area, distributed over 20 communities. On extremely sheltered limestone dyke-slopes a rich zonation pattern could be distinguished: it consisted from its upper to its lower limit of the following zonal communities, dominated by (1) Lichenes vegetation, (2) *Entophysalis deusta*, (3) *Blidingia minima*, (4) *Pelvetia canaliculata*, (5) *Fucus spiralis*, (6) *Ascophyllum nodosum*, (7) *Fucus serratus*, (8) *Polysiphonia* species and *Ceramium rubrum*, (9) *Laminaria saccharina* and (10) *Codium fragile* (Fig. 10.3). Wooden jetty poles and palisades harboured an algal vegetation deviating from the growth on stone

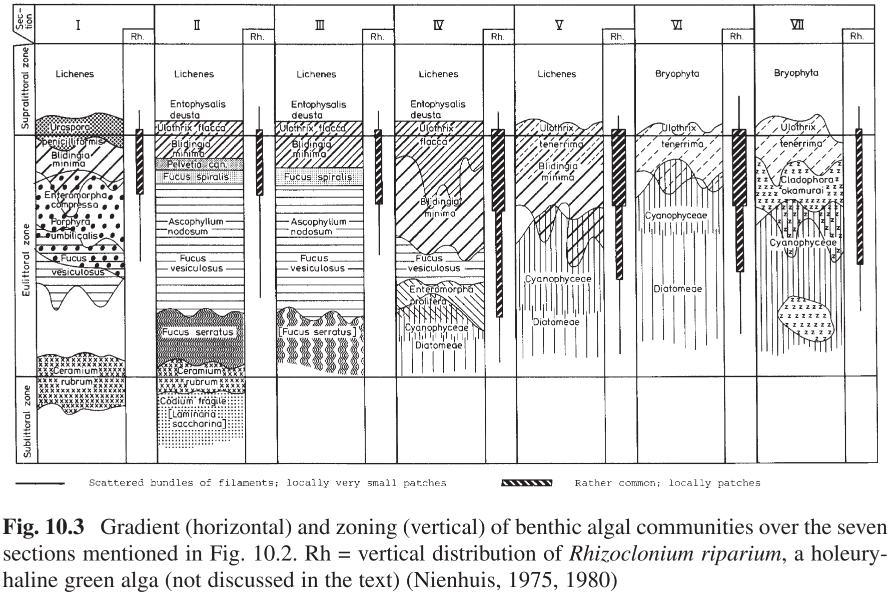


**Fig. 10.3** Gradient (horizontal) and zoning (vertical) of benthic algal communities over the seven sections mentioned in Fig. 10.2. Rh = vertical distribution of *Rhizoclonium riparium*, a holeuryhaline green alga (not discussed in the text) (Nienhuis, 1975, 1980)

dykes. The zonation pattern of the large brown algae was lacking, and consequently *Blidingia minima* was able to overgrow almost the entire upper half of the eulittoral zone.

Section III. The algal vegetation in section III was an impoverished one as compared with that in section II, and this was due to the more outspoken estuarine conditions such as the low and fluctuating salinity of the water (average 10–15‰ Cl⁻). Fifty-six species have been distinguished distributed over 11 communities. The euryhaline communities growing in the supralittoral zone and in the upper parts of the eulittoral zone in section II were also represented in section III. The communities dominated by *Ascophyllum nodosum* and *Catenella repens* flourished well. The communities in the lower parts of the eulittoral zone and the sublittoral zone were only fragmentarily represented. In addition to the low and fluctuating salinities the lack of suitable stony substrates caused this poverty. Most of the available boulders were covered by a thin layer of sediment, which prohibits the settlement of epilithic algae.

Section IV. Here the largest salinity fluctuations occurred in the course of the year. The average chlorinity values varied between 10 and 1‰Cl⁻. Consequently, marine, relatively stenohaline algal communities did not occur in this section. Only euryhaline communities covered the dykes in the supralittoral and eulittoral zones. Some freshwater communities joined these assemblages in the most land inward parts of section IV. A *ca.* 0.5 mm thick layer of silt covered the sheltered dyke-slopes. In many localities an algal mat overgrew the dyke that gradually decreased in cover when reaching lower levels. In the lowermost part of the eulittoral zone and in the sublittoral zone silt was transported intensively during each tidal cycle. Consequently, the substrate was instable and benthic algal growth of some importance was excluded. The water was heavily loaded with silt particles and this prevented the sunlight to penetrate into the sublittoral zone. This hampered the development of algae. On all stone and wood substrates a thin layer of silt was deposited, which played a major role in the settlement and maintenance of the algal vegetation. Hardly any differences could be observed between the algal growth on a stony substrate and on a wooden pole. Green and blue-green algae came strongly to the fore. Only 49 algal species have been identified, distributed over 10 communities. The community dominated by *Ascophyllum nodosum* was replaced by stunted forms of *Fucus vesiculosus*, which reached here its upstream boundary (Fig. 10.1). The epilithic, widely distributed and highly characteristic community dominated by *Blidingia minima ramifera* covered the eulittoral zone, unless too much silt has been deposited; this community occurred throughout the year. Owing to the increased sedimentary deposits the number of epilithic species decreased again, especially in the lower eulittoral and sublittoral zones. Diatoms and blue-green algae grew on the silt; these species were not restricted to the stone dyke-slopes but they also occurred on mud flats, salt marshes, etc.

Section V. Gradually mosses took the position of the epilithic lichens in the supralittoral zone, often accompanied by phanerogams and green algae. Marine algal species were lacking. *Fucus vesiculosus* was absent. Only (hol-) euryhaline green and blue-green algae and freshwater algae, able to live under slightly brackish conditions (*Ulothrix* spp., *Cladophora okamurai*), have been encountered. In total 24 species have been observed distributed over 6 communities (Fig. 10.3). The most characteristic community in the upper half of the eulittoral zone was dominated by *Blidingia minima ramifera*. Land inwards, where the influence of freshwater increased, this vegetation type became less common and dense. In localities without the dominance of *Blidingia* the *Ulothrix tenerrima* community often covered the upper half of the eulittoral zone. The *Ulothrix* growth was sometimes ephemeral on bare substrates, but sometimes almost permanent. During hard winters and dry summers the *Ulothrix* community disappeared almost completely; it bloomed in late winter and spring.

Section VI. Fresh river water (average chlorinity lower than 0.3‰$Cl^-$ flew through the Biesbosch and a considerable amount of silt was transported. The benthic algal vegetation was confined to the lower parts of the supralittoral zone and the eulittoral zone, and it consisted of 25 relatively euryhaline green and blue-green algal species distributed over 8 vegetation units, which were almost identical to those that were encountered in segment V. In the eulittoral zone Cyanophyceae and Diatomeae dominated. Soft silt was present everywhere, and numerous transitions existed between hard substrates covered with a thin film of silt and stone and wood covered with a thick sediment deposit of several centimetres.

Section VII. The freshwater tidal area of the major rivers was characterised by euryhaline green and blue-green algae and a small number of strictly freshwater species. A number of 31 taxa have been identified, distributed over 10 communities. The communities distinguished in the Biesbosch much resemble those in section VI: Bryophyta vegetation, *Ulothrix tenerrima* community, *Microcoleus vaginatus* community, *Vaucheria* species community and Cyanophyceae-Diatomeae vegetation.

The distribution pattern of benthic algal communities on hard substrates has been related to three macro-gradients in the environment: (1) exposure to wave action: section I is (semi-)exposed, sections II to VII were sheltered; (2) the salinity of the water decreased gradually from the coastal marine environment, via the brackish estuaries into the freshwater tidal area; (3) the amount of sediment, deposited on the dyke-slopes, increased land inwards; in the freshwater tidal areas almost all hard substrates were covered with a layer of silt.

The most striking phenomenon on dyke-slopes was the zoning pattern of large fucoid algae (Figs. 10.1 and 10.3). On semi-exposed dykes along the coast of the North Sea and in the mouths of the sea-arms the zonation of Fucaceae was absent, except in sheltered localities like harbours. Along the sheltered estuaries proper the embankments were overgrown with a characteristic zonation. Further inland the fucoids disappeared, one after another, as a result of the decreasing salinity. *Fucus serratus*, living in the lower eulittoral zone, occurred down to 12–13‰$Cl^-$. *Ascophyllum nodosum* and *Fucus spiralis* were roughly limited by the 10‰$Cl^-$ isohaline. *Fucus vesiculosus* is an euryhaline species that went as far upstream as the 1‰$Cl^-$ isohaline.

The numbers of algal species found in each section showed large differences (Fig. 10.4). The highest numbers were found in the Oosterschelde and Grevelingen (section II). Upstream the number of benthic algal species diminished sharply:

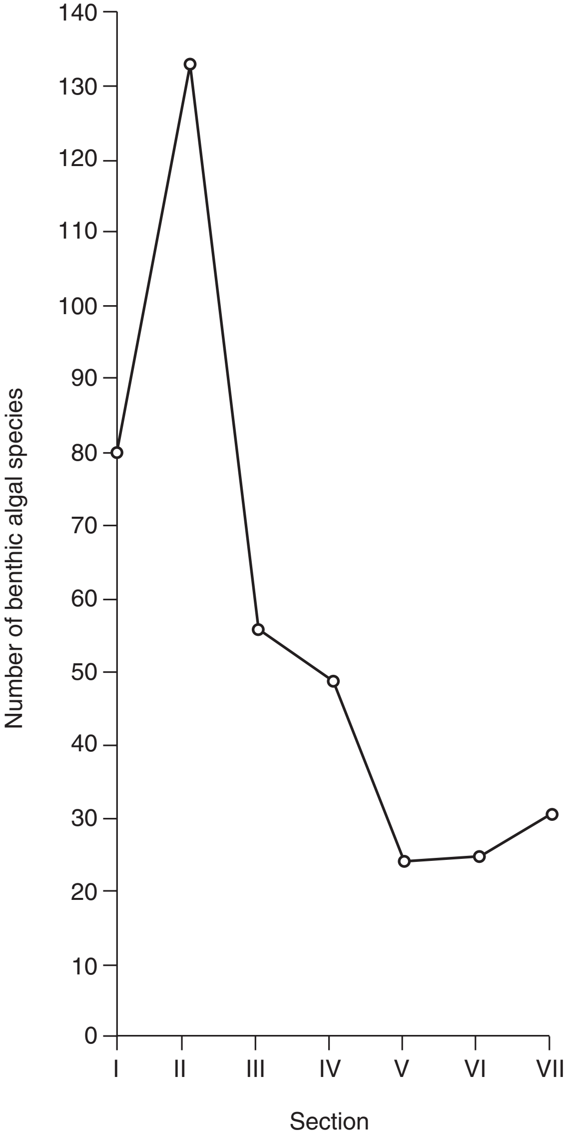


**Fig. 10.4** Number of benthic macro-algal species on hard substrates occurring in the seven sections mentioned in Fig. 10.2. The brackish-water minimum is located in section V (Nienhuis, 1975, 1980)

between 10‰and 15‰$Cl^-$ a reduction of more than 50% occurred, which meant that a large part of the algae was not able to withstand low and fluctuating salinities. Large fluctuations in salinity, characteristic for section IV did not coincide with a large decrease in the number of species. The species number was at a minimum in the oligohaline Hollands Diep and Westerschelde (section V); here species occurred that penetrated from the marine environment into this slightly brackish area (a.o. *Rhodochorton purpureum*, *Hildenbrandia prototypus*, *Fucus vesiculosus*, *Urospora penicilliformis*, *Ulothrix flacca*, *U. pseudoflacca*, *U. subflaccida*, *Blidingia marginata*, *Ulvaria oxysperma* and a number of blue-green algae), further species which inhabit the complete salinity range form sea-water into freshwater (a.o. *Rhizoclonium riparium*, *Blidingia minima*, and several blue-green algae), and species which have their main distribution in freshwater, with only a slight tolerance for brackish water (a.o. *Cladophora okamurai*, *Ulothrix tenerrima*, *U. variablis*, *U. oscillarina*). In the freshwater tidal area (sections VI and VII) the number of freshwater species did not rise significantly.

The salinity of the water was not the only responsible factor for the distribution pattern in the meso- and oligohalinicum and in the freshwater tidal area. The dyke-slopes in these sections were covered with an instable layer of silt, and therefore only a few species were able to grow on these mobile river alluvia. Most species were concentrated high up in the intertidal belt because of the obvious unsuitability of the substrates in the lower parts of the intertidal belt. The combination of current strength and mobility of the substrate inhibited algal growth in deeper water. Besides the factors mentioned it is reasonable to assume that diminished transparency, strong eutrophication and pollution of the water kept down the diversity of the algal flora in the lower reaches of the rivers. Along the North Sea coast and in the mouths of the estuaries the number of marine algal species was notably lower than in the Oosterschelde. The salinity of the water did not act as a limiting factor, but the composition of the substrate and exposure to wave action did. The sea coast is built up of instable sand beaches on which algal growth is hardly possible. Moreover, tidal currents, wave action and scouring sands prevented the dyke-slopes from being overgrown by benthic algae.

#### 10.2.1.2 Brackish Water Minimum in Species Diversity

The distribution of marine algae over the entire estuarine range of a river has been examined in many areas in western Europe, and the hypothesis of the 'brackish-water minimum' (Remane, 1934 and Remane and Schlieper, 1971) offers a good explanation for the changes in diversity along this gradient. According to Gessner and Schramm (1971) evolutionary reasons rather than others may explain the reduced species diversity in brackish waters: In the course of millions of years, aquatic organisms have adapted to sea-water on the one hand, and to freshwater on the other. In contrast to seawater and freshwater habitats, brackish waters are ephemeral, appearing and disappearing so rapidly over geological time spans that there is insufficient time for adjusting to, and populating such new environments. Newly formed brackish waters challenge potential immigrants physiologically and force them to adapt to aberrant salinity conditions. Hence the first immigrants of the new brackish water areas are euryhaline species. Presumably speciation in brackish waters is so slow that it is not only beyond human observation but also makes hardly any progress during the ‘lifetime’ of a given brackish-water system. Wolff (1973) studied the distribution of the benthic macrofauna along the estuaries in the SW Delta, and he noted a significantly decreasing number of species along the salinity gradient, hence confirming the brackish-water minimum hypothesis.

The hypothesis of the ‘brackish-water minimum’ of Remane could be confirmed by the distribution pattern of the benthic green, brown, red and blue-green algae in the estuaries in the SW Delta. Stream upwards of the brackish-water minimum, however, the number of freshwater algae showed only a slight increase, attributable to mobility and unsuitability of the substrate, tidal movements, current strength, diminished transparency, eutrophication and pollution of the river water. A limitation is that only the river channel has been investigated by me, and it might be assumed that when stagnant or semi-stagnant habitats (oxbow lakes; cut off channels) were added to the survey, the number of freshwater species would have been considerably higher. It might also be that water pollution has decreased the number of freshwater species: during my survey the water of the Rhine entering the SW Delta was severely polluted, and oxygen concentrations reached only values of 30–40%. The water of the river Meuse, which mainly fed the Biesbosch and Hollands Diep had a better quality with oxygen concentrations of 70–80% (Contact-Commissie voor Natuur-en Landschapsbescherming, 1972). Non-polluted stagnant or semi-stagnant freshwater systems or even brackish waters (like parts of the Baltic area), which are fringed by reed and rushes and with rooting, submerged water plants, harbour a multiple of the multicellular algal species growing along the channels of Rhine, Meuse and Scheldt (Waern, 1952).

An objection might be that my data (Nienhuis, 1975) do not represent a full baseline study, because during my surveys (1966–1973) the Delta project was already in full swing, and this might have changed some environmental factors (e.g. turbidity and sedimentation) particularly in the northern brackish part of the Delta.

#### 10.2.1.3 Gradients and Zoning of Benthic Algae on Soft Substrates

The surface area of the sediment substrates available to benthic algal growth in the SW Delta largely exceeds that of hard substrates. The soft intertidal substrates can be divided into a number of habitat types (Fig. 10.1): (1) Eulittoral and supralittoral beaches and sand banks in front of dune ridges along the North Sea coast, exposed to wave action. The sand is almost continuously in motion and hence the benthic algal growth is scarce. (2) Sand- and mudflats in the sublittoral and eulittoral zones of the estuaries. In the relatively sheltered euhaline and polyhaline Oosterschelde and Grevelingen the extensive sand- and mudflats consisted of sediment, ranging from coarse grained sand to silt. The macrophyte communities distinguished were dominated by *Zostera* species (*Zostera noltii* and *Z. marina*), *Enteromorpha* species (e.g. *Enteromorpha prolifera* and *E. linza),*and at lower eulittoral and sublittoral spots on mussel banks *Ulva* species, e.g. *Ulva rigida* and *U. lactuca* together with a dwarf form of *Fucus*, *Fucus vesiculosus* f. *mytili*. On sand- and mudflats in the meso-, oligohaline and freshwater tidal areas the most conspicuous macro-algae were *Vaucheria* species (e.g. *Vaucheria compacta*), able to settle on instable silt. (3) Salt marshes, including brackish marshes, brackish pastures ('gorzen'), and beach plains in the upper eulittoral and supralittoral zones of the euhaline, polyhaline and mesohaline sections. (4) Reed marshes and osier fields in the eulittoral and supralittoral zones of the oligohaline and freshwater sections of the estuaries. Habitats (3) and (4) are mainly dominated by gradients of higher plants communities. The polyhaline salt marshes show a clear zoning of marine algae in between the higher plants (Fig. 10.5). The mesohaline and oligohaline marshes have a less conspicuous algal zonation, mainly dominated by green algae and blue-greens.

In Fig. 10.5 a number of integrated phytosociological units have been distinguished, (1) the Spartinetum anglicae in the eulittoral zone, (2) the Puccinellion maritimae in the lower supralitoral zone and (3) the Armerion maritimae in the upper supralittoral zone (cf. Beeftink, 1966).

1. The highest parts of euhaline and polyhaline mud flats were occupied by the Spartinetum anglicae with mono-cultures of *Spartina anglica* and *Salicornia europaea*, widely distributed communities, covering large areas of the salt marshes. Dominant benthic algae were a loose-lying dwarf form of *Fucus*

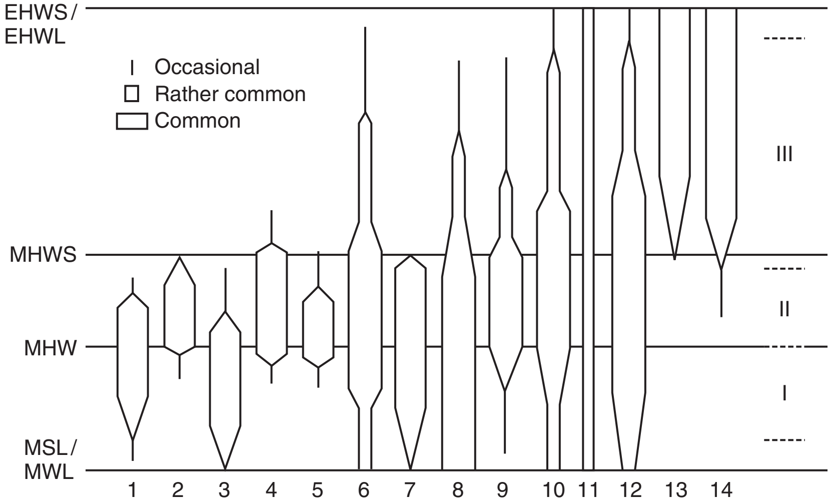


**Fig. 10.5** Vertical distribution and abundance of dominant and frequently occurring benthic algal species or species-groups in the polyhaline salt-marsh environment of the SW Netherlands. 1 = *Fucus vesiculosus* f. *volubilis*; 2 = *Bostrychia scorpioides*; 3 = *Vaucheria subsimplex* + *V. velutina*; 4 = *Vaucheria coronata*; 5 = *Vaucheria intermedia*; 6 = *Ulothrix* species; 7 = *Blidingia minima*; 8 = *Enteromorpha* species; 9 = *Percursaria percursa*; 10 = *Rhizoclonium riparium*; 11 = *Schizothrix calcicola*; 12 = *Microcoleus chthonoplastes* + *Lyngbya aestuarii*; 13 = *Nostoc* species; 14 = Haptophyceae. MSL = mean sea level (*ca.* NAP) in tidal area; MWL = mean water level in non-tidal area; MHW = mean high water level in tidal area; MHWS = mean high water level at springtides; EHWS = extreme high water level at springtides; EHWL = extreme high water level in non-tidal area. Approximate vertical distribution in the tidal area of (I) Spartinetum anglicae, (II) Puccinellion maritimae, (III) Armerion maritimae (Nienhuis, 1987)

*vesiculosus*, viz. *Fucus vesiculosus* f. *volubilis*, a complex of mat-forming *Vaucheria* species, and the suboptimal occurrence of a number of green algae.

2. The general salt-marsh vegetation, the Puccinellion maritimae had its most luxuriant development in the eu- and polyhalinicum, between mean high water and mean high water spring. Common species of higher plants were *Puccinellia maritima*, *Aster tripolium*, *Suaeda maritima*, *Limonium vulgare*, *Triglochin maritima*, *Plantago maritima* and *Spergularia media*. The communities were dominated by the green algae *Rhizoclonium riparium*, *Percursaria percursa*, *Enteromorpha torta* and *Vaucheria* species, and on the dryer spots a dominance of Cyanophyceae. At non-grazed creek banks *Halimione portulacoides* dominated, comprising the red algae *Bostrychia scorpioides* and *Catenella repens*, and further *Vaucheria* species, *Blidingia minima*, and in spring *Ulothrix* species.
3. Above mean high water spring the Armerion maritimae vegetation thrived, with *Juncus gerardii*, *Festuca rubra*, *Agrostis stolonifera*, *Artemisia maritima*, and *Glaux maritima* locally dominating. These fully terrestrial communities, exposed to saline spray during storms, offered a dry and extreme habitat for algae, protected by a cover of mucous, such as terrestrial Cyanophyceae (e.g. *Nostoc* species) and Haptophyceae (e.g. *Apistonema* species).

The salt marsh is a harsh environment for aquatic plants, living along a gradient from the sea to the land. The loose-lying algae in the lower marsh are totally dependent on tidal movements and extreme actions of wind and waves. In the upper marsh climatic influences of rain, sunshine and frost are predominant. In the lower marsh small fluctuations in soil moisture content and salinity occur and the abundance of the algal mats is hardly affected by short periods of frost, but drift ice is fatal. In the upper marsh during periods of desiccation, extremely low moisture contents of the sediments coincide with extremely high salinities, affecting the algal mat negatively: the algae bleach, die off and finally disappear.

In many cases the algal flora of a salt marsh is only an ephemeral aspect of a landscape dominated by terrestrial higher plants. There is an obvious negative relationship between the coverage of the phanerogams and the algae. Extremely dense, perennial higher plant vegetations hardly contain any algae (e.g. *Halimione portulacoides* bushes and *Festuca rubra* swards). Higher plants with a clear seasonal trend (*Triglochin maritima*) compete with the underlying algae for space and light and may cause die back of the algal vegetation. When the higher plant coverage decreases, opportunists (e.g. Cyanophyceae) may take their chance to bloom. The middle marsh between mean high water and mean high water at springtides forms the best habitat for algae with regard to species number and constancy of the algal mat (Fig. 10.5). The more disturbance of the sediment, the lower the number of dominant species and the larger the changes in abundance of the algal mat.

Grazing and consequent treading and manuring of the soil favours a few generalists. Sensitive species like *Bostrychia scorpioides* and *Fucus vesiculosus* f. *volubilis* disappear, just like woody phanerogams and epiphytes, and open spots are formed that may be filled up with filamentous green algae. Generalist green algae like *Rhizoclonium*, *Percursaria* and *Enteromorpha torta* are very abundant under these conditions. Heavy grazing and trampling of the soil finally destroy the vegetation of higher plants and create a habitat where only colonists like *Ulothrix* species and blue-green algae may occur.

At the level of the Puccinellion maritimae the salt-marsh algal vegetation comprised a component growing on firm clay, abrasion edges and creek walls. This was a transition habitat to stone sea walls, wooden harbour constructions, etc. A number of species, growing together in varying abundance, were characteristic for this hard substrate habitat in the marsh: *Callithamnion scopulorum*, *Polysiphonia urceolata*, *Ceramium deslongchampsii*, *Sphacelaria nana*, and turfs of *Sphacelaria rigidula*. These species were far more abundant as epilithic algae on sea walls in the undergrowth of *Ascophyllum nodosum* and *Fucus vesiculosus*. These habitats are rare in the salt marsh and occur only in localities where erosion prevails over sedimentation (Nienhuis, 1987). Most of the habitats described, have vanished from the SW Delta, particularly the transitions between stone, wood, firm clay and softer sediments (see Section 10.2.2).

### *10.2.2 Gradients and Zoning of Benthic Algae in Perspective*

After the flood disaster of 1953 dyke revetments of asphalt came into use in the SW Delta, which method became the usual practice in recent years. The new dykes are large robust constructions, preferably with a straight profile and a wide base, under which the former small landscape elements were permanently buried. The modern dyke revetments are uniform, made of asphalt, asphalt-concrete and concrete blocks, and the holes in between the stone (the former microhabitats) were filled in with concrete spoil. Gradually, the intertidal environmental variation of the past largely disappeared. The heightening and strengthening of the Delta dykes according to the present standards (Chapter 9), resulted on the one hand in a safe, uniformly smoothened coastline, but it meant on the other hand a massive destruction of small landscape elements and microhabitats and a silent levelling down of the ecological values.

The loss of landscape structures, occurred both on the seaward and the landward side of the sea walls, e.g. the loss of specific inland habitats like ‘karrevelden’ and ‘inlagen’ protected by a secondary dyke. In Chapter 9 has been explained that from their very existence the embanked islands in the SW Delta were attacked by the sea. Exposed dykes, e.g. along the northern shore of the Oosterschelde, were continuously undermined, and as a precautionary measure a secondary ‘sleeping’ dyke was built land inwards of the primary embankment. The marine clay of the fields in between the two dykes was used for dyke building, and by doing this low-lying wetland areas were created, prone to saline seepage (‘inlagen’), deteriorated by the digging of peat (cf. Chapter 3). Clay was indispensable for the throwing up of solid embankments, and this rare resource was also gained at the inland side of the secondary dyke, using horse pulled carts and wheelbarrows, thus creating marshy ‘chart fields’ (‘karrevelden’). Needless to say, the agricultural value of the levelled arable fields decreased significantly; they could only be used for grazing sheep and as hay fields.

Not only the ecological quality of the artificial rocky shores of the Delta estuaries has suffered during the reconstruction after 1953, but also quantitatively the length and surface area of embankments carrying a full zoning of estuarine algal communities has drastically declined: from *ca*. 300 km of original dykes in 1950, only a few kilometres were left (excluding the Westerschelde). There is, however, a positive signal: the diversity of specific groups of invertebrates and marine benthic macro-algae in the enclosed estuaries is steadily increasing, owing to the stable marine environment and the increased number of sublittoral stony habitats... and the unremitting efforts of field biologists such as phycologist Stegenga (2005), continuously in search for new species.

The gradients and zoning of benthic algae on salt marshes, just as the hard substrate communities, can be counted among the echo from the past. Many of the habitats described, have completely changed owing to the execution of the Delta project (Section 10.3). Of the original sand- and mudflats in 1955, 47,000 ha, an area of 18,000 ha was left in 1986, that is a decrease of 60%. In the Oosterschelde alone roughly 11,000 ha were changed irreversibly, areas that disappeared under water or ran dry permanently, or were cut off by secondary dams. Of the original 8,000 ha of tidal salt marsh in the SW Delta only 3,700 were left in 1986 after the completion of the storm surge barrier in the Oosterschelde, and of this area roughly 2,700 ha is occupied by the drowned Seaftinghe polders (Section 10.4) (Smies and Huiskes, 1981; Nienhuis, 1987). And the picture is even worse because the area of sand flats and salt marshes that remained in the Oosterschelde is gradually declining (10 ha year$^{-1}$) by erosive forces (Geurts van Kessel, 2004; Section 10.3). The most diversified salt marshes and beach plains in the marine-sandy reach have been annihilated during the Delta project (e.g. Springersgors, Grevelingen estuary, transition to the sandy dunes; Zandkreek, very sheltered, rich in biodiversity, and Bergen op Zoom marsh, Oosterschelde, transition to the Pleistocene cover sand). Polyhaline marshes in the Oosterschelde suffer from erosion, and they gradually disappear under water. The Westerschelde is the only estuary in the SW Delta that still harbours extensive brackish marshes (Saeftinghe; Fig. 10.9).

## 10.3 The Delta Project

### *10.3.1 The Delta Project and its Consequences*

On February 1, 1953, a north-westerly storm induced tides to 3.4 m above normal levels, breached approximately 180 km of coastal-defence dykes and flooded 160,000 ha of polder-land in the SW Delta. As many as 1,835 people lost their lives in this large storm flood, more than 46,000 farms and buildings were destroyed or damaged, and approximately 200,000 farm animals drowned (Slager, 2003).

The Delta project, formalised in 1957 by an act of the Dutch parliament, was conceived as an answer to the continuous risk of flooding, which threatens lives and property in this low-lying region. The need for continuous coastal reconstruction measures has intensified over the years as a result of population growth, land subsidence and rising sea level. The potential threat of storm surges from the North Sea had already led to the closure of the Brielse Meer in 1950. The core of the Delta Project, to maintain a safe coastline as short as possible, called for the closure of the main tidal estuaries and inlets in the SW Delta, except for the Westerschelde and the Nieuwe Waterweg (Fig. 10.6). Along the Westerschelde the existing dykes have been raised, for reasons of continued international shipping access to Antwerp (see Section 10.4). In the Nieuwe Waterweg, the shipping route to the main port of Rotterdam, the construction of the Maeslantkering, a barrier protecting Rotterdam from storm surges, was finished in 1997. This enterprise was considered to be the final phase of the Delta project.

As said, the Delta project formally started in 1957. A prerequisite for the construction of the primary sea walls in the mouths of the estuaries was the need to reduce tidal-current velocities in the estuaries, before the construction of the primary barriers could be undertaken. Tidal velocities were lowered by constructing secondary compartmental barriers (Zankreekdam, Grevelingendam and Volkerakdam; Fig. 10.6) to reduce the extent of the Delta area subject to tidal influence. This resulted, in turn, in a reduced tidal volume and, therefore, lower current velocities through the main estuaries. The former (semi-)estuaries Veersche Gat and Grevelingen were closed off from the North Sea by high sea walls in 1961 and 1971, respectively, and turned into non-tidal lakes or lagoons filled with brackish or saline water, whereas the Haringvliet was closed in 1970 by the construction of large sluices, meant to function as an outlet for the rivers Rhine and Meuse (Fig. 10.6).

The original plan for the Oosterschelde estuary called for a dam across the mouth of the estuary, a distance of 9 km, to be finished in 1978. The tidal basin would then have been changed into a stagnant lake filled with – polluted – water from the river Rhine. But the final form of the present barrier differs drastically from the simple dam that has been envisaged originally. Through the 1960s and early 1970s, conservationists and fishermen provoked an awareness in many people of the need to protect the area's outstanding natural resources and its unique tidal habitat, including an extensive shellfish (oyster) industry, the only one in the Netherlands. The Dutch government decided to change the design of the dam in 1974. After several years of desk studies the Dutch parliament accepted in 1976 a compromise solution: a storm surge barrier. On the one hand the barrier allows the reduced tides to enter the estuary freely, thus safeguarding the tidal ecosystem, including the plant and animal communities. On the other hand the barrier guarantees safety for the human population and for the properties of the inhabitants when storm floods threaten the area. This barrier design marked a turning point in the Dutch political decision-making process with regard to the natural environment. The storm surge barrier was constructed between 1979 and 1986 in the western inlet of the estuary (Fig. 10.6; Nienhuis and Smaal, 1994). The barrier was considered the crown on the Delta Plan. Bombastic words were written on the proud Delta

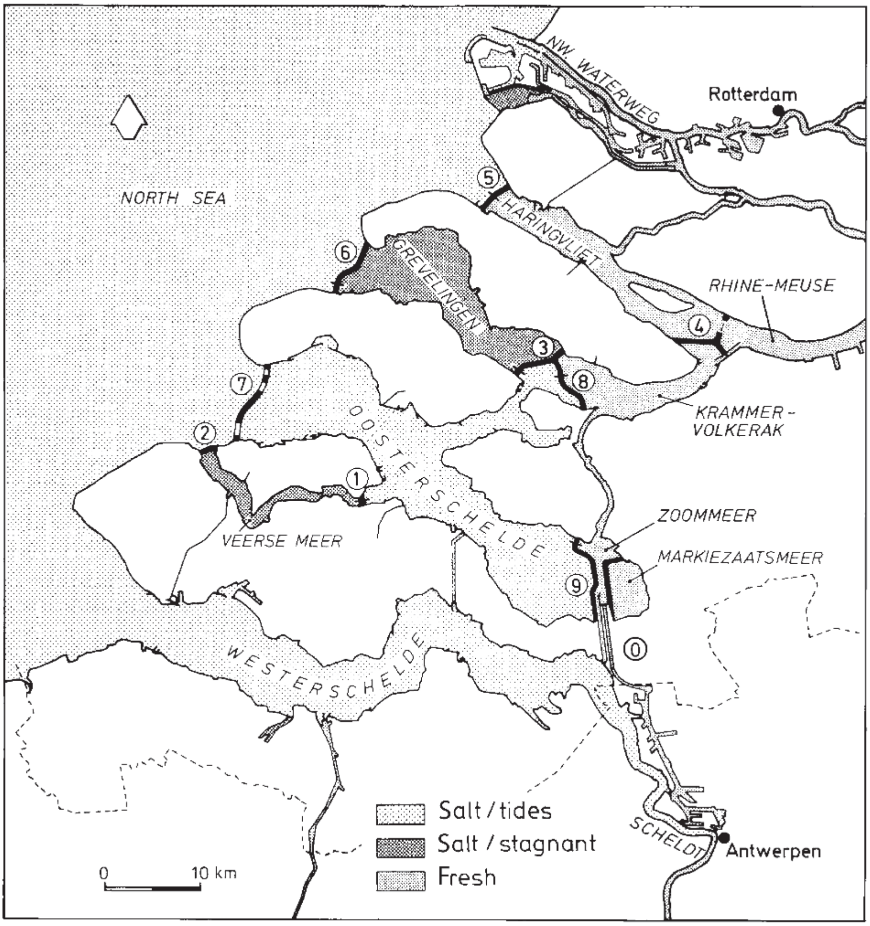


**Fig. 10.6** Map of the Delta area of the rivers Rhine, Meuse and Scheldt in the SW Netherlands, with various water bodies as resulting from the Delta project engineering scheme (year of enclosure in brackets); 1 = Zandkreekdam (1960); 2 = Veersegatdam (1961); 3 = Grevelingendam (1964); 4 = V olkerakdam (1969); 5 = Haringvlietdam (1970); 6 = Brouwersdam (1971); 7 = Oosterschelde storm surge barrier (1986); 8 = Philipsdam (1987); 9 = Oesterdam (1986). Markiezaatsmeer has been closed off from Zoommeer by Markiezaatsdam in 1983. The connection between Oosterschelde and Westerschelde was already closed in 1867 (0 = Kreekrakdam). Projects preceding the Delta act of 1957, such as the closure of the Brielse Maas (1950), the Braakman (1952) and the construction of the flood barrier in the Hollandse IJssel (1958) near Rotterdam, have not been indicated (Nienhuis and Smaal, 1994)

Works. I quote: ‘The former archipelago of isolated, sometimes forgotten islands changed in a short period in a delta of new possibilities, a junction of multicoloured activities, connected to the other parts of the Netherlands by dams and bridges. Inland lakes were created for amenity purposes, industry and new employment arose’ (Van der Maas, 1986).

The Delta project is considered as the culmination of a long tradition of land reclamation and defence against the sea. Almost the entire area of the land around the estuaries was reclaimed from the sea in a trial-and-error process, over more than a millennium of constructing and repairing dykes in the muddy salt marshes and the former peat bogs. The combination of the rising sea level and subsidence of the reclaimed land (particularly the peat areas), dramatically changed the difference in surface levels between sea and land. Most polder-land now lies far below the level of the sea (see Fig 3.2: land subsidence versus sea-level rise). The positive state of mind about the chosen solution for the Oosterschelde gradually tempered in the course of the years. The disturbed hydrodynamic tidal balance in the estuary enhanced the erosion of the tidal flats: all flats, managed as precious nature reserves, will gradually disappear under water (Section 10.3.4.). In fact, the closing of the four main branches of the Rhine–Meuse estuary brought the natural transitions between fresh-, brackish- and saltwater to an end. The complicated interplay between deposition and erosion of marine and river sediments in all four estuarine areas was ceased, and large uncontrolled changes in long-term hydrodynamic and geomorphologic processes were set in motion. The original ‘natural’ habitats disappeared, and were replaced by man-made habitats. This is reflected in the changes in biodiversity: characteristic estuarine species disappeared (cf. Section 10.2.1.1), as was the case with migratory species (e.g. fish species), used to travel between the rivers and the sea. However, an increasing number of exotics have established themselves, covering large subtidal and intertidal areas (e.g. the Japweed, *Sargassum muticum* and the Japanese oyster, *Crassostrea gigas*; De Jonge and De Jong, 2002).

The flood disaster of 1953 has not been followed by an evaluation of the practice of traditional water- and land management. Instead, the event worked as a catalyst for the decision to persist with large-scale measures in the existing tradition: to build larger and more rigid dams. There was a strong conviction that technology would always remain to be able to control the energy of the sea. The execution of the Delta project brought Dutch water engineers world fame. The skills and experience gained became a significant export product of the Netherlands: Dutch engineering firms were asked to plan and execute similar large water projects in other parts of the world. For many countries the Dutch approach became the model for water management technology (Smits et al., 2006).

The execution of the Delta project, which followed centuries of smaller interventions, triggered several (unexpected) environmental problems. The building of the Delta dams rigorously cut off the hydrologic and ecologic river continuum, both at the seaside as well as at the side of the rivers. The vertical and horizontal zoning of biotic communities, as illustrated in Section 10.2, changed in a pattern of isolated freshwater and marine compartments. The annihilation of the dynamic tidal gradient was foreseen by ecologists, but their voice was not heard in the 1960s, when the provision of safety after the 1953 disaster was the main societal issue, and ecological arguments hardly played any role (Nienhuis, 2006). The disappearance of a unique tidal Delta, in favour of safety for the human population: it was in fact not done to bring that up after the horrendous disaster of 1953. Ecologists, of course, did worry about the consequences of the Delta Plan, and their arguments have played a decisive role in the political choice in favour of the saline Grevelingen, and the semi-tidal Oosterschelde. To illustrate this, I will quote a judgement in 1970 of my former director: ‘When we think about our own country, we may be short about the Delta Plan. This scheme does not mean management but complete annihilation’ (Vaas, 1970). This statement is typical of those days. Annihilation means destruction. The statements were made, but in an academic setting, and at that time hardly anyone took note of these words. Besides my work as a scientist involved in aquatic ecology, I have made statements on the ‘values’ of the Delta on several occasions. In 1982 I published a very negative ecological balance sheet of the ecological effects of the Delta project. The balance showed that the rare ecological features disappeared and that the common features appeared (Nienhuis, 1982).

The past 20–25 years the appreciation for ecology as a science and for ecological values has increased enormously. The understanding has grown that estuaries, with their tidal rhythm and their gradients from saline to freshwater, are ecologically much healthier than the present separated and isolated waters. The Delta waters developed into instable aquaria, difficult to manage. There are problems caused by Cyanobacteria in the Volkerak-Zoommeer, by stinking sea lettuce (*Ulva* species) in the Veerse Meer, by eroding sandy shoals that eventually disappear under water in the Oosterschelde, by turbid water and the appearance of annoying exotic species in the Grevelingen. Only 20 years have passed since the construction of the storm surge barrier in the Oosterschelde was finished. The crown on the Delta Plan has deteriorated during that short period to a rattling set of false teeth in the mouth of the estuary. Now, in the 21st century even engineers of the State Department for Public Works and Water Management speak freely about the ‘New Delta’, about the return of tidal dynamics, about the reconstruction of the natural connections between the separated water bodies, under the prerequisite of full maintenance of safety for the human population (Provincie Zeeland, 2003). The near-disasters of 1993 and 1995, the river floods, have amplified these ideas. Climate change is said to lead to increased river discharges, and the Delta of Rhine and Meuse is needed, just as before 1953, for the discharge of superfluous river water to the sea. Working on living rivers also implies working on a living SW Delta (Nienhuis, 2006).

### *10.3.2 The Northern Part of the SW Delta*

The area considered comprises the Haringvliet, Hollandsch Diep, Biesbosch and the rivers Nieuwe Merwede and Amer (Fig. 10.6; compare Fig. 4.4). Until 1870, an important part of the Rhine water flowed through the Biesbosch area, depositing large amounts of suspended solids, and had its main outflow to the North Sea through the Haringvliet. Between 1860 and 1870 both the Nieuwe Merwede and the Nieuwe Waterweg were dug to improve navigation and water discharge (Chapter 5). The river Meuse, discharging into the river Waal, was given its own outlet to the Amer by the digging of the Bergsche Maas at the beginning of the

20th century. The Haringvliet is the main outlet of the rivers Rhine and Meuse. On average about 880 $m^3 s^{-1}$ of Rhine water or 40% of the average river discharge reached the Haringvliet estuary whereas the remainder was discharged mainly along the Nieuwe Waterweg. The average discharge of the Meuse amounted to 330 $m^3 s^{-1}$, all of which reached the Haringvliet estuary. Other freshwater sources were insignificant, so the average freshwater discharge through the Haringvliet was about 1200 $m^3 s^{-1}$. The area has experienced a complex history of inundations by the sea and rivers, land reclamation and dyking, regulation and channel construction (see Chapters 4, 5 and 9). Continuous sedimentation and dyking of large intertidal areas decreased the water storage capacity, which caused an increase in the average tidal range in the Biesbosch area from *ca.* 1 m in 1850 to *ca.* 2 m in 1960 (Ferguson and Wolff, 1984).

The estuarine ecosystem consisted of a fresh- and brackish-water tidal system, the largest of this type in Europe. It included a characteristic flora and fauna distributed along an environmental gradient, with several marine species in the western Haringvliet, brackish-water species in the eastern Haringvliet and Hollandsch Diep, and freshwater species in the Biesbosch, Amer and Nieuwe Merwede. The vegetation consisted of large stands of reeds and rushes, merging in the east into a large freshwater tidal area, the Biesbosch, with tidal forests and reed marsh areas (cf. Chapter 18). The brackish part of the Haringvliet estuary was characterised by extensive mudflats and large areas of brackish meadows and beds of bulrushes (*Scirpus*) and reed. Its invertebrate and fish fauna was characteristic for the meso-oligohaline part of estuaries with, for example, ragworms (*Nereis diversicolor*) and flounder (*Platichthys flesus*) as dominant species. The area was rich in birds, e.g. a large breeding colony of avocets (*Recurvirostra avosetta*). The freshwater tidal part of the estuary was characterised by extensive willow coppice, reed-beds, stand of bulrushes and tidal flats. Its flora and fauna were not particularly rich in species, but nevertheless extremely interesting from the viewpoint of nature conservation, because of the fact that terrestrial and freshwater organisms had to live under tidal conditions. Also the bird fauna was very characteristic with breeding colonies of cormorants (*Phalacrocorax carbo*), grey herons (*Ardea cinerea*) and night herons (*Nycticorax nycticorax*) and large numbers of waterfowl in winter. Among the mammals, the otter (*Lutra lutra*) was still common around 1900 in the Hollandsch Diep and Biesbosch, but had become extinct by 1940. Harbour seals (*Phoca vitulina*) still occurred in 1953, but had nearly disappeared from the area at the end of the 1960s.

Notwithstanding the wealth of the flora and fauna of the Haringvliet estuary, the gradually increasing pollution of the waters of the rivers Rhine and Meuse became more and more apparent. The average oxygen saturation in the river Rhine in summer in the period 1965–1968 was 48%, in the Meuse 73%. The invertebrate and fish fauna of the Rhine proved to be impoverished. Cormorants disappeared from the area as breeding birds, most probably owing to water pollution, and the same phenomenon was observed for harbour seals (Wolff, 1973; Ferguson and Wolff, 1984).

A primary function of the former estuaries was the discharge of river water to the North Sea. The construction of the Volkerakdam (finished in 1969) and

Haringvlietdam (finished in November 1970) was needed to convert the Haringvliet–Hollands Diep estuary into an inland freshwater basin. The Haringvliet sluices regulate the water distribution in the enclosed Rhine–Meuse Delta since November 1970. At low Rhine discharges ($Q < 1{,}700\,m^3\,s^{-1}$), the sluices are closed to prevent salt intrusion. With increasing Rhine discharge the sluices are gradually opened during low tide on the North Sea. At high Rhine discharges ($Q > 9{,}000\,m^3\,s^{-1}$) the sluices are completely open. Consequently, current velocities and residence times greatly vary with Rhine discharge (Smit et al., 1997).

The closure of the Haringvliet and the Volkerak is obviously hindering the unrestrained discharge of river water during peak floods. The 1995 river flood has opened the eyes of the river managers for that problem, and measures are taken now to mitigate that problem, both along the Large Rivers proper (core decision of physical planning ‘Room for the River’; www.ruimtevoorderivier.nl; Van Stokkom et al., 2005; see Chapters 20 and 21) as well as in the SW Delta region. A problem may arise when an extreme river flood coincides with a north-westerly storm flood at the North Sea, which requires the storm surge barriers to be closed.

Sealing off the estuaries in the SW Delta has led to the accumulation of polluted sludge in the northernmost river branches (Fig. 10.7). Although an increase in sedimentation was expected as a result of the closure of the Haringvliet in 1970, the large quantity of polluted sediments that settled in subsequent years in the Dutch delta overran all predictions. Biesbosch–Hollands Diep and Haringvliet became the downstream chemical depot for the Rhine and Meuse rivers. More than 150 million cubic metres of highly polluted sludge have settled here.

Before the closure of the Volkerak and Haringvliet dams, a morphological equilibrium existed between depth profiles and currents; the marine and fluvial silt

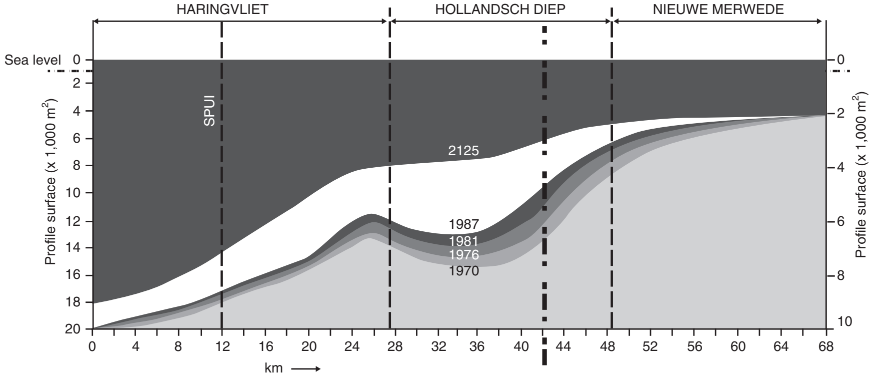


**Fig. 10.7** Surface of cross-sectional profiles in the enclosed Rhine–Meuse Delta between 1970 and 1987, and a prediction for 2125, indicating the amounts of silt deposited. Surface area of the eastern Hollandsch Diep (to the right of the bold line) refers to the North side, connected to the Nieuwe Merwede (Adapted from Van Berghem et al., 1992 in Smit et al., 1997)

mainly accumulated in the intertidal areas. After the closure, channel profiles became oversized and consequently large amounts of sediments were deposited in the former tidal channels. These sediments mainly originated from the rivers Rhine and Meuse. The tidal channels of the upstream part of the Delta, including the Nieuwe Merwede, filled up first, in the early 1970s. In later years, sediment became deposited further west as the upstream parts had reached a new equilibrium with flow rates. Nowadays, about 5 million cubic metres of sediment are deposited annually in the Amer, Nieuwe Merwede, Hollands Diep and Haringvliet (Fig. 10.7). Sand is mainly deposited in the Amer and Nieuwe Merwede, while silt is deposited in the Hollands Diep. The finest silt particles settle in the Haringvliet. However, this pattern changes with river discharge. When river discharges are high, this gradient shifts to the west; silt which is deposited in the east, may be resuspended and also transported further into westerly directions. Between 1970 and 1990 the cross-sectional profiles of the Amer, Nieuwe Merwede and Hollands Diep were reduced by 10–20% (Fig. 10.7), coinciding with an average net sedimentation of more than 0.5–2 m in 20 years. With the present sluice management, the sedimentation process will continue until a new equilibrium has been established, within 1–2 centuries (Smit et al., 1997).

The former gently sloping intertidal flats were not adapted to the new situation, comprising only a small vertical tidal amplitude and lower current velocities. After 1970, erosion by wind-induced waves has changed the gentle slopes in most intertidal areas into steep edges, roughly 0.5 m above mean sea level. Consequently, the ecologically important intertidal zone almost totally disappeared under water. The vegetation border of wind-exposed intertidal areas in the Haringvliet, for example, has receded by about 100 m between 1970 and 1984. These eroded sediments also contributed to the filling up of the channels. During the 1980s and 1990s most banks have eventually been protected with riprap dams, in order to avoid further erosion.

The quality of the underwater sediment in the Nieuwe Merwede–Hollands Diep stretch is mainly determined by the pollution level of the sediments that were deposited after 1970. Sediments deposited in the early 1970s have the poorest quality (pollution class 4), since pollution was then at its peak. The most recent sediments are less polluted (class 2 or 3). Consequently, sediment quality at the surface should improve going from the Amer and Nieuwe Merwede to the Hollands Diep. However, a considerable transport of polluted silts takes place at high river discharges, causing the downstream players to be polluted as well. Most of the 90 million cubic meters deposited between 1970 and 1989 is polluted (class 3) or extremely polluted (class 4), and is concentrated in the Hollands Diep (see also Chapter 14) (Smit et al., 1997).

Fortunately, the quantity of pollutants in river effluents has steeply decreased in recent decades, and the toxic sediments are now being covered with relatively clean sediments, but the underlying potential negative effects are still immanent. It is likely that, even if the original sources of pollution should be removed, contaminated sediments would continue to deliver emissions over many decades (Smit et al., 1997).

The lack of tidal currents in the Delta compartments is the cause of many of the environmental problems that recently emerged. However, it is technically possible to bring tidal rhythms back into the area. If the Haringvliet sluices are to be turned into a storm surge barrier, it can be hypothesised that the natural dynamics of the northern part of the SW Delta, could be restored, comprising tides, and a salinity and sedimentation gradient. A connection with the developing sandy islands in the coastal Delta, where a new shallow sea is emerging, could upscale the natural values by a substantial amount (Stikvoort et al., 2002; www.rikz.nl; www.ecologisch-herstel.nl).

Experiments to reintroduce reduced tidal movements in the Haringvliet have been carried out and were successful. If the Haringvliet estuary is to be restored, this should be done as soon as possible, since irreversible geomorphological processes, combined with the extinction of migratory species (particularly fish species) are continuing. Opening of the Haringvliet sluice means also the (partial) restoration of tidal movements in the Biesbosch, an area created during the storm flood of 1421 (Chapter 9). In that year the former polder, the Grote Waard, was swallowed by the sea and turned into a shallow freshwater tidal area, and it took the river Rhine four centuries to fill up most of the area with sediments to above sea level. During this period, the Biesbosch was a vast and unique freshwater tidal area, the largest one in Europe (Kuijpers, 1995; Kerkhofs et al., 2005).

### *10.3.3 Krammer-Volkerak*

During the most severe period of pollution from the Rhine and Meuse, the Krammer–Volkerak (Fig. 10.6) was closed off from the Haringvliet in 1969, and this prevented the contaminated river water to enter the adjacent estuarine branch. The enclosed water mass, including the Zoommeer (Fig. 10.6) was conceived as a freshwater system, almost exclusively fed by the discharge from a few brooks originating on the higher grounds, although some input of Rhine and Meuse water had to be accepted. Over the years, however, it became clear that nutrient accumulation, causing mass blooming of blue-green algae, nevertheless occurred, fed by agricultural run-off, mainly brought by the smaller rivers from the Pleistocene cover sands in the east. A recent survey of possible solutions to the eutrophication problem was carried out. One suggestion was to flush the artificial lakes with enough freshwater, in order to decrease the residence time of the eutrophicated water and hence to prevent the development of algal blooms. The problem is that this measure cannot be applied in dry summer periods when little river water is available, but algal blooms are at their peak. Changing the Volkerak-Krammer into a saltwater lake or a semi-tidal estuarine area are the suggested directions for a sustainable solution, but the remaining problem is that the farms bordering the lake need a continuous freshwater supply (Tosserams et al., 2000; www.rikz.nl; www.ecologisch-herstel.nl).

### *10.3.4 The 'Crown' on the Delta Project, the Oosterschelde*

In 1986 the building of the storm surge barrier in the Oosterschelde was finished (Fig. 10.6). Owing to this enormous technical and financial effort, two thirds of the tidal movements in this estuary have been maintained. The proper estuarine characteristics of the Oosterschelde, however, were lost. The estuarine branch was cut off from the river, and the connection with incoming nutrients, and the transition zone between salt- and freshwater, came to an end. The deterioration of the natural system, i.e. the irreversible erosion of the tidal flats, is continuing. The construction of the barrier and the compartmentalisation dams have considerable consequences for the geomorphological processes in the estuary. The decrease in tidal volume owing to the building of the storm surge barrier means that a new equilibrium has to develop towards channels with a smaller cross section. In general terms the former tidal gullies are too deep now, and the slopes of the intertidal flats are too steep (Fig. 10.8). Because of a shortage of imported sand this is a very slow process, which is predicted to take hundreds of years. Meanwhile, as a result of the tidal reduction, the wave energy dissipation is concentrated in a smaller vertical zone of the tidal flats, resulting in an increased erosion. This erosive process is no longer counterbalanced by sedimentation processes due to the diminished tidal energy. The result is a continuous net erosion of the intertidal area, and deposition of sand and silt on the bottom and slopes of the channels and gullies. This phenomenon is

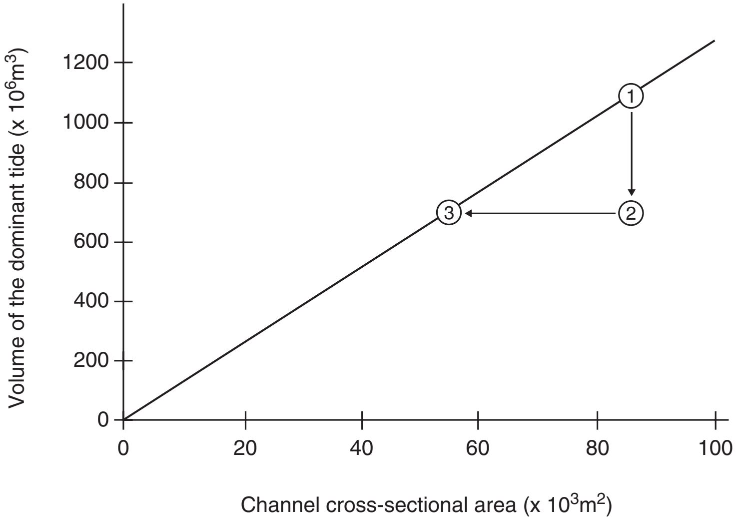


**Fig. 10.8** The 'sand hunger' phenomenon in the Oosterschelde after the construction of the storm surge barrier in 1986. The decrease in tidal volume (vertical axis) necessarily leads to an erosive decrease in the cross section of the tidal channels (horizontal axis). 1 = original equilibrium; 2 = disturbed equilibrium; 3 = new equilibrium; vertical arrow = decrease in tidal volume; horizontal arrow = decrease in channel cross section (Derived from Mulder and Louters, 1994)

called ‘sand hunger’. This process will lead to an estimated loss of 15% of the present surface area of the intertidal flats and the salt marshes, over a period of 30 years, and a massive loss of intertidal habitats over 100–200 years. A consequence of the new hydrodynamic regime is that the Oosterschelde has changed from a sediment-exporting system into a sediment importing system. This imported material, mainly fine sediments (< 50 µm), is deposited in the tidal channels, where the shear stress is not sufficient for resuspension. Locally these fine deposits are smothering the habitat conditions for benthic organisms (Mulder and Louters, 1994). In summary, the natural values of the Oosterschelde will gradually decline, because both intertidal and subtidal benthic invertebrate communities are seriously impeded, and animals higher up in the food chain (mainly waders and fish) will also suffer from these irreversible changes.

Partial restoration of the estuarine gradient is a feasible option, by reintroducing a quantity of freshwater from the river Rhine via the Krammer–Volkerak (Fig. 10.6). The connection between the stagnant non-tidal saltwater Grevelingenmeer (Fig. 10.6) and the sea has already been restored in a restricted way. But the lake is still lacking its essential estuarine characteristics, that has, for example, led to the total disappearance of a large vegetation of eelgrass, *Zostera marina* (see Chapter 16) The flushing of the lagoon, however, can be enhanced by expanding the capacity of the already existing siphon in the eastern dam, connecting Grevelingen with the Oosterschelde. The connection between the stagnant, brackish Veerse Meer – suffering from massive blooms of the green alga *Ulva lactuca* – and the tidal Oosterschelde has already been accomplished in 2005 (Fig. 10.6; www.rikz.nl).

## 10.4 The Scheldt River and Estuary

The environmental history of the Scheldt river and estuary (Westerschelde–Zeeschelde) is excluded from the main topics of this book, but when it comes to the treatment of the SW Delta, a short survey of the fate of the Scheldt is indispensable. The SW Delta is the area where the mixing and interplay of water from Rhine, Meuse and Scheldt took place for millennia. The course of the Schelde (the present Oosterschelde) was only interrupted in 1867 by the closure of the Kreekrakdam (Fig. 10.6), forcing the Scheldt discharge through the present Westerschelde. The Scheldt is a well-studied international river, and several monographs and many detailed studies have been published on ecological phenomena (e.g. Meire and Vincx, 1993; Meire et al., 2005; Meire and Van Damme, 2005; Van den Bergh et al., 2005). The Westerschelde–Zeeschelde is in fact the only complete estuary left in the Delta (I exclude the Ems estuary from the Delta proper, because this system in the northern part of Germany is beyond the direct impact of Rhine and Meuse water), and this makes the ecological values of the Scheldt particularly significant (Fig. 10.9). As part of the Delta project the major estuaries in the SW Delta have been closed off from the sea, and consequently the larger part of the brackish-water gradient, and the freshwater tidal area were annihilated, stressing the significance of the only remaining estuary proper, the Scheldt estuary.

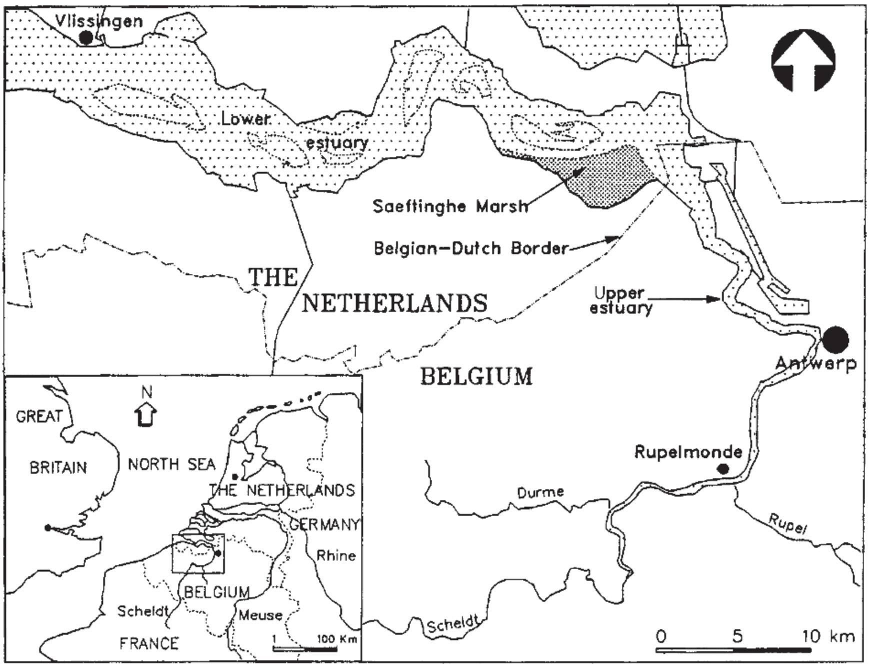


**Fig. 10.9** The Scheldt river and estuary, with Westerschelde (until Belgian–Dutch border) and Zeeschelde (from the Dutch border stream upwards) (Zwolsman and Van Eck, 1993)

### 10.4.1 Hydrography and Biogeochemistry

The Schelt River starts in the north of France and flows into the North Sea near Vlissingen (The Netherlands) (Fig. 10.9). It is a typical rain-fed lowland river with a total length of 355 km and a fall of 110 m at most. Its catchment area, approximately 21,800 km$^2$, has around 10 million inhabitants. The tidal estuary extends 160 km upstream of Vlissingen, to the town of Gent, where the tidal forces are impaired by sluices. The tributaries of the Durme and Rupel, are also under tidal influence and considered part of the estuary. The Dutch part of the estuary (the lower estuary, Westerschelde; 55 km) is characterised by flood and ebb channels, separated by intertidal sand- and mudflats. Where the Zeeschelde (the upper estuary, the Flemish part; 105 km) starts, it changes quite rapidly into a one-channel system. Due to the funnel shape of the estuary the maximum vertical tidal range is about 100 km upstream, in the freshwater zone. The mean tidal amplitude varies from 3.8 m near the mouth to a maximum of 5.3 m south of Antwerpen, and down to 2 m near Gent. The estuary is well mixed with a smooth transition between salt- and freshwater. The polyhaline zone is 40 km long, and the mesohaline and oligohaline sections are 40 and 10 km, respectively. The Scheldt is one of the smaller international European rivers, with an average discharge amounting to

104 $m^3 s^{-1}$ at Rupelmonde (Rupel mouth), and with a maximum value of 207 $m^3 s^{-1}$ and minimum value of 43 $m^3 s^{-1}$ (Van den Bergh et al., 2005).

The estuary and its tributaries are used as a major drain for industrial and domestic wastes, a substantial part of which is untreated. In 2000 the city of Brussels still discharged untreated wastewater through the Zenne and Rupel in the Schelde estuary (Fig. 10.9). The estuary's performance as a biochemical filter between the land and the North Sea relies on both the received loads and its internal organisation to process them. Rehabilitation efforts should address both aspects. All biochemical processes would benefit from reduced discharges from inland water treatment and creation of buffer areas for retention. Organic carbon input to the Schelde estuary exceeds 100,000 t $year^{-1}$, and most of it is cycled inside the estuary, causing a high oxygen demand (Frankignouille et al., 1996). High loads of ammonium enter the estuary through diffuse discharge from agricultural areas. Aeration is the most important oxygen influx in the estuary, and this capacity could be improved by the creation of more intertidal and shallow areas, where the surface to volume ratio is high. Removal of nitrogen through anaerobic denitrification is most effective in low intertidal mudflats; bioturbation by deposit feeders will enhance this process. Phosphorus enters the estuary through point sources from domestic waste, doubling the natural concentrations; however, there is no process to eliminate it from the system. If it is not assimilated, it is eventually buried through deposition in sheltered areas, but this is not a sustainable solution because it can always be remobilised. Toxic substances of different types enter the estuary from industries, towns, and agricultural areas. Little is known about their bioavailability and impacts on the ecological functions (Van den Bergh et al., 2005).

Temperate, well-mixed, tidal estuaries are generally characterised by the presence of a maximum turbidity zone in the region of low salinity. The maximum turbidity zone consists of an area where a large amount of cohesive sediments are accumulated and where these sediments are continually deposited and resuspended by the tidal flow. The distribution of suspended matter is influenced by a range of interrelated processes, e.g. temperature and biological activity, freshwater discharge and salinity, hydrodynamic conditions and turbulence, mineralogical composition, chemical conditions, aggregation and flocculation. This combination of hydrodynamic conditions, in particular the presence of several sources of fine suspended matter, and the flocculation process, led in the salinity zone 2–10‰(PSU) to a bottom sediment that contains locally a high percentage of fine material, e.g. fine sand to mud, sometimes even a non-compacted, mobile, fluid mud layer (Meire et al., 2005).

## *10.4.2 The Estuarine Food Web*

Due to the high content of allochthonous and autochthonous detritus, microbial activities in the Schelde estuary are intense. Oxygen depletion occurs frequently and annual gross bacterial production exceeds net primary production even in the marine part. However, bacterial production and detritus are not passed on to higher trophic levels (Herman et al., 2000); the establishment of the food web in the Schelde estuary relies on primary production. There are no records of extended submersed aquatic vegetation in the past or the present, probably due to the combination of high current velocities and turbidity. This leaves phytoplankton and phytobenthos as the base of the food web. Primary production in the Schelde is extremely light limited. Other threats to the phytoplankton population are peak river discharges, causing mortal shifts toward higher salinity zones.

All higher trophic (faunal) levels are sensitive to oxygen depletion. Zooplankton, food for macrobenthos and fish, faces problems in selecting suitable food particles from the high concentrations of suspended particulate matter (Herman and Heip, 1999). The role of macrobenthos is multiple. It transmits energy to fish and birds. Bioturbating deposit feeders affect benthic oxygen and nitrogen cycling. Filter-feeder grazing controls phytoplankton populations and algal blooms in eutrophic conditions, especially in shallow well-mixed estuaries (Herman et al., 1999). Distribution patterns of macrobenthic populations are influenced by salinity, tidal regime, current velocity and sediment texture and quality. Filter-feeders need intertidal or shallow habitat and have narrow tolerance ranges for current velocities. Cockles (*Cerastoderma edule*) and mussels (*Mytilus edule*) previously were abundant up to the Dutch–Belgian border. Cockles are now restricted to the western part of the estuary, and mussels have almost disappeared from the estuary. Their retreat to a narrower habitat range might be related to salinity extremes, caused by freshwater discharge manipulations near the Dutch–Belgian border. According to the postulated brackish-water minimum (Remane and Schlieper, 1971), macrobenthic diversity in the freshwater section of an estuary is expected to be higher than in the brackish section. However, in the upper freshwater Zeeschelde only opportunistic oligochaete species survive the current water and sediment quality (Ysebaert et al., 1998).

The Schelde estuary is important as a wintering and stopover place for migrating waterfowl along the East Atlantic flyway. Waders feed mostly on sheltered mudflats with moderate mud content; the sandy exposed flats and plates with poorly established benthic communities function as resting places. The decline of diving ducks in the Westerschelde might be linked to evolutions in the shellfish supply. Water transparency and fish are limiting factors for piscivorous birds. Pollution, overfishing and habitat destruction heavily reduced fish populations in the Westerschelde, and fish disappeared altogether in the Zeeschelde by the 1970s. Some species are recovering, but many migratory species are still unable to complete their life cycle. Temporary anoxia in the Zeeschelde, the sluice complex in Gent, and embankments prevent them from reaching suitable spawning grounds upstream in the catchment. The Zeeschelde itself lacks suitable spawning habitats; in the Westerschelde shallow sheltered refuges, which serve as nursery grounds for juvenile marine fishes, have reduced in surface area. Common seal (*Phoca vitulina*) and harbour porpoise (*Phocoena phocoena*) used to be quite common in the Westerschelde. In present times the combination of polychlorinated biphenyls, cadmium, and organotin compounds hinders seal reproduction (Meire et al., 2005; Van den Bergh et al., 2005).

### *10.4.3 Past and Future of an Estuary*

Pieces of the turbulent environmental history of the Schelde basin have been described in Chapter 9. It reveals and endless story of more than 1,500 years of gain and loss of land. Since the early Middle Ages tidal marshes were reclaimed by embankment to create agricultural land, and since the middle of the 20th century for industrial and urban developments. Even between 1900 and 1990 roughly 20% of the then existing surface of the Schelde basin was lost owing to reclamations. In the Zeeschelde a relatively large surface of freshwater tidal marshes, a rare habitat in Europe (cf. Section 10.3.2), is present, but the most upstream sections are completely void of intertidal habitat. The habitat quality of the tidal marshes is poor, and in the current setting of massive embankments there is no space for new marsh development. Fortunately, one of the largest brackish-water marshes along European estuaries could be saved as an important nature reserve, the Saeftinghe marsh near the Belgian–Dutch border; Fig. 10.9). As mentioned in Chapter 9, the flood of 1570 took some polders created in the Middle Ages, and the Saeftinghe polder was never reclaimed because of a conflict between the Belgian and the Dutch governments. The quarrel was about the retention capacity of the Westerschelde flood plain: in case a flood was threatening the harbour of Antwerpen, the Saeftinghe wetlands could bring some relief for the city.

To guarantee the safe access to the ports along the estuary for ever larger ships, but mainly to the port of Antwerpen, large-scale dredging of the maritime access routes in the Westerschelde and in the lower Zeeschelde is required. Most dredging takes place at the bars where ebb and flood channels merge and at the port sluices. Some bars have been deepened more than 5 m and a further deepening is required. Although some sand is extracted from the estuary, most dredged material is relocated within the estuary at some specified dumping locations. In the Zeeschelde, about 367,000 t dry weight of polluted fine sediments are removed yearly from the system. A substantial area of intertidal habitat was lost due to dyke building. Embankments and infrastructure works fragmented the remaining habitat and disrupted continuity with the river basin. In order to protect the land against storm floods from the North Sea all dykes along the estuary (more than 700 km) have been heightened and strengthened. Therefore, the base of the dykes needed to be widened, which was mostly done on the marshes and not on the landside of the dyke. By now, over more than 50% of the total length of the estuary lacks tidal marshes in front of the dyke. This has severely disrupted the connectivity of marshes along the salinity gradient (Meire et al., 2005).

The recent evolution of habitat area in the Westerschelde is characterised by a decrease of low dynamic area, e.g. mudflats and shallow water characterised by low physical stress, and an increase of high dynamic area, e.g. deep water and sand flats characterised by high physical stress. The total surface area of intertidal mudflats decreased and the ratio of sheltered-to-exposed flats decreased. Future evolution of habitat morphology will depend on a series of factors, sea-level rise, lowering of the sea bottom (subsidence), dredging and reclamation can all influence the tidal regime. A clear trend is already visible: tidal amplitude near Antwerpen increased substantially, about twice as much as at the mouth of the estuary. It is obvious that inevitable human intervention in the highly dynamic Westerschelde has led, and will necessarily lead in the future to continuously changing ecosystems (Meire et al., 2005).

## 10.5 Conclusions

- The millennia long gain and loss of land, concomitant with intensive land use and exploitation of the flora and fauna, has marked the estuarine SW Delta. In the early 20th century this process had resulted in a large variation of small landscape elements, and microhabitats, and among them an artificial rocky shore.
- A reconstruction is given of the characteristic tidal gradients (horizontal) and zoning patterns (vertical) far upstream the rivers Rhine and Meuse, recognisable in the first half of the 20th century. The well-studied distribution patterns of hundreds of benthic macro-algae have been used as an example, including the illustration of the ‘brackish-water minimum’.
- The flooding disaster of February 1, 1953 induced the Delta project, originally meant to close off the main estuaries by massive sea walls, and turn them into freshwater lakes. The internationally rare estuarine gradients, the majority of the original mud flats and salt marshes and ecological zoning patterns on hard substrates were annihilated, and changed into non-resilient marine and freshwater compartments sealed off by large sea walls and locks.
- Ecological motives did not play any role in the original decision-making process in the 1950s, but the past 30 years the appreciation for environmental values has increased considerably. Arguments for nature conservation have played a decisive role in the political choice in favour of the saline Grevelingen, and the semi-tidal Oosterschelde.
- From the very beginning of the Delta project numerous long-term environmental problems asked for mitigating solutions, e.g. the accumulation of polluted Meuse, and mainly Rhine sediments in the Hollands Diep, Nieuwe Merwede, Biesbosch area, and the nutrient accumulation by agricultural run-off, causing mass blooming of blue-green algae, in the Krammer–Volkerak.
- The Delta project, one of the larger civil engineering projects on earth, brought world fame to Dutch civil engineers. The positive state of mind about the chosen solution for the Oosterschelde tempered, however, in the course of the years. The understanding has grown that estuaries, with their tidal rhythm and their gradients from saline to freshwater, are ecologically much more ‘healthy’ than the present separated and isolated waters.
- The disturbed hydrodynamic tidal balance in the Oosterschelde estuary resulted in continuous net erosion of the intertidal shoals, and filling up of the tidal channels (‘sand hunger’). The almost total loss of the intertidal flats over a period of many decades, comprising valued benthic life and waterfowl, will depreciate the natural values of the estuary. The increase of the sublittoral biodiversity (e.g. marine benthic algae), however, is much appreciated.

- The Westerschelde–Zeeschelde is the only complete, though severely manipulated and polluted, estuary left in the SW Delta. The estuary is regulated and constricted between massive sea wall impeding natural processes of sedimentation and erosion. Continuous dredging of the main channel is necessary for the accessibility of the main port Antwerpen.
- Studies of biogeochemical pathways and food webs revealed significant ecological values of the Scheldt. Although the general habitat quality is poor, the estuary harbours one of the largest European brackish-water marshes, now an important nature reserve (Saeftinghe marsh).

# Chapter 11
# Human Intervention in Tributaries of the Large Rivers

## 11.1 Introduction

The catchments of the main rivers Rhine and Meuse comprise the entire Delta, as delineated in this book, including numerous smaller tributaries. In Fig. 11.1 an arbitrary number of these smaller rivers and brooks have been depicted. The present geographic position is shown, but just as the main rivers, these streams have changed their position in the course of the centuries, they have been regulated, and some of them were dammed, and lost their position as a tributary.

From prehistoric times, up to the 20th century, water courses played an important role in the regional economies of the Delta. Waterways were the arteries for the transport of people and goods, and most medieval towns originated at the confluence of a main river and a tributary (Table 11.1), a strategic position, allowing the town councils to levy toll on passing merchandise. The town markets played a central role in the provision of the hinterland with goods and services (cf. Chapters 3 and 4). Fortification of towns had been in practice since antiquity (Chapter 2), but in the 10th century feudal lords began to develop the private fortress-residence known as the castle. This type of fortified dwelling served the twofold function, of residence and fortress, because of the conditions of medieval life, in which war was part of every day's practice. It is known that numerous castles have dominated the river scene of the Delta, and ruins and remnants of tens of these castles have been excavated along the main rivers and tributaries (Table 11.1). A few of them have been restored and function as part of the cultural heritage of the Middle Ages.

After gunpowder and cannons became available in the late Middle Ages, both castles and city walls became much more vulnerable, and there was less point to a castle as a fortification. Gradually the medieval castles were demolished or rebuilt and changed into country seats, often surrounded by gardens and encircled by a canal. Many new country seats were built in the period 1600–1800 along all tributaries of the main rivers, and particularly along the Kromme Rijn, Utrechtse Vecht and Amstel by the wealthy merchandisers from Amsterdam and Utrecht (Table 11.1).

The physical differences between the lowland tributaries of the Rhine, compared to the tributaries of the IJssel and Meuse, are obvious (cf. Fig. 2.8). The brooks feeding the rivers IJssel and Meuse have their source on higher grounds, some tens

P.H. Nienhuis, *Environmental History of the Rhine—Meuse Delta,*

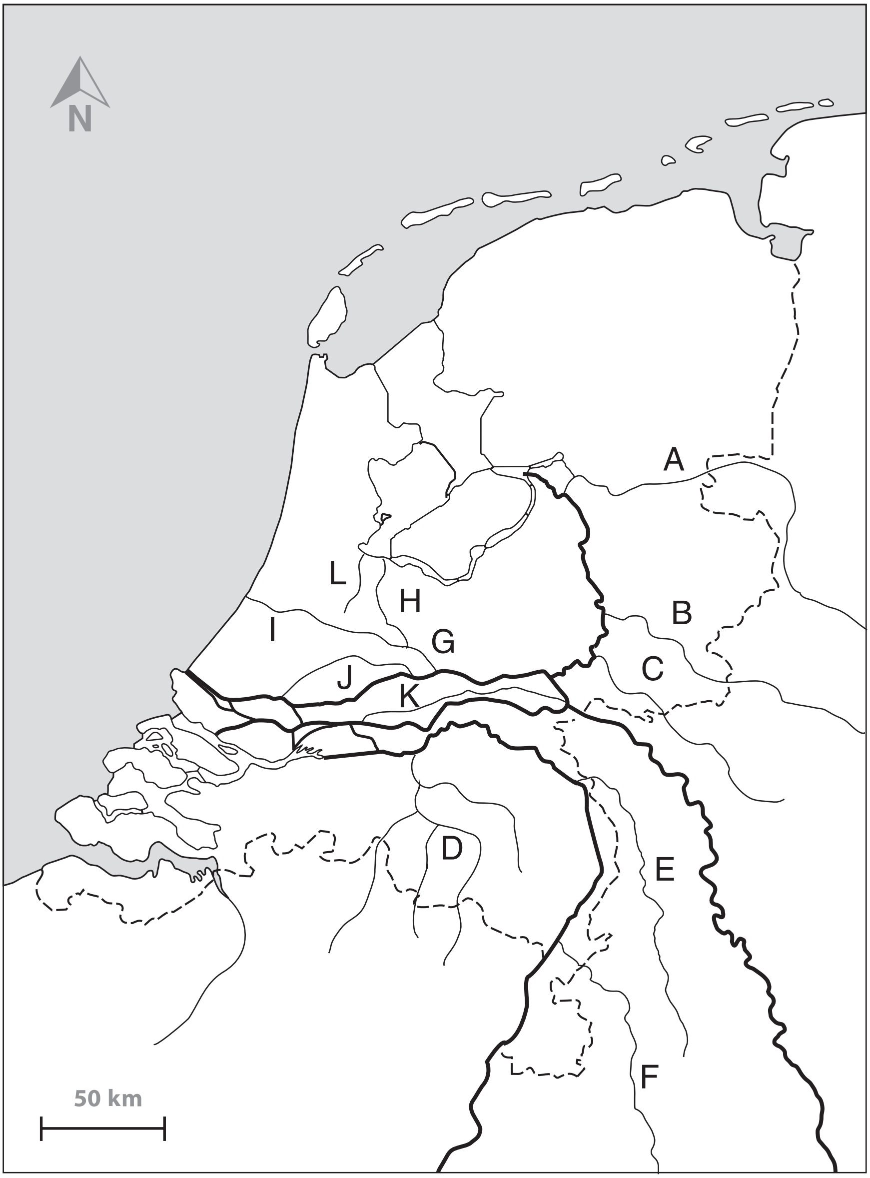


**Fig. 11.1** A number of tributaries and confluents of Rhine (Rijn) and Meuse (Maas) in the Delta. A = Overijsselse Vecht; B = Berkel; C = Oude IJssel; D = Dommel; E = Niers; F = Roer; G = Kromme Rijn; H = Utrechtse Vecht; I = Oude Rijn; J = Hollandse IJssel; K = Linge; L = Amstel

to hundreds of metres above the level of the main river. From the late Middle Ages until the 20th century, far beyond the introduction of the steam engine, the drop of these brooks has been used to power the paddle-wheels of numerous watermills (Table 11.1).

**Table 11.1** Tributaries and branches of the rivers IJssel, Rijn and Maas, and main medieval towns founded at the confluence of the main river and the tributary, or at (the mouth of) the river branch

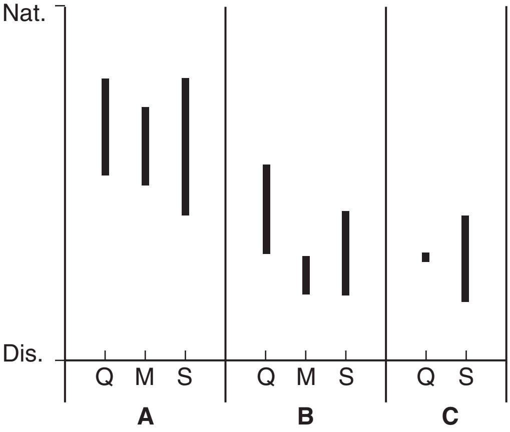
| River/brook | Town | 1 | 2 | 3 |
|---|---|---|---|---|
| IJSSEL | | | | |
| Vecht | Zwolle | X | X | X |
| Berkel | Zutphen | X | X | X |
| Oude IJssel | Doetinchem | X | X | X |
| RIJN | | | | |
| Kromme Rijn | WijkbijDuurstede | X | XX | – |
| Oude Rijn | Utecht, Leiden | X | X | – |
| Hollandse IJssel | Gouda | X | X | – |
| Vecht | Utrecht, Weesp | X | XX | – |
| Amstel | Amsterdam | X | XX | – |
| Linge | Tiel, Gorinchem | X | X | – |
| MAAS | | | | |
| Dommel | ‘s-Hertogenbosch | X | X | X |
| Niers | Gennep | X | X | X |
| Roer | Roermond | X | X | X |

1 = medieval castles; 2 = country seats founded after 1600, X = scattered, XX = numerous; 3 = watermills propelled by hydropower. See Fig. 11.1 for geographic positions of brooks; Kromme Rijn dammed in 1122; Oude Rijn dammed in *ca.* 1200 at Katwijk; Hollandse IJssel dammed in 1285, storm surge barrier in 1958; Linge dammed in 1306 at Tiel. Position of towns depicted in Figs. 2.10 and 3.7

It is an understatement that all brooks and small rivers have been influenced by man. Particularly in the 20th century the enforced drainage of agricultural land, resulting in the lowering of the groundwater table, has deprived many brooks of their original flow, and has led to desiccation in summer of the adjoining pastures and arable land. On the other hand, the increased dynamics in discharge, caused by the regulation works to fight the continuous threat of flooding, have enhanced the instable erosive characteristics of many brooks, resulting in erosion and incision of the brook bed during peak floods. On top of all these changes in the landscape, the discharge of organic loads, the effluent of sewage treatment plants, the unplanned load of untreated sewage water and atmospheric deposition have further deteriorated the brook environment (Nijboer et al., 2000; Verdonschot, 2000b) (see also Chapter 14).

Figure 11.2 shows the present ecological quality status of numerous Delta brooks. The natural situation is referring to ‘natural’ reference brooks, combined with the share of characteristic species still present in brooks of a ‘good ecological quality’. The majority of the brooks are presently in a (severely) disturbed state. The largest number of characteristic species is found in upper courses of quickly running brooks, in contrast with slowly running lower courses of brooks, comprising only very few characteristic species in a low number of brooks. Lower course in particular have been canalised (normalized) decades (or longer) ago, and are strongly charged with organic material and nutrients (Verdonschot, 2000a and b). In summary, the ‘ecological quality’ of brooks in the Delta, expressed in diversity and abundance of water-plants and macrofauna, was in 2000 less than 50% of the quality in 1950 (RIVM, 2003).

**Fig. 11.2** The range of the present relative ecological quality status of numerous (more than 100) Delta brooks. The natural situation is referring to 'natural' reference brooks, combined with the share of characteristic species still present in Delta brooks of a 'good ecological quality'. Vertical axis: Nat. = naturalstatus; Dis. = present (strongly) disturbed status. Horizontal axis: **A** = upper course; **B** = middle course; **C** = lower course. Q = Quickly running brooks (30–80 cm $s^{-1}$); M = moderately running brooks; S = slowly running brooks (10–50 cm $s^{-1}$) (Derived from Verdonschot, 2000b)



The aim of this chapter is to give a survey of the environmental history of a number of brook systems in the Delta. The chapter will not focus on changes in plant an animal life (see Chapters 7, 14, 15, 17, 18 and 19), but changes in landscape structure and functioning will get ample attention. Characteristics of the brooks debouching on the river IJssel will be shortly mentioned. The Dommel catchment will be elaborated as an example of a typical lowland brook, a tributary of the Meuse. The rigorous changes of the landscape will be covered, from dense forests and marshes in Roman times to the 'normalised' river bordered by maize fields at present, together with some clear signs of changing views for the future as witnessed by the recent 'nature development' projects. Some typical pursuits from the past will be covered, the fine-tuned irrigation systems of hay fields, and the conflicts of interest between farmers and millers. The water pollution of the Dommel basin, that reached its highest point in the decades after World War II, will be briefly surveyed. The environmental position of the town of 's-Hertogenbosch, and its gradually developing impact on the river landscape at the head of the Dommel, will be highlighted.

## 11.2 Groundwater- and Surface Water-Fed Brooks Along the IJssel

The Veluwe is a large elevated area, composed of Pleistocene cover sands and ice-pushed glacial ridges of sand and gravel (see Fig. 2.8). This massive area contains an enormous quantity of groundwater, resulting from a precipitation surplus over a long period of time. This water percolates through the sandy soil, and eventually comes to the surface again as seepage water, mainly at the eastern and southern slopes of the area, the transition area to the main rivers IJssel and Nederrrijn.

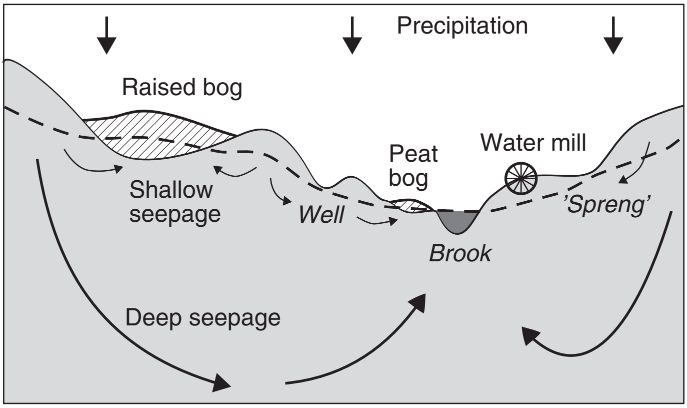


**Fig. 11.3** Scheme of the hydro-cycle in which shallow and deep seepage feed raised bogs, wells, peat bog and a brook can be recognized, respectively. On the right bank of the brook an artificial well ('spreng') is indicated; the water is flowing through a trained millrace onto the paddle-wheel of a watermill. Broken line = groundwater level; hatched = peat bog

The man-manipulated sources of brooks, where groundwater comes to the surface, are mainly concentrated along the eastern and southern borders of the Veluwe. The same process counts for the river Meuse (Gestuwde Maas; Chapters 5 and 13) that has incised its bed into the older cover-sand layers. In many cases the groundwater percolates through a marshy area, either a raised bog or a peat bog, concentrates into a small brook, the brooklets unite into a wider brook, etc. (Fig. 11.3). In historic times many brooks discharged water from the Veluwe massive onto the river IJssel and the Zuiderzee. Deep seepage water can travel over large distances, e.g. from the Veluwe underneath the Nederrijn–Lek to the Betuwe, a distance of more than 20 km: In the decoy in nature reserve Regulieren near Culemborg in the Betuwe, in between the rivers Lek and Linge (Fig. 3.9) seepage water was (and is still) used to keep the decoy-pond open during winter. The sources of the larger brooks indicated in Fig. 11.1 are located outside the Delta in Germany (e.g. Vecht, Berkel, Niers, Roer) or Belgium (Dommel).

Already many centuries ago the power generated by the natural drop of the brooks was efficiently used. Water-power is a very old and reliable source of energy for mechanical drive; in contrast, wind-power is unreliable. And, moreover, the Veluwe spring water was cleaner and softer than the surface water in the Central Delta. At the Veluwe *ca*. 200 watermills have been in operation; far out the largest number were paper mills, together with a suite of other types of mills, and among them a considerable number of corn mills. In the 17th century writing paper was in great demand; paper mills had their high days in the second half of the 18th century (Table 11.2). Artificially dug water sources were exploited, where groundwater was forced to come to the surface; this flow of water was guided through a trained brook onto a watermill (see Section 11.3.1.5). These millraces-connected-to-an-artificial-well ('sprengenbeken') were (and still are) characteristic for the Veluwe. Many of these

**Table 11.2** Development of the number of paper mills in action on the Veluwe between 1600 and 1950 (Voorn et al., 1985)

| Year | N |
|---|---|
| 1600 | 0 |
| 1700 | 90 |
| 1750 | 160 |
| 1850 | 120 |
| 1900 | 20 |
| 1950 | 0 |

wells were dug in the 17th to 19th century, but the use of flowing water certainly started centuries earlier. The oldest record of a watermill, a flourmill, at the Veluwe dates back to 1025. The maintenance of a system of millraces was labour-intensive. Inflowing sand and leaves had to be removed continually, plant growth had to be cut down, and broken sheet pilings demanded regular repair. To keep a strong drop the brooks were frequently 'swept' with birch besoms; this job was usually done on Saturday afternoon. Then the rooted-up mud could settle during the day of rest, the Lord's day, before the paddle-wheel had to be restarted on Monday (Hagens, 1998; Renes et al., 2002).

Flowing water from the 'sprengenbeken' was also used to irrigate hay fields ('vloeiweides'; see Section 11.3.1.4.), to operate fountains and to fill canals and ornamental fish ponds at country houses. A good example of a fully fledged system of watermills and millraces is shown in Fig. 11.4. The late medieval castle Cannenburch is situated on the transition from the high Veluwe to the lower IJssel basin, where a number of brooks eventually discharge there water on the river. A watermill is already mentioned from the 15th century, just as a number of artificial fish ponds. In the 17th century an artificial system of millraces was constructed fed by water from the Veluwe brooks and wells. Figure 11.4 shows the efficient use of water from the brooks in the 19th century, spread over at least 14 watermills, mainly paper mills (De Vries and Van der Woude, 2005). Now in 2006 only remnants of some mills have left.

The small rivers Vecht, Berkel and Oude IJssel drain into the IJssel (Fig. 11.1). These brooks originate somewhere in Germany and enter the IJssel catchment as typical small lowland rivers, mainly fed by surface water. At many places in the brook-basins, where water stagnated, marshy bog-peat was formed, and only at the most elevated rain-fed spots raised bog grew. Every winter period the brooks overflowed their borders, and flooded the adjoining fields. These floods were not experienced as detrimental: it was just part of everyday life. The summer spates, in contrast were very disadvantageous to the harvest of field crops. Gradually, in the course of the 19th century, the number of summer floods increased, and the winter floods grew in intensity. It was only in the course of the 20th century that the winter floods were experienced as a real nuisance; and hence they have been well documented. The most notorious years with floods were 1926 (disastrous), 1946, 1947 and 1960.

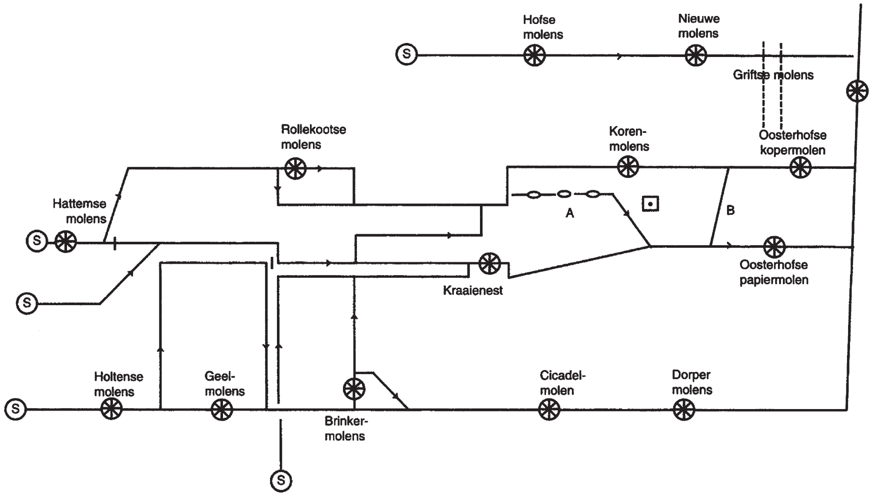


**Fig. 11.4** Scheme of a fully fledged system of watermills and millraces at the late medieval castle Cannenburch at the Veluwe. A watermill is already mentioned from the 15th century. In the 17th century an artificial system of millraces was constructed. This figure shows the efficient use of water from the brooks in the 19th century, spread over at least 14 watermills, mainly paper mills (De Vries and Van der Woude, 2005). S = well; paddle-wheel = watermill; A and B = recent connections between millraces; castle Cannenburch is indicated between A and B as a dot in a square

This increasing incidence of flooding was caused by several human activities, e.g. the cultivation of the 'waste' lands, resulted in the disappearance of the vegetation, the 'sponge' collecting superfluous water. The connection of natural depressions in the field, and the digging and canalisation of water courses and brooks formed another cause. Originally, the rainwater was collected in depressions covered with a dense marsh vegetation, in between the cover-sand ridges. During the cultivation phase, from the 12th century onwards, the original vegetation was removed, and connective trenches were dug between the depressions, leading to the drainage of water. In this way interconnected water courses originated, cutting through the cover-sand ridges. These artificial brooks became wider and wider, and dispatched their rainwater in periods of heavy rainfall quickly onto the main brooks and further onto the river, while the river IJssel itself was also in spate. This resulted in periodical flooding of the lowland stretches in the basins of the main brooks. The IJssel received simply too much water to be adequately discharged into the Zuiderzee. Some present-day brooks are artificially dug canals, originally intended as navigation canal between the IJssel and the hinterland. The river Berkel, e.g. was in the early Middle Ages a dead arm of a tributary of the river Vecht; in 1250 a sandy ridge was cut forcing the Berkel westwards into the direction of the IJssel (Driessen et al., 2000).

# 11.3 Environmental History of the Dommel Catchment, a Case Study

## *11.3.1 The Dommel Catchment*

### 11.3.1.1 Environmental History of the Dommel

The river Dommel originates in Belgium, flows through Noord-Brabant, is confluent with the river Aa in ‘s-Hertogenbosch into the Dieze, and debouches into the river Meuse. The Dommel is a typical slowly flowing lowland brook, its length is 146 km, with a slope of 35 m. Several smaller brooks are entering the Dommel, like the Aa, Beerze, Kleine Dommel, Tongelreep, Reusel and Run (Verdonschot, 2000a; Figs. 11.1 and 11.5). These lowland brooks are not fed by natural wells (as the brooks on the Veluwe), but originally received their water from raised bog areas.

In prehistoric times the higher grounds in the area were covered with deciduous forest (oak and birch), as witnessed from palynological records, while the lower lands were covered with fens and local patches of peat-bog. Man did not play a significant role in landscape development (Pedroli and Borger, 1990). In Roman times the lower Dommel basin was covered with forests and marshes, as witnessed by Caesar in De Bello Gallico (as mentioned by Van Heurn, 1776–1778). In the Middle Ages agricultural practice extended, and much of the deciduous forest was cleared and converted into open range land. The brooks were lined with marshy forests, where willow, ash and alder dominated. During summer the spongy raised bog areas only gradually released water downstream to the brooks. During winter, however, the brook valleys were completely flooded. The brooks discharged large amounts of water and overflowed their banks, and the brook valley changed into a marsh. These inundations

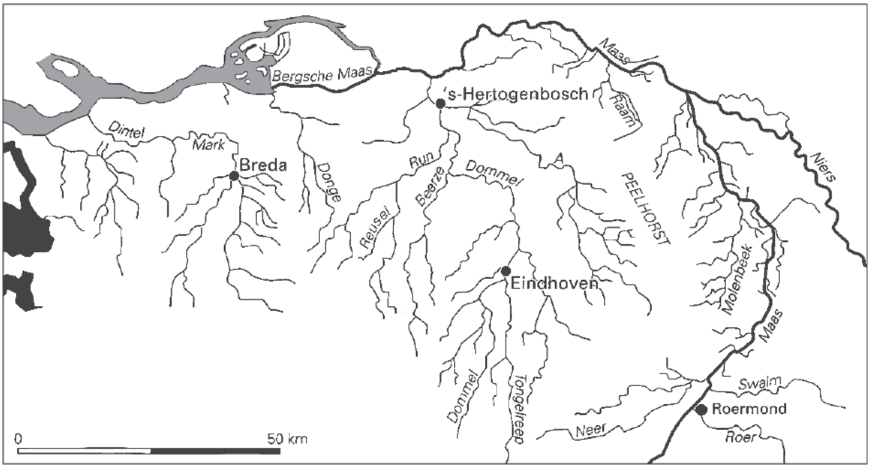


**Fig. 11.5** Dommel catchment with tributaries, e.g. the Aa, Beerze, Run, Reusel and Tongelreep

were considered important because at each inundation the brook deposited a thin layer of fertile silt, very much appreciated by the local farmers. The best silt was deposited by brooks flowing through seepage areas, where the water absorbed lots of calcium owing to its long stay in the sandy soil. Meadows without regular calcium fertilization gradually acidified and offered a low production of grass.

Where small human settlements were founded, the brook forests were stubbed up, herbs and grasses grew up, and cattle were allowed to graze on the village commons. The borders between lots were lined with hedges used as cattle fences. The meadows close to the village and lining the brook were used as pastures during the summer period. The meadows farther away from the brook were used as hay fields, and even more remote the natural marsh forests and brook valley forests remained, and man took his share from the remaining wilderness. The most prominent resource of the brook valley was wood. The marshy forests were managed as coppice, and the wood of a variety of pollard trees, such as willows, poplars, alders, ashes and oaks was intensively used. The thinner branches and twigs were used as faggots, longer and more solid branches and taller trees were used as timber. The peaty parts of the brook valley functioned as wet peat (turf) for fuel. The freely meandering brook frequently cut off meanders where peat formation continued, and where the locals gained peat (Moller Pillot, 1979; Caspers and Post, 1996; Pedroli and Borger, 1990)

From olden times human settlements were situated on the transition from the higher sandy grounds to the brook valley, where there was plenty of water and wood. The settlements were gradually surrounded by cultivated fields. The cattle was grazed in the brook valley and in the forests that long ago changed into heath lands; cattle and game animals were fenced out from the arable fields by hedges and wooded banks. Cattle was kept overnight in a stable, using the widespread ‘potstal’ (Dutch) system. The stable floor was covered with a layer of sods, cut from the heath fields. During the night the manure of the cattle mixed with the sods, and this process continued for a period of time. After a couple of months the stable was emptied, and the contents were brought onto the arable fields. The fields were fertilized and the surface level was gradually raised with the contents of the ‘potstal’. Large areas of grassland were necessary to feed the livestock and to fertilise the arable fields.

According to Caspers and Post (1996) this rural agrarian society did not change fundamentally until approximately 1800. It was a poor but sustainable society: there was no squandering of natural products, such as manure, sods of turf, wood, etc., and the common use of part of the wilderness, and part of the cultivated land enhanced the sustainable use of resources. Although the proprietary rights remained formally in the hands of the landlord, the settlers had restricted consumer rights, mainly benefiting the poor, such as the common meadow and the free gathering of dead wood and ears of corn.

But gradually the situation changed. Most tributaries of the Dommel have been canalised from the Middle Ages onwards, but small stretches of the river bear some original features of the (historic) meandering brook. The navigability of the Dommel was poor; one could only sail with a small boat from ‘s-Hertogenbosch to Boxtel, halfway Eindhoven (Fig. 11.5), a distance of *ca.* 20 km. Upstream exploitation of raised bogs and heath lands accelerated the current flow in the river, leading to downstream flooding. Cutting off of meanders and scooping out of the riverbed, measures meant to alleviate the flooding problems, eventually appeared to aggravate the annoyance. In the second half of the 20th century the number of flash floods increased again, owing to the unbridled increase of built up ‘petrified’ areas in the Dommel basin.

During the ‘normalisation’ works in the period 1950–1970 large stretches of the river were straightened and canalised, mainly to accommodate flash floods caused by increased discharges from drained agricultural areas and urban areas. The Dommel suffered from the same problem as almost all streams in river-land: the ‘sponge’ function of the basin and the capillaries was gradually abolished. In fact, a whole screed of changes had turned the Dommel and its tributaries into artificial streams. The brooks were improved by scooping out the riverbed, straightening the bends and meanders and widening narrow stretches. Diversions were dug to avoid flooding of larger towns (Boxtel; Eindhoven). Roughly 90% of the basin has been provided with weirs, which will form a major obstacle for the ‘re-naturalisation’ of the basin. Further, some watermills still present in the basin, are situated at a diversion of the river, while a weir holds the water in the river proper. In urban areas the main bottlenecks are formed by vaulting and culverts. In the brooks crossing the Wilhelminakanaal (position in Fig. 5.3) siphons were constructed underneath the canal to maintain the discharge of the brook. These siphons are hardly passable for fish.

Dykes proper are not present in the basin, but some stretches of tributaries are bordered by embankments. The only polder in the Dommel basin is situated east of the lower Dommel, right above ‘s-Hertogenbosch. Fixed concrete banks and river bottom are to be found around bridges and other engineering constructions and in urban areas. Eroding outer bends have often been protected with rip-rap, hindering the natural sedimentation and erosion processes. In ecological restoration project these defences will have to be removed, but this is hardly possible in built-up stretches and along arable fields. The basin contains *ca.* 10 sand-catchers in the lower and middle Dommel, devices to avoid silting-up of the riverbed and to concentrate contaminated silt and sand (e.g. zinc from Budel; cf. Chapter 13), in order to prevent downstream deposition. Almost everywhere in the Dommel floodplains the wooded banks were pulled up after 1950 and replaced by barbed wire. Rye fields have changed into maize fields. Keeping artificial fish ponds, where mainly carp was cultivated, was a widespread and small-scale trade that lasted for centuries. During summer the water level in the ponds was falling, and the fish was concentrating in the deeper parts of the ponds, where it could be easily caught. After 1945 many fish ponds were abandoned and the culture of carps was concentrated and industrialized (www.dommel.nl; www.kaderrichtlijnwater.nl).

#### 11.3.1.2 The River Aa

The river Aa is a main tributary of the river Dommel (Fig. 11.5). As with the river Dommel, a main problem for the farmers, from the Middle Ages onwards, were the continued periods of flooding of vast areas of low-lying fields along the brook.

Brabant was seen as an ‘inferior’ area, and improvement of the drainage capacity of the rivers had no priority. In fact, the marshy inaccessible Peelhorst, where the Aa had its origin, was seen as a natural defence line against the incursions of bands of soldiers from Gelre (Deckers, 1927). From the 17th to the 19th century the Aa, was made navigable, and provided with locks to allow smaller boats to sail from Helmond to ‘s-Hertogenbosch. The construction of the Zuid–Willemsvaart (1822–1826) partly replaced the navigation function of the river (cf. Chapter 5). Before 1620 numerous watermills prevented the navigability, and induced flooding. The millers used the drop of the river to work their mills, and hence regulated the flow of water. That gave a lot of conflicts between millers and farmers along the river, as will be explained in Section 11.3.1.5. Flooding of the floodplains along the brooks in winter was seen as beneficial to the hay fields, because a thin layer of fertile silt was deposited (Section 11.3.1.4). For the river Aa, however, the annual flooding changed from a blessing into a curse. The Aa has its source in the Peel, an extensive area of raised bogs. The systematic exploitation of the raised bogs of the Peel started in the mid-19th century. The area was drained, and trenches and canals were dug to drain the peat area, resulting during winter in the flow of large masses of acid peat-water that flooded the downstream fields, deteriorating the quality of the soil.

Just as with the river Dommel rigorous ‘solutions’ were contrived to fight the flooding problem. The brook and its tributaries were canalised in the early decades of the 20th century, meanders were straightened or filled in, and stretches were diverted through artificial straight canals. The recently changed views on nature conservation gave rise to ‘nature development’, i.e. the re-meandering of semi-natural stretches, the construction of ‘nature-friendly’ banks, and the ‘re-furnishing’ of old meanders (Caspers, 1992; www.aaenmaas.nl).

#### 11.3.1.3 The Values of Seepage Water

The deleterious effects of eutrophicated Rhine and Meuse water on biodiversity will be explained in Chapter 14, and the lower stretches of the river Dommel are equally charged with the levelling effects of too much plants nutrients. The hydrocycle of the upstream parts of the Dommel catchment is dominated by the infiltration of groundwater and by seepage water that is slowly leaking through the underground (Fig. 11.3). The distance between precipitation and seepage may vary between several metres and hundreds of kilometres. Considering the seepage pressure, differences in elevation play a major role; compare, for example, the flow of shallow seepage bridging the distance between a sandy outcrop and a downhill meadow or the flow of deep seepage, from the Kempen Plateau in Belgium to the Dommel catchment over a distance of 100 km, and a difference in altitude of 75 m (Fig. 11.3). Seepage is also controlled by the permeability of the underground. Porous spots may act as sources, where the water is vigorously forced up. Seepage is a quite common phenomenon in Brabant, but it is concentrated in the brook valleys along the geological fault-line of the Peelhorst, and on the border strips between sand and clay deposits. The longer and the deeper the water stays in the underground, the more oligotrophic and the richer in calcium it becomes. Brooks and brook valleys fed by seepage remained open during periods of frost, in contrast with ditches and fenland pools. Waterfowl taken by surprise by a sudden spell of severe frost, took refuge in these habitats. Frost damage was prevented by irrigating the grasslands with ‘warm’ seepage water, which had a rather constant temperature of *ca*. 5°C. Owing to the fact that this water was rich in calcium, the diversity of higher plants increased, and the farmers got a more abundant hay harvest. The distractions of groundwater in favour of drinking water supply, and industrial and agricultural use caused everywhere a sinking groundwater table and a lowered seepage pressure. The reduction of the flow of deep seepage water is seen by Caspers and Post (1996) as a main cause for the impoverishment of the local flora and fauna in the Dommel catchment. Another threat to groundwater quality is eutrophication, mainly by nitrate; phosphate is less deleterious because it adheres to soil particles.

#### 11.3.1.4 Water Meadows

Irrigated meadows, so-called water meadows, were engineered to enhance the production of grass and hay. The system is based on the principle that the flow of oxygen-rich irrigation water enhances oxidation processes in the soil, dissolves the nutrients and makes them readily available for plant growth. It is said that this way of irrigation has the same effects as ploughing a field. Another effect is that the irrigation water carries dissolved nutrients and suspended clay and loam particles. The irrigation water, originating from brooks and wells, has a slightly higher temperature than stagnant water. Warming up the soil in early spring, gives rise to an early production of grass, already in April. It was supposed that the irrigation water is suppressing the growth of harmful organisms, which attack the quality of the grass, under the condition that the water is continuously flowing; it should not stagnate.

Irrigation was seen as a cheap but labour-intensive way of fertilising the soil. Irrigation was done from early winter to March–April, and during short periods in the growing season. It was a subtle system. The incoming flow of water, derived from the brook, was regulated by small dams and sluices, and led into the upper trench. The idea was that the irrigation water should flow via smaller trenches slowly but steadily over the inclining meadows, down to the lower trench, and eventually back to the brook (Fig. 11.6). It was again a subtle system, of simultaneous irrigation and drainage. In order to keep the water flowing, the system of trenches had to be cut open and maintained each year. Stagnation of water led to the growth of sedges and rushes, altogether making up a bad quality of hay. During a spell of severe frost the irrigation was stopped.

This system of irrigation and water meadows, applied to enhance the production of grass and hay, is a very old technique, presumably applied over large parts of Europe for over 1,000 years. In the course of the 20th century the technique is

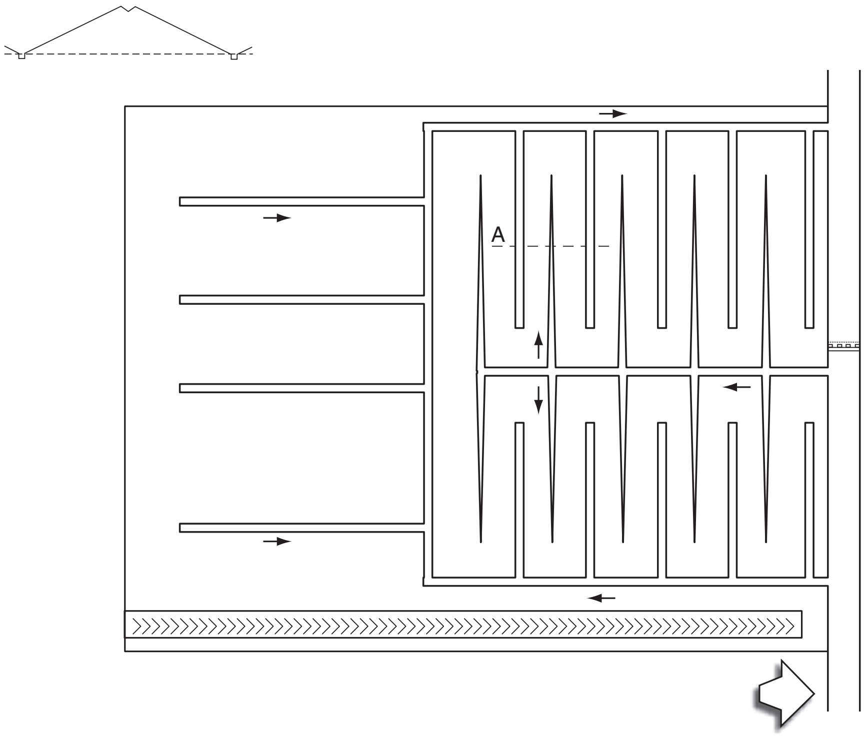


**Fig. 11.6** Scheme of a system of water meadows. Arrows indicate the direction of the flow of water. The trench on the right contains a dam diverting the water over the water meadows. A = section in left upper corner. For further explanation see text Section 11.3.1.4 (Burny, 1999)

completely abandoned, and replaced by mechanised agricultural practice and the use of artificial fertiliser (Rackham, 1995). In the Rhine–Meuse Delta water meadows were also widespread, along tributaries of the river IJssel (Veluwe; Achterhoek), and the river Meuse (Dommel; Aa). Figure 11.7 shows a scheme of a water meadow system from the Kempen, along a tributary of the brook Aa (Burny, 1999). The system of water meadows of the Meuse tributaries was abandoned in the early decades of the 20th century. The upper and lower trenches were no longer cut open in autumn, a necessary measure for the successful irrigation and drainage of the fields. In the abandoned meadows rainwater started to stagnate, and the meadows changed quickly into a marshy area were sedges and rushes thrived, followed by wild shoots of willow and alder, ending up in alder brake and willow-groves as we know them nowadays. In short, as soon as the careful annual maintenance by man of a water meadow system is left undone, the wilderness prevails within one growing season (Rackham, 1995; Burny, 1999).

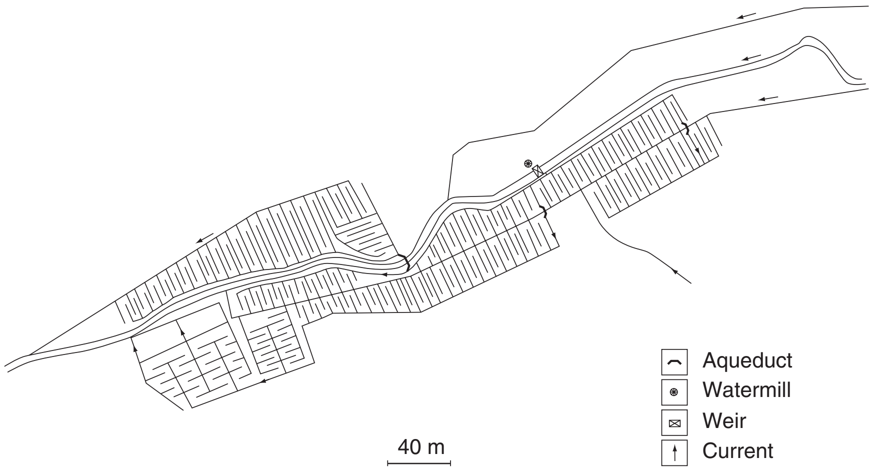


**Fig. 11.7** Scheme of a system of water meadows at the watermill of Ellikom on the river Aa. For further explantion see text Section 11.3.1.4 (Adapted from Burny, 1999)

#### 11.3.1.5 The Miller Contra the Farmer (and the fisherman?)

Water and wood were the two bountiful resources that made the brook valleys most attractive places to settle. The water of many wells and brooks eventually feeding the river Meuse was clean until World War II, and could be used as drinking water without purification. Stretches of brooks with industrial watermills were of course polluted. From the early Middle Ages onwards the courses of almost all brooks were regulated in the course of time, in order to irrigate the fields and to facilitate the many watermills. The brooks were straightened, diverted, or ‘led up’ (trained), i.e. that the water was directed through an almost horizontal, slightly inclining artificial trench, in order to reach eventually a larger fall of water to move the paddle-wheel, or to irrigate higher situated fields (cf. Fig. 11.3). River bends and meanders were diverted or dammed up, using sheet pilings, and constructions made of tree-trunks stuffed with faggots and grass-sods. Larger wooden sluices (as described in Chapter 3) were constructed by experienced carpenters (Caspers, 1992).

The water of the brook was indispensable and used far various purposes: as drinking water and household water, to do the washing (and the whitening on the bleaching-greens), to water the vegetable gardens and the cattle, to fill the fish ponds, to irrigate the water meadows, to ‘water’ the trunks of pine and other trees, and last but not least to operate the paddle-wheels of a variety of watermills: corn mills, oil mills, sawmills, tan mills (bark-mills) to grind the bark of oak as raw material for tanneries; mills to grind the bones of cattle as raw material for the production of dyes; and later on in the 18th and 19th century paper mills. It is no use saying that these mills caused severe pollution of the water in the brooks, and this became a real nuisance along particular stretches of the Dommel (see Section 11.3.2).

In the pre-industrial age winter inundations of the fields bordering the brook were welcome, because during each flood a thin layer of fertile silt was deposited on the (water) meadows. The (unnatural) inundations during summer were a different story. Here the interests of farmers and millers were fully conflicting. The main interest of a miller was the continuous movement of the paddle-wheel of his mill. Particularly water mills used for grinding corn had a main interest in damming up the water from the brook in a reservoir by means of a sluice, which could then gradually be drained to propel the mill. Consequently, upstream of the mill the meadows were inundated and the hay rotted on the fields, and downstream of the weir lack of water induced problems of desiccation of the soil and a too low flow of water. Watermills, particularly corn mills in the Dommel basin were already founded between 1000 and 1300, perhaps earlier (Deckers, 1927). In the 19th century 32 watermills were situated on the Dommel, causing major flooding problems and loss of income for farmers. For many centuries there have been (legal and illegal) fights between farmers and millers, and considering the economic importance of a watermill, many millers gained legal rights to dam up the water of the brook (Brabants Landschap, 1999).

Halfway the 19th century the arguments of the farmers became louder and louder to end the outdated rights of the water-millers. After the example of the water boards in Holland, similar institutions were erected in Brabant, e.g. in 1863 the ‘Water board Dommel basin’ (Anonymous, 1963). The water board took rigorous measures. During the ‘normalisation’ of the brooks, many weirs were removed, and watermills were abandoned or demolished. This process was intensified after Word War II during the re-allotment of land, when entire centuries-old historic landscapes were annihilated. The Dommel and its tributaries were deepened, widened and straightened, measures that are continued onto the present day. From then on large-scale draining started in Brabant, supported by new agricultural views (dry soil is more productive than wet soil). Draining became a main activity, spreading over ever larger areas of re-allotment and land use schemes. Draining was executed by cutting deep trenches and digging in drainage pipes. Next to low-lying ‘waste’ land, entire catchments of brooks were drained in the course of the 20th century. As a result the groundwater level of the entire cover-sand area of Brabant has been lowered dramatically.

Before World War II the farmers were forced by the elevated groundwater levels to house their cattle long after wintertime. Moreover, grass growth was retarded by the combination of water-logged soil and the low temperature of the inundation water. At present the cows can be turned out to pasture earlier in the year. The dry fields allow the farmers, using heavy machines, to cultivate their fields earlier in the year. In summer the too low groundwater level is compensated by sprinkling. From a depth of *ca.* 10 m groundwater is pumped up, and this measure is aggravating the further lowering of the groundwater level. The Dommel catchment is drying out at places where it was once wet, and flooding is replaced by drought damage (Anonymous, 1963; Pedroli and Borger, 1990; Caspers, 1992). Only very recently, re-wetting measures and water retention measures are taken in local ‘nature development’ projects.

The ‘miller against the farmer’ is a well-documented conflict. Only a few references are made in the literature, however, to the negative relationships between watermills and migratory fish species, or between watermills and aquatic ecosystems in general. For example, the ecological impact of watermills on salmon decline is only poorly elaborated and not quantified. According to Lenders et al. (in prep.) the Atlantic salmon became a victim of construction and operation of watermills over a period of 600 or maybe even more than 700 years: large portions of its habitat were destructed and the remaining habitat was often not accessible anymore. Increased fisheries and water pollution eventually finished off the salmon population in the larger part of its natural geographic distribution range (cf. Chapter 8). Knowledge regarding the possible hydrological effects of watermills and accompanying hydropower dams on the migration and reproductive biology of salmon strongly indicate for adverse effects of watermills on salmon stocks from the Middle Ages onwards. Although the evidence for this phenomenon in the Delta is meagre, it is worth to be considered.

### *11.3.2 Water and Soil Pollution*

Increasing urbanisation and industrialisation, e.g. textile and leather factories and tanneries, at the end of the 19th century and particularly in the 20th century led to deterioration of the water environment in the Dommel basin. In 1937 the first sewage water treatment plant in the catchment was built, but most sewage water was untreated until far after World War II. Particularly in the period 1950–1970 most brooks suffered from oxygen deficits, caused by the discharge of untreated sewage water containing large amounts of organic material and detergents containing phosphates. In 1963 the entire stretch between Eindhoven and ‘s-Hertogenbosch was completely anaerobic in summer, with an average annual oxygen concentration of less than $5\,\mathrm{mg\ l^{-1}}$ (Anonymous, 1963).

Over the past 35 years water pollution has been alleviated. Large-scale introduction of sewage water treatment after 1960 resulted in significant improvements of the quality of the surface water. After 1970 phosphate was replaced by other chemicals, and gradually the use of refractory pesticides (such as DDT) in agricultural practice was abandoned. At present the most important source of water pollution is the intensive agriculture practice, comprising the problems of the organic slurry residues and the abundant use of artificial fertiliser. These compounds are discharged with rainwater and cause over-fertilisation of the river water. Specific pesticides (e.g. lindane) are still forming a problem. The number of sewage treatment plants increased rapidly, and now in 2007 the overall water quality in the Dommel catchment is satisfactory to good. Dommel water is not used as source for drinking water; instead groundwater is used as raw material. In modern sewage water treatment plants 95% of the organic material are removed, whereas 75% of the nitrogen- and phosphorous compounds are removed. Roughly 60% of the heavy metals, such as lead and zinc, form compounds with silt and are thus rendered harmless. Other pollutants like salts and pesticides are only partly bound to silt (www.phys-tue.nl).

A specific source of pollution is formed by the zinc factory in Budel, founded in 1892. The remote Dommel region, close to the Belgian border, was considered very well-suited for zinc production, because this part of the Netherlands contained zinc ore, and had ample flowing water. The factory in Budel is a major producer of zinc: over 200,000 t of zinc are produced annually, mainly processing zinc ore from abroad. The acidic waste water from its zinc refinery contains zinc and other metals (tin, copper, nickel, manganese, chromium, lead and iron). Until 2000 the conventional process for treating this waste water was used, which involved neutralising it with lime or limestone, which results in large quantities of gypsum contaminated with heavy metals. Budel has developed a bioprocess that uses sulphate-reducing bacteria to capture and recycle zinc and other metals in its waste water as metal sulphide precipitate. The metal sulphide precipitate is recycled into the refinery feedstock. This process has resulted in a 10- to 40-fold decrease in the concentration of heavy metals in the refinery wastewater, and eliminated the production of metal-contaminated gypsum which is a hazardous solid waste by-product (OECD, 2001).

Sandy soils, in the border area of Belgium and the Netherlands (the Kempen region), are heavily contaminated by atmospheric deposition of cadmium and zinc from the nearby smelters. Groundwater contamination by leaching from these low retention soils is obvious, and high cadmium and zinc concentrations in groundwater in the area are frequently reported. Notwithstanding the improved zinc production technology, historic heavy metal pollution is still a serious environmental problem. The concentrations of zinc and cadmium in arable fields around the zinc factory at Budel are still far too high (De Ruijter et al., 2004). For over 20 years the Budel site has been a favourite research locality for several research groups, studying the ecological and physiological effects of zinc exposure to various organisms, and to predict present or future risk of groundwater contamination by metal leaching from the soil (e.g. Posthuma et al., 1992; Wilkens and Loch, 1997; Rutgers and Breure, 1999; Tobor-Kaplon et al., 2006).

### *11.3.3 Human Occupation of the Dommel Basin: ‘s-Hertogenbosch*

#### 11.3.3.1 From the Middle Ages to the 18th Century

Many books have been written about the history of ‘s-Hertogenbosch. Most stories deal with the fate of the well-known and sometimes unknown people, that put their mark on the history of the town. Other stories dwell in detail into the cultural, religious, architectural and town-planning aspects (Kuijer, 1999; Vos, 1997) A few recent documents deal with ‘s-Hertogenbosch as ‘water town’, in which the fight against floods, and water management get ample attention. Information on the ecological history of the town is scattered in the literature, therefore I made a compilation of relevant information from sources dealing with the ongoing occupation of the landscape by urbanisation, the marked impact of the military history, the history of developing trade and industry, and of deterioration of the water bodies, and the recent reconstruction and solution of environmental problems (Van Heurn, 1776–1778; Deckers, 1927; Hoogma and Steketee, 1996; Van Oudheusden, 2001; Verhagen, 1998; www.grootestroom.nl/binnendieze.html).

‘s-Hertogenbosch is situated in the delta of the rivers Dommel and Aa, confluent into the river Dieze, and debouching into the river Maas (Fig. 11.5). Under the cold and dry tundra climate at the end of the last Ice Age, approximately 15,000 years ago, prevailing westerly winds removed massive amounts of sand from the Meuse valley and from the dry bottom of the North Sea onto the mainland, which was intersected with riverbeds, that ran dry during the cold period. This Pleistocene sand is covering large parts of the drainage basin of the Dommel.

On one of these cover-sand ridges (higher than NAP + 2.75 m) ‘s-Hertogenbosch was founded, surrounded by marshlands, comprising of alder stands, and spots with growing peat and brushwood (Fig. 11.8). The settlement had an open connection with the river Meuse, which meant that it was exposed to unpredictable, changing water levels. The elevated sandy ridges between the streams offered the local inhabitants some protection against regularly occurring floods. The amplitude of the Maas discharge must have been significantly smaller than it is nowadays. The settlement Empel, known for its excavations of an ancient Roman temple (Verhagen and Chambon, 1995), is situated at a location considerably below the present high water level of the Maas. The first inhabitants of ‘s-Hertogenbosch, this ‘new town near the woods’ (‘wood’ is ‘bosch’ in Dutch), built their houses on one of the sandy ridges, bordered by the Dommel at the west side, and the Aa at the east and north side. During the period in which the pioneers brought land under cultivation they dug a considerable number of drainage trenches in the marshy soil. Many of these disappeared in the course of time, but some of them were excavated and widened and made suitable for shipping with small boats.

After the construction of the first town wall, earthen ramparts, the inhabitants of ‘s-Hertogenbosch gradually started to heighten the marshy grounds within their settlement. The official foundation of the town dates back to 1184–1185. It is not clear which canals of the Dieze, called Binnendieze in ‘s-Hertogenbosch, originally belong to the natural basin of the rivers, and which ones have been dug. The sand from the newly dug canals was used to heighten the lower parts in town, where houses could be built. The town grew quickly and it is known that stone walls and town gates were already built in the late 13th and early 14th century (charter of 1307). At the same time the old courses of the rivers, partly natural partly artificial, were maintained, which gave ‘s-Hertogenbosch its unique network of small watercourses, the Binnendieze.

Owing to its favourable location, the new settlement quickly grew into one of the larger cities in the Delta. The Dieze became the fairway for tradesmen from ‘s-Hertogenbosch to Meuse and Rhine, the main routes in Europe of the Middle Ages. The confluence of Dommel and Aa made transport of goods by ship to and from the hinterland self-evident. As means of transport roads did not play a significant role until far into the 18th century, and these connections consisted of hardly passable cart-tracks. Drinking water and food, like fish and water birds, were plentifully

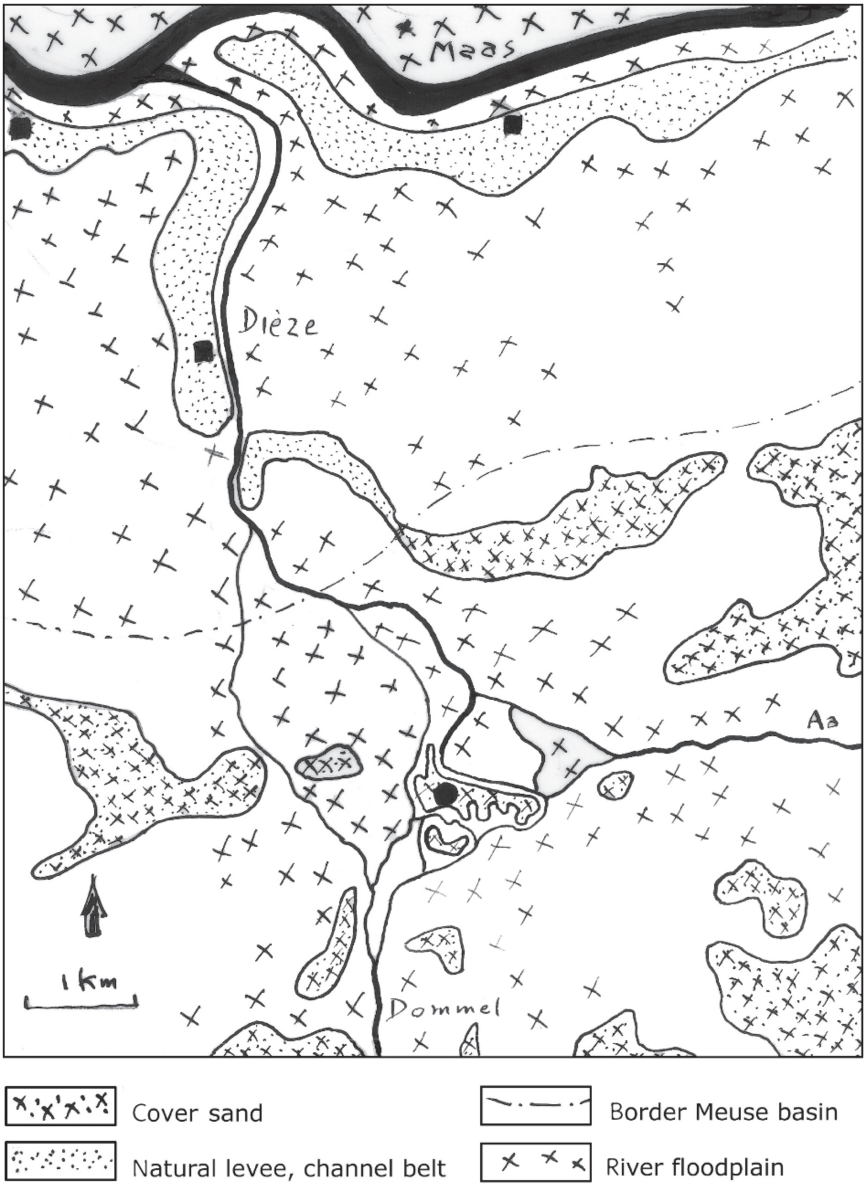


**Fig. 11.8** ‘s-Hertogenbosch in the 12th century (black dot), founded on a cover-sand ridge in the floodplain of the river Maas, the delta of the small rivers Dommel, Aa and Dieze. Black squares = excavated Roman settlements (Adapted from Hoogma and Steketee, 1996)

available. The elevated sandy grounds in the south delivered wood for building purpose, and the fertile Maas valley was suitable for pastures, hay meadows and arable land. The clay from the Maas floodplains was amply available as resource for the fabrication of building bricks. Bricks were reinvented in the second half of the 12th century as building material; the skill of making bricks was lost after the departure of the Romans. In military terms the wetlands and marshes surrounding the town were strategically of great importance, but they were also indispensable as supplier of peat as fuel.

The Dieze is older than the town, which implied that the street pattern in old 's-Hertogenbosch was dictated by the courses of the small rivers. Along these streets narrow, elongated lots were occupied, leading from the street down to the stream This allowed the inhabitants to practise their trade at the backside of their house, at the waterside, where workshops and small warehouses were built. Originally the banks of the Binnendieze were overgrown with natural vegetation, but erosion and sedimentation changed the riverbed continuously (Fig. 11.9). The tradesmen started to build wooden facings to canalise the water course, a private initiative of the owners of the lots. Gradually, a process of 'petrifaction' took place, starting with the building of brick quay walls, to facilitate loading and unloading from yard to ship. The increasing population demanded space for building houses in the protected town. Owing to the lack of building ground from the 15th century onwards the people in 's-Hertogenbosch started to make brickwork overarching the Dieze, and to build their houses on these masonries. Gradually the watercourses became vaulted over distances of hundreds of metres, not only by buildings but also by a large number of brick bridges (Figs. 11.9 and 11.10). The course of the Binnendieze became invisible in the urban scene over considerable distances. In the 16th century the town was built over: in 1525 approximately 10,000–15,000 people lived in the fortress.

In every day's rural live the Binnendieze was essential. Housewives took drinking water and did their laundry in the stream. Numerous tradesmen, like brewers, cloth-dyers, blacksmiths and tanners made ample use of the flowing water of the Dieze. Ships with goods and fuel sailed on and off at many small businesses. Hundreds of open sewers drained off their waste water into the stream. For centuries it was a common habit to dump garbage, dung, etc. into the river, although already in the early 16th century severe fines were levied, in case of negligence of the local regulations (cf. Chapter 14). Many diseases have hit the medieval population of 's-Hertogenbosch, ignorant of the consequences of using severely polluted water, and of living under unhygienic conditions. From the early 14th until far in the 18th century 's-Hertogenbosch has been infested by smaller and larger outbreaks of bubonic plague. It started with the Black Death, a combination of bubonic, pneumonic and septicaemic plague strains. It devastated the Western world from 1347 to 1352, killing 25–50% of Europe's population and causing or accelerating marked political, economic, social and cultural changes (cf. Chapters 2 and 3). The long-term effects of the plague were even more profound, the Black Death was the first epidemic of the second plague pandemic, a series of cyclic outbreaks of the disease which recurred until the 18th century. The European population declined steadily for at least a century after 1350 (Gottfried, 1983). Although

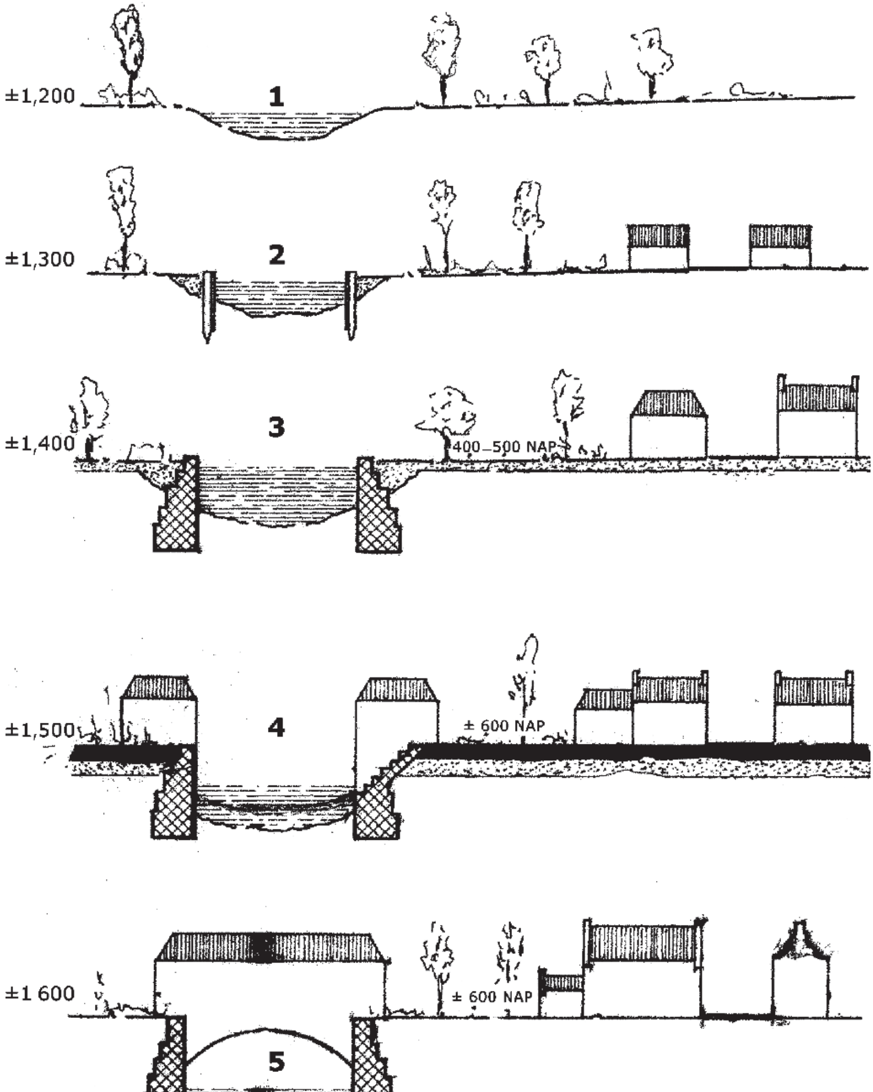


**Fig. 11.9** The encroachment of ‘s-Hertogenbosch on the Dieze floodplains between the 12th and the 17th century. (1) Situation around 1200, the foundation of ‘s-Hertogenbosch, in a natural floodplain; (2) situation around 1300, the first houses of wood and loam were built, and wooden facings along the Dieze were constructed; (3) situation around 1400, elevated ground level, brick revetments and houses; (4) situation around 1500, further elevation of the ground level, roughly to the present-day level, NAP + 6 m; (5) situation around 1600, the vaulted river, see Fig. 11.10. See also text Section 11.3.3 (Drawing H.A. Becks, derived from Verhagen, 1998)

**Fig. 11.10** The medieval vaulted river Dieze crossing ‘s-Hertogenbosch (Photograph K. Kars, 2004)

no detailed information about the impact of the Black Death in ‘s-Hertogenbosch is at my disposal, we may assume that the plague also hit the population of the town. Between 1439 and 1442 another plague epidemic stroke a large part of the Netherlands, and also ‘s-Hertogenbosch. It is documented that this epidemic lasted for 4 years continuously, and it decimated the population of the town (Van Heurn, 1776–1778). In 1531 a plague epidemic combined with famine hit the town.

‘s-Hertogenbosch is situated in a river delta, and that has become decisive for its existence. Time after time the ground level of the town has been heightened by sand, household and construction garbage and scooped out mud from the Binnendieze. Notwithstanding the efforts to keep their feet dry, the inhabitants were frequently hit by river floods, on average once every 30 years (Van Heurn, 1776–1778, and recent data). A number of documented floods are given in Table 11.3; the list is not exhaustive.

‘s-Hertogenbosch has always been a centre for trades and commerce. During centuries trading barges transported people and goods to Gorinchem, Dordrecht, Amsterdam and ‘s-Gravenhage, and cargo was shipped to Bergen op Zoom, Brugge and Antwerpen. The markets in Brabant and Holland were provided by Brugge via ‘s-Hertogenbosch (Fig 3.7). Via the international trade to Rheinland (Germany), the Meuse area, and via the North Sea to Norway, Sweden and North Russia, a variety of products were imported, like metals (lead, tin, copper), tar, herring and salt. Wood was brought in from Germany and Russia. The producers of woollen cloth imported dyes from overseas, like woad (*Isatis tinctoria*; blue dye), weld (*Reseda luteola*; yellow-brown), and madder (*Rubia tinctorum*; red). Products from ‘s-Hertogenbosch, like beer, beaten iron, cloth and leather were the return cargo.

**Table 11.3** A number of documented, devastating river floods in ‘s-Hertogenbosch. The cathedral St. Jan, founded in the 13th century, is situated at one of the most elevated places in town. In 1223 the floor of the church was situated at NAP + 4.51 m (recalculated). The present height is NAP + 6.35 m, presumably dating back to 1515 (Van Heurn, 1776–1778; Deckers, 1927; and recent data)

1446 – Town flooded; cathedral St. Jan can only be reached by boat
1529 – Town flooded; water levels unprecedented high
1531 – Town partly flooded; plague and famine
1573 – Town almost entirely flooded; water does not reach cathedral St. Jan
1598 – Town walls damaged by flood in winter
1622 – Town walls severely damaged by flood and pack ice in winter
1709 – Ice dam in river Maas; severe damage to town wall and bridges
1726 – Town partly flooded; ice layer of 30 cm
1740 – Town almost entirely flooded
1757 – Highest flood ever (NAP + 6.68 m); town entirely flooded; in low-lying streets 1.5 m water
1850 – Ice dam in river Maas; town partly flooded
1861 – Town partly flooded
1876 – Town almost entirely flooded; NAP + 6.10 m
1880 – Town flooded; floor cathedral St. Jan flooded
1995 – Flood 31 cm below town level, NAP + 4.95 m; cellars flooded

#### 11.3.3.2 Intervention in the 19th and the 20th Century

Navigability of the Aa, one of the connecting streams to ‘s-Hertogenbosch, has always been a problem owing to the steep fall. The large peat resources in the hinterland that could only be reached via the river Aa, however, were of vital importance for the town. Centuries went by without a proper solution for this transport problem. Finally, it was in the 17th century that a partial canalisation plan, comprising the building of sluices, for the river Aa was executed. In 1627 this adaptation was finished, and barges loaded with peat were able sail from Helmond to ‘s-Hertogenbosch. However, the shipping route came in a state of decline, owing to lack of maintenance of the waterway, and struggle between the governmental bodies about the management of the Aa. The same counted for the river Dommel. The river Dommel has always been a suitable river for the maintenance of a number of watermills (see Section 11.3.1.5).

At the end of the 19th century the transport of goods along the Aa–Binnendieze ceased. The building of the canal Zuid Willemsvaart (Fig. 5.3) from 1822 to 1826, between ‘s-Hertogenbosch and Maastricht, which ran over a distance of approximately 1,300 m right through the heart of the town, played an important role in this loss of the main function of the Binnendieze. Numerous old water courses lost their function and were filled in, and the still existing branches were only scooped out, to enhance the flow through of river water. But maintenance of the streams, however, had low priority.

Until the end of the 19th century ‘s-Hertogenbosch remained the old gated fortress decked with a considerable number of bastions. Every winter the water of Maas and Waal splashed against the walls of the town (see Section 5.4.5: Beerse Maas). The fact that the surroundings of the town could be inundated had provided excellent services for military purposes in the past. But the 'modern' military means made town walls obsolete, and the status as a fortress was lifted in 1874 ('Vestingwet'; Bastion Act), and that opened the possibility to enlarge the town beyond its ramparts and walls. For that purpose the layouts of the town had to be heightened several metres by sand. Large excavators were constructed to dig the sand out of sand pits – the Iron Man is such a sandpit, named after the excavating machine. After 1900 the town grew, and grew, until the capital as it is nowadays, 25 times the surface area it had in the 19th century, with 140,000 inhabitants (Fig. 11.11). A comparison between Figs. 11.8 and 11.11 shows that the medieval Maas landscape has completely disappeared. The river Maas is canalised and constricted in its narrow basin. Some small nature reserves, remnants of the marshes of the Beerse Maas are left. The majority of the city outskirts are situated in the former Maas floodplains. The city is constricted and bordered by the modern 'city walls' the motor highways and main roads, provided with noise baffles. The straight railway connections built in 1860–1870 are still remarkable landmarks. The harbour, once the centre of trades and transportation to the river Maas and further destinations, has lost its commercial function.

During the 20th century the deterioration of the Binnendieze progressed, and both the cultural and the natural qualities of these town canals decreased quickly. The loss of the transport function of the fairways kept simmering over a low flame, with consequent decay and dilapidation of the buildings, the vaulting and the bridges. Sewage treatment plants for water that entered the Binnendieze from the Dommel were not available, and a closed sewer system for the inner town was non-existent. The water became more and more polluted owing to unlimited discharges of sewage water. The Binnendieze became a dead, black and stinking open sewer.

In 1969 the town council of 's-Hertogenbosch decided to fill in the larger part of the Binnendieze, to pull down several fronts of ancient streets and to modernize the inner town in favour of a better traffic circulation plan. But fortunately this disastrous decision has never been executed. Remarkably enough it was the much maligned function of the streams as an inner town sewer that saved the Binnendieze. As long as the inner town of 's-Hertogenbosch did not have a modern closed sewer system, the small river could not be filled in. This delay in execution meant the rescue of the Binnendieze. In 1972 the Ministry of Culture, advised by the Historic Buildings and Monument Commission, designated the inner city as urban conservation area, which meant that filling in the town canals was no longer a serious option. Changes in public attitude concerning the preservation of cultural and natural heritage enhanced the idea that repair and restoration of the Binnendieze would be a better solution than to fill up the historic courses.

To make a long story short, during a toilsome process the remaining 3,610 m of the original Binnendieze have been completely restored during the past 30 years. Now, in 2007, although the quality of the underwater sediment is still a local problem, the water is clean, water plants returned and even an occasional fish can be caught. A sailing trip over the Binnendieze is now a prime tourist attraction: the network of small watercourses, the vaulted passages and the medieval backsides of the houses interspersed with ancient gardens. Normally town canals are situated at the front side of the houses (cf. Amsterdam, Chapter 14). In 's-Hertogenbosch the

**Fig. 11.11** ‘s-Hertogenbosch in 2000. The rivers Maas, Dieze, Dommel and Aa, although regulated and normalised, can be recognised (compare Fig. 11.8). The inner city is situated at the confluence of the rivers Dommel and Aa; 1 = City Market Place; 2 = St. Jans Cathedral (cf. Table 11.3). The southern borderline of the Beerse Maas (Chapter 5) is crossing the areas of the town built up after World War II. Irregularly shaped grey spots = semi-natural wetlands and peat lakes; regularly shaped grey spots = excavations, sand pits were sand was gained for the raising of proposed routes of railways, and roads and built-up areas in the former floodplain of the river Maas

Binnendieze is flowing at the backside of the premises (Fig. 11.10), which gives this scheme its unique character (Van Heurn, 1776–1778; Deckers, 1927; Hoogma and Steketee, 1996; Van Oudheusden, 2001; Verhagen, 1998; www.grootestroom.nl/binnendieze.html).

## 11.4 Conclusions

- Seepage from the Pleistocene cover sands and the ice-pushed sand ridges was mainly concentrated in brook valleys. The water was oligotrophic, rich in calcium and had a rather constant temperature of *ca*. 5°C, and was hence attractive both for farmers (water meadows) and hunters (concentrations of waterfowl in winter).
- The system of irrigation and water meadows, applied to enhance the production of grass, is a medieval technique: the flow of oxygen-rich irrigation water from the brook valleys enhances oxidation processes in the soil, dissolves the nutrients and makes them readily available for plant growth. In the course of the 20th century the technique is completely abandoned, and replaced by mechanised agricultural practice and the use of artificial fertiliser.
- The use of watermills, particularly corn mills, is dating back to the Middle Ages. The interests of farmers and millers were fully conflicting. The main interest of a miller was the continuous movement of the paddle-wheel of his mill. The water of the brook was dammed up in reservoirs, which could then gradually be drained to propel the mill. Consequently, upstream of the mill the meadows were inundated and the hay rotted on the fields, and downstream of the weir lack of water-induced problems of desiccation of the soil and a too low flow of water.
- After the Middle Ages artificially dug water sources were exploited, where groundwater was forced to come to the surface; this flow of water was guided through a trained brook onto a watermill. These millraces-connected-to-an-artificial-well (‘sprengenbeken’) were characteristic for the Veluwe.
- The rural agrarian society in the flood basins of the brooks did not change fundamentally until approximately 1800. The society was poor but to some extent sustainable: there was no squandering of natural products, such as manure, sods of turf, wood, etc., and a restricted part of wildlife and harvest was available for common use.
- In former centuries annual winter floods inundating the brook basins were not experienced as detrimental: it was just part of everyday life. The summer spates, in contrast were very disadvantageous to the harvest of field crops. Concomitant with the increased regulation works the number of summer floods increased, and the winter floods grew in intensity. It was only in the course of the 20th century that the winter floods were experienced as a real nuisance.
- In the 20th century the enforced drainage of agricultural land, resulting in the lowering of the groundwater table, has deprived many brooks from their original flow, and has led to desiccation in summer of the adjoining pastures and arable land.

- The increased dynamics in discharge, caused by the regulation works to fight the continuous threat of flooding, have enhanced the instable erosive characteristics of many brooks, while water pollution is still a problem.
- During the ‘normalisation’ works in the period 1950–1970 large stretches of the small rivers and brooks were straightened and canalised, mainly to accommodate flash floods caused by increased discharges from drained agricultural areas and urban areas. The ‘sponge’ function of the brook basin and the capillaries was gradually abolished.
- Nowadays the Pleistocene cover sands are drying out at places where they were once wet, and flooding is replaced by drought damage. Only very recently, re-wetting measures and water retention measures are taken in local ‘nature development’ projects.
- Groundwater in the border area of Belgium and the Netherlands, is still heavily contaminated by atmospheric deposition of cadmium and zinc from the nearby smelters.
- ‘s-Hertogenbosch, founded at the end of the 12th century, is situated in a river delta, and that has become decisive for its existence. Time after time the ground level of the town was heightened. Notwithstanding the efforts to keep their feet dry, the inhabitants were frequently hit by river floods, on average once every 30 years. The river Binnendieze, a network of small watercourses, and vaulted passages, lined with medieval buildings, functioned as the main route for (polluting) trades and commerce.
- Until the end of the 19th century ‘s-Hertogenbosch remained the old gated fortress, comprising a system of dilapidated water courses. Every winter the water of Maas and Waal splashed against the walls of the town. The status as a fortress was lifted in 1874, and now in the 21st century ‘s-Hertogenbosch has a built-up surface area that is 25 times larger than in the 19th century.
- The medieval river landscape has completely vanished. The rivers Maas, Dommel and Aa are fully canalised and regulated. Remarkably, some kilometres of the original Binnendieze have been completely restored during the past 30 years. Now, in 2007, the water is relatively clean, water plants returned and even an occasional fish can be caught.

# Part III

# History of Industrial Pollution and its Control

# Chapter 12
# Changing Rhine Ecosystems: Pollution and Rehabilitation

## 12.1 Introduction

Over the centuries Father Rhine, the great European river draining into the North Sea, has inspired many writers, poets, painters and the like (e.g. Schmidt et al., 1995). The river Rhine has also stimulated many scientists to the writing of detailed surveys of the geography and biology of the river basin, comprising the physical, chemical and ecological characteristics of the aquatic and terrestrial ecosystems. I only refer to the standard works of Lauterborn (1916, 1917, 1918), Kinzelbach and Friedrich (1990), Tittizer and Krebs (1996), and publications of the ICPR (1991, 1994, 1998)/IKSR (1987, 1997, 1999a, b, 2002a, b, c). In recent policy-relevant documents the eco-history of the river is often ignored or briefly summarised. Obviously it is more satisfying for policy makers to cover the successes of recent ecological restoration measures than to describe the historic failures and causes of river destruction (cf. Reeze et al., 2005). It is true, the recent rehabilitation of the water quality of the Rhine is remarkable, but habitat loss of this main European navigation route is irreversible and can never be restored.

Cioc (2002) published a comprehensive environmental history of the river Rhine (mainly the Upper, Middle and Lower Rhine), frequently referring to, and based on data of the above-mentioned German authors, and many others. His book starts in 1815, where at the Congress of Vienna ‘the Rhine passed from local hands to global hands’. For centuries the hundreds of local landowners bordering the Rhine quarrelled with their neighbours over fishing holes and birded islands, built dams that increased the number of sandbars and floods, defended their ‘staple’ and ‘transfer’ privileges and manned their numerous toll booths (as summarised by Cioc from a document of ‘Rheinstrombaudirektor Langen’ of 1950). The ‘global hands’ belonged to the institutional control of the Central Commission for Rhine Navigation, founded by the Congress of Vienna which placed the Rhine under an international regime designed to accelerate the free flow of trade along the river. According to Cioc (2002), the Rhine Commission unwittingly created a variant of what Hardin (1968) has called ‘the tragedy of the commons’: all of the riparian states had a vested interest in maximising their share of the Rhine’s commerce and trade, while none felt any real responsibility for preserving it as a riparian habitat. All would

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come to bemoan the degradation of the river, yet none had any strong incentive to take action unilaterally.

The strength of Cioc's (2002) eco-biography is that it covers in a helicopter view both the deterioration and the rehabilitation of the Rhine's ecosystems. His historic scope is, however, limited. Most of the original Rhine habitats in the Lower Rhine and the Delta Rhine had already vanished or had irreversibly changed in 1815, as is shown in Chapters 2, 3 and 4. The year 1815 might arbitrarily be seen as marking the aggravation and acceleration of human impact on a central European river basin, starting with ambitious regulation works for flood mitigation and to serve the demands of navigation. The industrial revolution led to the exploitation of the non-renewable energy sources (mainly coal), and the unbridled expansion of the chemical industry, and consequent severe chemical pollution, recently followed by partial ecological rehabilitation. The aim of this paper is to give a concise survey, mainly borrowed from Cioc (2002), of the eco-history of the international river Rhine, as the main contributor to the surface water of the Netherlands (70% of the country is (in)directly fed by Rhine water). The history of pollution and rehabilitation of the Rhine Delta cannot be understood without knowledge of its international dimension. In-depth studies on the ecology of plant and animal groups and case studies on selected geographic locations will often refer to the status of the Rhine in general, as presented in this chapter.

## 12.2 The Rhine, its Subdivisions

The river Rhine is 1,320 km long and flows from the Swiss Alps through Switzerland, France, Germany and the Netherlands to the North Sea. The 185,000 km$^2$ catchments area of the Rhine extends over parts of Switzerland, Italy, Austria, Liechtenstein, Germany, France, Belgium, Luxembourg and the Netherlands and is populated by about 50 million people (Table 12.1 and Fig. 12.1). A number of industrial centres such as Basel, the Ruhr region and Rotterdam are situated along the Rhine, formerly a wild stream, meandering through a wide floodplain, today a vital shipping route. In the year 2000 the transport on the river at the Dutch–German border was about 162 million tonnes and is expected to rise up to approximately 200 million tonnes in 2015 (Wetzel, 2002). The river is also of importance for the water supply for agriculture and the drinking water provision for about 30 million people. Twenty-one hydropower plants on the Rhine mainstream have a total installed capacity of several thousands of megawatts (MW). The Rhine catchments can be subdivided into a number of geographic stretches; I will mainly follow the description given by Cioc (2002; Fig. 12.2).

The *Alpenrhein* tributary system is generally regarded as the Rhine's main headwater. The flow begins in southeastern Switzerland along the southern flank of the St. Gotthard massif. The river first acquires the name 'Rhine' (as distinct from Alpenrhein or Aare) at the westernmost end of Lake Constance, where the water leaves the lake and begins its northwesterly journey to the North Sea. The exact demarcation point is an artefact: kilometre '0' commences at the Constance Bridge. Each subsequent

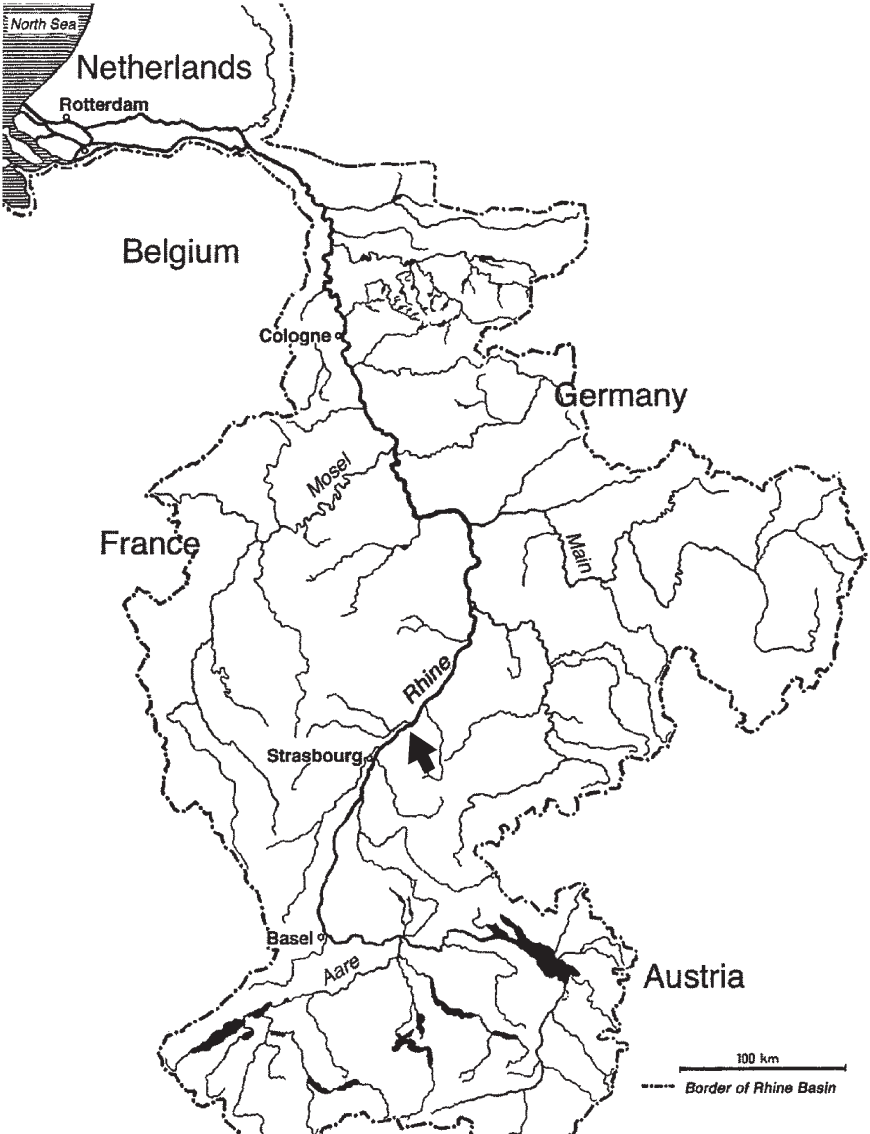

**Fig. 12.1** The Rhine catchments and tributaries Arrow north of Strasbourg: Iffezheim dam, the most recent weir built in the 1970s, leaving a weir-less stretch of 675 km to Rotterdam (Adapted from Cioc, 2002)

kilometre is marked by large signs on the banks until the river reaches Hoek van Holland at 1,033 km. The Alpenrhein tributary system, however, is usually reckoned as part of the Rhine's total length. That is why the Rhine is 1,320 km long, and not 1,033 km as the signpost at Hoek van Holland might suggest.

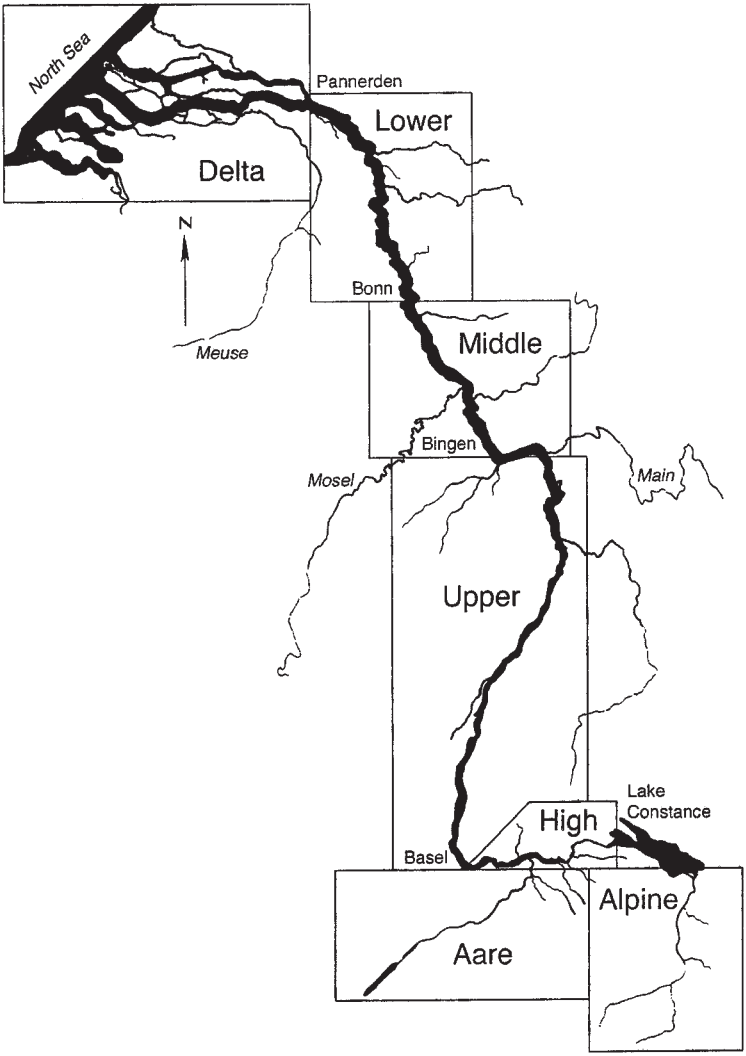

**Fig. 12.2** The major subdivisions of the Rhine. The Delta Rhine is the major subject of this book (Cioc, 2002)

The *High Rhine* (from 0 km at Constance to 168 km at Basel) flows westward between the Jura Mountains and the Black Forest, serving for most of its way as a border between Switzerland and Germany. Alpine features still prevail: the current is swift and unpredictable, owing to the influx of many mountain tributaries, e.g. the Aare tributary system. Local navigation on the High Rhine, a hazardous enterprise in the past, has been eased somewhat by the construction of hydroelectric dams and locks, giving the river the profile of a descending staircase. Aluminium,

**Table 12.1** Hydrological characteristics of the Rhine basin (www.iksr.org; www.riwa.org)

| | |
|---|---|
| Length (km) | 1,320 |
| Catchments (km$^2$) | 185,000 |
| Catchments in the Netherlands (km$^2$) | 25,000 |
| Q (m$^3$ s$^{-1}$) at Lobith | 2,300 |
| Qmin (m$^3$ s$^{-1}$) at Lobith | 790 |
| Qmax (m$^3$ s$^{-1}$) at Lobith | 12,000 |
| Average speed (m s$^{-1}$) at Lobith | 0.5–1.5 |
| Rain/melt | R/M |
| Cl (av.) at Lobith (mg l$^{-1}$) in 1992 | 175 |
| Cl (av.) at Lobith (mg l$^{-1}$) in 2000 | 92 |
| Oxygen (av.) at Lobith (mg l$^{-1}$) in 1973 | 5 |
| Oxygen (av.) at Lobith (mg l$^{-1}$) in 2000 | 10 |

textile, chemical and other industries have grown up alongside the dams to take advantage of the plentiful water supply and cheap hydroelectricity.

The *Upper Rhine* (168 km at Basel to 528 km at Bingen) is the uppermost stretch of the river open to North Sea traffic. The Rhine leaves the Alps at this point and begins its northward flow, picking up the waters of the Neckar and Main along the way. Politically, the Rhine forms the eastern boundaries of Alsace and Lorraine, the two provinces once claimed by both the Germans and the French. The Upper Rhine's natural velocity is slow, and its natural riverbed is braided and curved. However, it has been so thoroughly re-engineered that it has lost its original character and is reduced to a straight canal. It was here that German engineers first began to shorten and straighten the river as well as to drain its wetlands, clear its forests and scoop out its islands. They removed 82 km of oxbows and curves between Basel and Worms alone, reducing the river distance between these two cities by almost 25%. It was also here that French engineers in the 1920s designed and built the Grand Canal d'Alsace (from Basel to Breisach), a testimony in concrete to France's permanent link to Rhine shipping (Fig. 12.4).

Today, the Upper Rhine has been so tightly harnessed and controlled that it rarely floods anymore. It once hosted a broad expanse of now-vanished oak and elm forests. Notwithstanding its artificial and denuded look, the Upper Rhine is still home to much of the river's remaining original flora and fauna. This paradoxical situation stems from the fact that the original riverbed still flows just east of the Grand Canal, providing the last remnants of a natural river terrain as a small sanctuary for native animals and plants.

The *Middle Rhine* (528 km at Bingen to 655 km at Bonn) carves its way through the Rhenish Slate Mountains, where it merges with the Mosel, its largest (regulated) tributary, at Koblenz. This stretch of the river, where most tourists congregate on their visits to the Rhine, was declared in 2002 a world heritage site by UNESCO because of its beautiful landscape. It is also the first stretch of the river basin that is solidly 'German' on both banks. Outwardly, the Middle Rhine appears more natural than other parts of the river, largely because its high hills and canyon walls have constrained industrial growth and urban sprawl. But extensive engineering work has been carried out below the surface of the water where it is not visible to the eye. Hundreds of underwater rock hazards have been removed from its bed and bank, including those that once made the Lorelei so dangerous to ships.

The *Lower Rhine* (655 km at Bonn to 867 km at the Pannerdens kanaal near the German–Dutch border), still ‘German’ for most of the way, is quite different from the Middle Rhine. Not restrained by mountain obstacles, the river is free once again to meander in a northwesterly direction toward the Rhine–Meuse Delta. Its trajectory takes it through the Rhineland–Westphalian coal region (the Ruhr area), where it picks up the waters of the Erft, Wupper, Ruhr, Emscher and Lippe along the way. Much like the Upper Rhine, it has been shortened, straightened and canalised to improve navigation. Most of its islands have also been removed. To a far greater extent than anywhere else on the river, the Lower Rhine’s entire drainage basin has been massively re-engineered to service the needs of industry. It is, in fact, the only stretch of the river where as much attention has been paid to the catchment area as to the riverbed itself. Large dams now capture virtually every drop of runoff from the water-rich hills. These dams provide freshwater for urban and industrial use even during dry spells. The Emscher and Erft have been turned into open-air sewers in the 1970s, while the Lippe has become the main feeder stream for the region’s canal network. The Rhine, meanwhile, functioned as the ultimate dump, gathering coal residues, petrochemicals and other industrial wastes and ‘exporting’ them downstream to the Dutch Delta. Urban congestion exacerbated the problem, for the Lower Rhine is home to the agglomeration of cities that make up the Rhine–Ruhr region. The Lower Rhine and its tributaries, especially the Erft and Emscher, were among the most polluted river systems of Europe, but recent rehabilitation measures have certainly improved the water quality.

The *Delta Rhine* (867 km at the Pannerdens kanaal to 1,033 km at Hoek van Holland) flows westward through the Netherlands to the North Sea. The Pannerdens kanaal, built by the Dutch in the 18th century to ease shipping and to control flooding, bifurcates the Rhine into the Waal and Nederrijn–Lek, both of which flow into the common Rhine–Meuse Delta (Fig. 4.8). The Waal is the main Rhine branch: it receives on average two thirds of the Rhine’s waters. The rest of the flow goes to the Nederrijn–Lek and to a third Delta branch, the IJssel river. The Delta Rhine is linked to Rotterdam via the Waal and Nieuwe Waterweg, to Amsterdam via the Amsterdam–Rijnkanaal, to Antwerp via the Schelde–Rijnkanaal, and to the IJssel estuary (formerly the Zuiderzee) via the IJssel, thus permitting Rhine traffic to reach the North Sea by a wide variety of harbours. Rotterdam is far out the most important of these harbours. The Delta Rhine is far less cluttered industrially than the Lower Rhine, except around Rotterdam, where oil refining and petrochemical production take place on a large scale (Cioc, 2002). The main part of the environmental history of the Rhine–Meuse Delta, as covered in this book, is devoted to the Delta Rhine.

## 12.3 Changing Rhine Ecosystems

Since time immemorial the river Rhine is used and reshaped by man. The growing human population and the growing need for wood, both for building and fuel, led to the large-scale felling of the hardwood floodplain forest along the High and Upper Rhine, already between 800 and 1200, and presumably earlier. In the 7th century 75% of the river floodplains were occupied by forests and 25% by fields; in the 13th century it was already the opposite: 25% of the forest remained, and 75% was transferred into fields, either fallow or exploited. The eradication of the floodplain forests continued in the 14th–16th century (Fig. 12.3) (Lauterborn, 1917). The large-scale cutting down of trees drastically enhanced riverbed erosion, and the sediments were transported downstream by water and wind, where they settled and formed river dunes and sandy natural levees. The late-medieval large-scale felling of forests, leading to unbridled erosion and sedimentation processes, introduced extensive changes in river ecosystems, loss of habitats of river-bound fauna, and the introduction of plants and animals preferring relatively warm and dry habitats (Tittizer and Krebs, 1996).

**Fig. 12.3** Massive deforestation in favour of charcoal burning in the 16th century in the Vosges (Van Zon, 2002)

From the year 1000 onwards the extension of commercial trade, the growing number of settlements and the development of agriculture led to the building of levees and dikes along the Lower Rhine. Owing to the construction of bypasses and the digging of canals, gradually the Rhine lost its original structure. Before the steam age, bulk trade on the Rhine consisted mostly of a downstream flow of raw timber (oak, fir, spruce, pine) from the Black Forest to the Delta, the so-called Holland rafts, in which the vessel and the product were one and the same thing. Upstream trade was a difficult undertaking at best, requiring towpaths and animal or human muscle, and the need to change ships frequently along the way. A journey could take weeks or more depending on the vagaries of the wind, the speed of the current and the availability of horses and men. The arrival in 1816 of a British steamship in Cologne heralded a new era. From then it became feasible to haul bulk goods (coal, ores, grains) quickly and cheaply upstream by steam-powered tugs and barges, greatly increasing the number of industrial ports, commercial centres and trading routes on the upper stretches of the river. It also, of course, signalled the era of smoke-filled skies and industrial air pollution along its banks (Cioc, 2002).

Although changes in the Rhine ecosystems date back to Roman times and before, radical, large-scale Rhine regulations started around 1800. The first phase ran from 1815 to 1900, comprising the Tulla Rectification Project (1817–1885), a most drastic enterprise, mainly for reasons of flood control (Tulla, 1825). The Upper Rhine was provided with an artificial bed of uniform width: 200–250 m between Basel and Mannheim. The river's length was reduced by 82 km, and a significant amount of land, *ca.* 10,000 ha was reclaimed for cultivation and for city growth. The Tulla rectifications intensified the process of bed erosion: the up to 12 km wide river basin was now forced into a straightjacket of 200–250 m, and thousands of sandy islands and gravel banks eroded and disappeared underwater. During the period 1880–1900 the Lower Rhine stretch between Cologne and the German–Dutch border was regulated, and adapted for navigation purposes to a water depth of 2.5 m at low water (Tittizer and Krebs, 1996).

More recent Rhine rectification projects started around 1900 and are still continuing until the present day. In the early decades of the 20th century a considerable number of hydro-dams containing hydroelectricity plants were built in the course of the High Rhine. The river's rock walls and steep slope (150 m over a 142 km stretch) made it an ideal location for the production of hydropower. Engineering work on the High, Middle and Lower Rhine forced the German and French governments to improve the works in the Upper Rhine. The Tulla Project had concentrated on flood control, not navigation. In fact, the rapids that had inadvertently resulted from the original rectification work had all but eliminated ship transport between Mannheim and Basel. Flood control, in other words, worsened the Upper Rhine as a transportation route. The goal of the next phase of the rectification project was to create a riverbed 2 m deep and 88 m wide that would permit all-year navigation from Mannheim to Strasbourg and eventually to Basel. Dykes, dams and wing dams were needed, as were reinforced riverbanks and harbours. As the first phase of the project neared completion in the 1920s, it became possible for large ships to travel beyond Mannheim (the endpoint of Rhine shipping during most of the 19th century) to the new ports of Karlsruhe and Kehl/Strasbourg for most of the year (Cioc, 2002).

However, the measures on the route farther upstream from Strasbourg to Basel encountered many natural and political setbacks. The political problems were, of course, caused by the events during World War I and II. After World War I the Germans could no longer obstruct the rectification work between Strasbourg and Basel: The 1919 Versailles Treaty gave France direct control over the left bank (Alsace) as well as the legal right to develop the Upper Rhine's hydroelectric potential. The Grand Canal d'Alsace was designed, and built during the period 1921–1959, envisaging the canalisation of the main river, and the construction of eight hydroelectric plants spread roughly evenly apart from Basel to Strasbourg. The basic idea was to divert nearly all of the river water from its original bed, and channel it into a canal-and-lock system running parallel to the river's left bank. Aside from producing hydroelectric power, the Grand Canal was to serve as a transportation link between Basel and Strasbourg (Fig. 12.4). The German interests were strongly counteracted by the construction of the Grand Canal. The Tulla Project had already disrupted the natural hydrology of the Upper Rhine and substantially lowered the groundwater level. The building of the Grand Canal lowered the water level in the remaining Rhine basin with another 2–3 m, and led to consequent lowering of the groundwater table in the German border state (Cioc, 2002).

After World War II, the French built three hydroelectric plants and locks during the years 1952 to 1959, partly with post-war international funds. Franco-German

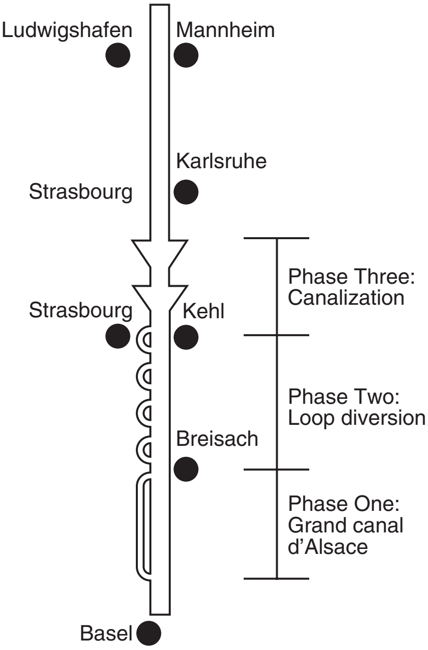

**Fig. 12.4** Schematic diagram of the normalised Upper Rhine today. Between 1921 and 1978, engineers experimented with a variety of techniques designed to balance the needs of hydroelectric development, navigation, agriculture and erosion control. Iffezheim weir is located in between Strasbourg and Karlsruhe (Cioc, 2002)

rapprochement, however, put a halt to the final completion of the Grand Canal Project in its original form, especially once it became clear in the 1960s that the canal did in fact endanger water supplies, urban sanitation and agricultural productivity in the German state of Baden (part of Baden–Wurttemberg after 1952). A new agreement left the already completed portion of the Grand Canal intact. However, the stretch from Breisach to Strasbourg/Kehl (site of the next four planned hydroelectric plants) was re-engineered following the so-called Loop Solution, a plan worked out jointly by German and French engineers. The Loop Diversions allowed the Rhine to continue flowing in its original bed for most of this stretch. At four points, the water was diverted to hydroelectric plants and locks. France agreed to this more-expensive solution only after the Germans agreed to the full canalisation of the Mosel river (Fig. 12.4).

The Loop Diversions helped to alleviate the water table problems in Germany, but not the erosion problems that had been confounding engineers since rectification work began in 18I7. Severe scouring of the main channel and an increase in speed of the flowing river water became almost uncontrollable problems. Hydrodams alter deposition patterns in two contradictory ways: the in-river reservoirs above the dams collect gravel, sand, and silt that would otherwise continue to flow downstream, thus diminishing the natural sediment load of the river; meanwhile, as it returns to the river, the water that pours out of the turbines below the dams scours the bed, thus greatly augmenting channel erosion at that point. In 1969, the French and German governments built two more in-river systems; the final hydro-lock was constructed at Iffezheim in 1977 (Fig. 12.1), which was specifically designed to ease some of the erosion problems below the Loop Diversions. Then, in 1978, river managers began dumping millions of tonnes of sediment, gravel and rock into the river downstream from Iffezheim in order to compensate for the sediment loss caused by the upstream dams. These measures to stabilise the riverbed have to be repeated annually, and they are certainly not resolving the problem that had persisted since the days of Tulla (Tittizer and Krebs, 1996). The continuous dumping of gravel is only retarding the erosion process in the riverbed of the Lower Rhine and part of the Delta Rhine. At Lobith where the Rhine enters the Netherlands, the main riverbed is lowering 1–2 cm each year. At many more downstream locations continuous dredging of sills and dumping at scouring sites is necessary, in order to facilitate navigation and prevent unsafe situations, such as the undermining of the stability of the groynes and the artificial dykes. In sharp bends where the scouring effects are maximal, the river bottom is metalled with large blocks of stone in order to prevent further erosion (RWS, 1996).

What are the resultant ecosystem changes over the past centuries? The ‘natural Rhine’ is a prehistoric image. Deforestation from Roman times onwards, aggravated in the late Middle Ages, unleashed erosion and sedimentation processes, that continue until the present day. Figure 12.5 illustrates the process of canalisation of the Rhine, from a richly braiding and meandering river to a navigation canal in the course of 1.5 centuries. Lauterborn documented the changes in the biology and the landscape features of the river Rhine from 1896 to 1926, and Kinzelbach and others from 1972 onwards (Tittizer and Krebs, 1996). Virtually all of the Rhine’s lowland forests, meadows and marshes have disappeared over the past 200 years. In 1815, floodplain enveloped around 2,300 km$^2$ of the river. This floodplain once formed a single continuous river corridor, varying in width from a few hundred metres to 15 km and stretching over 1,000 km from Lake Constance to the Delta mouth. By

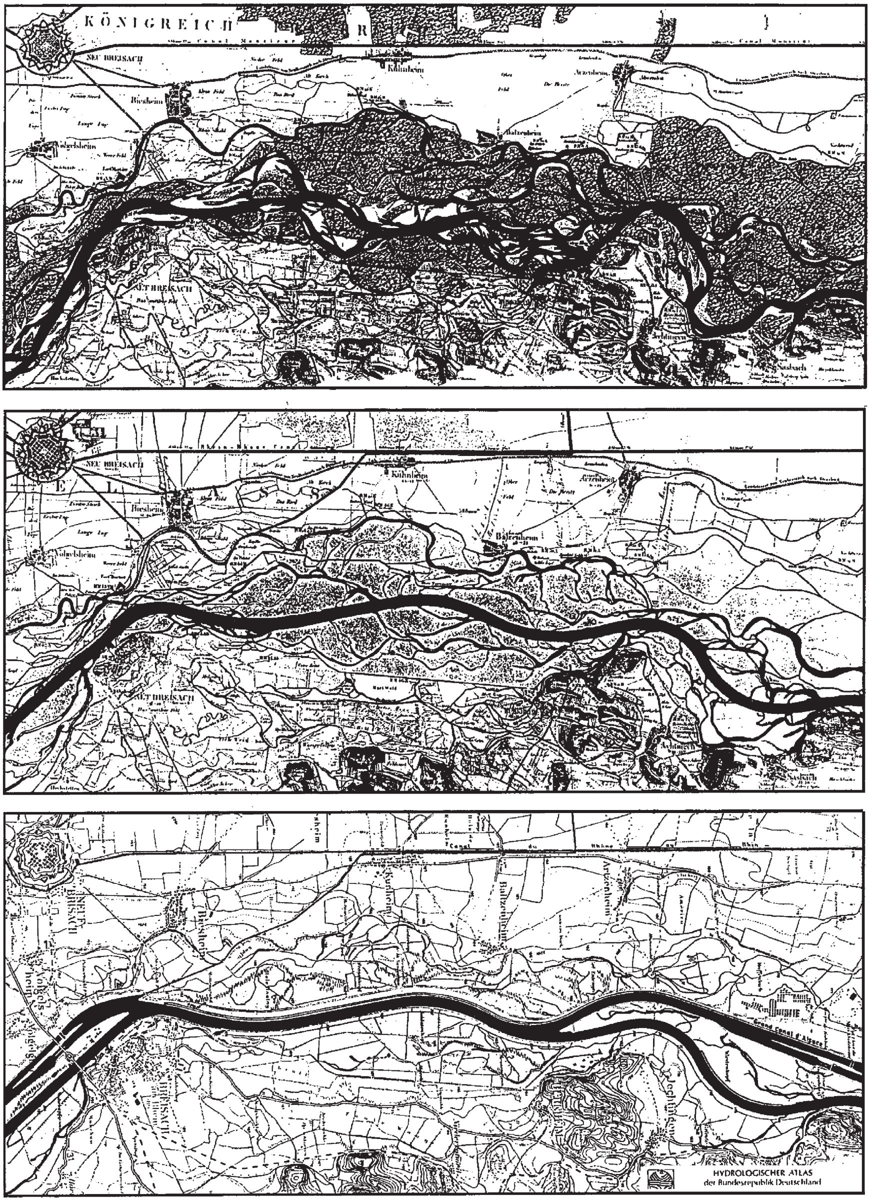

**Fig. 12.5** The Upper Rhine at Breisach (see Fig. 12.4) in the course of time. Upper panel: meandering river before the Tulla rectifications in 1828; middle panel: after the Tulla rectifications in 1872; lower panel: after the building of additional weirs and bypasses in 1963 (Keller, 1978–1979)

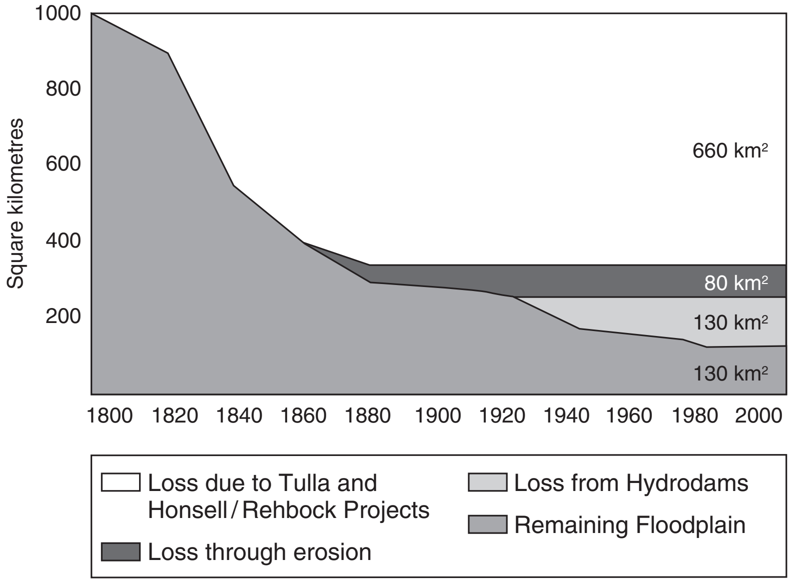

**Fig. 12.6** Floodplain loss on the Upper Rhine between 1800 and 1996 (ICPR data in Cioc, 2002)

1975, most of this land had been taken over by farms, pastures, businesses, train tracks, roads and cities. The High Rhine lost 86% of its floodplain, the Upper Rhine 85% (Fig. 12.6), the Middle Rhine 96% and the Lower Rhine 98%. Less than 500 of the original 2,300 km² is still subject to periodic flooding – and even most of that 500 km² is now part of the human-built up environment (IKSR, 1997).

## 12.4 Severe Pollution and the Deterioration of Biodiversity

### *12.4.1 From the Industrial Revolution to an Open Sewer*

Mining and metallurgy set the pace for modern industrial development. The use of coal as fuel for machine power, and the application of the steam engine to iron smelting, created the civilisation based on wholesale extractions and consumption of age-old irreplaceable resources. The Ruhr region, a Lower Rhine tributary, had everything in one place from the outset: vast quantities of coal, good transportation routes and ready markets in every direction. It was also ruled by a government willing to translate coal into industrial and military power regardless of the environmental impact. According to Cioc (2002), never before had there been such a concentration of power and pollution in one place, and never since such a clear-cut case of the payoffs and perils of the 'carboniferous age'.

The Rhine–Ruhr is synonymous with ‘iron and steel’. Before the industrial revolution, Europeans commonly smelted iron ores in specially designed blast furnaces that produced pig iron (cast iron), using a technology first developed on the Lower Rhine in medieval times (cf. Chapter 3). Charcoal, made from charred wood, was the main fuel throughout Europe (Fig. 12.3). In the early 18th century, British industries began switching from charcoal to coal for iron production as their forests disappeared and the price of imported timber steadily climbed. By the mid-19th century coke (coal purified by heating to increase its carbon content) had replaced charcoal as the preferred fuel in European metallurgy. In addition, each improvement in manufacturing tended to reduce the amount of coal needed in iron production. Whereas in 1850 it took 10 t of coal to produce 1 t of iron, by the end of the century 1 t of coal could produce 2–3 t of iron. Nearly all of the imported ore came up the Rhine through Rotterdam. Coal and iron transformed the Rhineland–Westphalia region from an agrarian to an industrial landscape in a remarkably short time. By 1900, mines, factories and smokestacks filled the space where only a few decades earlier trees, birds, orchards, grains and root crops had reigned. These industrial transformations had a profound impact on the region’s river and stream hydrology. Each tonne of pig iron required some 7,000–12,000 l of water. Each tonne of coal took 1,250–1,800 l of water for cleaning and other purposes. Coking and other processing could bring that total up to 3,000 l of water per tonne of coal. Vast quantities of water were consumed and not replaced, and as the number and size of the industries climbed, so did Westphalia’s water deficit. By the end of the 19th century water shortages, and the connected problem of waste removal, had become persistent sources of concern.

A step toward improving Westphalia’s water supply was taken in 1899 to enhance the quantity and quality of the water supply on the Ruhr through the construction of dams in the Ruhr watershed. Over the next 70 years, the Ruhr Dam Association constructed enough dams to hold 469 million cubic metres of water. The Mohne reservoir (1913: 135 million cubic metres) alone submerged over 12 km$^2$ of farm and meadow land; six villages were affected, 200 public and private buildings flooded, and more than 700 people displaced. The environmental and human costs were acceptable to most Germans at the time, because the dams promised to satisfy Westphalia’s most immediate and pressing industrial need: large amounts of clean water (Cioc, 2002).

Coal (and later supplemented with lignite) was the driving force behind the Rhine chemical industry for most of the 19th century. It was coal that fuelled the steam plants that powered the chemical factories, just as it was coal that fired the steamships that transported raw materials and finished goods on the Rhine. It was also coal by-products that provided the basic resources for nearly all chemical production. This dependency meant that almost all of the early Rhine chemical firms clustered on the Lower and Middle Rhine, and on the Neckar, Main and Wupper tributaries, where coal was plentiful and the transportation network most intensive. The hazards of common chemicals were known in Europe long before the industrial age. Oil of vitriol (sulfuric acid), aqua fortis (nitric acid), aqua regia (hydrochloric and nitric acids), lime, mordants and tannic acid were all well-recognised toxins used in gold and silver smithies, leather tanning, cloth dyeing and other commercial activities. Typically the manufacturers and users of these chemicals dumped their wastes directly into the closest streams, without giving much thought to the downstream inhabitants or the organisms in the river, trusting in the well-recognised but little understood 'self-cleansing' capacity of rivers (Lauterborn, 1911). But pre-industrial firms also tended to be small operations, and the range of poisons they used was limited. The damage they inflicted on rivers was almost always confined to a small stretch that could be 'sacrificed' to commercial activities with little danger or harm to the entire stream (Cioc, 2002).

In the 19th century pollution-intensive industries, once confined to small river stretches, began to grow in size and numbers, still maintaining the 'solution-by-dilution' method to get rid of their waste. Nineteenth-century chemistry in the Rhine basin revolved around five basics products: acids (e.g. sulphuric acid), alkalis, fertilisers, explosives and dyes. Acids were used in dye production, cloth bleaching and in smithies. Alkalis, mainly sodium carbonate, were in demand for soap production, textile dyeing, cloth bleaching and glass making. The demand for synthetic fertilisers (super-phosphate from 1840 onwards) grew vastly in the 19th century. The production of nitrogen-based explosives (dynamite, based on nitroglycerine and siliceous earth, 1867) became also booming business. Synthetic dye production, derived from coal tar ingredients, and using large quantities of arsenic acid, had an immediate and dramatic impact on air and water quality in the Rhine basin. Finally, the organic effluents of the pulp and paper industry and the sugar beet industry consumed a lot of the remaining oxygen in the river water.

One of the most intractable problems that afflicted the mining companies during the first decades of 1900 was the removal of phenol (carbolic) from Emscher and Ruhr wastewater. Phenol was a hazardous by-product of the coking and coal tar industries. It had some industrial applications, but most firms considered it a waste product and simply dumped into nearby streams. Most of the phenol (around 6,000 t each year) found its way to the Emscher, the rest to the Ruhr, and most of the phenol eventually flowed untreated into the Rhine. Flushing a problem downstream was not a strategy that normally caused any consternation for the Emscher and Ruhr cooperatives; it was, in fact, their preferred method of waste removal. But phenol was more than just a waste product: it was a public relations nightmare for the coal industry. Phenol had an easily recognisable odour, one that aroused the commotion of riverbank residents and put regulatory agencies on the scent. Salmon, eel and other 'fatty' fish absorbed phenol into their bodies as they swam through contaminated streams; if caught by fishermen before they had a chance to shed the poison, the fish stank and were inedible (Cioc, 2002; cf. Chapter 8).

Coal was the main accelerator of industrial activities in the 19th century. By the 20th, however, new forms of energy came to the fore. Hydroelectric power, petroleum-based fuels and nuclear fission allowed the chemical industry to invade river spaces that had largely been spared the ecological damage of industrialisation. While hydroelectricity generates electricity without pollution, it causes many disturbances to river ecology. The building of dams entails the flooding of forests and meadows, the destruction of riparian habitat, the transformation of vegetation and animal communities, and in some cases the submersion of entire towns and villages. In-river dams are particularly lethal to migratory fish, most famously salmon, because they sever the link between a river's mouth and its headwaters. Dams also trap agrochemicals, pesticides, heavy metals and other toxic substances, turning reservoirs into chemical time bombs. By the 1920s it was already becoming clear to many industrial leaders that the Rhine's hydroelectric potential would be tapped out long before the Rhine's ever-growing energy needs were met. So they began to look to petroleum as an alternative energy source. As with hydroelectricity, the chemical industry provided much of the impetus, though the rapid growth of the automobile industry equally functioned as a stimulus. European petroleum firms built a few Rhine refineries in the 1920s, but the first true petrochemical factory did not come on line until 1953. Ultimately, the Netherlands was a main beneficiary of the petroleum age, and a large oil harbour at Rotterdam was developed from the 1960s onwards (Cioc, 2002).

By the 1960s it was clear to many industrialists that even petroleum was not keeping pace with the Rhine's energy needs, and the oil crisis of 1973 further underscored Europe's fragile dependence on the volatile politics of the Middle East. Increasingly the riparian governments turned to nuclear energy for their salvation, and according to Cioc (2002) by the mid-1980s the Rhine was on its way to becoming one of the world's most 'nuclearised' rivers. Urban sprawl, which in the 19th century had largely been confined to Rhineland–Westphalia, gradually encroached upon the Rhine-Main, the Rhine-Neckar, Alsace and Basel regions. As the cities expanded in size and number, the river's meadowlands and forests disappeared, greatly reducing the living space of the riparian flora and fauna. There were other environmental consequences as well. Hydrodams on the High and Upper Rhine put an end to the annual salmon migration, contributing to the extinction of the Alpine salmon industry. Nuclear plants, meanwhile, began to draw such vast quantities of Rhine water to cool their reactors, and return it to the river at such an elevated temperature (up to 3°C higher), that it became detrimental to downstream organisms and plants.

Urban growth on the Upper Rhine brought another problem to the forefront: sewage disposal. Modern sanitation networks, pioneered in London in the 1830s, spread to other industrialising regions of Europe during the second half of the 19th century. The early systems were quite primitive, consisting mostly of 'water closets' linked via a pipe or canal to a nearby river. Since most of these systems lacked purification plants, rivers that ran through major urban centres soon began to choke in human excrement. The first major conflict on the Rhine arose in 1897, when the city of Mannheim began dumping its untreated excrement into the river just 13 km upstream from where the city of Worms extracted its drinking water. After a protracted legal battle in German court, Mannheim was absolved of all responsibility and Worms was told to construct a costly filtration system or find a different water supply. Mannheim's victory helped set off a chain reaction of irresponsible behaviour. Basel, Strasbourg, Ludwigshafen and many other cities felt free to dump their untreated (or partially treated) sewage into the Upper Rhine, safe in the knowledge that there were no serious national or international consequences to fear from downstream cities. By the late 1930s, however, the situation had deteriorated significantly. All river water on the Lower Rhine from Bonn to the German–Dutch border was polluted to one degree or another. One of the main reasons was that because of the much greater industrial activity upstream, the river was not capable of cleansing itself before it reached the Lower Rhine (Cioc, 2002).

Chemicals are the primary pollutants on the Rhine, as they are on all of the world's major industrial rivers. Hundreds of different chemicals find their way into rivers every day, but three groups cause the greatest concern: heavy metals (zinc, copper, chromium, lead, cadmium, mercury and arsenic), which enter rivers primarily at industrial and mining sites; chlorinated hydrocarbons, such as polychlorinated biphenyl (PCB) and, until it was banned, dichlorodiphenyltrichloroethane (DDT; cf. Chapter 14); and phosphate-based and nitrogen-based substances, chiefly fertilisers and detergents. Nowadays it is common use to remove the greater part of these chemicals in water treatment plants before they enter the river (see Section 12.5), but that was not the case before 1970.

For rivers, there are two other critical non-biological pollution categories: thermal and chloride. Thermal pollution refers to all human-induced changes in the river's water temperature. In practice, it almost always means that power plants have artificially raised the temperature by dumping heated wastewater from their cooling facilities into the river. An alteration in temperature is not toxic per se, but it does affect the number and composition of species capable of living in the streambed. Chlorides are common salts that enter the river through a variety of agricultural and industrial activities. In 1885 the chloride (Cl) load of the Rhine at the Dutch–German border amounted to 50 kg $s^{-1}$, and it gradually increased to 150 kg $s^{-1}$ in the early 1940s. After a slight dip during World War II, by 1985–1990 the Rhine's chloride load had reached an unprecedented level of 390 kg $s^{-1}$ (Fig. 12.7). Thereafter it is only slightly decreasing to 230 kg $s^{-1}$ in 2000 (Jülich, 2003). Only about one fourth of this salt was derived from natural sources, mostly from rocks in the river's basin; the remaining three fourths came from anthropogenic sources. The Alsatian potash plants, clustered around the silvinite mines near Mulhouse on the Upper Rhine, accounted for nearly half of the human-induced salt load. Most of the river's chloride load came from sodium chloride, a waste product that results when silvinite is transformed into potassium chloride for use as a fertiliser. The Mosel tributary was the second biggest contributor to the Rhine's chloride content, with the salts coming primarily from a variety of French and Luxembourg sources. The remainder of the river's chloride load came from soda-works and mine water from the Ruhr region, and from agricultural run-off all along the river. With an average Cl concentration of 250 mg $l^{-1}$ in the 1970s, and 100 mg $l^{-1}$ in 2002 at the German–Dutch border, the river Rhine is still a slightly brackish river, and not a purely freshwater one (Jülich, 2003).

### *12.4.2 Deterioration of Biodiversity*

The worst industrial accident in Rhine history occurred at the Sandoz chemical plant in Basel–Schweizerhalle in 1986. It began when a storage facility burst into

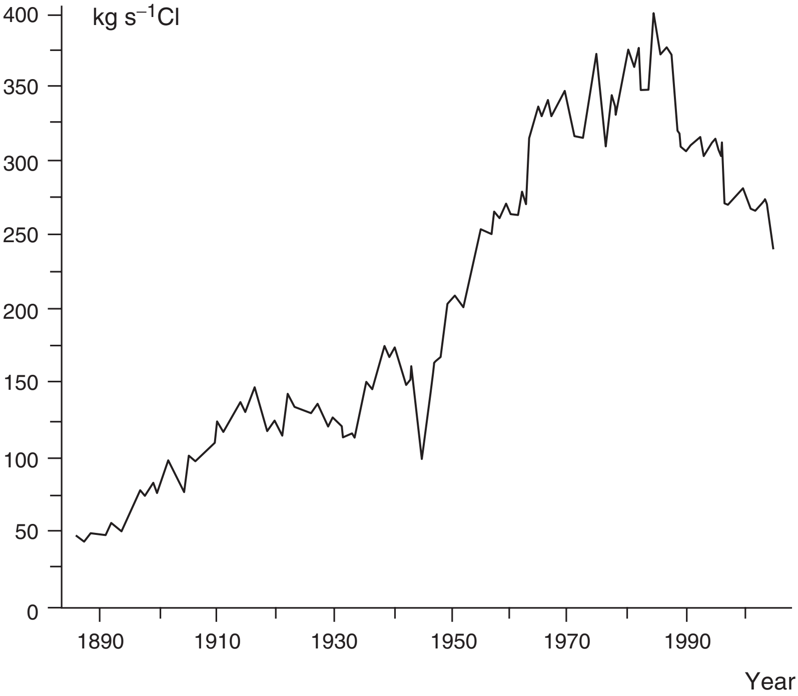

**Fig. 12.7** Chloride load (kg s$^{-1}$ Cl) of the Rhine water at Lobith over the period 1885 – 2000 (Derived from Jülich, 2003)

flames shortly after midnight on November 1, igniting over 1,000 t of insecticides, herbicides, fungicides, fertilisers and other agrochemicals. Because the facility was not equipped with a modern sprinkler system, firemen had to douse the blaze the old-fashioned way: by squirting millions of litres of water onto the facility. The fire hoses contained the blaze in a matter of hours, but the douse water flushed *ca.* 10–30 t of unburned chemicals into one of the plant's industrial sewers. From there the chemical brew found its way to the Rhine and began to scour the riverbed as it flowed downstream. Among the released chemicals were several insecticides, all highly toxic to fish. Within days the entire eel population from Basel to the Lorelei lay dead or dying. Grayling, pike, zander and other fish species on the Upper Rhine survived only if they happened to be in a few sheltered backwaters and tributaries when the chemicals reached that stretch of the river. Even the fish that survived struggled in the aftermath, since the chemicals wiped out most of the invertebrates upon which they depended for nourishment. It took several weeks before urban sanitation facilities could begin drawing water from the Upper Rhine again, months before the river's micro-organisms started a comeback, and years before the eel population returned to normal levels. It is supposed that, notwithstanding its immediate destructiveness, the accident left no permanent mark on Rhine flora and fauna

(Kinzelbach and Friedrich, 1990; Weidmann and Meder, 1994). Environmental disasters trigger societal initiatives: the Sandoz accident meant a great impetus for the Rhine Action programme for improvement and continuous monitoring of the Rhine ecosystems (IKSR, 1987; ICPR, 1994).

The Rhine's invertebrate populations have severely been affected by engineering and the loss of riparian vegetation, though the record is far from clear because the first systematic investigations took only place in the early 20th century (Lauterborn, 1916, 1917, 1918), by which time the negative impact of river engineering was already being felt. The survival of any particular native species, and the success of any non-native one, depended on whether changes in the river's bed, bank and floodplain increased or decreased its habitat, and whether water pollution augmented or reduced its food supply. The so-called lithophiles, organisms that adhere to hard surfaces, such as freshwater limpets, snails, leeches, sponges, moss animals (Bryozoa) and hydroids (Coelenterata) have generally prospered in the new Rhine environment, for obvious reasons. Previously confined to the canyon walls of the High and Middle Rhine, many native lithophiles have been able to spread via the new rock-lined embankments to nearly every habitat of the river. Several exotic species have also crawled to the Rhine via canals and embankments, or have been transported there on the hulls of ships (see Chapter 17). In the Upper Rhine the number of leech species (Hirudinea), for instance, grew from 4 in 1900 to 12 in 1980, while the number of moss animals (Bryozoa) rose from 4 to 9 during the same period, and Crustacea from 3 to 13, Mollusca from 20 to 30 species. All have expanded at the expense of those organisms that depend on a soft rather than hard surface (Tittizer and Krebs, 1996).

Anthropogenic impact is clearly shown in the numbers of macro-zoobenthos species in the Upper, Middle and Lower Rhine. More than 150 species of Bryozoa, insects, molluscs, crustaceans, leeches, flatworms and sponges were estimated in 1900, decreasing to *ca*. 80 in 1900–1920 (data of Lauterborn, 1917, 1918), further decreasing to 25 in 1972, and thereafter steadily increasing to 125 in 1988 (Tittizer and Krebs, 1996), and even higher numbers in recent years (www.iksr.org). An important environmental variable in the restoration of benthos species richness is the improved oxygen conditions of the water, from less than $5\,\mathrm{mg\ l^{-1}}$ in 1970–1975 to almost $10\,\mathrm{mg\ l^{-1}}$ in 1995. The graph in Fig. 12.8, however, is mainly shaped by three groups of insects crucial to the Rhine's food chain, the mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddis flies (Trichoptera), which all have fallen drastically in the past century. All three groups are highly dependent on unpolluted and oxygen-rich water and are therefore good indicators of river quality. Their species numbers, which was estimated at 111, of the total of 160 benthos species mentioned in Fig. 12.8, in the period 1900–1920, dropped to 3 in 1971. Species richness rose again as water quality began to improve after 1975, and tens of species have already been found again in the Rhine in the 1990s (Tittizer and Krebs, 1996).

Floodplain insects (beetles, bugs, flies and dragonflies) have also been affected by Rhine engineering, though the exact impact is obscured because data on floodplain fauna from the past are only scantily available. The considerable loss of floodplain habitats and the increased amplitude of water levels suggest that the fauna was far more richer in the past. Most insects utilise the streambed itself only

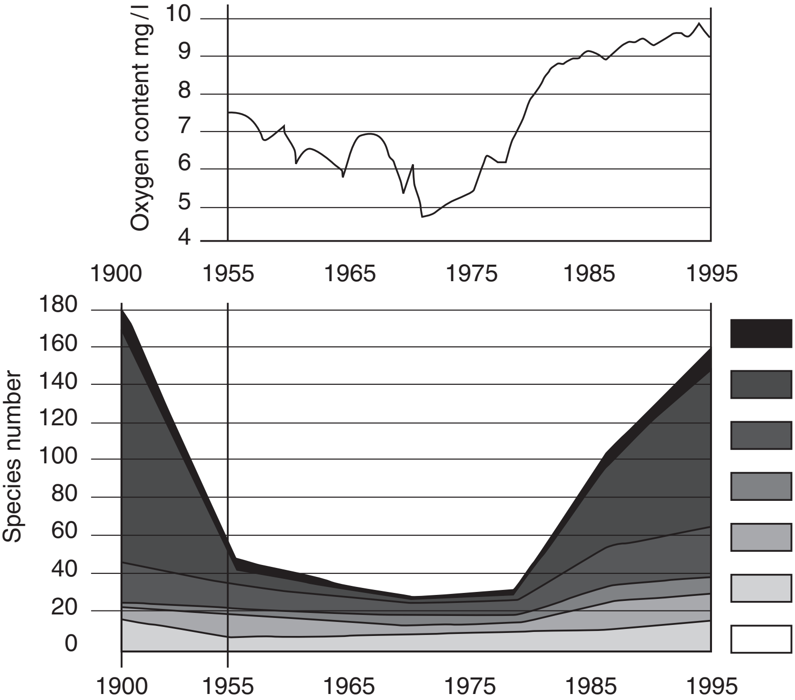

**Fig. 12.8** The relationship between the Rhine's oxygen content and the number of invertebrate species the river supported, in between 1900 and 1995. The legends (shades of grey) refer to groups of invertebrates, from bottom to top: sponges, flatworms, leeches, crustaceans, molluscs and insects The graph is mainly shaped by insects (mayflies, stoneflies, caddis flies) (black-dark grey) which have fallen drastically in the period 1955–1980, but recovered thereafter. Pollution-sensitive insects have benefited most from cleanup efforts (ICPR data in Cioc, 2002)

during the larval stage, but even the non-aquatic phases of their life cycle keep them mostly within the floodplains. Many are still found in great variety on the Rhine, including dragonflies (around 50 species) and beetles (hundreds of species).

Habitat loss and water and soil pollution annihilated many invertebrate species. By 1975, the year generally considered to be the peak year of Rhine pollution, most of the Upper and Middle Rhine belonged to Class II or Class III ('moderately' to 'strongly' polluted), while the Lower Rhine stood at Class III and Class IV ('strongly' to 'completely' polluted). The entire navigable Rhine, in other words, was so polluted that all natural biological conditions had been compromised, with the level of degradation increasing as the water moved downstream (Fig. 12.9).

Wolff (1978) reviewed the degradation of Lower Rhine and Delta Rhine ecosystems at the deepest point of the Rhine pollution. The picture is grim. The food webs in the Rhine appeared to be simple. The phytoplankton was probably fed on by the rather scarce zooplankton, although the latter category also may take the abundant detritus. However, neither phytoplankton nor detritus were apparently exploited to

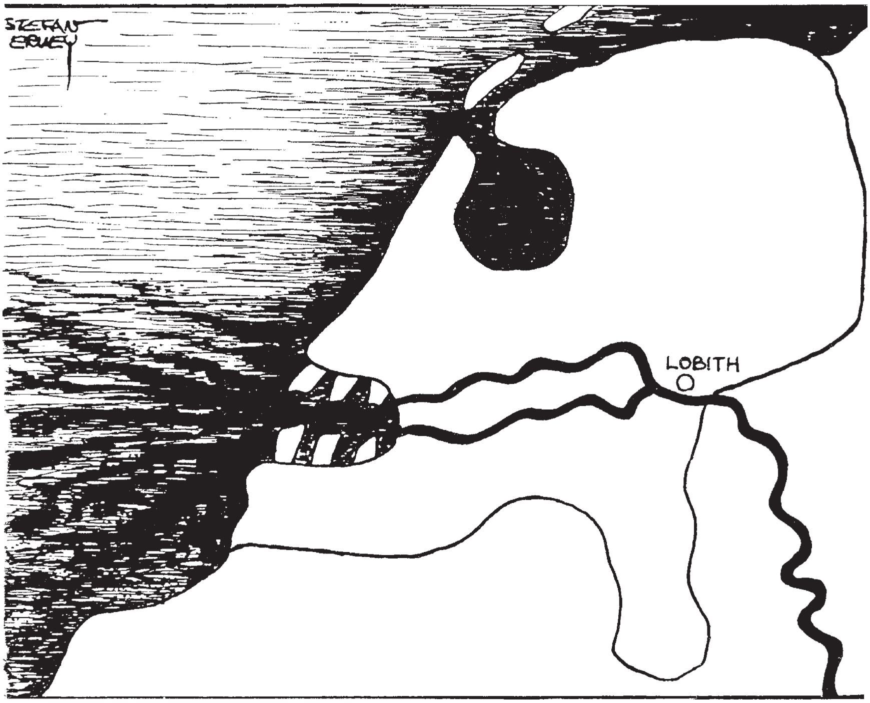

**Fig. 12.9** The dead river Rhine in 1975 enters the Netherlands at Lobith. Cartoon by Stefan Verwey, as published by Geelen et al. (1982)

any extent by a filter-feeding benthic fauna, notwithstanding the fact that the transport of detritus across the river was conspicuous. The only benthic animals of any quantitative importance were the deposit-feeding Oligochaeta (*Tubifex tubifex* and other species). Dependent on the amount of deposition of silt and detritus, locally up to 1 m per year, their numbers amounted to many thousand square metres. This source of food most probably was being exploited by several fish species, for instance roach, and diving ducks such as pochard (*Aythya ferina*) and tufted duck (*Aythya fuligula*). Only in this way could the abundance of roach and pochard (40,000 individuals along a few kilometres of the river) be explained. All other steps in the food chains were absent or very insignificant in the early 1970s. A picture of a very simply structured ecosystem thus arose, in which only the food chain 'sewage–detritus–oligochaetes–cyprinid fishes or diving ducks' was of any importance.

Notwithstanding this grim picture, the situation has never been so negative that the entire food web of the Rhine was extinguished, at least not qualitatively. Obviously, vital elements in the food chain retreated in relatively clean habitats of the tributaries, and survived. Fish species can be taken as indicators for the quality of aquatic ecosystems. Table 12.2 shows that the number of indigenous fish species in the Lower Rhine basin ran down from 40 in the early 19th century, to 28 in the

**Table 12.2** Changes in the number of fish species in the Lower Rhine. A = indigenous species; B = exotic species (Wetzel, 2002)

| Time period | A | B |
|---|---|---|
| Before 1815 | 40 | 0 |
| 1815–1910 | 38 | 1 |
| 1910–1950 | 33 | 1 |
| 1950–1975 | 28 | 3 |
| 1975–1989 | 35 | 4 |
| 1990–2000 | 37 | 9 |

period 1950–1975, and increased again to 37 in recent years. The overall picture, however, is blurred by the increasing numbers of introduced exotic species. The causes of this phenomenon will be discussed in Chapter 17.

## 12.5 Ecological Rehabilitation

Concerted effort by the riparian states since 1963 has reversed the downward spiral, and the Rhine is now on its way to ecological recovery in three critical areas: water quality, biodiversity and floodplain restoration. The greatest achievements so far have come in water quality. Though there are still some problem areas – notably the Emscher and Erft – water in the Rhine basin is considerably purer than it was during the peak pollution years of the mid-1970s. In the Alpine stretches, Class I/II is the rule, with the water only slightly compromised in purity by the presence of industries and cities. Even Lake Constance, which in 1979 had a phosphorus content three times higher than tolerable levels, is considerably cleaner than it was before. The navigable Rhine is also much cleaner than it was 30 years ago, with Class II the standard in the upper stretches and Class II/III in the lower stretches. Two of the most problematic chemical classes, heavy metals and chlorinated hydrocarbons, have been brought under control. Even phosphorus and nitrogen levels have begun to decline, though nitrogen levels in particular are still a cause of concern. The quality of Rhine water will no doubt continue to improve as new mitigation technologies are developed and put in place, and the day may soon arrive when the entire Rhine will belong to Class I/II, according to Cioc (2002) about the best that an industrial river can hope to achieve.

Significant progress has also been made in re-establishing the Rhine's biodiversity. While the river no longer supports the full flora and fauna of the past, there has nonetheless been a remarkable comeback both in the number and diversity of plant and animal species. Figure 12.8, depicting macro-zoobenthos changes in the Rhine over the past century, became the hopeful sign of biological rehabilitation in the river Rhine: from the large species richness of the early 20th century, via the through of pollution and de-oxygenation in the 1970s, back to considerable numbers of invertebrates (IKSR, 2002c).

Van den Brink et al. (1996) discussed the diversity of aquatic biota in the Lower Rhine. The present species richness in the main channels is still relatively low, despite major water quality improvements. Although the present biodiversity has vastly improved when compared with the situation a few decades ago, it is evident that many species are eurytopic, including many exotics. Further biodiversity recovery is hindered because of river regulation and normalisation, which have caused the deterioration and functional isolation of main channel and floodplain biotopes. The importance of connectivity differs among the aquatic species. Floodplain lakes contribute significantly to the total biodiversity of the entire riverine ecosystem. The redevelopment of active secondary channels is required to restore the most typical riverine habitats and biota (see Chapter 14). At present the Lower Rhine main channels have a low diversity of aquatic macro-invertebrates, and particularly the diversity of typical riverine taxa is still at a low level. On the other hand, unlike aquatic insects, the biodiversity of snails, mussels and especially macro-crustaceans is at present higher than during the start of the 20th century.

During the latest surveys for the ICPR ‘Rhine 2020’ Programme more than 300 species or higher taxa were recorded. Most of the species occurred in the Higher Rhine and in the southern Upper Rhine. The number includes 28 species or higher taxa of neozoa (exotics), and the biomass of these aliens exceeds that of native species (IKSR 2002c; see Chapter 17).

The present diversity of aquatic macrophytes in the main channels of the Rhine is rather poor as compared with the former situation or with the present diversity in floodplain lakes. At present, about 70% of the species recorded have been found only in the floodplain lakes. The other 30% can be found both in the main channel and floodplain lakes biotopes. Although the historical data are scarce, it can be concluded that many species have disappeared or became rare. Deterioration of aquatic macrophytes in this regulated river is probably caused by increased river dynamics, e.g. larger differences between summer and winter water levels, higher stream velocities and a higher frequency of summer spates. The reduced number of oligo- and mesotrophic species and an increase in the eutrophic ones may indicate an increase in eutrophication. The number of exotic aquatic macrophytes in the Rhine and its floodplains is low (Van den Brink et al., 1996).

The ‘Salmon 2000 Programme’ coordinated by the International Commission for the Protection of the Rhine (ICPR, 1994) has now been integrated in the programme on the sustainable development of the river Rhine ‘Rhine 2020’ whose main objectives are ecological restoration, flood prevention and groundwater protection (ICPR, 1998). Due to the improvement in water quality the number and abundance of the majority of fish species have increased and the Atlantic salmon (*Salmo salar*), which was formerly extinct, now occurs in some tributaries again, mainly favoured by restocking experiments. The biological inventory of 2000 (IKSR, 2002a) gave evidence of an impressive regeneration of the biotic communities of the Rhine, revealing over 60 fish species, substantially more than that published by Wetzel (2002). The indigenous ichthyofauna consists of 44 fish species and of these only the Atlantic sturgeon (*Acipenser sturio*) has not been recorded. Atlantic sturgeon disappeared because of excessive fishing, closure of the Rhine–Meuse

Delta and river channel degradation in the German part of the Rhine (cf. Chapter 8). The migratory allis shad (*Alosa alosa*) and twaite shad (*Alosa fallax*) which had disappeared from the river have again been recorded. The presence of the young of rheophilous species such as barbel (*Barbus barbus*) shows that the river provides enough dissolved oxygen for their existence. Most species other than the migratory species are self-sustainable, but the overall species composition is skewed towards a few ubiquitous ones, such as roach (*Rutilus rutilus*) and bream (*Abramis brama*).

The results of the salmon programme for several tributaries of the Rhine (e.g. Sieg, Ahr, Our, Ill, Bruch) show that there is a good chance that a self-sustaining population of Atlantic salmon will become established. The most northerly dam in the main course of the Rhine, the Iffezheim dam (Fig. 12.1), was built from 1970 to 1975. In order to restore the migration route of fish a fish pass was built at the Iffezheim dam from 1998 to 2000; this is Europe's largest fish pass on the Upper Rhine. Over a distance of *ca*. 300 m, fish pass through 48 pools and surmount an average elevation of 11 m depending on the water level, between the downstream and upstream sections. The upper part of the pass consists of 37 individual pools, each with a surface area of 15 $m^2$ and a mean water depth of 1.5 m. For the passage of invertebrates (macro-zoobenthos) the bottom of each pool is covered with a substrate made of large stones and additional passage holes. The success of the fish passage in Iffezheim will help to implement the next fish pass at Gambsheim. This will enable anadromous fish, such as salmon and sea trout, to bypass the dams across the Rhine and reach their spawning sites in the Rhine tributaries of the Black Forest and the Vosges Mountains. Still more ecological improvements are necessary for achieving this objective (Heimerl et al., 2002).

A considerable number of exotic fish species are present in the Rhine basin, but they do not dominate the fish community. Some of these exotics entered the Rhine basin because of the connection with the Danube basin through the Rhine-Main–Danube canal (cf. Chapter 17). The present fish fauna is dominated by eurytopic cyprinids. Rheophilous species have declined in numbers and anadromous fish have become scarce or extinct. Phytophilous northern pike (*Esox lucius*) and rudd (*Scardinius erythophthalmus*) decreased in density with the decline of riverine vegetation in the Rhine. Sea lamprey (*Petromyzon marinus*) and river lamprey (*Lampreta fluviatilis*) are common but have decreased in numbers due to the closure of the Zuiderzee in 1932 and the closure of the Haringvliet in 1970. However, since the 1980s captures of these species in the Rhine–Meuse Delta have slightly increased (Brenner et al., 2004).

The full impact of the restoration work, of course, will not be visible for a long time to come. Floodplain forests reach their full maturity only after hundreds of years. Pioneer plants must first take root, then later come poplars and other light woods, then willows, then alders and ash, and finally elms and oaks. Toxic build-up of heavy metals and micro-pollutants in sediment deposits will also continue to affect riparian life long after the factories that produced them are closed. Possibilities for the restoration of the river Rhine are limited by the multipurpose use of the river for shipping, hydropower, drinking water and agriculture. Further recovery is hampered by the numerous hydropower stations that interfere with downstream fish migration, the poor habitat diversity, the lack of lateral connectivity between main channel and floodplains, and the cumulative unknown effects of thousands of synthesised components in water and soil.

The present results of rehabilitation measures are all the more remarkable because they represent a departure from the river regime that prevailed on the Rhine for over a century and a half. Until 1976, when the Rhine Ministers passed the first pollution conventions, the story of Rhine water quality was a story of decline. Since then, water purity has improved with each passing year. Similarly, until 1978 when the last dam on the Upper Rhine was completed, river rectification invariably meant the loss of floodplain space. Since then, small portions of the floodplain have been restored at a few key locations, and more space will no doubt open up in the coming decades (Cioc, 2002). Even for the river Emscher, in the 1960s and 1970s the most polluted open sewer, a policy of restructuring is underway. The permanent international exhibition for architecture and design ‘Emscher Park’ provides a workshop for the future of obsolete industrial areas, including the rehabilitation of ecological values, so far as still present (Wood, 2001).

## 12.6 Conclusions

- The Rhine basin (1,320 km, 185,000 km$^2$) is shared by nine countries with a population of about 50 million people and provides drinking water to 30 million of them. The Rhine is navigable from the North Sea up to Basel in Switzerland and is one of the most important international waterways in the world.
- Floodplains were reclaimed and forests were felled as early as the Middle Ages, and virtually all of the Rhine’s lowland forests, meadows and marshes have disappeared over the past 200 years.
- In the 18th and 19th century the channel of the Rhine has been subjected to drastic changes to improve navigation as well as the discharge of water, ice and sediment, e.g. a reduction in length of over 100 km, and the construction of numerous hydro-dams and weirs.
- Coal was the main accelerator of industrial activities in the 19th century. By the 20th century new forms of energy came to the fore. Hydroelectric power, petroleum-based fuels, and nuclear fission allowed the chemical industry to invade river spaces that had largely been spared the ecological damage of industrialisation.
- From 1945 until the early 1970s water pollution due to domestic and industrial wastewater increased dramatically. Hundreds of different chemicals found their way into rivers every day, among which heavy metals, chlorinated hydrocarbons, pesticides and organic micro-pollutants caused the greatest concern.
- Habitat loss and water and soil pollution annihilated many plant and animal species. By 1975, the year generally considered to be the peak year of Rhine pollution, the entire navigable Rhine was so polluted that all natural biological conditions had been compromised, with the level of degradation increasing as the water moved downstream.

- Concerted effort by the riparian states since the 1960s has reversed the downward spiral, and the Rhine is now on its way to ecological recovery in three critical areas: water quality, biodiversity and floodplain restoration. The greatest achievements so far have come in water quality.
- Possibilities for the restoration of the river Rhine are limited by the multipurpose use of the river for shipping, hydropower, drinking water and agriculture. The poor habitat diversity, the lack of lateral connectivity between main channel and floodplains and the cumulative unknown effects of thousands of synthesised components in water seriously hamper further rehabilitation.
- With the improvement of water quality in the Rhine the dissolved oxygen concentrations are satisfactory for fish throughout the year. Both fish and macro-invertebrate communities, however, contain very few species with narrow ecological requirements. Often exotic species dominate the benthic macroinvertebrates.
- The full impact of the restoration work will not be visible for a long time to come. Floodplain forests reach their full maturity only after hundreds of years. Toxic build-up of heavy metals and micro-pollutants in sediment deposits will also continue to affect riparian life long after the factories that produced them are closed.
- A significant positive recent development is the EU Water Framework Directive: EU member states are required to compile river basin management plans and rivers should have a good ecological status by the year 2015.

# Chapter 13
# Changing Meuse Ecosystems: Pollution and Rehabilitation

## 13.1 Introduction

Considerable differences exist between the Rhine and the Meuse (Fig. 13.1). First, far more water flows down the Rhine: an average of 2,300 $m^3\ s^{-1}$ enters the Netherlands at Lobith. Flow in the Meuse is not only much lower (230 $m^3\ s^{-1}$ on average at Eijsden/Borgharen) but exhibits much greater seasonal variance. The Meuse's maximum flow is 150 times greater than its minimum flow, whereas the difference between the minimum and the maximum in the Rhine is 'only' a factor of 20. In terms of catchment size, the Rhine is Europe's fourth biggest river, after the Volga, the Danube and the Vistula. In terms of length and flow, however, it is the third biggest. The Meuse lags significantly behind, in ninth place. The Rhine is the largest river of Western Europe, concerning its drainage area and length; the Meuse is one of the smaller rivers (Petts, 1989).

Water levels in the river Meuse are more or less permanently controlled by weirs, in order to make the river navigable. There is a marked contrast between the Delta branches of the Meuse and the Rhine. The Rhine branches are embanked along their entire length, whereas only the lower stretches of the Meuse downstream of Mook/Boxmeer have dykes. Behind the dykes, the land between the Rhine branches is mostly low-lying polder. So, if the dykes were to fail, the consequences would be disastrous. Large parts of the basins of the Large Rivers and the Central Delta would soon be covered by metres of water. The Meuse upstream of Mook has no dykes. In this part of the country, the river flows through a valley, gently sloping upwards, and forming natural levees. In this area there are no polders which need to be protected against flooding, and consequently, floods along this stretch of the Meuse are not a threat to human life. Nevertheless, the consequences of flooding across the intensively used river basin should not be underestimated. The river basin has been occupied in the course of centuries by numerous human activities, town expansions, villages, industries and infrastructural works (Middelkoop and Van Haselen, 1999).

The aim of this chapter is to present a concise survey of the environmental history of the international river Meuse. As an important European river, the resources of the Meuse have been exploited from prehistoric times onwards, but the normalisation

P.H. Nienhuis, *Environmental History of the Rhine—Meuse Delta,*

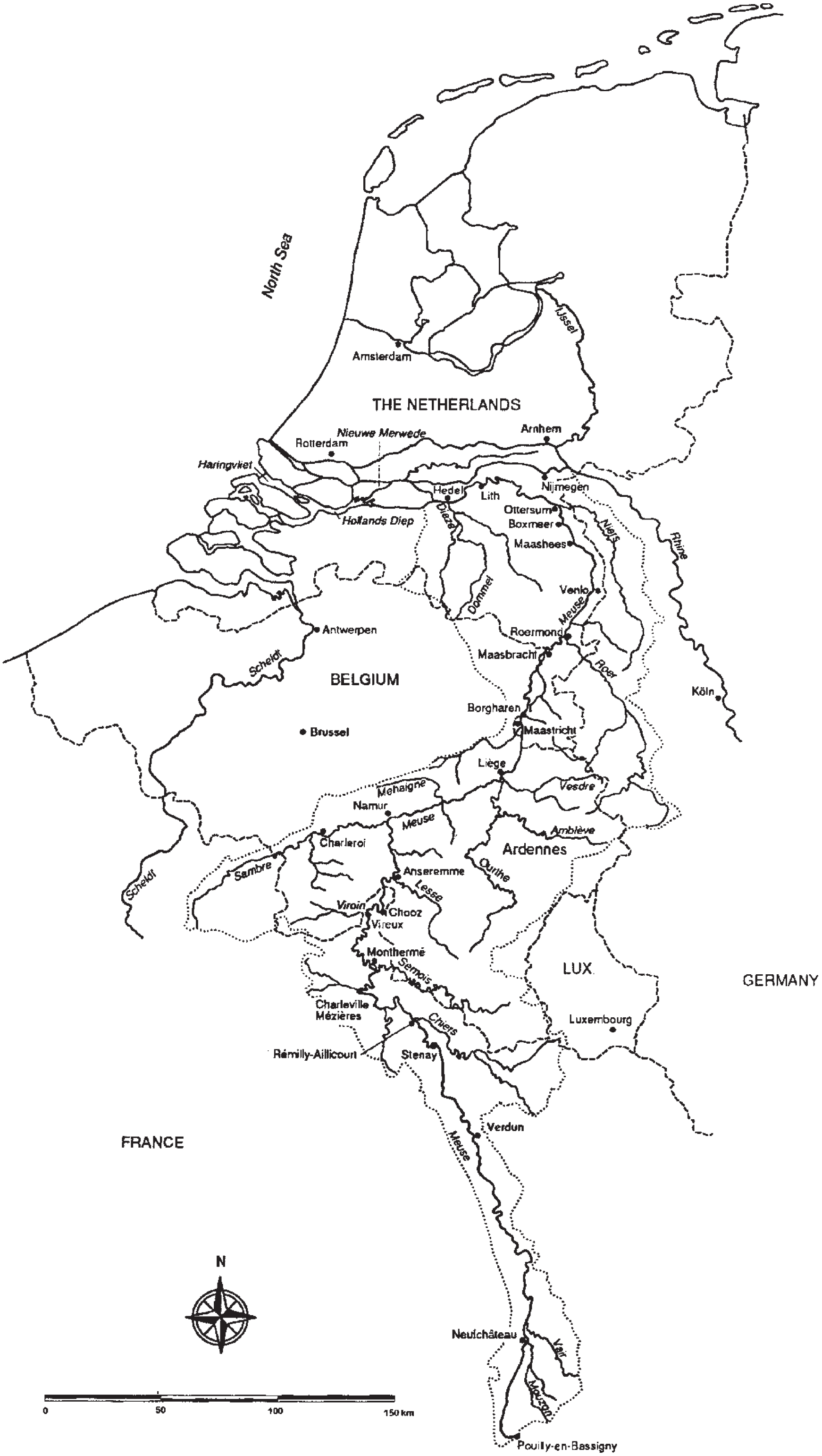

**Fig. 13.1** The catchment area of the river Meuse (Van Leussen et al., 2000)

process that started in the 19th century has severely aggravated the breakdown process of the original ecosystems. Finally hopeful signs of recent ecological rehabilitation will be discussed.

## 13.2 The Meuse, its Subdivisions

The Meuse basin has a temperate climate, with rivers that are dominated by a rainfall-evaporation regime, which produces low flows during summer and high flows during winter. The Meuse basin can be subdivided into three major geological zones (Fig. 13.1): (1) the Lotharingian Meuse (upstream of Charleville-Mézières). This part of the Meuse basin mainly consists of consolidated sedimentary Mesozoic rocks; (2) the Ardennes Meuse (between Charleville-Mézières and Liège). Here the river transects the Paleozoic rock of the Ardennes Massif; and (3) the lower reaches of the Meuse (downstream of Liège). The Dutch and Flemish lowlands are formed by Cenozoic unconsolidated sedimentary rocks. The hydrological conditions of the Meuse basin are to a large extent a reflection of the geology of the basin. The average annual precipitation amounts 800–900 mm year$^{-1}$ in the southern part of the basin, around 700–800 mm year$^{-1}$ in the northern part of the basin and more than 1,000 mm year$^{-1}$ in the Ardennes. The average discharge of the Meuse at the outlet (Hollands Diep) is approximately 350 m$^3$ s$^{-1}$. This corresponds to a precipitation surplus of almost 400 mm year$^{-1}$ (De Wit et al., 2002). The discharge of the river Meuse shows great fluctuations. Discharge levels at Borgharen, the representative measuring point for the Dutch part of the Meuse, range from 10 m$^3$s$^{-1}$ during very dry periods to 3,000 m$^3$ s$^{-1}$ in periods of heavy rainfall in the catchment area. The average annual discharge at Borgharen is 230 m$^3$s$^{-1}$. The distribution of the river discharge over the year, averaged over the period 1911–1991, is presented in Fig. 13.2. The figure also indicates two extreme years: 1966 as a typical wet year and 1976 as a typical dry year (Van Leussen et al., 2000).

The upper course of the Meuse is steep and erosive. The largest gradients, up to 5 m km$^{-1}$, are found in the tributaries that spring in the Ardennes/Eifel Massif (Semois, Viroin, Lesse, Ourthe, Amblève, Vesdre and the upper reaches of the Rur). From Neufchateau to Maasbracht the Meuse has a rather constant gradient of on average about 0.5 m km$^{-1}$. However, the floodplain of the Meuse changes moving from south to north. In the southern part of the basin the Meuse flows through a hilly landscape with wide floodplains. Here the Meuse is partly regulated by weirs and partly flanked by a lateral canal. Even during an average flood, a wide floodplain gets inundated. These inundations cause a weakening of the flood. This explains why flooding events in the southern part of the Meuse basin often do not cause serious problems in the central and northern part of the basin. In the central part of the Meuse basin between Charleville-Mézières and Liège the Meuse is captured by the Ardennes Massif. In this stretch the Meuse is completely regulated with weirs and it

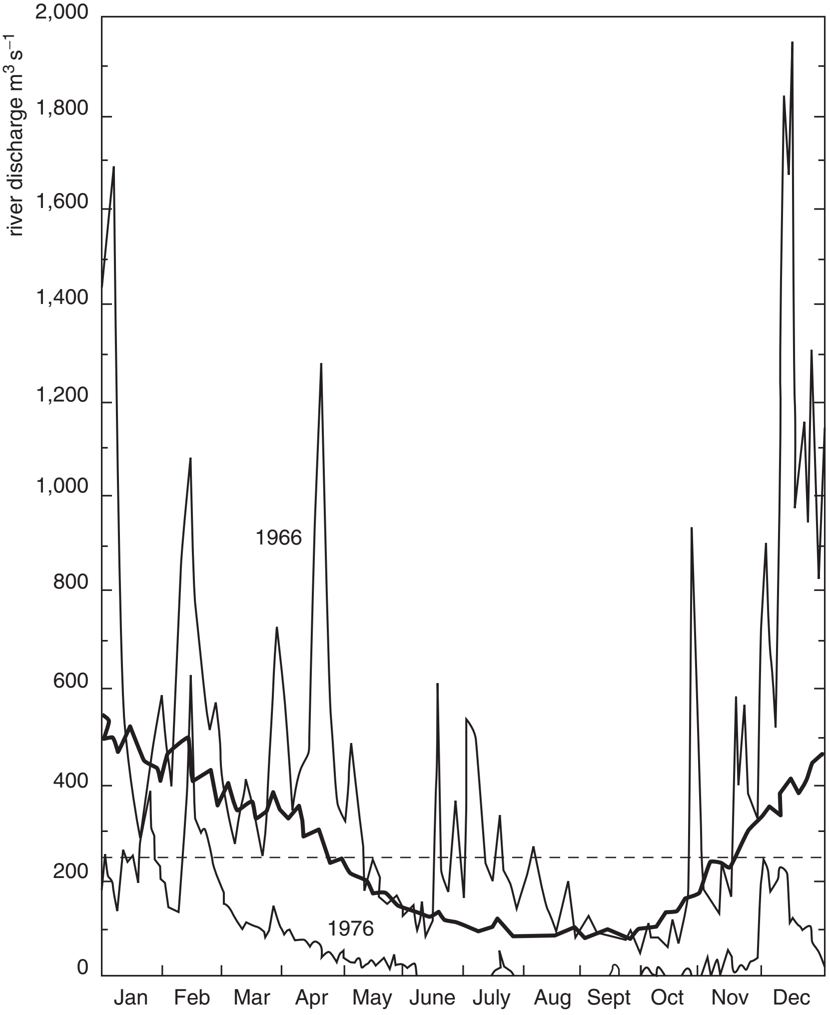

**Fig. 13.2** Distribution of river discharge over the year: mean values over the period 1911–1991 (thick line), and examples of a typical wet year (1966) and a typical dry year (1976). The average annual value is indicated with a broken line (230 m$^3$ s$^{-1}$) (Van Leussen et al., 2000)

flows through a narrow steep valley where flood waves are hardly weakened. The width of the floodplain (winterbed) in the northern part of the Meuse basin generally varies between 200 m and 2 km. Between Borgharen and Maasbracht there are no weirs and the river is flanked by a lateral canal. Further north the Meuse (Gestuwde Maas) is regulated with weirs and becomes a typical lowland river. Gravel extractions along the Gestuwde Maas in the second half of the 20th century changed the former floodplains in a 'Swiss cheese' (Fig. 13.3). Downstream of Mook/Boxmeer the river is embanked (Berger, 1992; De Wit et al., 2002; cf. Chapter 5).

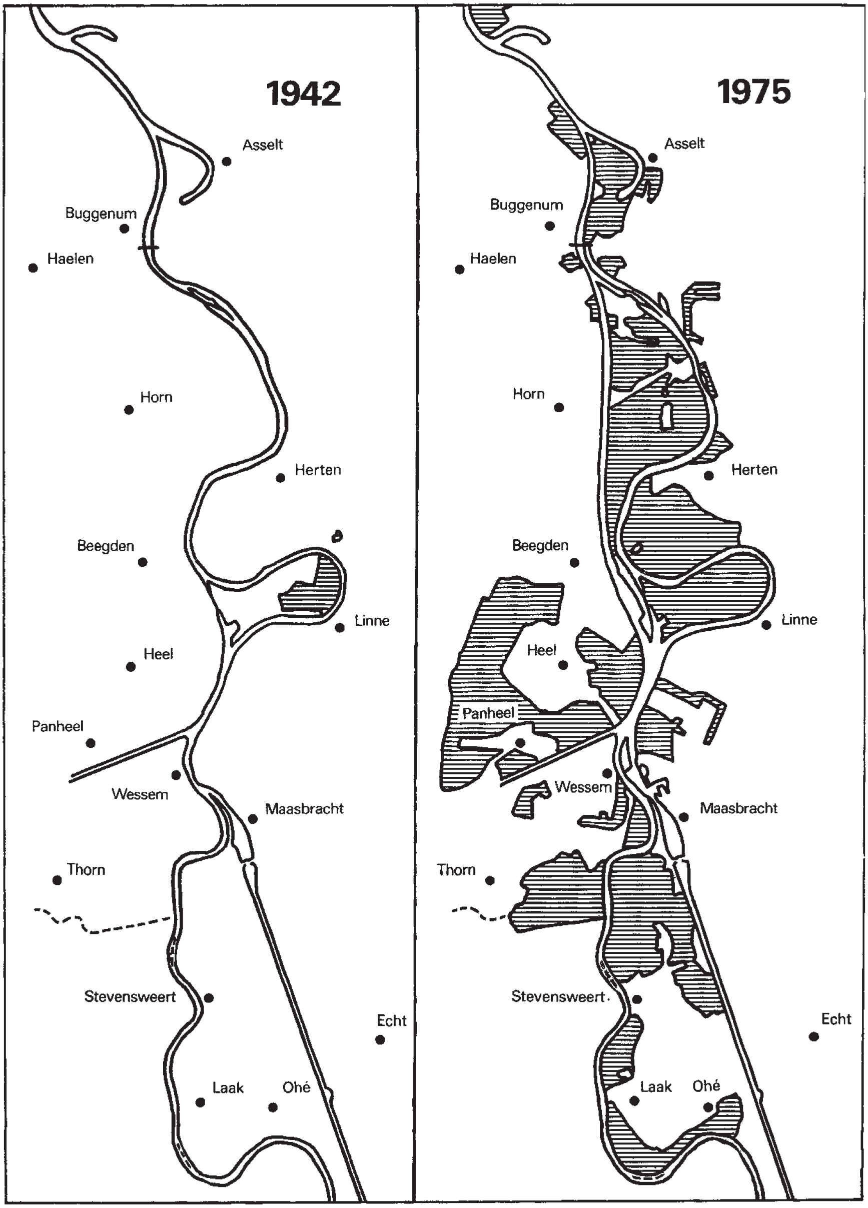

**Fig. 13.3** Gravel excavations (horizontally hatched) along the river Meuse (Gestuwde Maas in the Delta) in 1975 compared to 1942. Scale: largest lake *ca.* 2 km in width (Zonneveld, 1987)

The Meuse originates at an altitude of 409 m above sea level at the Plateau of Langres in the north of France and discharges some 900 km further into the Haringvliet in the west of the Netherlands, from where it enters the North Sea by

**Table 13.1** Hydrological characteristics of the river Meuse (www.cipm-icbm.be)

| | |
|---|---|
| Length (km) | 900 |
| Catchment (km$^2$) | 33,000 |
| Catchment in the Netherlands (km$^2$) | 6,000 |
| Q (m$^3$ s$^{-1}$) at Eijsden | 230 |
| Qmin (m$^3$ s$^{-1}$) at Eijsden | 20 |
| Qmax (m$^3$ s$^{-1}$) at Eijsden | 1,900 |
| Rain/melt | Rain |
| Cl (av.) at Eijsden (in mg l$^{-1}$) in 2003 | 40–50 |

forming with the Rhine and Scheldt a complex system of channels, nowadays entirely dammed for flood control. The catchment area of the river (Fig. 13.1; Table 13.1) is around 33,000 km$^2$ and is situated in France (9,000 km$^2$; river length 492 km), Belgium (13,500 km$^2$; river length 194 km), Germany (4,000 km$^2$), Luxembourg (600 km$^2$) and the Netherlands (6,000 km$^2$; river length 239 km). The Meuse crosses the border between Belgium and the Netherlands at Eijsden, at an altitude of 45 m above sea level, and then runs through the city of Maastricht, after which it forms the border between Belgium and the Netherlands for some 47 km. This stretch of the river is called Grensmaas (Border Meuse). From Stevensweert onwards, the Meuse runs entirely on Dutch territory. Further downstream, the river has been provided with weirs to make it navigable. Downstream of the weir at Lith, tidal influences are present (Van Leussen et al., 2000; cf. Chapter 5 for details).

## 13.3 Changing Meuse Ecosystems

Ever since the first human settlement, human activities have affected the regime of the river Meuse. Agriculture, forestry and urbanisation have changed hydrological processes that relate to soil conditions and land cover, such as infiltration, evaporation and transpiration. However, the overall effect of these changes on the regime of the Meuse is not unequivocal and hard to quantify. Far more pronounced are the human impacts on the river network. Over large stretches the Meuse has been regulated, deepened and canalised. Weirs, locks, canals and reservoirs have been constructed all over the Meuse basin. All these river works have been motivated by the need to use the river as a reliable source for water supply, electricity production and navigation. During low flows these river works have a strong impact on the discharge regime of the Meuse. A number of canals are fed by water of the Meuse. These canals are not only used for navigation but also play a crucial role in the water supply of Flanders and the southern part of the Netherlands. Together these canals discharge almost 50 m$^3$ s$^{-1}$, partly to areas that are located outside the Meuse basin. Reservoirs are found in the upper branches of the Rur, Viroin, Semois, Sambre, Amblève, Ourthe and Vesdre (Fig. 13.1). These reservoirs are mainly used for electricity production, drinking water supply and (low) flow regulation. The total area located upstream of the reservoirs is relatively small and therefore the reservoirs have only a limited potential to be used for flood reduction in the river Meuse (De Wit et al., 2002).

Three phases can be recognised in the Meuse normalisation process (Micha and Borlee, 1989).

### *13.3.1 First Canalisation (1800–1880)*

At the end of the Napoleonic Empire in 1815, the Treaty of Vienna charged riverside dwellers with the work of improving the regime and 'facilitating' navigation. Navigation was improved by transforming the deep stretches of the river into navigable passes. These passes were made by constructing longitudinal underwater piers which maintained the water at a minimum depth of 1.5 m at low water. The towpaths were improved by raising them to a height of 3.5 m above low water mark, in order to prevent them from being flooded, and by increasing their width to 2 m. These were the first systematic changes carried out on the Meuse. However, with the development of boat transport, in particular following the building of canals (Liège-Maastricht with draught of 2 m), the pass system was abandoned in favour of the canalisation of the channel of the Meuse. In 1853 the building of mobile weirs with lateral locks began, and ended in 1880 when canalisation reached the French border. The Belgian part of the Meuse then numbered 23 weir locks from Hastiere to Vise.

### *13.3.2 Adaptation and Stagnation (1880–1918)*

During that period the government of Belgium was less concerned with the river Meuse than with the development of the railway system, and consequently very little innovative work was carried out on the Meuse. The flood of December 21 and 22, 1880, the largest rise in the water level of the century, revealed serious shortcomings of the river engineering works that had been undertaken in the past. As a result many river curves were straightened and the channel was normalised, and by the end of the 19th century, the entire canalisation of the Meuse was gathering momentum. The presence of water has always been one of the main reasons for the growth of villages and towns. Gradually, imperceptibly, the scattered villages met to form a continuous urban ribbon. Lack of space in the valley forced the population to encroach on the the river's channels. Classic examples of towns that developed in this way are Dinant and Liège. Gradually the floodplain bed has been largely sacrificed and the main encroachments are the result of urbanisation, and of road and rail expansion. Riverside dwellers have long taken advantage of the alluvial deposits for farming purposes, but today these forelands have almost completely been occupied by urban expansion.

Industrialisation and population growth required improved means of transport. Roads situated in the floodplain have always existed, but initially these were only narrow towpaths and tracks. From the late 18th century onwards these roads were modernised and became metalled, covered with impermeable materials, which only increased the areas along which rainwater could flow down, resulting in a greater supply of water to the river than before. Another human invention which constantly competed with the main functions of the river was the growing railway system. Railway tracks encroached onto the floodplain, resulting in raised walls and embankments, and straightened and narrowed riverbeds. Even sandy islands were connected to the river foreland, in order to create space for railways. Numerous examples exist of such changes along the Meuse, were the natural room for the river was transformed into rigid man-made constructions.

### *13.3.3 Modernisation (from 1918 to the Present Day)*

With the development in trade and industry, transport networks had to become more efficient, and to remain competitive the river navigation system had to be modernised. The chronology of the process of modernisation undertaken since 1918 led to the division of the Belgian Meuse into the lower and upper Meuse, from the Dutch border to Namur and from Namur to the French border, respectively. It was in fact the lower Meuse which was the first to be developed; the upper Meuse kept until recently the features created during the period of initial canalisation in the 19th century. The new programme to improve navigation on the Meuse began around Liege in 1923. It had three goals: (1) To improve navigation on the Meuse by reducing the number of locks and to increase their size and moorage space on the river. In the sections of the river between the locks, the mooring places were brought to a depth of 2.6 m, but later attained 3 m and even more when dredged. (2) To improve the flood regime by regulating the channel bed, increasing depth profiles and removing old weirs. These old-fashioned weirs with their raised foundations and narrow openings constituted obstacles to the free flow of water at peak discharges. (3) To build hydroelectric power stations downstream, to develop the river's energy potential utilising the drop in water level between the new weirs. This entire programme was only implemented in 1927 when in response to the disastrous flooding of 1926 the State set up a commission and made special funds for major works available.

Weirs of a new type whose channels are closed by lift-up sluice gates and swinging flush-boards, electromechanically operated, were built from 1930. Simultaneously, a new campaign to remove the islands of the lower Meuse, which constituted obstacles to the free flow of water, was launched. From 1900 until recently tens of islands in the Belgian Meuse have been removed, and river management is still aiming at the extirpation of gravel and sand deposits from the channel. Since the 1960s navigation has progressed: motor barges have been replaced by push boats with four barges, each 76.5 m by 11.4 m. The locks must therefore be at least 185 m long and 24 m wide. The modernisation in the Dutch border – Namur section resulted in a strong reduction of the number of weir locks. The river has been, or will be systematically deepened to 5 m to allow a continuous draught of 3.5 m. In the meantime all the natural banks have been straightened, comprising the filling in of too wide stretches, the elimination of gently sloping zones and the building of vertical or slightly sloping concrete banks. The width of the Meuse channel finally met the recommended standard size of 100–150 m.

It was only in 1983 that the modernisation programme set up in 1960 passed Namur and continued upstream towards the French border. This modernisation has two aims, viz. to make the Meuse navigable for ships up to 1,350 t, and to effectively combat flooding. Due to the current reduction in river traffic, it appeared not to be necessary to make the upper part of the Belgian Meuse navigable for 9,000 t ships. This meant that the nine old manual weirs had to be retained, and could simply be replaced by new weirs with electromechanical flush-boards. Additional channel improvements remained necessary, but it is not expected that the changes resulting from this modernisation should drastically modify the aquatic environment of this stretch of the Meuse (Micha and Borlee, 1989).

## 13.4 Severe Pollution and the Deterioration of Biodiversity

### *13.4.1 The Industrial Revolution and its Consequences*

More than 2,000 years ago, iron ore was already used by the inhabitants in the area between the Sambre and the Meuse, and the presence of coal and metal has largely determined the industrial development in the Meuse catchment. Although coal mining began as early as the 13th century, the development of the coal industry was slow until the invention of the fire pump in the 18th century. In the 19th century, Charleroi became the heart of the 'pays noir' (the black country), the country of the coal-mines. This area was, together with the Liege region, the centre of the rapidly industrialised Belgium. At the beginning of the 19th century, the industrial revolution which started in England brought profound changes in traditional metallurgy industry. The use of coke instead of charcoal, and the use of steam engines instead of hydraulic energy, resulted in the shift of metallurgy centres from the forest regions of Ardennes to the coal-mining sites of the Sambre–Meuse region. In the 19th century, Wallonia became the economic heartland of Belgium, as Flanders had been in the Middle Ages. Indeed, after Britain, industrial Wallonia and especially the Sambre–Meuse coalfield was the cradle of the industrial revolution of the European continent. As more industries turned to the use of steam power in their mechanisation, so the demand for coal grew. It became the main source of power for much of the country, and most of the coal industry grew up alongside the other industrial regions in the Walloon provinces. Although it provided a good source of employment, it resulted in ruined landscapes in the search for coal, with slag-heaps springing up and air pollution at a dangerous level. Much of these heavy industries were concentrated in a relatively small area, namely the Haine–Sambre–Meuse valleys, which were characterised by a standard of living, with cramped, concentrated housing, and a very working-class way of life. Steel factories were built alongside coalfields as their mechanised processes were usually fuelled by large demand of coal, and Belgian steel was rapidly used to improve the country's infrastructure such as bridges and railways (www.trabel.com).

In 1930 an air pollution disaster occurred in the Meuse Valley, Belgium: 3 days of weather inversion in this 24-km industrial valley trapped pollutants released by coke ovens, steel mills, blast furnaces, zinc smelters, glass factories and sulphuric acid plants. This industrial pollution in the form of sulphur dioxide killed 63 people and made 6,000 more ill; the combination of sulphur dioxide and fog droplets combust formed tiny particles that penetrated deeply into the human lungs (Nemery et al., 2001).

In addition to coal, large amounts of matrix material, such as sandstone and clay stone were mined. The coal was separated from this matrix material by means of flotation techniques. The separation techniques used in the extraction of ores were based on the same principle as those used in coal production, i.e. on differences between the density of the ore and of the matrix material. The separation techniques were far from efficient, and therefore the waste water still contained high levels of metal-rich particles. This waste water was initially discharged untreated into the surface water system. As a result, until the beginning of the 20th century, the concentration of coal particles in the Meuse was so high that during periods of low river discharge the water was black. The heavy metals deposited in the Meuse basin were mostly derived from liquid industrial wastes and the contamination concentrates in the clay fraction of the sediment. In the Meuse sediments this resulted in a clear relationship between the percentage soil fraction less than 2 micrometre and the concentration of heavy metals, but a rather weak relationship with distance to the source of the pollution, the industrial region of Liege (Rang and Schouten, 1989).

Important ore reserves were discovered near Aachen, in the catchment of the Inde, a tributary of the Rur, and near Plombières, in the Belgian part of the Geul catchment (see Fig. 13.4). The exploitation of zinc and lead ores began in the early Middle Ages and reached its peak between 1820 and 1880. The mines were exhausted in the 1930s and exploitation ceased. The extraction of lead from the huge waste tips on former mine sites continued into the 1950s (Rang and Schouten, 1989).

### *13.4.2 Severely Polluted Sediments*

Investigations over the last 15 years have revealed the presence of strongly polluted sediments throughout the Delta floodplain of the Meuse River and its tributary, the Geul River. Most of the polluted sediments date back to the industrial revolution in the Meuse Basin (early 19th century) and consist of the heavy metals (e.g. zinc, cadmium and lead) and of more recently deposited organic contaminants, e.g. polyaromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). The Meuse

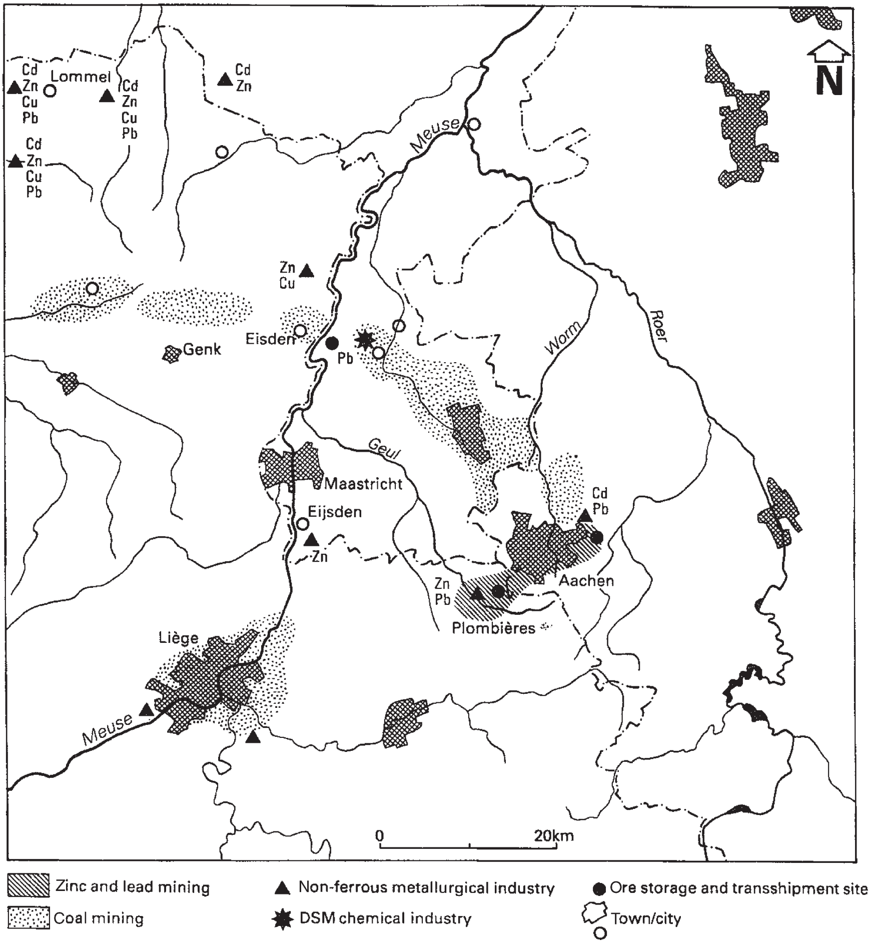

**Fig. 13.4** Coal-mining areas and heavy metal mining (mainly zinc and lead) and industrial plants in the Grensmaas region (Meuse and tributaries, e.g. Geul) (Rang and Schouten, 1989)

and Geul rivers redistribute significant amounts of contaminated sediments during floods. After erosion during high water the polluted river sediments that have been deposited on the floodplain form a secondary source of pollution that can have a strong and long-lasting effect on the quality of the river silt. The highest concentrations are found in the top 20 cm of the soil. After being deposited during a flood, the fresh deposits are mixed with the topsoil in a matter of weeks. This mixing occurs by ploughing and by biological activity, which has caused a considerable increase in the heavy metal concentration of the topsoil over the years. At a depth of approximately 50 cm beneath surface level though, concentrations have decreased to 20–25% of the upper soil layer. In isolated meanders and other former stream channels that have been filled in during the last centuries, the depth of strongly polluted soils may reach a level to 4 m below the surface (Schouten et al., 2000).

Some of the original major industrial and coal-mining sources of contamination have disappeared for years now, but their pollutants are still moving through the river system. Other sources of contaminated flood deposits include agricultural activities and waste disposal of urban regions without sewage treatment. Within the Netherlands alone, strongly polluted sediments cover more than 100 km$^2$ of the floodplains. Floodplain and riverbank erosion during major floods release older layers of polluted deposits to be re-deposited elsewhere on the river forelands. While some of this area is urbanised, most of it is used for agriculture and, hence, these polluted sediments represent a direct risk to human health. Under the strict Dutch soil laws, one has to completely remove all contaminated sediments if intervention values are exceeded. If these deposits are impossible to clean, they have to be permanently stored in safe disposal sites. In the Meuse valley, this would virtually mean removing top 0.5 m of large parts of the river forelands.

Like many European rivers, the Meuse has been used as an open sewage system for the last centuries. With the rise of industry in the Liege area from 1820 onwards, the Meuse River became increasingly polluted and the aquatic ecosystem was virtually destroyed. Not only dissolved matter but also polluted sewage-sludge as well as solid wastes and colliery waste have been dumped in the river. About two thirds of the metal load accumulates in the freshwater basins and floodplains before the rivers discharges into the North Sea. The enrichment of the sediments with heavy metals in the Meuse River reached its climax much earlier than in the Rhine basin. From studies of sediment pollution in relation to soil development in the Dutch part of the Meuse valley, it can be concluded that sediment pollution, began more than 350 years ago. It reached its peak about 100 years ago in the late 19th century, coinciding with the zenith of ore mining in the Belgian part of the catchment (Rang and Schouten, 1989; Schouten et al., 2000).

The oldest silted-up abandoned meander of the Meuse that could be dated from old maps and documents by Rang and Schouten (1989) is at least 300 years old. Old documents from the second half of the 16th century and the first half of the 17th century report rapid channel changes during this period. A document from 1559 describes a disastrous flood that resulted in an appreciable shift of the Meuse channel. Given that the oldest deposits in the channel studied, proved to be the most polluted it can therefore be inferred that the greatest pollution of Meuse silt occurred before the channel was silted-up, i.e. at least 90–130 years ago. Although based on scanty data, Table 13.2 summarises the heavy metal contents of the deposits of known age.

**Table 13.2** Mean heavy metal contents (in mg kg$^{-1}$) of former and recent channel deposits of an abandoned meander of the Meuse near the confluence with the river Geul (Rang and Schouten, 1989)

| Location | Age (years) | N | Zn | Pb | Cd | Cu |
|---|---|---|---|---|---|---|
| Former channel | 350 | 1 | 154 | 84 | 1.0 | 27 |
| Former channel | 120 | 1 | 8,000 | 1,406 | 24.7 | 67 |
| Gravel pit | 10 | 2 | 1,660 | 530 | 27.0 | 160 |
| Present channel | 1 | 5 | 1,600 | 390 | 21.8 | 90 |

In Meuse river sediment deposits that are 1,000–2,000 years old, dug at a depth of 1 m, the concentration of Zn is 105 mg kg$^{-1}$, Cd 0.4 mg kg$^{-1}$, Pb 31 mg kg$^{-1}$ and Cu 22 mg kg$^{-1}$. This is considerably lower than the values found in deposits that are 350 years old (Table 13.2). It should be realised that half of the difference in the degree of pollution can be attributed to the differences in soil type, and at greater depth the heavy metal content may have changed since deposition, because of leaching. The heavy metal contents of the various soils at 1 m depth give a reasonable indication of the concentrations in the Meuse silt at the moment of sedimentation. It can safely be assumed that the increase in the heavy metal content of the Meuse silt certainly began more than 200 years ago. It has to be realised that, since the Meuse River flows through the Ardennes, where these metals occur in the rocks, the sediments contain heavy metals like zinc, cadmium and lead by nature. Levels of these background concentrations, however, are very low, causing no significant human- or eco-toxicological risks.

Besides heavy metals, flood deposits of the Meuse River contain organic contaminants such as mineral oil, PAHs, PCBs and HCB. The contamination may form a direct threat to public health and to the ecosystem. Some of these contaminants originate from local sources, such as leaking oil tanks or the use of agricultural pesticides on agricultural land. PAHs and PCBs may be related to coal mining in the Meuse catchment. Other sources include agricultural activities and the urban regions with no sewage treatment facilities. Sediment sampling surveys in Belgium 2 days after the flood of 1995 revealed that the fresh Meuse flood deposits upstream from Liege were much less polluted than downstream deposits; concentrations of zinc, lead, cadmium and PAHs increased downstream. Concentrations of zinc exceed the Dutch intervention level at the locations in the industrial area of Liege. PAH concentrations increase at Namur as a result of coal-mining activities along the Sambre in the Charleroi area. Liege is the main source of heavy metal contamination in the Meuse River sediments. Downstream from Liege, the first major opportunity for the river to deposit sediments is at Maastricht, where the Meuse floodplain is widening. During major floods, thick layers of strongly polluted sediments have locally been deposited in the floodplain behind the weir of Maastricht. Onwards from Maasbracht, the quality of the sediments slightly improves and the area of strongly polluted soils is restricted to recent channel fills and forelands alongside the Meuse (Schouten et al., 2000).

The Geul River is the main point source in the Netherlands of the Meuse river heavy metals (Fig. 13.4). The Geul River is responsible for 10% of the lead-load in the Meuse River downstream of Maastricht, as well as 8% of the zinc-load and 5% of the cadmium-load (Leenaers, 1989). Geul River sediment pollution originates from former ore-mining activities in the Belgian part of the catchment. The heavy metals in Geul sediments are present mainly in the sand fraction as the contamination originates from mine tailings. There is a clear decrease in concentrations along the banks of the Geul River in the downstream direction. The bulk of the contaminated sediment has not yet reached the confluence of the Geul and the Meuse rivers, just downstream of Maastricht.

### 13.4.3 Water Quality

The history of the accumulation of pollutants in the sediments is in sharp contrast with the fate of pollutants in the water column of the Meuse over time. But first of all it has to be stated that little historic information exists regarding the physical and chemical characteristics of the water of the Meuse. It is, for example, simply not known to what degree the Meuse water was charged with (soluble) heavy metals a century ago. Micha and Borlee (1989) stated that the only exception is formed by the data regarding the load of suspended matter. Lemin et al. (1987) compared their recent data to that assembled by investigators in 1883. The total amount in suspension has clearly increased since 1883, especially for flows exceeding 100 m$^3$ s$^{-1}$ (Fig. 13.5). Thus, for a flow of 1,000 m$^3$ s$^{-1}$ the quantity of suspended matter being transported according to the lines of regression obtained was 30 mg l$^{-1}$ in 1883 and 204 mg l$^{-1}$ in 1983. Calculated on the basis of mean flows, the concentration of suspension matter in the Meuse at Liège has tripled over the last century. The total discharge of suspended matter in the 1980s into the Meuse between Namur and Liege, originating from the quarries (*ca.* 30,000 m$^3$ year$^{-1}$), from metallurgical industry (*ca.* 15,000 m$^3$ year$^{-1}$) and from thermal power stations (*ca.* 5,000 m$^3$ year$^{-1}$), is in the order of 50,000 m$^3$ year$^{-1}$, but this is largely offset by current dredging in the order of 80,000 m$^3$ year$^{-1}$. Consequently, the cause of the spectacular increase in concentrations of suspension matter probably resulted from the canalisation of the river which could no longer overflow its forelands and was thus withdrawn from the deposition of sediment on its alluvial plain (Lemin et al., 1987).

There is a serious lack of reliable data on water quality from the period 1950–1970 and before. Indirect evidence suggests that the quality of Meuse

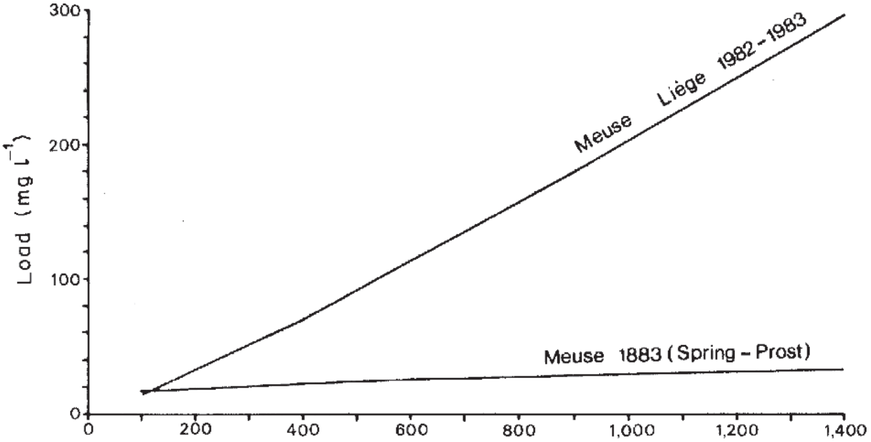

**Fig. 13.5** A century's evolution in the relationship between the suspended matter load in the Meuse and the river's discharge at Liège (in Micha and Borlee, 1989, adapted from Lemin et al., 1987)

water before 1970 was far more better than the quality of Rhine water. As far as can be derived from existing data for the entire Meuse, the water quality decreased after 1960, reached a lowest point around 1970, and showed a gradual improvement since then. The main problem remains the diffuse loading of pollutants, mainly from agricultural origin, such as pesticides, nutrients and pathogens. After 1950 the oxygen content of the Meuse water showed a steady decline, but after 1970 owing to the systematic building of sewage treatment plants, the situation has markedly improved. Only in the Belgian stretch of the Meuse, downwards of Namur, the oxygen saturation may still reach values below 50%. Until 1975 the Meuse saw a tremendous increase in phosphate load, but a considerable decrease has set in thereafter. Nitrogen, particularly nitrate load increased over the years, but since the introduction of a denitrification step in sewage treatment plants around 1993, the situation has considerably improved. The salinity load of the Meuse water has hardly changed since 1960, and is at a relatively low level, compared to the river Rhine. The chloride content in the Delta Meuse is on average 40–50 mg $l^{-1}$, with maximum values lower than 100 mg $l^{-1}$. Salinity is one of the few parameters on which the Meuse water scores better than the river Rhine, in contrast with the situation around 1970 when the Meuse scored in all respects better than the Rhine. Heavy metal concentrations have strongly declined since the early 1970s, cadmium, mercury and lead even with a factor 10–50. Industrial bromides and fluorides remain a significant problem. Over the past 10 years a main problem is formed by pesticides (more than 10 years ago the analytical methods were not sensitive enough), mainly herbicides such as atrazin and diuron, and resistant pathogenic microorganisms (Volz et al., 2003).

### *13.4.4 Deterioration of Biodiversity*

Since ages the ecosystems of the Meuse have undergone modifications of increasing importance: e.g. a marked reduction of water flow, a drastic increase in the suspended material being transported, a significant load of heavy metals and organic pollutants particularly burdening the ‘memory’ of the deposited sediments, severe eutrophication of the water and the annihilation of the original floral and faunal communities. Stringent normalisation of the river Meuse and many of its tributaries, together with the booming developments during the industrial revolution, have drastically changed the river landscapes. Encroachment on the channel bed has, in particular, led to the destruction of numerous habitats, including their flora and fauna. Thus, aquatic and semiaquatic plant communities, which only develop in shallow water along the gently sloping banks of the river, have been virtually eliminated by the construction of vertical, often concrete, banks. These marginal zones also served as spawning grounds for species of limnophilic fish, and consequently these species have been severely impacted by the channel engineering works. Moreover, the systematic deepening of the Meuse to 3–5 m has led to the destruction of the gravel zones for rheophilic species, suitable for a number of invertebrates and fish linked to them (Micha and Borlee, 1989).

The contrast between the French Meuse and the lower Belgian Meuse is striking. Nowadays, in France, one quarter of the catchment area is covered by forests, while arable fields, grassland, sheep rearing farms and built-up areas account for the remainder. Industry was mainly concentrated in the Chiers basin but there is currently a marked decline in industrial activities. The scant population is relatively scattered over the area, except for several sizeable towns. The area south of the Sambre and Meuse line in Belgium was centuries ago covered for the greater part by forests, which underwent intense deforestation to meet the needs of new industries and those of breeding and agricultural development. Thus, the pastures that covered 21% of the Walloon area in 1846 represented 30% in 1910. In Belgium, the catchment area is now occupied by forests of deciduous trees and spruce (Ardennes), intensive farming (cereals and beetroot), pastures and orchards. In the 19th century industrial plants spread throughout the whole of the basin: blast furnaces, rolling mills, collieries, stone quarries, glassworks, paper mills, tanneries and textile industries, appeared along the Meuse and its tributaries, and drew the workers towards the larger towns, such as Liège, Charleroi, Namur, etc. Industrial activities became concentrated along the Sambre, downstream from Charleroi and along the Meuse upstream and downstream from Liege. Nowadays, however, industrial activities in these areas, as in France, have been in marked decline for several decades (Micha and Borlee, 1989).

The temporal changes of the aquatic communities in the Meuse are not easy to trace for there is very little regularly collected data available from the past. On the other hand, the contrasting evolution of the upper and lower Belgian Meuse is clearly revealed by various studies. It may be assumed that the upper Meuse provides a model of the historical character of the lower Meuse, which has been modified most dramatically during the 19th and 20th centuries. By taking a few representative links from the trophic chain of the Meuse ecosystem, Micha and Borlee (1989) presented the temporal and/or spatial evolution of the phytoplankton, macrophytes, macro-invertebrates and fish in the river basin.

Two important studies were carried out on the phytoplankton of the Belgian Meuse in the summers of 1946 and 1953 (Symoens, 1957) and in the autumn of 1981 (Descy, 1983). Although it is very difficult to compare the two sets of data, assembled at different times, using different techniques, at different seasons (summer versus autumn), and expressed in different ways, it is nevertheless possible to draw some preliminary conclusions by limiting attention to the sector upstream from Namur. Comparing the plankton assemblage in 1946–1953 with that in 1981, it can be said that species characteristic of eutrophic conditions are dominating now, such as Cyanophyceae, Chlorophyceae and Euglenophyceae, both in terms of species numbers as well as in primary production. Species signifying an oligotrophic tendency in the 1950s are currently absent from the plankton (Micha and Borlee, 1989).

Among the benthic vegetation, macrophytes (filamentous algae, aquatic mosses and vascular plants) develop essentially in a shallow zone along the channel margins, with a maximum depth of *ca.* 1.5 m. For the macroscopic algae, the qualitative and quantitative data from the 1970s have shown their sensitivity to water pollution which is revealed by marked changes in the composition of the stocks. In general, the reduction in delicate species in favour of species tolerant of pollution is a sign of the degradation of the water quality along extensive stretches of the river. The communities of vascular aquatic (hydrophytes) and sub-aquatic (helophytes) plants in the Belgian Meuse were well developed before the 'modernisation' for navigation. However, Micha and Borlee (1989) have found only a few systematic studies to confirm that image, and old postcards and photographs best testify to the temporal evolution. There is a striking contrast between the French and the Belgian part of the Meuse, and the obvious reason for the floristic diversity in the French Meuse is the maintenance of the diversity of habitats, which has been little affected by the alterations to the channel bed and its banks. The scarcity of vascular plants downstream from Namur is mainly the result of habitat loss. In the Meuse around Liege, the total disappearance of aquatic plants is also linked to water pollution. The status of this macrophytic vegetation in the Belgian Meuse could therefore in the 1980s be characterised as 'catastrophic' (Micha and Borlee, 1989).

The sources available relating to the benthic macro-invertebrates, which allow a temporal comparison, are limited to the upper Belgian Meuse and come from the samplings of Damas (1939) during the 1930s and from some recent authors. Recently considerably more species of macro-invertebrates have been listed than Damas did in the 1930s, but the larger number of taxa currently reported is partly attributable to a more thorough sampling and to the progress made in taxonomy. According to Micha and Borlee (1989) this means that one must take great care when comparing and interpreting historic data with recent findings.

Ketelaars and Frantzen (1995) studied the macro-invertebrate fauna at several localities along the entire Meuse. Both the French section and the Dutch section of the river contained some typical species characteristic for a clean to moderately polluted river. But in the Belgian stretch between Namur and Liege a very impoverished macro-invertebrate assemblage was found. Diversity was very low, and 60% of the taxa are confined to stagnant waters. The dominant and subdominant species are all tolerant to a high degree of organic pollution. Some groups of worms are commonly associated with soft depositing substrates and can reach very high densities when voluminous loads of suspended solids concur with high organic enrichment. Most oligochaete worms are tolerant to elevated concentrations of organic carbon as well as heavy metals.

The macro-invertebrate assemblage at Hermalle-sous-Argenteau, just downstream of Liege, is typical for a grossly degraded river ecosystem. This is obviously the result of the extensive pollution caused by the discharge of industrial and municipal effluents in the Liege region, illustrated by the drop in oxygen content of the water downstream the Liege region to 4 mg $1^{-1}$ and high concentrations of heavy metals, PAHs, herbicides and faecal bacteria at the Belgian–Dutch border. Data show that the impoverishment of the macro-invertebrate fauna in the river Meuse begins much further upstream, at the confluence with the river Sambre at Namur, but that the most dramatic changes in abundances of practically every macro-invertebrate group were found downstream the region of Liege (Ketelaars and Frantzen, 1995).

According to recent investigations by Usseglio-Polatera and Beisel (2002) parts the French stretch of the Meuse River may be considered as a 'healthy river', exhibiting both a high biodiversity and a 'reasonably good' water quality. A dramatic decline in the stream integrity was observed in the middle reaches, demonstrating the influence of a high degree of human impact on stream quality. This sector was influenced by domestic effluents and by industrial pollution (Sambre confluence, Namur urban area), resulting in a negative water quality. Furthermore, regulation for navigation and ship traffic resulted in a decline of both benthic habitat mosaic heterogeneity and littoral habitat stability. Indeed, canalisation changed the characteristics of invertebrate habitats through channel straightening and eradication of pool-riffle sequences, together with a reduction of the substrate mosaic heterogeneity. Unpredictable pulses of turbulence and elevated suspended solids following passage of commercial navigation vessels, especially in large linear waterway sections, negatively affect riparian habitats and their macro-invertebrate communities. In addition, the construction of solid embankments has led to an artificial channel, reducing the availability of littoral refugia. This combination of factors contributed to a drastic reduction of stenotopic taxa in macrobenthic assemblages.

The invasion of the different sections of the Meuse by invertebrate exotics (cf. Chapter 17) strongly depends on accessibility. The Dutch Meuse from Maasbracht can be invaded easily either by ship transportation, by active migration or simply by drifting from the river Rhine (via connecting canals). The Ardennen Meuse can be invaded by ship transportation. Exotic species have indeed been introduced mostly between Namur and Liege where heavy navigation occurs. From Namur the upstream migration of exotic species progresses regularly, which suggests that, besides transport by ship, it may be due to active migration. Part of the upper Loraine course is not navigable, but navigation takes place in the canal de l 'Est running parallel to the river with some short common reaches. Therefore if some ship transportation occurs then the invaders should easily reach Pagny-sur-Meuse (127 km), the uppermost navigable point of the Meuse. The non-navigable head of the river, as well as the tributaries, can be invaded only through an active spread of the invaders. However, in some cases canoeing activities might also facilitate the transportation of exotic species (e.g. in the River Lesse) (Micha and Borlee, 1989).

Considering the current fish zoning schemes for larger rivers (cf. Chapter 15), the Belgian Meuse corresponds to the barbel zone; if one takes into account the various human activities taking place in the catchment area and in the channel of the river (flow regulation, canalisation, etc.) downstream from Namur the Belgian Meuse is situated in a zone falling somewhere between a barbel zone and a bream zone (Micha and Borlee, 1989). The fish fauna of the river Meuse basin has been investigated and described by several authors during the last decades, but papers usually refer to geographically limited parts of the whole watershed. The total number of fish species is presently estimated at 51 species, while the number of native species is 34, and the number of exotic species reaches up to 17 species, from which 13 species are considered as naturalised (i.e. are able to reproduce successfully in the Meuse basin). Eight species are extinct: Atlantic salmon (*Salmo salar*), allis shad (*Alosa alosa*), twaite shad (*Alosa fallax*), European sturgeon (*Acipenser sturio*), houting (*Coregonus oxyrhynchus*), sea lamprey (*Petromyzon marinus*), river lamprey (*Lampetra fluviatilis*) and flounder (*Platichthys flesus*) (Kestemont et al., 2002).

Over-intensive fishing led to the extermination of sturgeon at the end of the 19th century and contributed to the disappearance of the Atlantic salmon. Certain introduced species (e.g. the mollusc, *Potamopyrgus jenkinsi*) offer no major problem for the indigenous biotic communities. Others, however, pose a serious problem, e.g. the pumkinseed (*Lepomis gibbosus*), which is a threat for many amphibians and fish species, and the American crayfish (*Orconectes limosus*), which has become very abundant in the Meuse, and has contributed to the extermination of the indigenous European crayfish, *Astacus astacus* (Micha and Borlee, 1989).

## 13.5 Ecological Rehabilitation

During the last two centuries a lot of adaptations have been made to the river Meuse, especially to make the river navigable for ships or to reduce the incidence of flooding. As a result of these adaptations, the original landscape changed or even disappeared. Being dependent on rainwater, precipitation in the French and the Walloon part of the river basin directly affects the amount of water in the river. As a result water levels and flows in the Meuse can be very unpredictable. Meuse water is the raw material source for the production of tap water of 6 million people. This number is sure to increase in the future. Large volumes of Meuse water are consumed by the process industry, where it is used as process water, cooling water and for other applications. Meuse water is used in agriculture, as well. All these consumers require the quality of Meuse water to be of an increasingly higher standard. The water companies have to use costly and complicated purification methods to make river water fit for human consumption.

A total of nearly 8 million people live in the Meuse basin. They produce an estimated $20\,m^3\,s^{-1}$ of waste water. This is an enormous burden on the Meuse, a river which is swollen by rain water and which discharges at its mouth no more than $30–50\,m^3\,s^{-1}$ for days or weeks on end. An adequate management of waste water (sewage water purification) is therefore of vital importance for the quality of Meuse water. Most local authorities treat their waste water before it ends up in the river. But in France and Belgium in particular there is a lot of work to be done in this respect. The European waste water directive stipulates that all local authorities carry out adequate waste water treatment by 2005 at the latest. Fortunately, the discharges of waste products by industry and nuclear power stations have decreased to a large extent in the past 25 years. This has been achieved by the building of waste water purification plants, more stringent laws and regulations, modern manufacturing technology and the closing down of obsolete plants. However, there is still a lot to be done. The river Meuse still suffers from harmful substances like bromide, cadmium, ammonium and phosphate. These substances are to be found not only in water but also as sediments in rivers and floodplains.

The Sambre–Meuse region in Wallonia, southern Belgium is a traditional coalfield area where heavy industry is in decline and where there is little to attract light industry. Coal mining in the Sambre–Meuse region began to decline in the 1960s because of cheaper coal imports, exhausted coal seams and alternative cheap energy sources such as oil, and environmental concerns. In 1984, the last of many collieries closed in the Charleroi coalfield, and the decline of this industry eventually led in turn to the decline of mining and steel production in the urban centre of Charleroi, practically ending a long tradition. A great increase in unemployment ensued. Liège, the largest city in this region, has managed to maintain some of its established industries and attract new investment, primarily thanks to the extensive development of its transportation network. The Sambre–Meuse region, however, requires significant new investment to raise it from its depressed state (ICPM, 2002; Volz et al., 2003).

As a result of the introduction of strict environmental laws concerning the dumping of toxic substances into the rivers within Europe, the water quality of the Meuse, including the quality of suspended material, has also improved in recent years. In particular, concentrations of zinc and cadmium during low and moderate flows have decreased considerably since 1980. In contrast to the Rhine River, the concentrations of organic toxic substances have not improved much in the Meuse. The sewage discharge to the Meuse from Wallonia is still largely untreated. There remain a few major sources of industrial heavy metal pollution, but very likely this is only minor in comparison to the magnitude of pollution released during the 19th century. Although, zinc and cadmium concentrations may have dropped slightly since 1984, different floodplain sediment studies conclude that no overall improvement of flood sediment quality took place during the 1990s (Van Leussen et al., 2000).

In agriculture insecticides and fertilisers are frequently used. By far the greater majority of these substances have not been manufactured on a natural basis and as a result they are either not biodegradable or only to some extent. Rainfall causes part of these contaminants to end up in the river or to integrate into surface water by way of metalled surfaces and sewage systems. However, research and pilot projects have resulted in more and more environment-friendly alternatives. These, together with more stringent laws, and European directives (e.g. Water Framework Directive) bode well for the future (ICPM, 2002).

It is for sure that this accumulation of human impacts on the Belgian part of the river Meuse has resulted in a general and rapid deterioration in the ecosystems in the basin. As for the lower Meuse, alterations to make way for navigation of ships of 9,000t have destroyed all the important habitats. According to Micha and Borlee (1989) thought should be given to restoring these sectors in the future, by recreating shallow riverside zones suitable for aquatic macrophytes, for the macro-invertebrates which are linked to them, and for the reproduction of many species of fish. In the 1950s, the Atlantic salmon became extinct in the Meuse basin, mainly owing to the construction of navigation weirs. A rehabilitation programme of Atlantic salmon in Belgium started in 1987. Stockings are being performed in six tributaries of the river Meuse, using eggs, parr and pre-smolts obtained from foreign hatcheries. By the end of 1998, numerous young salmon have been released in the wild, especially in the river Ourthe basin. In most of the cases, the evaluation of stocking operations indicates good adaptation of parr in the tributaries where they have been stocked. However, fish mortality occurs when smolts pass through the turbines of the hydropower stations in the river Meuse (5% per power plant), and most of the fish passes located downstream of Namur are not suitable for anadromous fish migration (Prignon et al., 1999).

Notwithstanding a number of successful ecological restoration projects the river Meuse can only be considered as a completely regulated and ‘normalised’ river, with the exception of some very valuable stretches in France. The upper reaches of the Meuse, the Lotharingian Meuse, offers the best possibilities for ecological rehabilitation. The French upper Meuse still harbours rich ecosystems adapted to flood pulses and fluctuating water levels. Intensive agricultural practices, however, are demanding and the species-rich floodplain grasslands are under heavy pressure of fertilisers, and quickly disappearing. Flora and avifauna are both influenced by agricultural management. The closer the farmers’ management is to traditional farming, the more likely the chance that the diversity of meadow plants and bird life can be preserved. Results of ecological studies have been used in a number of programmes aiming at conservation of local patrimonial species (flora, avifauna) and habitats. Since 2002 the French Meuse floodplains are now partly under the application of agri-environmental schemes aiming at reducing fertiliser inputs and postponing mowing dates (Branciforti et al., 2002).

A major change of approach in the protection of the river banks has been under way for some 15 years in France. Instead of the continuous fixation of the eroding forelands, the natural erosion and sedimentation processes are given more room now. Another aspect is that the unhindered flow of Meuse water is obstructed by many thresholds and dams that have in the past been used, in the upstream and middle part, to regulate water intake for watermills, and on the downstream part to manage navigation, as water intakes for canals, and for various mills. The dilapidated state of these works, some of which are virtual ruins, demand stringent measures. Compromises have now been found to lower the crests of the works and to equip them as fish passages (Vosges), which is a priority measure, and will be considered for all operations to come.

The basin of the French Meuse comprises tens of meanders, oxbow lakes and bypasses, originating from ancient natural as well as artificial cuttings, the latter as part of hydraulic operations or from old mill-races. Now, the existing water bodies play a major role in the hydraulic and biological equilibrium of the river, by adding a great deal to the diversity of the ecotone between the dry land and the river channel. Nevertheless, the isolated water bodies follow their natural evolution: they are silting-up and gradually become dry land. To preserve these sites, and to restore the biodiversity of the aquatic environment, it is necessary to reconnect them with the river proper. From 1994 to 2001, nearly 30 river branches were managed in such a way, that the hydraulic link between the water body and the Meuse was restored. More projects are planned for the future (Goetghebeur, 2002).

There is a significant contrast between the relatively unspoiled Lotharingian Meuse and the Dutch Meuse, the cesspool for inorganic and organic pollutants of upstream origin. The high water levels in the river Meuse in 1993 and 1995 have caused considerable social and economic damages, affecting some 10,000 people. Since then, it was more than clear that even higher dykes would not solve the problems: sufficient space for the river and a good international cooperation between the three neighbouring countries would be the main requirements to alleviate future flooding events in the river Meuse. As a direct result of these floods the project 'Maaswerken' (Works on the Meuse) was initiated (see also Chapter 5). This integrated project aims on the one hand to reduce the chance of flooding, and on the other hand to develop natural areas, and stimulate economic development by furthering water transport. To this end, the Meuse will be deepened and broadened over a length of 200 km. The extracted gravel will be exploited to co-finance the project. Additional measures include the (re-)construction of embankments, sluices and 'clay shields' that will drive up groundwater on the riverbanks.

The costs of the Maaswerken project increased dramatically in areas were the floodplain sediments along the Meuse were highly polluted with heavy metals (e.g. zinc, cadmium and lead) and organic contaminants (e.g. PAHs and PCBs). These contaminated sediments represent a form of diffuse pollution and are redistributed during floods. A new policy of dynamic soil management was developed within the Maaswerken project in order to control the costs of the measures, while maintaining the original river management goals, and reducing the risk to human health and the environment. Under strictly defined conditions the contaminated sediments may be used for the construction of embankments and new dykes, and clay-rich contaminated sediments from the floodplains can be used as filling material in the deep local holes created by former and new gravel extractions (cf. Fig. 13.3; Schouten et al., 2000). It seems a clever 'solution' evoking, however, much resistance among the local population.

Heavy metals evoke paradoxical reactions among scientists. On the one hand these toxic elements pose a threat to human health and the environment, on the other hand the highly protected zinc flora became the victim of the more stringent environmental policy. The flowering plants, the zinc violet, *Viola lutea* subsp. *calaminaria*, *Thlaspi caerulescens* and the grass *Festuca ovina* subsp. *guestphalica* belong to the zinc flora, adapted to elevated zinc concentrations in the soil water. *Viola lutea*, once a locally rather common species, is now a severely threatened red list species. The zinc flora flourished thanks to the zinc mines in the catchment of the river Geul, a tributary of the Meuse (Fig. 13.4). Zinc mines and ore washing sites in the basin of the river Geul were exploited in the 19th century and before. But the zinc industry became obsolete, and the last factory was closed in 1937, and the past 50 years 90% of the unique zinc flora has disappeared. A factor that enhanced the loss of the zinc flora was the fact that the grasslands containing the zinc flora have been intensively fertilised with lime and other nutrients for decades after World War II, losing their toxic characteristics and favour the growth of competitive species. The zinc flora is only artificially maintained now in a small zinc reserve along the Geul (Lucassen et al., 2003).

Flood reduction is one of the aims of the Grensmaas project, as part of the Maaswerken. Due to its rain-fed and thus unpredictable character, the river Meuse definitely needs more than only an integrated Grensmaas management. Competitive relations between mining activities, nature and recreation, safety for the habitants, agriculture and water winning, have seriously slowed down the execution of the process. The upland area, mainly located in the Walloon and French regions exists of numerous small tributaries and wetlands. The better the functioning of this natural catchment upstream, the higher the amount of rainwater that can be retained, the higher the chance that a rainfall period is finished before the soil gets saturated. Theoretical solutions (www.wwf.nl) suggest that by tens of small cheap measures in various upper stream tributaries of the Meuse, like the Amblève, Ourthe, Semois, Sambre, Vesdre, etc., it will be possible to retain the rainwater just long enough to avoid extreme water damages downstream. A prerequisite for the actions to increase retention capacities in upland areas on the one hand, and the storage capacities in lowland on the other, is that the three Belgian political-administrative regions need to considerably improve their urban and land use water management.

Summing up, important stretches of the upper and lower Meuse are now on their way to ecological rehabilitation, but the quality of the Belgian Meuse is seriously lagging behind. It has to be realised that concerted actions by the riparian states to improve the quality of the environment have only started in 1994 by the Agreement of Charleville-Mézières, and the foundation of the International Meuse Commission (www.cipm-icbm.be). In contrast, ecological improvement of the river Rhine has a far longer history: the International Rhine Commission (ICPR) was founded in 1950. Possibilities for the restoration of the river Meuse are limited by the multi-purpose use of the river for shipping, hydropower, drinking water and agriculture. The rehabilitation of the Meuse is further retarded by conflicting international interests. The poor habitat diversity, the lack of lateral connectivity between the main channel and the floodplains, and the cumulative unknown effects of pollutants (e.g. herbicides) seriously hamper further rehabilitation.

A significant positive recent development is the EU Water Framework Directive: EU member states are required to compile river basin management plans and rivers should have a good ecological quality by the year 2015.

## 13.6 Conclusions

- The Meuse catchment (900 km; 33,000 $km^2$) is shared by five countries with a population of about 8 million people, and provides drinking water to 6 million people. The Meuse is an erratic rain-fed river; it is an important waterway in Western Europe, navigable from the North Sea up to Sedan and Verdun in France.
- Floodplains were reclaimed and many forests were felled as early as the Middle Ages, and virtually all of the Meuse's lowland forests, meadows, and marshes have disappeared over the past 200 years. Parts of the French upper Meuse maintained a relatively good ecological quality.

- In the late 18th, 19th and 20th centuries the channel of the Meuse has been subjected to drastic changes to improve navigation, to exploit the natural resources, and to reduce flooding, e.g. a reduction in length, the removal of islands and the construction of numerous hydro-dams and weirs including shipping locks.
- For many centuries natural resources of coal and heavy metals were exploited in the catchments. Coal was the main accelerator of industrial activities in the 19th century, and the Walloon coalfields can be considered as the cradle of the industrial revolution on the European continent.
- Severe pollution with heavy metals and organic micro-pollutants reached its climax earlier than in the Rhine basin. Ore mining was at a maximum at the end of the 19th century, and water pollution due to domestic and industrial waste water turned the Meuse into an open sewer.
- Indirect evidence suggests that the quality of the Meuse water around 1970 was relatively better than that of the Rhine. Around 2000 the situation has reversed: salinity is one of the few parameters where the Meuse scores better than the Rhine.
- Occupation of the catchments, encroachment on the narrow channel bed, habitat loss and water and soil pollution annihilated many plant and animal species. Serious contamination of floodplain sediments in the lower Meuse basin with heavy metals and organic pollutants is a threat to public health and the quality of the environment.
- Concerted action by the riparian states to improve the quality of the environment has only started in 1994 (foundation of the International Meuse Commission; in contrast: the International Rhine Commission was founded in 1950). Important stretches of the upper and lower Meuse are now on their way to ecological rehabilitation. The quality of the Belgian Meuse is seriously lagging behind.
- Possibilities for the restoration of the river Meuse are limited by the multipurpose use of the river for shipping, hydropower, drinking water and agriculture. The poor habitat diversity, the lack of lateral connectivity between the main channel and the floodplains, and the cumulative unknown effects of pollutants (e.g. herbicides) seriously hamper further rehabilitation.
- Notwithstanding the improvement of water quality in the Meuse the dissolved oxygen concentrations are not satisfactory for fish throughout the year. Both fish and macro-invertebrate communities contain very few species with narrow ecological requirements. Sometimes exotic species dominate the benthic macro-invertebrate assemblage.
- The rehabilitation of the Meuse is retarded by conflicting international interests. Toxic build-up of heavy metals and organic contaminants in sediment deposits will continue to affect riparian life long after the factories that produced them are closed.
- A significant positive recent development is the EU Water Framework Directive: EU member states are required to compile river basin management plans and rivers should have a good ecological quality by the year 2015.

# Chapter 14
# Pollution and Rehabilitation of the Aquatic Environment in the Delta

## 14.1 Introduction

The assumption that the impact of water and soil pollution in proto-historic times and in early historic times was only local and insignificant is contradicted by recent investigations. Environmental archives such as peat bogs, lake sediments and polar ice, have greatly helped to assess both ancient and recent atmospheric heavy metal deposition and its sources on a regional and global scale. A classical example is lead pollution. Increased lead emissions during ancient Greek and Roman times have been recorded and identified in many long-term archives such as lake sediments in Sweden, ice cores in Greenland and peat bogs in Spain, Switzerland, the United Kingdom and the Netherlands, based on analyses of $^{206}$Pb/$^{207}$Pb isotope ratios and lead concentrations in in situ samples. The main sources have been industry, including coal burning, ferrous and non-ferrous smelting, and open waste incineration until *ca.*1950 and leaded gasoline use since 1950 (Weiss et al., 1999).

The first signs of atmospheric lead pollution date back to 3,500–4,000 years ago. There was a small, but clear peak during the Greek–Roman period around AD 0. Ice-core analyses from Greenland revealed that during the Roman Empire 70% of the global atmospheric lead pollution came from the Roman-operated Rio Tinto mines in what is now southwestern Spain. The global demand for silver increased dramatically after coinage was introduced in Greece around 650 BC. But silver was only one of the treasures extracted from its ore. The sulphide ore smelted by the Romans also yielded an enormous harvest of lead. Because it is easily shaped, melted and moulded, lead was widely used by the Romans for plumbing, stapling masonry together, casting statues and manufacturing many kinds of utensils. Adding to the toxic hazard, Romans used lead vessels to boil and concentrate fruit juices and preserves. All these uses presumably contributed to the chronic poisoning of Rome's peoples (Rosman et al., 1997).

About AD 1000 a major and unreversed increase in lead deposition occurred; varved lake sediments disclose pollution peaks at about AD 1200 and AD 1530, which match the marked medieval increase in mining and metal production. The greatest lead emissions to the atmosphere all over Europe occurred between 1950 and 1980 due to traffic exhaust caused by the rapidly increasing use of cars and

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leaded gasoline along with increased industrial emissions. This peak was followed by a major improvement due to environmental legislation (Renberg et al., 2000).

Just like airborne pollution with toxicants, water pollution has also its chronic international dimension (e.g. PCBs in seals; Section 14.5.3.). One of the major recent environmental burdens, triggered by the introduction of artificial fertiliser at the end of the 19th century, is the widespread effect of eutrophication, a process blurring the gradients between nutrient-poor and nutrient-rich habitats and eventually levelling down biodiversity. In this chapter I will focus on the history of regional pollution of the Rhine–Meuse Delta. Nuisance caused by increasing population pressure, particularly expressed in polluting urban trades, is documented from the Middle Ages on. The history of environmental pollution is the story of endless conflicts of interest, often between interests of public health and ecology on the one hand, and economic ones on the other: e.g. conflicts between the extraction of drinking water and dumping of sewage; conflicts between the economic incentives of the post-World War II manufacturing of synthetic non-degradable compounds; and the harmful accumulation of these complex chemicals in aquatic and terrestrial food webs.

The aim of this chapter is to give a brief review of the hydrology, water quality, pollution history and consequent rehabilitation and of the rivers Rhine and Meuse in the Delta, as far as these items are not covered in Chapters 12 and 13. Despite extensive literature surveys on the ecology of river biota (e.g. by Admiraal et al., 1993; Van de Brink, 1994; Van den Brink et al. 1990, 1994, 1996; Van Urk and Smit, 1989), historical information of the impact of pollutants on river biota and food-web functioning appears to be scarce. The collection of comprehensive data sets started only after World War II, and reliable eco-toxicological work was reported from the 1970s onwards. Pioneer work on the impact of PCBs on aquatic biota was done by Koeman et al. (1969). In this chapter the dominant and chronic eutrophication symptoms of the Delta waters get ample attention. The history of water and sediment pollution in the river basins in the Delta will be elaborated in a few selected cases. Next to an historic case study (Amsterdam), recently emitted and deposited chronic residues of heavy metals and organic micro-pollutants will get attention. Case studies on the pollution history of a few selected species will end this chapter.

## 14.2 Hydrology and Water Quality

The discharge of Rhine and Meuse together in an average year is *ca*. 2,530 $m^3$ $s^{-1}$ (2,300 + 230) measured at the border of the country (Lobith; Eijsden). In the 1960s roughly 40% of the river water reaching the SW Delta debouched via the Nieuwe Waterweg directly into the North Sea. About 45% flowed into the Haringvliet, and finally entered the North Sea (these percentages have changed after 1970, depending on the management regime of the Haringvliet sluices). Owing to the residual Gulf Stream along the Dutch coast, the Rhine water is mainly transported in a

50–70 km wide zone into northern directions (Fig. 14.1). Roughly 6% of the original Rhine water finally enters the Wadden Sea, and after more than 200 days 1–2% of this river water ends up in the Skagerak, north of Denmark. This bay functions ultimately as a sink for nutrients and particles with adhered pollutants from Dutch and German (Ems, Weser, Elbe) rivers (Fig. 14.1; Eisma, 1987). Via the northern branch of the Rhine, IJssel, 8–15% of the Rhine run-off flows into the IJsselmeer, and finally enters the western Wadden Sea (Bijlsma and Kuipers, 1989).

It is common policy to drain superfluous surface water of the Delta onto the North Sea, and consequently the larger part of the Delta is continuously provided with water from the river Rhine, especially in the drier years. The water distracted from the Rhine is distributed by a system of pumping stations, weirs, main water courses, retention reservoirs and polder ditches to the outlying districts of the country. Eventually, most of the surface water in the Delta is mixed up with Rhine water (the 'invisible' Rhine; Fig. 14.2). The residence time of this inlet-water from the Rhine covers a variable period, from days to several months, depending on the management strategy of the polder board (Claassen, 1983).

Data on loads of chemicals on the river basins obtained before 1950 should be interpreted carefully. Data on the P- and N-load, covering the period 1955–1998, are given in Fig. 14.3. The load of total nitrogen (N) originating from the discharge of Rhine and Meuse has increased over the period 1955 to 1970–1980 roughly by a factor 2, whereas the total P (phosphorous) load has increased by a factor 5–7. Contrary to the N-load, the P-load decreased slowly after 1980. The concentrations of nutrients in the river increased even more markedly than the load: a fivefold increase for N and a tenfold increase for P, with a decreasing trend after 1980. The increased concentrations of nutrients in the Rhine–Meuse water resulted in a three- to fivefold rise of N and P concentrations in the Dutch coastal waters. The increase of nutrient concentrations and loads in the Westerschelde estuary showed a similar dramatic trend over the past 30–40 years. The average nutrient loadings on Dutch coastal waters reflect the discharges of river water: during the 1980s Rhine and Meuse contributed roughly 60% to the total N- and P-load; the residual current of oceanic Channel water added 30% and only 1–2% came from the river Scheldt (Van der Veer et al., 1988; Van Buuren, 1988). A decreasing trend of the nutrient loads carried by the Rhine and Meuse has set in after 1980–1981, far more markedly for P than for N. Some 10 years ago total phosphorous levels were approaching the levels of the 1960s (0.4–0.6 kg $s^{-1}$). N decrease set in slowly after 1990, but the picture is erratic, and in recent years (1995–2000) the loads were increasing again up to the values of the 1970s (Fig. 14.3).

Before 1960 the discharge of Rhine and Meuse water had a significant impact on the estuaries in the SW Delta (cf. Chapter 10); roughly 100 $m^3$ $s^{-1}$ of river water reached the Grevelingen (50%) and the Oosterschelde (50%) estuaries. But since the damming of the northern estuarine branches freshwater impact is reduced to almost zero. Particularly the construction of the Volkerakdam in 1969 deprived the southern estuaries of their direct influx of river water. In the present situation the Oosterschelde, Grevelingen and Veerse Meer are mainly loaded with nutrients from agricultural run-off, treated waste water and drainage canals. The saline water bodies

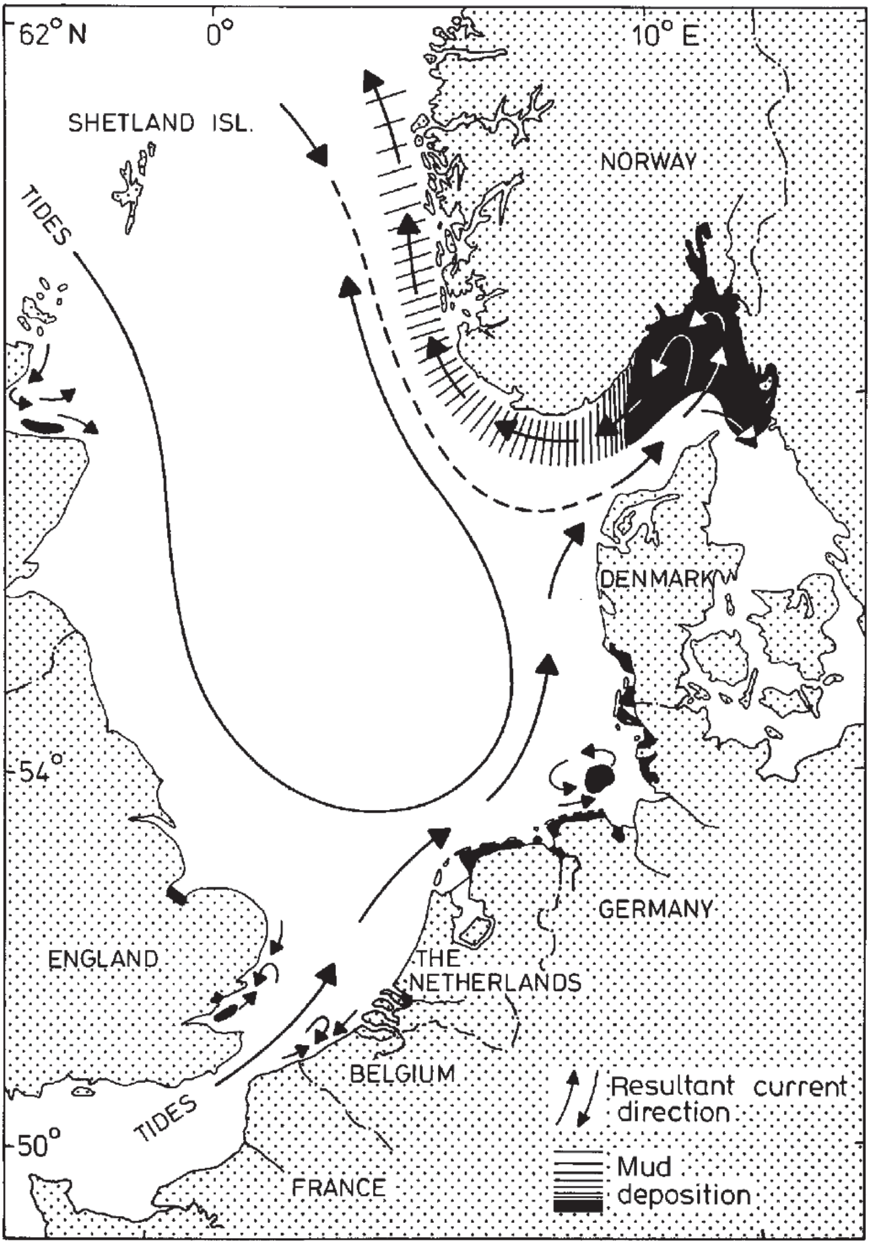

**Fig. 14.1** Main currents and distribution of suspended material and resultant transport directions (arrows), and locations of recent contaminated mud deposits and older deposits (Eisma, 1987)

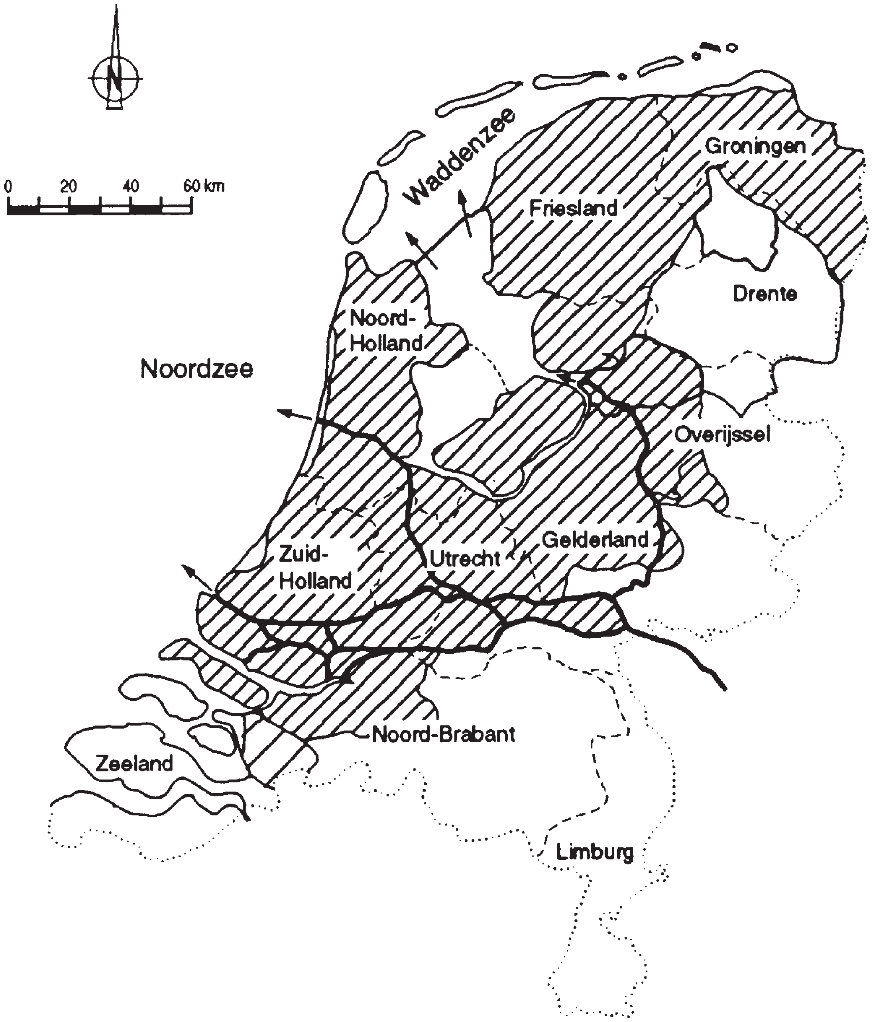

**Fig. 14.2** The 'invisible' Rhine. The area of the Delta influenced by Rhine water in an average year in the period *ca.*1970–1980 (hatched) (Claassen, 1983; data Rijkswaterstaat)

in the SW Delta were spatially separated during the Delta project. Consequently each of these former estuaries has its own water quality background and its own specific water regime (Nienhuis, 1993).

In Table 14.1 water quality data for Rhine and Meuse are presented, covering the period *ca.*1870–2000. The most negative point of 1971 is clearly discernable for almost all chemical parameters, except, e.g. for nitrate (1991) and sulphate (Rhine, 1991). Compared to 1870 the average water temperature in both rivers increased with 4°C. The data of 1971 indicate extremely negative environmental conditions

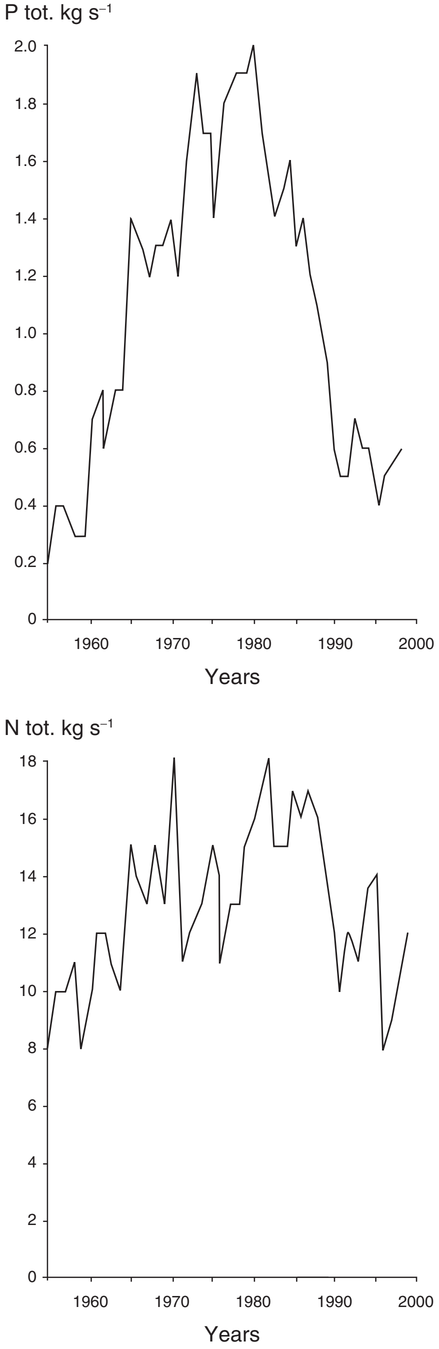

**Fig. 14.3** Loads of total P and total N in kilograms per second carried by the rivers Rhine (Lobith) and Meuse (Eijsden) to the catchments in the Delta, averaged annually over the period 1955–1998. The loads of the Rhine and the Meuse are assumed to contribute respectively 90% and 10% to the total value. Data until 1985 have been derived from Van der Veer et al. (1988), as reworked by Nienhuis (1993). Data after 1985 have been derived from www.riza.nl and www.neerslagmagazine.nl

**Table 14.1** Water quality parameters of the Lower Rhine (Lobith) and Meuse (Eijsden) from approximately 1870 to 2000. Historical data of *ca.* 1870 as derived by Van den Brink, 1994. Annual average values based on weekly measurements are presented for 1971, 1991 and 2000 (data from Van den Brink, 1994; RIWA, 2001, 2004)

| | | Rhine | | | | Meuse | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1870 | 1971 | 1991 | 2000 | 1870 | 1971 | 1991 | 2000 |
| Temp | °C | 10.9 | 13.3 | 14 | 14.7 | <10 | 14.3 | 14.5 | 14.4 |
| $O_2$ | mg l$^{-1}$ | nd | 4.4 | 10.2 | 10.1 | nd | 8.5 | 7.4 | 8.4 |
| pH | | nd | 7.4 | 7.8 | 7.8 | 7.5 | 7.8 | 7.5 | 7.8 |
| $HCO_3$ | mg l$^{-1}$ | 160 | 157 | 167 | nd | 172 | nd | 185 | nd |
| Cl | mg l$^{-1}$ | 13 | 236 | 201 | 92 | 15 | 45 | 62 | 32 |
| $SO_4$ | mg l$^{-1}$ | 35 | 75 | 78 | 57 | 28 | 70 | 52 | 37 |
| Na | mg l$^{-1}$ | 5 | nd | 103 | 57 | 7 | nd | 36 | 24 |
| K | mg l$^{-1}$ | 5 | nd | 7 | 5 | 4 | nd | 4 | nd |
| Ca | mg l$^{-1}$ | 50 | nd | 89 | 70 | 59 | nd | 79 | nd |
| Mg | mg l$^{-1}$ | 10 | nd | 12 | 11 | 6 | nd | 8 | nd |
| $NO_3$ | mg l$^{-1}$ | 0.3 | 2.5 | 3.9 | 2.8 | nd | 1.9 | 2.7 | 3.1 |
| $NH_4$ | mg l$^{-1}$ | 0.2 | 2.9 | 0.4 | 0.1 | nd | 1.6 | 0.7 | 0.2 |
| $PO_4$ | mg l$^{-1}$ | 0.05 | 0.3 | 0.08 | 0.09 | 0.07 | 0.67 | 0.37 | 0.19 |
| t-P | mg l$^{-1}$ | 0.15 | 0.95 | 0.27 | 0.18 | 0.22 | 0.94 | 0.49 | 0.3 |
| Zn | µg l$^{-1}$ | nd | 301 | 30 | 15 | 24 | 330 | 78 | 30 |
| Pb | µg l$^{-1}$ | 3 | 34.7 | 5 | 2.9 | nd | 53.5 | 9 | 5.3 |
| Hg | µg l$^{-1}$ | <0.05 | 3.11 | 0.05 | 0.02 | <0.05 | 0.29 | 0.05 | 0.02 |
| Cd | µg l$^{-1}$ | <0.04 | 5 | 0.1 | 0.06 | <0.04 | 6.12 | 0.5 | 0.24 |
| PCBs | µg kg$^{-1}$ | 0 | nd | 24 | po | 0 | nd | 22 | po |
| PAHs | µg kg$^{-1}$ | 0 | nd | 0.98 | po | 0 | nd | 0.11 | po |

nd = no data; po = data presented otherwise

in the river Rhine: brackish water with dangerously low oxygen concentrations, and unprecedented high heavy metal concentrations. In the river Meuse in 1971 both oxygen and chloride did not show extreme low, respectively high values, but heavy metals did show extreme values, for zinc, lead and cadmium even higher than in the Rhine. The data on PCBs and PAHs are inconsistent; compared to the data of 1991 there is a decreasing trend in both rivers, but since 1994 a stagnation was observed, and the concentrations in the Meuse basin, measured in fish body fat and presumably in sediment, showed even a reversed trend (Pieters et al., 2004). Section 14.5 will continue on the scope of the pollution problem in the 1970s and the chronic consequences for present-day ecosystem functioning.

## 14.3 Eutrophication: A Chronic Environmental Problem

### *14.3.1 The Eutrophication Process in Shallow Peat Lakes*

Up to the mid-1950s, most shallow peat lakes in the Central Delta and in the NW Delta were oligotrophic to mesotrophic, with clear water and well-developed littoral vegetation. From the 1950s onwards the lakes became eutrophied, and in extreme cases polluted, by run-off from agriculture and industry as well as from discharges of untreated household wastes. The major causes of lake eutrophication, however, were caused by external inputs of nutrient-rich (N, P) and polluted waters from the rivers and canals. The steadily increasing load of plant nutrients in the water of the river Rhine (Fig. 14.3; Table 14.1) left its seemingly irreversible mark on all wetlands and peat lakes in the Delta (cf. Fig. 14.2). The light climate in the eutrophied lakes has changed from a clear-water to a turbid-water state, one of the two equilibria, or alternate stable states, in which the lakes tend to exist (Scheffer, 1998). These conditions, reflected in high turbidity, have led to loss of submerged macrophytes and of piscivorous fish, mainly the northern pike (*Esox lucius*), which was used to take shelter in the vegetation. Other predatory fish such as pikeperch (*Stizostedion lucioperca*) and perch (*Perca fluviatilis*) have become scarce. The existing planktivorous fish biomass, especially bream, but also roach (*Rutilus rutilus*) and silver bream (*Blicca bjoerkna*), has concurrently increased to levels that are among the highest for any temperate lake (1,000 kg fresh weight per hectare). Consequently the larger-bodied zooplankters (*Daphnia* spp.) have been replaced by smaller zooplankters, the *Bosmina* species and rotifers. In short, eutrophication of these lakes has been accelerated by food-web changes working hand in hand with bottom-up effects, mainly the increased N- and P-inputs (Fig. 14.4). The result has been persistent Cyanobacteria blooms, deterioration of underwater light climate and loss of macrophytic vegetation in most of these shallow lakes (Gulati and Van Donk, 2002).

Since about 20 years attempts to mitigate this environmental problem are on their way. The most important measure, of course, is treatment of river water at the source in sewage treatment plants, but this does not alleviate the nutrient loads from diffuse sources and internal eutrophication. But there are other solutions, particularly useful in inland floodplain lakes and peat lakes with a long residence time of the water mass. Biomanipulation, a change in biological structure by removing and/or stocking living organisms, complements nutrient reduction in lake restoration: if applied in conjunction with other measures, it speeds up the processes of lake rehabilitation. There is widespread consensus that biomanipulation probably has a much higher success rate in shallow than in stratified deep lakes. The main advantage of food-web manipulations in shallow lakes is the potential for re-colonisation of large bottom areas by macrophytes, which promote the clear-water state of shallow lakes through a number of mechanisms, summarised by Mehner et al. (2002): (1) Macrophyte beds can act as a refuge for zooplankton from fish predation; (2) the feeding efficiency of predatory fish such as perch and pike in macrophyte beds is higher than that of planktivorous or benthivorous cyprinids such as roach or bream; (3) high densities of phytoplankton, especially Cyanobacteria, rarely occur when dense macrophyte beds are present, suggesting that macrophytes compete with phytoplankton successfully for nutrients and may excrete allelopathic substances against Cyanobacteria; (4) conditions inside macrophyte beds may increase denitrification, thus contributing to a decreased availability of nitrogen for phytoplankton growth; and (5) resuspension of bottom material is generally lower

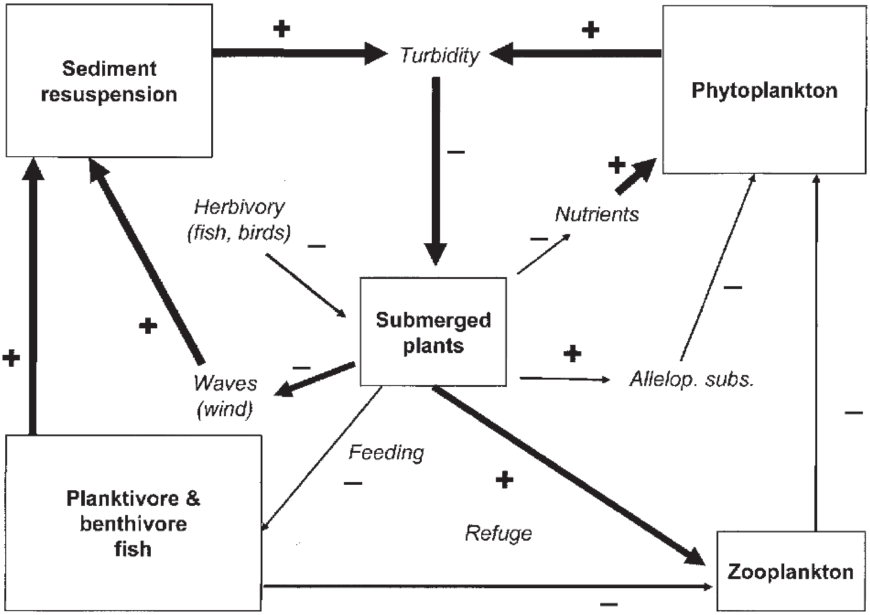

**Fig. 14.4** Diagrammatic illustration of the mechanisms and factors causing sediment resuspension and turbidity in shallow eutrophic lakes in the Delta. After restoration measures, submerged plants, which are adversely affected by turbidity, start to contribute to improved light climate through both their direct and indirect feedback effects. The thickness of the arrows indicates the relative importance of the feedbacks (Gulati and Van Donk, 2002). See text for explanation

in macrophyte beds than in uncovered bottoms. All these mechanisms work together towards stabilising or even enhancing water clarity, which in turn expands the water depth and bottom area where macrophytes can grow (Fig. 14.4). Recognition of this positive feedback mechanism has led to the theory of alternate stable states in shallow lakes, with rapid shifts occurring between a turbid, plankton-dominated state and a clear, macrophyte-dominated state (Scheffer, 1998).

In lakes in the Delta, the role of bream and planktivorous fish in general is crucial in many ways (Fig. 14.4). In the first place, the fish contribute importantly to in-lake recycling of nutrients and hence stimulates the eutrophication process. Secondly, as the fish feed size-selectively on the larger zooplankters (especially the daphnids), they adversely affect the zooplankton grazing, and the subsequent increase in phytoplankton and detritus causes high turbidity. Thirdly, the benthivores (especially bream) negatively influence the underwater light climate by resuspending the bottom sediments during their foraging activities (Fig. 14.4). Sediment resuspension can promote aerobic mineralisation of P in open water as well as recycling and fixation of P in Fe complexes if the redox potential is high (see Section 14.3.2). The planktivorous and benthivorous fish thus retard the pace of restoration by contributing to P-flux directly through their metabolic processes and to bioturbation in the upper sediment layer. Model studies have shown that more than 50% of the turbidity in shallow peat lakes in the Delta can be ascribed to sediment resuspension by benthivores. If measures to reduce the nutrient input at the source and suppression of remobilisation processes of nutrients from the bottom sediments fail, it would seem that there is no other option for lake rehabilitation measures than to reduce the stock of planktivorous and benthivorous fish. However, there are no ready-made ways of determining the amount of fish to be eliminated or restocked. In many Delta lake studies, about 75% reduction of the existing fish population is advocated so as to produce the desired effects (Gulati and van Donk, 2002; see also Section 15.7).

Submerged plants play a central role in eutrophication processes (Fig. 14.4). The development of macrophytes, however, which reinforces the process of lake clearing, has in some lakes (e.g. in Lake Veluwe in the late 1990s) reached nuisance proportions. The enhanced ability of the plants to invest in over-wintering structures leads to the prolongation of the macrophyte-dominated state. If the external nutrient loads continue to be high, once established, aquatic vegetation might reach nuisance proportions and adversely affect recreation (Gulati and Van Donk, 2002). Here, the rehabilitation of the aquatic environment encounters another opponent, the ever-increasing recreational demand for clean and clear water.

## *14.3.2 Eutrophication and Biogeochemical Processes*

Chemical research in floodplains has generally focused on hydrology and river water quality. Biogeochemical processes are far less known. Decomposition rates are, for instance, strongly determined by soil moisture content. In peatlands, water tables are a major factor controlling decomposition rates, and the breakdown rates increase under the influence of forced drainage. However, in addition to hydrological changes and surface water quality, several other factors have drastically changed in riverine areas. Although river water quality in the Netherlands has improved in recent decades, and nutrient loads and concentrations have decreased substantially (Fig. 14.3; Table 14.1), most floodplains are still highly eutrophic, because they have received massive amounts of nutrients by fertilisation (manure and fertiliser) for agricultural purposes. In the Delta, influxes may amount to 500 kg N and 75 kg P $ha^{-1}$ $year^{-1}$. Additionally, approximately 20–30 kg of airborne N per hectare per year is deposited in non-forest vegetation (Lamers et al., 2006).

The eutrophication of surface water and groundwater poses a severe threat to floodplains and inland fens. Over the decades nutrient influx from agricultural areas and sewage has led to a strong increase of $PO_4^{3-}$ and $NO_3^-$ availability. The forced drainage of agricultural land alleviates winter flooding, and allows the farmers to cultivate their land early in springtime (cf. Chapter 7). A disadvantage of this strategy is that during the growing season a shortage of surface water may arise. To compensate for this shortage, water from the Large Rivers is transported via canals and ditches all over the Delta, and directly or indirectly used on a large scale (Fig. 14.2). Owing to the input of this strongly eutrophicated water aquatic communities have lost their submerged plants and became dominated by fast growing, lemnid species and macro-algae. Thus, vast floodplain and fen areas (ditches, pools, lakes) showed a strong decline of their biodiversity and changed into species-poor plant communities. This type of eutrophication, in which nutrients are imported, is termed ‘external eutrophication’ to distinguish it from ‘internal eutrophication’ caused by internal mobilisation of nutrients. Internal eutrophication has also led to the deterioration of the Delta lowlands: the influx of alkaline river water enhances the decomposition of organic matter, by neutralising the organic acids in organic particles. Thus, overall mineralisation is stimulated, leading to eutrophication. In most peat lakes and marshes, the stimulating effect of calcium (as bicarbonates and carbonates) on decomposition and consequently on P-mineralisation appears to completely nullify any possible effects of calcium on P-binding, at the pH prevailing.

But there is something else. River water is characterised by relatively high concentrations of sulphate because of natural weathering of sulphate-containing rocks, anthropogenic dumping and sulphur run-off from agricultural areas. Groundwater and surface water are sulphate enriched by desiccation of the soil and by $NO_3^-$ pollution. In the first process, sulphate is mobilised from iron sulphide ($FeS_x$) deposits by oxidation and, in the second, $NO_3^-$ is used by denitrifiers to oxidise sulphides to sulphate. In freshwater systems, microbial sulphate reduction is generally limited by the availability of sulphate. Increased sulphate concentrations in marshlands will therefore stimulate sulphate reduction. As the consumption of organic acids is accelerated, overall decomposition will also be stimulated. In addition, the sulphide formation resulting from sulphate reduction generates alkalinity, stimulating the decomposition further. The sulphide formed binds to iron hydroxides in the sediment forming iron sulphides such as $FeS_2$ (pyrite) and FeS. As a result, $PO_4^{3-}$, the major limiting nutrient, is released from Fe P compounds and diffuses via the porewater into the surface water. This sulphate-driven internal eutrophication is a general process in river-fed waterlogged or flooded systems. Particularly those fens rich in easily decomposable peat will suffer from internal eutrophication due to alkaline, sulphate-enriched water (Lamers et al., 2002a).

For understanding the eutrophication-related deterioration of fens, it is essential to recognise both the internal and external sources of nutrient enrichment. In many cases, the increase in concentration of $PO_4^{3-}$ due to accelerated mineralisation appears to be much higher than the $PO_4^{3-}$ concentration of the inflowing waters. Reducing the phosphate influx, for instance, by chemical stripping of the nutrient (dephosphatising) or by flow through a constructed wetland (helophyte filter) or an extended supply route, is in this case insufficient to prevent eutrophication (Lamers et al., 2002b, 2006).

Many floodplains along rivers in the Delta show high concentrations of free iron in the soil moisture (up to 6,000 $\mu$mol $l^{-1}$), preventing the accumulation of free sulphide. Total soil iron concentrations range from 0.6% to 6% (100–1,000 $\mu$mol $g^{-1}$ DW), as a result of sedimentation from river surface water (the iron concentration in suspended matter being 3% for the Rhine). Higher concentrations of iron measured in floodplain soils are mainly the result of the discharge of anaerobic, iron-rich groundwater in the present or past. Upon reaching the aerobic top layer, iron is oxidized to iron hydroxides, and tends to accumulate. This may even lead to the deposition of iron stone or marsh ore, with Fe concentrations up to 50%, for instance in river and brook valleys where soils comprise a mixture of sand and peat (cf. Chapter 3: gaining iron in the Middle Ages).

At first glance, these high iron concentrations seem to be beneficial because of their high phosphate-binding capacity. Unfortunately, this high binding capacity has, in combination with the heavy fertilisation of floodplains, led to excessive loading of the soil's phosphate-binding sites. As a result, the phosphate concentration in pore water may increase to 20–200 times the original concentration during flooding, leading to concentrations up to 225 µmol $l^{-1}$. The phosphate saturation of iron-based binding sites has proved to be a powerful diagnostic tool to predict phosphate mobilisation during water logging or flooding. In combination with ammonium loading, this phosphate 'time bomb' provides a serious biogeochemical pitfall for the creation of species-rich wetlands, whose production is generally limited by the availability of nitrogen, phosphate, potassium or a combination of these nutrients. In iron-rich, mineral floodplain soils, sulphate pollution does not lead to extra phosphate mobilisation. The high availability of iron appears to be sufficient to sequester all sulphide produced without phosphate being mobilised from iron–phosphate complexes (Lamers et al., 2006).

## 14.4 Water Pollution

### *14.4.1 Pollution as a Result of Human Intervention*

As long as humans have made use of water they have polluted the water, but we may assume that impact on the environment in proto-historic times and early historic times was insignificant and local. Annoying water pollution caused by urban trades dates back to the Middle Ages. Many trades discharged organic, decomposable waste (e.g. beer breweries; distilleries, sugar refineries in the 18th century using ox blood to purify the sugar solution), and the stenches and the processes of putrefaction caused great nuisance to the citizens. Nuisance was also caused by textile trades and related business as the printing of cotton, the bleaching of linen using milk and alkaline salts and the fulling of wool using urine. Furthermore tanneries, oil mills and soap boilers dumped their solid waste and their waste water in the town canals (cf. Chapter 11, 's-Hertogenbosch, and Section 14.4.2, Amsterdam). The dumping of industrial waste in the town canals was common practice until far in the 19th century. New large-scale industries founded in the 19th century outside the existing old towns became notorious for their water pollution and public nuisance until far in the 20th century. Water pollution increased dramatically, and fishermen complained about the taste of carbolic acid of their fish (cf. Chapter 8). Until

1945 the cleaning of sewage effluents was more an exception than a rule. As long as the municipalities did not extract their drinking water from their own polluted town canals, their sewage water problem could simply be solved by unloading their dirt to their downstream neighbours (Van Zanden and Verstegen, 1993). It was the era of the doctrine 'the solution to pollution is dilution'.

After World War II the building of sewage water treatment plants became booming business. In 1945 there were only some tens of plants in use in the Netherlands, increasing to 275 in 1965. In that year hardly 20% of the Dutch sewage water was treated, and phosphates, nitrates, heavy metals and organic pollutants could not be removed at all. The Water Pollution Act came into force in 1969, and consequently the number of treatment plants increased even faster to more than 500 in 1980, treating 12.2 million inhabitant equivalents (Van Zanden and Verstegen, 1993).

During the economic boom following World War II unbridled, large-scale disposal of chemical waste took place, and toxic waste dumps sprang up all over the Delta. Inventories from the late 1970s and 1980s revealed the unprecedented size of this form of groundwater contamination. Depending on the hydrological situation, soil pollution may penetrate deep into the groundwater. A few examples: In the Volgermeerpolder, a notorious dump of chemical disposal near Amsterdam, chlorinated benzenes were located in the groundwater 37 m below the surface level. In Gouderak chlorinated pesticides have been located that had penetrated underneath the Hollandse IJssel to the other side of the river (Copius Peereboom and Meerman, 1986). In the period 1950–1980 in the Krimpenerwaard *ca.* 5,000 ditches have been filled in with agricultural and household garbage, refuse from construction sites, and industrial spoil. As a result the soil and the groundwater became severely contaminated with heavy metals, polycyclic aromatic carbohydrates, chlorinated hydrocarbons and cyanides (www.alterra-research.nl), etc. The list is endless. I will deal with one historic case in more detail.

### *14.4.2 Water Pollution: The Case of Amsterdam*

In the Middle Ages water pollution became manifest at places were many people lived together, especially within towns. I will follow Van Rooijen (1995) in her description of the history of water use and abuse in Amsterdam. The town of Amsterdam was literally founded on a dam in the river Amstel, a tributary of the Rhine, debouching in the IJ–Zuiderzee (see e.g. Fig. 5.6). Amsterdam obtained municipal rights in 1306, and from then on the town had to defend itself: canals were dug and the spoil was used to throw up earthen walls that were reinforced to form the city ramparts. Sluices discharged at low water on the IJ (Zuiderzee). At high water the sluices were closed, avoiding brackish water intrusion in the city canals. It may be assumed that the water in the canals was still clean; this was of importance to the many traders that used the water in their fabrication processes, and among them the beer brewers. But the use, and abuse, of the river water increased rapidly, and already in 1413 the first bye-law was issued to prohibit the dumping of garbage in the IJ and in the canals. The town grew, the canals gradually silted-up and became more and more polluted. In 1530 the town council declared that the water from the canals was unsuited as drinking water but still 'good for use in the kitchen'. For drinking water rainwater cisterns were used, but these were also polluted by the dirt from the roofs of the houses, and the leaching of toxic lead from the gutters.

The economic boom in the Golden Age (17th century) aggravated the pollution of the surface waters. Not everyone had a cesspool on his yard, and the sewer-pipes for the discharge of human faeces emptied onto the canals. The canals were used as public dumping place and sewer, and eventually navigation was hampered by obstacles thrown into the channel. This conduct of the citizens was made punishable in 1634, but the observance of this prohibition was almost impossible. The continuous discharge of polluted water on the IJ was hampered by the intrusion of brackish water from the Zuiderzee. New canals were dug, and windmills were applied to drain the polluted town water. But at the end of the 17th century the canals became stinking sewers. The rotting amalgam of organic garbage that was dumped day in day out in the canals caused unbearable stench, particularly during summer. Well-to-do inhabitants of Amsterdam fled from the town, and settled, e.g. along the river Vecht. It was supposed that the bad odours that rose from the canals caused diseases; a relation with contaminated drinking water was not yet made (cf. Chapter 6).

The city of Amsterdam could not provide in its own need for drinking water, and clean water was collected in water barges from the river Vecht and sold at fixed mooring sites. The pollution of the canals was already rather serious in the 17th and 18th century, but in the 19th century it became worse. The population of Amsterdam increased rapidly, leading to ever-increasing pollution of the town canals, which functioned indeed still as open sewers. Next to household garbage and faeces, garbage from vegetable and fish markets, as well as from butcher's shops and slaughter houses was dumped in the town canals. Industrial garbage was also discharged into the canals: e.g. sewage of tanneries, ink factories and refuse from wax-candle and caustic soda factories (Van Rooijen, 1995). R. Fell mentioned in 1800 in his travel report that numerous dead dogs and cats floated in the canals of Amsterdam: 'In one of the canals I saw a carrion of a horse in a most horrible state of decay' (cited from During and Schreurs, 1995).

The majority of the Dutch population was dependent for its drinking water on the quality of the surface water. Drinking water should be clean, clear and odourless. In the early 19th century the first chemical analyses of surface water were performed, and after 1850 all larger cities did extensive research into the chemical composition of groundwater and surface water (Van den Burg, 1867; Van Riemsdijk, 1870). It were the joined medical inspectors that sounded the alarm bell in 1873, mainly concerned about the quality of the drinking water, and they presented the concept of a law against the pollution 'by faeces and other foul' of water, air and soil to the national government. In the report of the 'commission for the research of the drinking water' in 1868, the relation was laid between contaminated drinking water, and the lack of sewer systems on the one hand, and the outbreak of epidemics on the other. Until that time ‘bad vapours’ were held responsible for the outbreaks of cholera and typhus. But until the end of the 19th century Amsterdam remained a dirty city without a closed sewer system and continued illegal dumping in the canals; large areas of the city were not connected to a sewer system until the 1930s. In the course of the 20th century the central government became increasingly concerned with the supply and the quality of drinking water. Since 1909 the Amsterdam officials did bacteriological and chemical research on the quality of the water. But it would last until 1969, before the Water Pollution Act came into force (Van Rooijen, 1995).

### *14.4.3 The Early Decades of the 20th Century*

The first private environmental organisation, the ‘Nederlandsche Vereeniging tegen Water-, Bodem- en Luchtverontreiniging’ (Dutch Society against Pollution of Water, Soil and Air) was founded in 1909. Particularly the biologist N.L. Wibaut-Isebree Moens (1884–1965) played a very active role in this society (cf. Chapter 6). She was engaged in the Amsterdam Public Health Service, commissioned to control the quality of the surface waters in and around Amsterdam. The archives of the Netherlands Society of Aquatic Ecology contain a number of lecture notes from Mrs. Wibaut from the period 1940–1947, dealing with the water quality of the Dutch rivers far before World War II. I quote from these notes:

> The quality of the Rhine water is far from irreproachable, but it is purifying itself while flowing through the country. The same counts for the river IJssel, but the water is polluted at the outlets of towns and gasworks, and at places were it receives polluted water from the tributaries. The Zwarte Water (outlet of the river IJssel at Zwolle) can be counted among the most polluted surface waters. The same counts for the river Vecht, that may be characterized as an open sewer, but at the IJselmeer the larger part of the pollution load has been diluted. The river Eem is very polluted, charged by sewerages and industries. The harbours around the former Zuiderzee are also polluted. But all these polluters pale into insignificance beside the open sewer of Amsterdam. Stagnating sewage water in the town canals is fatal: sulphides are accumulating and the colour of the water turns black. The stench of the beautiful narrow canals of Amsterdam is disgusting. The sewage water of 500,000 inhabitants of Amsterdam is discharged untreated in the IJsselmeer.

Mrs. Wibaut has always been very critical about the self-purification capacities of the water of the Zuiderzee. But she admitted that the effects exceeded her expectations. At a distance of several hundreds of metres from the sewer pipe the water quality was already ‘satisfactory’. After the closure of the Zuiderzee in 1932, the tidal movements ceased, but in the 1930s the first sewage plants were built, and since then the situation slowly improved.

Before World War II some biologists were very concerned about the deteriorated river quality (e.g. Wibaut-Isebree Moens), but at the same time others (e.g. Jac. P. Thijsse) sounded the praises of the rivers in the Delta (cf. Chapter 6). Mrs. Wibaut perceived the river Vecht as an ‘open sewer’, Thijsse (1915) in his ode on the river Vecht characterised the water in Utrecht only as ‘dingy and turbid’. Was it only her professional engagement that Mrs. Wibaut – the public health employee – uttered her concern about water pollution? Did Thijsse – the naturalist and nature conservationist – deliberately close his eyes for the pollution, deterioration and normalisation of the Delta rivers and brooks? I do not know. What we may deduce from early 20th century reports is that untreated sewage water in canals in the larger towns, and water close to factory outlets and in stretches of the larger rivers and brooks was perceived as a great nuisance. Obviously, the stretches of canals and rivers filled with dead, stinking water were sacrificed stretches. The water pollution problem was perceived as a local problem, and a great demand was laid on the self-purification capacities of the water mass. In the case of Amsterdam the river Vecht provided the inhabitants with drinking water, until it became too polluted, and later on drinking water was gained from the coastal dunes along the North Sea.

## 14.5 Recent Water Pollution and Rehabilitation

### *14.5.1 The Scope of the Problem*

Three stages of river pollution can be distinguished covering more or less successive phases in pollution history. Many centuries ago pollution started with the discharge of organic substances in domestic waste waters, causing an increase of the chemical and biological oxygen demand, and resulting in a decrease of the dissolved oxygen concentration. This was followed by the pollution from heavy metals, being the combined result of mining and industrial activity. Discharge of industrial waste water became a serious problem during the process of industrialisation of the river valleys in the 19th century. The third stage is formed by pollution with man-made PCBs and PAHs, and various pesticides. These so-called organic micro-pollutants, which have been produced by the chemical industry, have been used and spread over the entire catchments, which gave rise to diffuse pollution. A basic problem in describing a reference situation for the water quality of the rivers is the lack of reliable data from the period before 1965. Analysis of dated sediment layers in the river floodplains have shown to be a helpful tool in reconstructing pollution history with heavy metals and organic micro-pollutants (Bij de Vaate, 2003).

Like many European rivers, the Rhine and Meuse have been used as open sewerage systems up to the middle of the 20th century. In Chapters 12 and 13 the pollution status of the international rivers Rhine and Meuse has been reported. The lowland stretches of these rivers functioned as the cesspool, and mainly followed the international trend. Heavy metal concentrations in the Rhine–Meuse Delta reached unprecedented high levels in the early 1970 and significantly declined thereafter with roughly a factor 10 (Table 14.1). The Rhine was carrying enormous quantities of non-biodegradable organic substances everyday, chiefly chlorinated hydrocarbons from pesticides and industrial processes. These substances passed through the biological sewage treatment plants without being removed from the water. The average concentrations of a number of micro-pollutants decreased, from peak values in the 1970s to very low values at present, except for the summed PCBs that remained at a level of 50 $\mu$g $l^{-1}$ (Bij de Vaate, 2003).

The increase in metal concentrations in the Delta Rhine started around 1900 and reached a peak around 1970. The concentrations of cadmium and mercury in river sediments were negligible around 1900; lead, copper, chromium and arsenic showed higher background values, between 40 and 150 $\mu$g $g^{-1}$ sediment, and zinc even 400 $\mu$g $g^{-1}$ sediment) (Van der Velde et al., 1991). About two thirds of the metal load had accumulated in the freshwater basins and floodplains before the river discharged into the North Sea. By the 1970s the accumulation of heavy metals in the Delta Rhine's silt had reached the point that far exceeded safe limits for zinc, copper, chromium, lead, cadmium, mercury and arsenic. Flocculation and filtration methods at sewage treatment plants were capable of removing the bulk of these contaminants from the drinking water supply, so they posed little danger to human consumers. But the river's silt had become too contaminated to be used in floodplains: every time the Rhine flooded, this silt was deposited onto the nearby fields, rendering them unsuitable for farming and grazing. The content of copper in the Delta river forelands, for instance, stood at more than 300 $\mu$g $g^{-1}$ in 1974, over six times the level considered safe for arable soils. Mercury and cadmium contents in the soil were 25 times higher than levels considered safe. Lead levels were seven times higher, arsenic and chromium levels four to five times higher than acceptable limits (Cioc, 2002).

The clean-up of the rivers started in the late 1970s and the 1980s but diffuse pollution from many sources is still a problem. As a result of this diffuse contamination, considerable amounts of heavy metals (e.g. zinc, cadmium and lead) and organic contaminants, e.g. PAHs and PCBs, have accumulated in the soils of the embanked floodplains. Hydrodynamic and morphodynamic processes erode, replace and redistribute sediment, meanwhile sorting out coarse and fine minerals as well as contaminants and organic particles. As a consequence, the spatial distribution of contaminants within floodplains is highly heterogeneous, and low pollutant concentrations can be found only a short distance from sites with relatively severe contamination. Although a major improvement in the water quality has been achieved over the last 25 years, contaminated river floodplains may impose serious limitations on nature rehabilitation. Persistent contaminants like heavy metals and organic pollutants bioaccumulate in water, sediment and soil organisms and further bio-concentrate in aquatic and terrestrial food webs (Kooistra, 2004).

For metals the actual toxicity at a particular temperature is closely related to metal speciation. While total concentrations in soils may be high, implying great toxicity risks according to the literature, bioaccumulation may be adventitiously low. Metal speciation is determined by redox conditions, pH and the concentration and type of dissolved organic matter. Low redox potentials at water logging or flooding, or acidic conditions favour the dissolving of a number of metals. High total concentrations will have a much smaller effect in calcareous soils than in more acidic soils, because the metals are hardly mobile. Since desiccation of soils generally leads to acidification through oxidation processes, including the oxidation of

Fe and S and nitrification, the acid neutralising capacity is a significant regulator of metal toxicity. If the acid neutralising capacity is sufficiently high, acidification does not lead to a drop in pH because all protons are neutralised. For S-rich wetlands, therefore, the ratio between the total concentration of S (the acidifying component) and that of calcium plus magnesium (representing the acid neutralising capacity) has proved to be a useful diagnostic tool to assess toxicity problems during drainage. Values exceeding certain reference values indicate that desiccation would lead to severe acidification and metal mobilisation. In conclusion, this means that data on the total metal concentrations, which are generally used in policy-making programmes, have to be combined with biogeochemical knowledge of the regulatory processes to allow toxicity to be properly predicted, or with an estimation of the fraction that is readily assimilated by organisms (Lamers et al., 2006).

### *14.5.2 The Reservoir of the SW Delta*

A large proportion of the pollution load transported by the rivers Rhine and Meuse has been deposited in the SW Delta where both rivers flow together. Especially in the northern part of the SW Delta the concentrations of chlorinated hydrocarbons and heavy metals in the sediment exceeded Dutch quality standards over a large surface. A closer look at the sedimentation area of Rhine and Meuse silt reveals the following pattern (see also Section 10.3.2). In the Nieuwe Merwede-Amer high contamination levels have been detected, affecting a sediment layer at least 2 m thick. This material was deposited between 1970 and 1975. The Hollands Diep has a thick layer of less polluted river sediment that was deposited in the years after 1975. However, more contaminated material from the 1970–1975 period is contained below this layer, based on estuarine sediments from the period before 1970. The different layers can be clearly distinguished from core samples taken from the area. It is recognised that the quality of the top layer of sediment will improve as the quality of the surface water becomes better. A relatively thin layer of polluted sediments (less than 0.1 m) is to be found in the most seaward estuarine stretch of the Rhine–Meuse, the Haringvliet, on top of older, mainly marine sediments. As sedimentation in this region takes place slowly, no positive changes are expected in the near future, although in the long term the quality of the top layer will improve as the main area of cleaner sedimentation will shift westward (Bijlsma and Kuipers, 1989).

The pollution in Biesbosch, Hollandsch Diep, Haringvliet and several other river branches is considered a major environmental problem. Chlorinated hydrocarbons have been associated with a number of negative effects on organisms of terrestrial as well as aquatic ecosystems. In the 1960s and early 1970s, fish-eating birds and mammals have been the conspicuous victims of contamination with DDT and PCBs. Studies on gulls, terns, cormorants and birds of prey have linked (some of) these contaminants with reproductive failure through eggshell thinning and subsequent breaking of eggs, mortality of embryos and little chicks, and morphological aberrations in chicks. The presence of heavy metals and organic micro-pollutants in benthic organisms is clearly higher in polluted areas than in less-contaminated areas. This has been verified for various organisms such as *Dreissena polymorpha*, *Tubifex* species, Chironomid larvae and also zooplankton. There are, of course, specific differences between individual species with regard to the type and amount of heavy metals found. In molluscs, for example, contamination levels are higher in species that live in the top layer of sediment than in surface dwellers (Bijlsma and Kuipers, 1989).

Contamination levels are changing over time. Bijlsma and Kuipers (1989) described a momentary impression, a snapshot taken after 1975 when the sediments in the western Haringvliet were more polluted than the sediments in the eastern Haringvliet and Hollands Diep. This is a consequence of the sedimentation process, which has influenced the quality of river sediments in the areas. These gradients are also reflected in the concentration of contaminants found in specific organisms. The cadmium content in the gills of *Anadonta anatina*, e.g. increased into the direction of the Haringvliet sluices: the levels in the western part of the basin (Haringvliet) were two to three times higher than those found in the eastern part (Hollands Diep). Similar gradients have been encountered with organic micro-pollutants. The eggs of tufted ducks and grebes, e.g. from the Haringvliet area appeared to have much higher levels of organic micro-pollutants than those of birds from less-contaminated reference areas. Inventories carried out in the area in the early 1980s have shown that the ecosystem in the Hollands Diep was functioning much better than that of the Haringvliet, obviously related to the quality of the underwater sediments. For instance, the biomass of fauna found on the riverbed has been shown to be higher in the Hollands Diep. This also applied to the number of fish and to the number of birds that feed on fish and fauna, living on the riverbed, such as cormorants, grebes and tufted ducks. But the snapshot shows also a relative image: compared with other large freshwater systems in the Rhine–Meuse Delta, the ecosystem of the Hollands Diep was poorly developed (Bijlsma and Kuipers, 1989).

### 14.5.3 Impact of Heavy Metals and Micro-Pollutants on River Food Webs

Many papers on the effects of heavy metals and micro-pollutants on river Rhine and Meuse biota and ecosystem functioning have been published the past 30 years, both on experimental results and results obtained in situ (e.g. Van der Velde et al., 1991; Hendriks and Pieters, 1993; Stronkhorst et al., 1993; Hendriks et al., 1995; Dirksen et al., 1995; Hendriks et al., 1997; Eijsackers and Doelman, 2000; and publications therein). My general impression is that conclusions referring to the impact of pollutants on ecosystem functioning are not unequivocal. It is true, some case studies of extreme effects on highly appreciated animals are continuously repeated in the literature. A classic example is the annihilation of the seal population in the Wadden Sea in the 1960s, owing to the impact of PCBs originating from the 'invisible' Rhine (Figs. 14.1 and 14.2) on their reproduction success (e.g. Reijnders, 1980). In many case studies elevated concentrations of pollutants have been detected in plant and animal tissues, but detrimental effects to their functioning are difficult to attain. This is the more so because the extreme peak loads of toxic substances mark a very short period in the history of the rivers Rhine and Meuse (1970–1975), and the chronic effects of diffuse sources are far more difficult to quantify. The most extensive studies in the 1980s and 1990s, applying improved detection methods (e.g. for organic micro-pollutants), were in fact executed too late to take the effects of pollution in the very act.

A lot of recent eco-toxicological work has been done along the main branches of the river Rhine, and some generalisations can be derived from a number of relevant studies (Hendriks and Pieters, 1993; Hendriks et al., 1995, 1997). Concentrations of some traditional micro-pollutants, like DDT, PCBs and mercury, tend to increase slightly in a downstream direction. Residues of heavy metals are higher in invertebrates than in fish, but the accumulation of organic compounds in invertebrate fat is half the level in fish fat. Aquatic invertebrates and fish species are sensitive to PAHs. For PCBs, it is mainly water birds and mammals which are at risk, whereas for cadmium invertebrates, birds and mammals appeared to be vulnerable. Elevated PCB contents have been shown for eggs of non-herbivorous water fowl. For highly bioaccumulating compounds the direct eco-toxicity may be less important than the dietary uptake, and further transfer via the food chain. Figure 14.5 shows the bioaccumulation of cadmium in the tissues of the zebra mussel, *Dreissena polymorpha*. This bivalve disappeared from the Rhine at concentrations of *ca.* 1 $\mu$g $l^{-1}$ cadmium in the river water. After the decrease of the cadmium concentrations in the river in the 1980s (cf. Table 14.1) the mussel returned (Van der Velde et al., 1991). Generally, with decreasing concentrations of toxicants in the river water, the deleterious effects on biota were less clearly discernable. During the 1990, related to theoretical quality standards, a certain impact of heavy metals and micro-pollutants on biota of the aquatic communities could yet not be excluded.

In the Rhine Delta, accumulation of micro-contaminants in terrestrial floodplain food webs has received little attention in comparison with aquatic communities. Hendriks et al. (1995) investigated organochlorine and metal concentrations in a terrestrial foodchain in river forelands along the river Waal. Samples of soil, earthworms (*Lumbricus rubellus*) and shrew (*Crocidura russula*, *Sorex araneus*) livers and kidneys were taken from two moderately to heavily polluted floodplains. Earthworms were selected as representative of invertebrate detritrivores. They make up more than 80% of the invertebrate biomass in floodplain soils and form a major part of the diet of moles (*Talpa europaea*), badgers (*Meles meles*) and shrews (Soricidae) and other predators. Bioconcentration values for heavy metals were in accordance with literature values for other polluted locations, confirming the high potential for cadmium accumulation in Lumbricidae. White-toothed shrews (*Crocidura russula*) and common shrews (*Sorex araneus*) were sampled for an indication of contaminant accumulation in carnivorous vertebrates. The work of Hendriks et al. (1995) on concentrations and accumulations of pollutants in the floodplain food web led to the careful conclusion, just as with the aquatic biota, that a certain impact of pollutants on terrestrial biota in the floodplain cannot be excluded, but that (negative) effects on ecosystem functioning could not be attained.

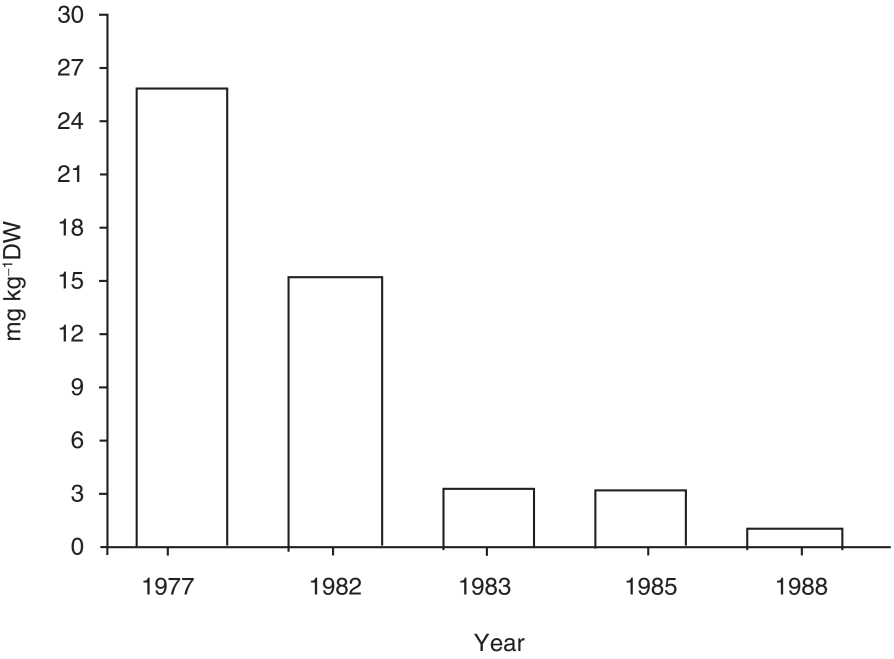

**Fig. 14.5** Concentrations of cadmium in tissues of the zebra mussel, *Dreissena polymorpha*, at Lobith (Rhine) in milligram per kilogram dry weight (Data compiled by Van der Velde et al., 1991)

## 14.6 Case Studies: Eel, Cormorant and Beaver

Several well-documented case studies are available of the possible effects of contaminants on the wax and wane of river-oriented animals in Rhine–Meuse ecosystems. I will in short deal with three examples, an omnivorous fish species, the eel, a carnivorous bird species, the cormorant and an herbivorous mammal, the beaver.

### *14.6.1 Eel*

Most eels (*Anguilla anguilla*) caught in the 1970s and early 1980s in the Large Rivers in the Delta had to be considered as chemical waste. The in 1981 allowed concentrations of PCBs in eel, maximum 5 mg $kg^{-1}$ eel, were far exceeded in the entire lower Rhine (10–15 mg PCB $kg^{-1}$) and Meuse (5–10 mg $kg^{-1}$; Roer tributary 30 mg $kg^{-1}$). The concentrations in eel from the Ketelmeer and the IJsselmeer were considerably lower (5 and 2 mg $kg^{-1}$ eel, respectively). The PCB concentrations in bream, roach, perch and pikeperch caught in the IJsselmeer were considerably lower (0.1–0.5 mg $kg^{-1}$) (Willemsen, 1983). Comparison of data from the early 1980s with studies from the 1990s showed that residues of many micro-pollutant compounds have decreased substantially. But recently the decline is suspected to level off. Residues of some specific compounds have not declined, and this trend is most striking for PCB153 and PCB180 in eel (Hendriks and Pieters, 1993).

The worldwide production of PCB's was estimated in 1983 at 1 billion tonnes. After the ban on the production and use of PCB in 1985 in the Netherlands, forced by several European directives, the amount circulating in the environment will for a long period be available for uptake in aquatic organisms. PCBs are considered harmful for human health, and since then the standards have been aggravated. The maximum allowed daily intake for humans of dioxin-like PCBs is since 1996 1 pg ($10^{-12}$ g) $kg^{-1}$ bodyweight $day^{-1}$ (www.vrom.nl). In 2007 the PCB levels in eels from the Large Rivers and inland waters are still above the recommended limit specified for human consumption. Eel consumption in the Netherlands is low, and an average consumer of wild eel runs no serious risk. Monthly consumption of *ca.* 150 g of wild eel from the Large Rivers, however, may after some years lead to an accumulation of dioxin-like substances in the human body in such a way that harmful effects on human health cannot be excluded (www.rikilt.wur.nl).

### *14.6.2 Cormorant*

The cormorant (*Phalacrocorux carbo sinensis*) is a fish-eating bird species for which a considerable amount of data are available. Already in 1961 the cormorant had disappeared as a breeding bird along the Delta branches of the Rhine and Meuse, including the Biesbosch area. Both persecution by man and water pollution were supposed to be responsible for the elimination of the bird populations. In 1970 adults found dead in the Biesbosch contained levels of PCBs high enough to cause their death (Koeman et al., 1973). From 1978 onwards several colonies (re-)settled in the Netherlands, amongst which was a colony in the Biesbosch, in the centre of the sedimentation area of the rivers Rhine and Meuse. In contrast to other new colonies which were rapidly increasing, numbers in the Biesbosch were fluctuating and remained relatively low. Incidental visits to the colony led to the suspicion of a low breeding success, and initial research in 1987 confirmed that breeding success was low. In a number of colonies along the major rivers (IJssel, Nederrijn and Waal) the reproduction rate was two to three times higher than in the Biesbosch, and it is four times higher in areas with a relatively low level of pollution (Dirksen et al.,1995).

A detailed analysis of reproductive performance in combination with chemical analysis of eggs and food from colonies in differently contaminated aquatic habitats was executed. The differences in breeding success between colonies were caused mainly in the egg-stage of breeding, to be attributed to eggshell thinning and increased embryonic mortality. The observed effects seemed to be related to chlorinated hydrocarbons. Significant correlations were found for concentrations of DDE (i.e. degraded DDT) with eggshell thinning and for concentrations of PCBs with hatching and breeding success. The correlations between concentrations of chlorinated hydrocarbons in eggs and biological effects measured in the yield were established both on colony and individual clutch level. The data strongly suggested a relation between persistent organochlorine contamination of aquatic food sources and breeding success of cormorants. Later studies concluded that the measured elevated PCB levels in eggs, resulting in reduced reproduction rates among cormorants, were caused by the intake of contaminated food (Boudewijn and Dirksen, 1995; Dirksen et al., 1995).

Cormorants mainly feed on bigger, often carnivorous inshore, non-migratory fish, such as Cyprinidae and Percidae species. Birds that remain in an estuary or river basin all year round, such as cormorants and oystercatchers, will build up higher levels and better reflect the local degree of contamination, than species such as terns that migrate to less-contaminated sites. Stronkhorst et al. (1993) observed for PCB-153 a biomagnification factor of 19 for the oystercatcher (egg:cockle) and for common tern only 5.5 (egg:clupeid). After hatching, the common tern chicks are being fed with very small marine fishes, probably less contaminated, than the larger fishes fed to cormorant chicks. Recent models based on laboratory and field studies show that cormorants are no longer affected by PCBs as they were in the 1960s and 1970s, and breeding colonies of this bird are now frequently found in the Netherlands (Hendriks et al., 1997).

### *14.6.3 Beaver*

The beaver (*Castor fiber*) in demand because of its fur, meat and odour glands, was overhunted throughout its range. The last beaver of the Delta was killed in 1826 (cf. Chapters 6 and 19). Reintroduction of this mammal was already considered in the 1960s, and eventually between 1988 and 1991 a number of beavers, caught in the river Elbe basin, were released in the former freshwater tidal area of the Biesbosch. A rather specialised dietary route leading to extreme accumulation of heavy metals has been described for the beaver. In 1990 the cadmium concentration of the soil in the Biesbosch was 27 times higher than that of the 16th century. As an added problem, the terrestrial soils which were no longer regularly flooded after the closure of the Haringvliet dam, showed clear signs of decalcification, which might enhance the uptake of cadmium by plants. Willow trees, *Salix* species, showed a remarkable capacity to accumulate cadmium in their bark, with soil contents ranging from 0.4 mg $kg^{-1}$ dry weight cadmium to a maximum of 1.0 mg $kg^{-1}$ dry weight, and bark contents ranging from 8.2 to 13.1 mg $kg^{-1}$ dry weight (other tree barks had typical contents of 0.3–0.7 mg $kg^{-1}$ dry weight cadmium). Contrary to what had been assumed, the introduced beavers fed almost exclusively on willow bark which constituted 100% of their diet in the main growth period (April–June) and 92% in the rest of the year. As a consequence, high cadmium contents were measured in the target organs (liver and kidneys) of some beavers found dead. Mortality during the first years after colonisation was probably partly caused by the difficulty which newly released animals had to conquer their own territory. It could not be ruled out, however, that cadmium contamination had induced increased mortality. The average cadmium concentrations in the beavers' food (6.9 mg $kg^{-1}$ dry weight) far exceeded the maximum tolerable concentration for large domestic herbivores (0.5 mg $kg^{-1}$ dry weight) (Nolet et al., 1994; Eijsackers and Doelman, 2000).

## 14.7 Present Status of River Pollution

The Rhine and Meuse Action Programmes, launched in 1987 and 1997 respectively, initially focused on water quality improvement (cf. Chapters 12 and 13). The countries sharing the Rhine basin, united in the International Commission for Protection of the River Rhine (ICPR), agreed upon a target reduction of at least 50% of the pollution caused by priority compounds by the year 1995, compared with the situation in 1985. Furthermore, water quality targets for the river Rhine were set for about 50 priority compounds, not only based on requirements for drinking water production and the protection of aquatic life, but also on human tolerance levels for fish consumption. The International Commission on Protection of the River Meuse (ICPM), in which the countries in the Meuse basin have been united from 1994, did not set specific targets for pollution reduction and improvement of the ecological quality. While there has been a substantial decrease in the level of pollution since the 1970s and 1980s, old deposits containing high concentrations of toxicants can still be found in surface layers of floodplains of the Meuse. At these locations effects of contaminants on survival, (re)production and abundance of aquatic and benthic species have been noted in laboratory and field studies. Investigations focusing on terrestrial invertebrates, though not carried out on a wide scale to date, have so far not shown similar effects.

Serious calamities in the river Rhine caused a political reveille, acting as an impetus for the rehabilitation of both the rivers Rhine and Meuse, viz. the endosulphan and the so-called Sandoz calamity in 1969 and 1986, respectively. After the fire at Sandoz in 1986 (see Chapter 12), improved chemical and biological early warning systems were set up along Dutch rivers. Two decades of monitoring have shown that peak exposures occur rarely in the river Rhine. In the river Meuse pollution accidents still occur including dissolved oxygen deficits upstream from the Grensmaas stretch (Bij de Vaate, 2003).

Although it is widely recognised that rivers contain tens of thousands of man-made substances, environmental research and management has until recently generally been limited to 100–200 priority substances or substance groups. In the 1990s, however, it was demonstrated that other, unknown substances are probably very important in the Rhine and Meuse rivers. In-depth studies confirm that only a small proportion of the toxicity, often less than 10%, can be assigned to known substances. For the remaining substances there is a lack of analytical detection methods or of toxicity data. Research into unknown substances is hedged in by uncertainties, but the results are strong enough to warrant more attention for other non-priority substances and sum-parameters such as gained from biomarker and bioaccumulation research (Hendriks et al., 1997).

Water quality of the Large Rivers has improved substantially in the last 30 years, particularly in the Rhine and to a lesser extent in the Meuse. This probably also applies for most of the surface water in the Netherlands that is fed by these rivers. The pollution problems that remain to be solved can be typified as persistent, relatively inconspicuous and difficult to master. The complexity of the remaining pollution is governed by the law of the diminishing returns: the curve of the costs of pollution control versus the results gained shows a downward trend. However, prolonged neglect of the remaining pollution problems may severely endanger the successful implementation of other rehabilitation measures (Leuven et al., 2000).

## 14.8 Conclusions

- The oligotrophic to mesotrophic status of the surface water in the Delta changed drastically in the 20th century. At present excess rainwater and groundwater is drained into the sea, and most of the surface water in the Delta is mixed up and replenished with eutrophicated Rhine water (the invisible Rhine).
- Chronic eutrophication of the Delta surface waters is one of the main remaining environmental problems, viz. external eutrophication by inputs of nutrient-rich polluted water (N and P), and the sulphate-driven internal eutrophication in systems loaded with organic material (floodplain lakes, peat lakes).
- Biomanipulation complements nutrient reduction in lake restoration, particularly in shallow lakes: if applied in conjunction with other measures, it speeds up the processes of lake rehabilitation.
- Annoying water pollution caused by urban trades dates back to the Middle Ages. The industrialisation in the 19th century magnified the problem, and entire stretches of rivers and connected groundwater, became severely polluted. Concerning its ecological impact, the disposal of non-biodegradabe organic substances after World War II aggravated the pollution problem. Rhine and Meuse have been used as open sewerage systems up to the middle of the 20th century.
- The Large Rivers were most severely polluted in the 1970s; the clean-up of the rivers started in the late 1970s and 1980s, and the obligatory building of sewage treatment plants after 1970 accelerated the cleaning process. Diffuse pollution from numerous sources, particularly from the river Meuse, is still a considerable problem. The application of biogeochemical knowledge of the regulatory processes in ecosystem rehabilitation is insufficient.
- Advanced eco-toxicological investigations in the 1980s and 1990s, applying sophisticated detection methods, were executed too late to take the effects of pollution in the very act.
- Pollution of the underwater sediments of the Biesbosch-Hollands Diep-Haringvliet is large problem owing to the accumulation of severely polluted sediments after the closure of the Haringvliet in 1970.

- Water quality in the Rhine and Meuse basins have improved substantially in the last 30 years; sediment quality lags seriously behind. At present, a certain impact of pollutants on aquatic and terrestrial biota riverine food web cannot be excluded, but irreversible negative effects on ecosystem functioning could not be attained.
- The pollution problems that remain to be solved (except the eutrophication problem) can be typified as persistent, relatively inconspicuous and difficult to master (mainly diffuse sources). Prolonged neglect of these problems, however, may severely endanger the successful implementation of rehabilitation measures.

# Part IV

# Ecology of Biota in a Man-Made Landscape: Deterioration and Rehabilitation

# Chapter 15
# River-Fish Fauna of the Delta

## 15.1 Introduction

Human impact through the ages has greatly changed the composition of the fish fauna in the Delta, both qualitatively and quantitatively. Systematic embankment of the Large Rivers was nearly accomplished in the late Middle Ages. However, up to the 18th century, the main channels were meandering and many river islands, flood-plain forests and snag habitats were still present. Later, the remnants of flood-plain forests were cleared, whereas snag was removed to facilitate shipping. River regulation and normalisation gained momentum in the 19th century and continues until the present day. The canalisation of the upper Rhine in the 19th century had far-reaching environmental consequences, particularly for the migratory fish species (cf. Chapter 8). The once anastomosing river system with islands, sand and gravel flats, a highly diverse system of various habitats in a dynamic environment, was transformed into a petrified canal with high current velocities (Van den Brink et al., 1996).

The Meuse was a relatively free-flowing river until 1918. In order to facilitate shipping on this rain-fed river, more than 70 weirs have since been built. As a result, the Meuse can be considered to be a chain of basins with long residence times in periods of extreme drought (Van Urk, 1984). The summer-beds of both rivers have become fixed by groynes and dykes which impede meandering and the formation of braided and secondary channels. As a result, the total flood-plain area has become drastically reduced, the river has incised itself into its summer-bed and the river forelands have silted-up. In the 18th and 19th century, dyke bursts occurred regularly during periods of high river discharges in combination with the incidence of ice in the river (Chapter 9). These dyke bursts resulted in tens of metres deep ponds which became filled with river water. Large-scale clay digging and sand and gravel extraction occurred in the 20th century resulting in many new waterbodies (cf. Fig. 13.3). After the great storm-flood disaster of 1953, plans were made to close the large estuaries in the SW Delta. During the execution of the Delta project almost all open connections between the Large Rivers and the North Sea were dammed up, again detrimental to migratory fish (Chapter 10).

In this context the present affected fish assemblage should be considered. The aim of this chapter is to present an overview of the vicissitudes of the fish communities

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in the Delta, restricted to freshwater fish and migratory species. Some notes on historic records will also be given. Already in the 19th century longitudinal zoning concepts were developed for the then still rather natural rivers, but after 1950 fish distribution connected to ecological traits has been best documented. The distribution of ecological fish guilds along the longitudinal river gradient, as well as along the transversal gradient, perpendicular to the main axis of the regulated river, will be dealt with. Recent river rehabilitation measures, the digging of secondary channels, appear to be successful for the restoration of rheophilic fish communities (fish with a preference for flowing water). The dominance of limnophilic bream (fish with a preference for stagnant water) in eutrophic lakes has negatively influenced the quality of aquatic ecosystems. Biomanipulation measures to remove the larger part of the bream stock will be discussed.

## 15.2 Prehistorical and Historical Records

Our knowledge of the fish fauna of the Rhine–Meuse Delta dates back to at least 6,000 years BP. Prehistoric data have been distracted from archaeological findings from human settlements, on levees bordering tidal creeks in the freshwater tidal area. Twelve fish species have been identified, with virtual certainty, based on remnants, such as fish-scales and fish-bones: pike, bream, roach, rudd, tench, wells, perch, ruffe, thin-lipped grey mullet, flounder, sturgeon and salmon (Louwe Kooijmans, 1985). All these species are still occurring in Delta waters, except the sturgeon (extinct) and the salmon (endangered). Written sources on fish and fisheries in freshwater bodies in the Delta date back to the late Middle Ages. Nijssen and De Groot (1975, 1987) mention Conrad Gesner who published his famous ‘Fischbuch’ originally in Latin (1555), but later in German (1563). In this book 72 pages are devoted to European freshwater fishes, showing at least 40 recognisable species. One of the first books on fish and fisheries in the Delta was the ‘Vis boec’, composed by Adriaen Coenesz in 1577–1580 (see Fig. 6.3). In the 16th and 17th centuries several works cover the fish fauna, but with the publication of ‘Systema naturae’ of Linnaeus in 1758 a new era started. He introduced the binominal nomenclature, just as we know it nowadays. Based on Linnaeus nomenclature, M. Houttuyn published his voluminous work on the entire natural history in the period 1761–1785, covering parts on fish, including living conditions of freshwater fishes in the Delta (Nijssen and De Groot, 1987). An increasing number of surveys were published in the 19th and 20th centuries dedicated to freshwater fish and fisheries (Van Emmerik and De Nie, 2006) far outweighed, however, by papers on marine fish and fisheries (www.wageningenimares.wur.nl).

Redeke’s (1941) work on fish in the Rhine–Meuse Delta is considered as a milestone; he designed one of the oldest, and most generally applied ecological classifications of fish species, based on the flow preference of adults. He distinguished rheophilic fish, i.e. some or all stages of life history are confined to flowing water; limnophilic (= stagnophilic) fish, i.e. all stages of life history are confined to lentic waters with macrophytes; eurytopic (= euryoecious) fish, the 'habitat generalists', i.e. all stages of life history can occur in both lotic and lentic waters); anadromous fish, i.e. adults migrate upriver to spawn; and catadromous fish species, i.e. adults migrate to sea to spawn. Although this classification is widely used, even today there is no general agreement on the position of every species in the Delta, and in some species different populations have developed different flow preferences. An example: three-spined stickleback and smelt have migratory (rheophilic) and non-migratory (eurytopic) populations; the bullhead is rheophilic (and endangered) in small streams, but eurytopic (and non-threatened) in large rivers, where nowadays it inhabits artificial, stony habitats such as groynes, that are totally absent in the lowland stretches of natural large rivers.

In his 'Hydrobiologie' Redeke (1948) described approximately 40 fish species, occurring in Delta waters. All these species are still occurring in Rhine–Meuse rivers and lakes, but among many of them there has been a dramatic decline in abundance, particularly among the rheophilic species (Table 15.1). All typical anadromous fishes, the rheophilic A1 species, were already rather rare or endangered in the 1940s. The most robust group comprises the eurytopic species; most species in this group were common in Redeke's (1948) days, and are still common. The recent decline of the eel, very common around 1948, is a remarkable fact (Dekker, 2004).

**Table 15.1** Ecological guild classifications of river fish species occurring in the Delta basins of Rhine and Meuse, grouped according to flow preference (After Quak, 1994)

| English name | Scientific name | Order | Reproductive guild | Feeding guild | Redeke, 1948 | Red list Rhine–Meuse |
|---|---|---|---|---|---|---|
| Rheophilic A: *All freshwater stages of life history are confined to the main river channel* | | | | | | |
| Rheophilic AI: *Migratory (ocean–river)* | | | | | | |
| River lamprey | *Lampetra fluviatilis* | Petr | Li | Det/Ben/Par | Ra | Vu |
| Sea lamprey | *Petromyzon marinus* | Petr | Li | Det/Par | Ra | En |
| Sturgeon | *Acipenser sturio* | Acip | Li/Pe | Ben/Pis | En | En/ex |
| Allis shad | *Alosa alosa* | Clup | Pe | PIa | En | En/ex |
| Houting | *Coregonus oxyrinchus* | Salm | Li/Pe | Ben/Pla | En | En/ex |
| Salmon | *Salmo salar* | Salm | Li | Pla/Ben/Pis | En | En/ex |
| Sea trout | *Salmo trutta trutta* | Salm | Li | Ben/Pis | RaR/RcM | Vu |
| Rheophilic A2: *Non-migratory* | | | | | | |
| Barbel | *Barbus barbus* | Cypr | Li | Ben | RcR/vcM | En |
| Chub | *Leuciscus cephalus* | Cypr | Li | Ben/Pis/Phy | VcM | Vu |
| Nase | *Chondrostoma nasus* | Cypr | Li | Per/Ben | RcR/vcM | En |
| Dace | *Leuciscus leuciscus* | Cypr | PI | Ben/Pla | RcR/vcM | Vu |
| Brook lamprey | *Lampetra planeri* | Petr | Li | Det | – | En |

(continued)

**Table 15.1** (continued)

| English name | Scientific name | Order | Reproductive guild | Feeding guild | Redeke, 1948 | Red list Rhine–Meuse |
|---|---|---|---|---|---|---|
| Stream bleak | *Alburnoides bipunctatus* | Cypr | Li | Ben/Phy | – | Vu/su |
| Brown trout | *Salmo trutta fario* | Salm | Li | Ben/Pis | ++ | En/ex |
| Minnow | *Phoxinus phoxinus* | Cypr | Li | Pla/Ben | ++ | En |
| Stone loach | *Barbatula barbatulus* | Cypr | Ps | Ben | ++ | Ne |
| Rheophilic B: *Some stages of life history are confined to well connected backwaters or tributaries* | | | | | | |
| Ide | *Leuciscus idus* | Cypr | PI | Ben/Pis/Phy | Co | Vu/su |
| Gudgeon | *Gobio gobio* | Cypr | Ps | Ben/Det | ++ | Ne |
| Burbot | *Lota Iota* | Gadi | LilPe | Ben/Pis | Rco | En |
| Spined loach | *Cobitis taenia* | Cypr | Ph | Det/Ben | ++ | Ne |
| Rheophilic C: *Some stages of life history are confined to slowly flowing brackish water (diadromous species)* | | | | | | |
| Smelt | *Osmerus eperlanus* | Salm | Li/Pe | PIa | ++ | Ne |
| Flounder | *Platichthys flesus* | Pleu | Pe | Ben | ++ | Ne |
| Twaite shad | *Alosa fallax* | Clup | Pe | PIa | En | En/ex |
| Eurytopic: *All stages of life history can occur in both lotic and lentic waters* | | | | | | |
| Eel | *Anguilla anguilla* | Angu | Pe | Ben/Pis | Vco | Vu/su |
| Perch | *Perca fluviatilis* | Perc | PI | Pla/Ben/Pis | ++ | Ne |
| Pikeperch | *Stizostedion lucioperca* | Perc | Ph | Pla/Ben/Pis | ++ | Ne[*] |
| Ruffe | *Gymnocephalus cernuus* | Perc | PI | Ben | ++ | Ne |
| Pumpkinseed | *Lepomis gibbosus* | Perc | Po | Pla/Ben/Pis | – | Ne[*] |
| Bullhead | *Cottus gobio* | Scor | Li | Ben | ++ | Ne |
| Three-spined stickleback | *Gasterosteus aculeatus* | Gast | Ar | Pla/Ben | ++ | Ne |
| Pike | *Esox lucius* | Salm | Ph | PIa/Pis | ++ | Ne |
| Schelly | *Coregonus lavaretus* | Salm | Li | Ben/Pla | – | En |
| Bleak | *Alburnus alburnus* | Cypr | Po | Pla/Ben | ++ | Ne |
| Wels | *Silurus glanis* | Silu | Ph | Ben/Pis | ++ | Ne |
| Asp | *Aspius aspius* | Cypr | Li | Pla/Ben/Pis | – | Ne[*] |
| Carp | *Cyprinus carpio* | Cypr | Ph | Ben/Pla/Phy | ++ | Ne |
| Gibel carp | *Carassius auratus gibelio* | Cypr | Ph | Ben/Phy/Det | – | Ne[*] |
| Bream | *Abramis brama* | Cypr | Po | PIa/Ben | ++ | Ne |
| Silver bream | *Blicca bjoerkna* | Cypr | Ph | Ben/Phy/Det | ++ | Ne |
| Roach | *Rutilus rutilus* | Cypr | Po | Pla/Ben/Phy | ++ | Ne |
| Limnophilic: *All stages of life history are confined to lentic waters with macrophytes* | | | | | | |
| Bitterling | *Rhodeus sericeus amarus* | Cypr | Os | Pla/Ben/Phy | Rco | Vu |
| Rudd | *Scardinius erythrophthalmus* | Cypr | Ph | Ben/Phy | ++ | Ne |
| Crucian carp | *Carassius carassius* | Cypr | Ph | Ben/Phy/Det | Co | Vu |
| Tench | *Tinca tinca* | Cypr | Ph | Ben/Phy/Det | ++ | Ne |
| Weatherfish | *Misgurnus fossilis* | Cypr | Ph | Det/Ben | Rco | Vu |

(continued)

**Table 15.1** (continued)

| English name | Scientific name | Order | Reproductive guild | Feeding guild | Redeke, 1948 | Red list Rhine–Meuse |
|---|---|---|---|---|---|---|
| Sunbleak | *Leucaspius delineatus* | Cypr | Ph | Pia | Rco | Vu |
| Ten-spined stickleback | *Pungitius pungitius* | Gast | Ar | Pla/Ben | ++ | Ne |
| Brown bullhead | *Ictalurus nebulosus* | Silu | Po | Ben/Phy/Pis | – | Ne* |

Order: Pleu = Pleuronectiformes, Perc = Perciformes, Scor = Scorpaeiformes, Gast = Gasterosteriformes, Gadi = Gadiformes, Salm = Salmoniformes, Silu = Siluriformes, Cypr = Cypriniformes, Clup = Clupeiformes, Angu = Anguilliformes, Acip = Acipenseriformes, Petr = Petromyzontiformes. Reproductive guild: Li = Lithophils (preference for hard substrates), Ph = Phytophils (preference for plants), Pe = Pelagophils (preference for open water), Ps = Psammophils (preference for sediment habitats), Ar = Ariadnophils (preference for enclosed nesting habitats), Os = Ostracophils (preference for bivalve molluscs), Pl = Phytolithophils, Po = Polyphils (After Balon, 1975a). Feeding guild: Par = Parasitic, Det = Detritivorous, Ben = Zoobenthivorous, Pla = Zooplanktivorous, Pis = Piscivorous, Phy = Phytivorous, Per = Periphytivorous (After Van den Brink et al., 1996; Lelek, 1987). Red list: ex = extinct as viable population, en = endangered, vu = vulnerable, su = susceptible, ne = not endangered, * = exotic species (Dutch Red list by De Nie and Van Ommering, 1998). Several rheophilic species were already indicated as endangered in Redeke (1948), others were common before World War II and are now endangered. ra = rare, co = common, rco = rather common, vco = very common. ++ = present, – = no status indicated. Some presently vulnerable or endangered species were before World War II rather common in the river Rhine (rcR) and very common in the river Meuse (vcM) (Table adapted from Aarts et al., 2004, and provided with additional data derived from Redeke, 1948)

## 15.3 Longitudinal Zonation Concepts for Large Rivers

Already in the 19th century eastern European ichthyologists had drawn up a rough classification system for the longitudinal succession of characteristic or dominant fish species that occur in rivers (as cited in Holcik, 1989). They divided the entire course of a river, from the source to the sea, into five basic zones: trout (*Salmo trutta*), grayling (*Thymallus thymallus*), barbel (*Barbus barbus*), bream (*Abramis brama*) and smelt (*Osmerus eperlanus*) zone. Huet (1949) improved this classic scheme by determining the characteristic physical and chemical parameters of each zone: the slope, the width, the depth, the current velocity and the water temperature. The following short description of the zones is based on De Nie and Van Ommering (1998), and adds some later subdivisions, and the present occurrence of the zones in the Delta.

1. Trout zone: narrow, shallow, fast flowing clear waters. The water is nutrient-poor and cold. The soil consists of clean gravel, sand and locally a little silt. Some authors have made further subdivisions of the trout zone, such as upper and lower trout zone. In the Delta only a few tributary brooks of the small river Geul (Meuse watershed; Fig. 13.4) possibly belonged to the trout zone.
2. Grayling zone: fast flowing clear waters. The water is a little richer in nutrients, the soil consists of gravel, sand and silt, and the brook is deeper and wider than the brooks in the trout zone. In the Netherlands the small river Geul and the upstream stretches of a few brooks belong to the grayling zone.

3. Barbel zone: wide, lotic, often clear waters. This is the middle reach of a river, running through sloping hills. The water is a little richer in nutrients than in the grayling zone. The characteristic fish species of the barbel zone require clean gravel for completing their life cycle. In the Delta only the uppermost part of the river Meuse, the so-called Grensmaas, belongs to the barbel zone. However, the dominant species here is chub (*Leuciscus cephalus*), not barbel. According to Volz and Cazemier (1991) two branches of the Rhine river system, the IJssel and the Nederrijn, show some morphological characteristics of the barbel zone.
4. Bream zone: stagnant or slowly flowing, clear or turbid waters. This is the traditional zone of the lowland river. The water is slightly nutrient-rich by nature. To the bream zone also belong the stagnant waterbodies that result from natural meandering processes and the more or less isolated stagnant waterbodies in the flood plains. The bream zone used to be very dynamic in space and time because of the ongoing ecological succession, creating a vast variety of habitats, like bare gravel bars, steep banks, sheltered waters with submerged vegetation, reed marshes and flood-plain forests. Originally the fish community inhabiting this zone was very species-rich. However, in recent times eutrophication has led to an over-abundance of the bream (cf. Section 15.7). Most stretches of the Large Rivers in the Delta belong to the bream zone.
5. Smelt zone: river mouths and brackish waters. This zone is subdivided into two sub-zones: the upper brackish water zone, called ruffe (*Gymnocephalus cernuus*) zone, and the lower brackish water zone, called flounder (*Platichthys flesus*) zone. The upper brackish water zone consists of a very dynamic landscape: the slow-flowing river deposits silt and the nutrient-rich water leads to ecological succession. Sometimes the water is brackish, so fish species that occur in this zone have to be adapted to this environment. This zone is important for diadromous fish. The lower brackish water zone, the estuary proper, is constantly influenced by the sea: the current velocities are determined by the tides, creating deep channels and sandbanks. The anadromous smelt and twaite shad had their spawning grounds here. Characteristic of the smelt zone is the large variability of all abiotic factors, causing this zone to be relatively species-poor by nature. The brackish water zones of the rivers Rhine and Meuse have been severely reduced by the building of dams and sluices (cf. Chapter 10). Besides the physical obstacle that a dam is to a migrating fish, this also poses additional problems to anadromous fish that try to migrate from the sea up the river, because they have to adapt their physiology from a saltwater environment to a freshwater environment in a very short time span.

This classical zonation of natural rivers according to characteristic fish species is not used very much anymore, because it has some serious shortcomings: (1) The practical usefulness and feasibility is low, because the zonation is based on, and intended for natural rivers, which have become rare in Europe and many other parts of the world. For example, the entire upper and middle Rhine belonged to the barbel zone, and the lower Rhine to the bream zone. Because of the strong anthropogenic influence this description is no longer valid, and at present the fish communities in virtually all parts of the river Rhine are alike (Tittizer and Krebs, 1996).

Anthropogenic waterbodies such as ditches, canals, lakes and pools, which are dominant in the Delta, do not fit in the zonation concept. However, this zoning can be valuable for the drawing up of references and targets for river rehabilitation, the planning of riverine fish reserves and for the valuation of the current fish assemblage in a river. (2) The fish zonation concept is based on only one life stage of fishes, namely the adult stage (Quak, 1994). The spawning and nursery habitat requirements of fish species were not included in the zonation concept. (3) Only the longitudinal, and not the vertical, transversal spatial and temporal dimensions have been incorporated into the fish zonation concept (Holcik, 1989). (4) The species composition of fish communities in various regions and streams is not homogeneous. Some characteristic species (grayling and bream) occur only in northwestern Europe, so this zonation concept cannot be applied to other geographical areas. For example, the Rhine has a very inhomogeneous fish fauna, caused by various specific geological events, so that the above-mentioned fish zonation is not entirely applicable. (5) The fish zonation concept is discrete, whereas the distribution and succession of fish species is not. The downstream change in the fish fauna is a gradual one, and the succession of fish zones in a river does not always follow the sequence outlined above. Inmost cases, it is not applicable to very large rivers like the river Rhine, because this river passes through large lakes, plateaus, etc. In the river continuum of the Rhine, the transition from the trout zone to the barbel zone can be located at three different spots (Tittizer and Krebs, 1996).

## 15.4 Developments After 1950 and Present-Day Fish Fauna

### *15.4.1 Fieldwork and Survey of Species*

De Nie (1996) and De Nie and Van Ommering (1998) recorded the species of freshwater fish considered to be declining in abundance or in distribution range in the Delta, or species that were extinct as native self-sustaining populations. Their assessment is based on historical records during the period 1945–1995 either in abundance, in catch per unit effort, or in range contraction from records of fish in 5 by 5 km grid squares. Twenty-four fish species are listed in the Dutch Red list of which three are considered susceptible, eight are vulnerable, six are endangered and seven extinct as self-sustaining, viable populations in the Delta or in the catchments of the Rhine and the Meuse (Table 15.1; Fig. 15.1). The eel (*Anguilla anguilla*) and the ide (*Leuciscus idus*) are susceptible because both have declined markedly in abundance over the last 50 years. A few records of the stream bleak (*Alburnoides bipunctatus*) exist today, even though the species was considered to be extinct in the 1930s. The crucian carp (*Carassius carassius*), river lamprey (*Lampetra fluviatilis*), sea trout (*Salmo trutta trutta*), chub (*L. cephalus*) and dace (*Leuciscus leuciscus*) have also declined in number over the last 50 years, although the number of grid square records for the sea trout and river lamprey have not markedly changed. By contrast the geographical ranges of the sunbleak (*Leucaspius delineatus*), bitterling

(*Rhodeus sericeus*) and weatherfish (*Misgurnus fossilis*) have all contracted over the past 50 years by more than 25%. The burbot (*Lota lota*), brook lamprey (*Lampetra planeri*) and minnow (*Phoxinus phoxinus*) have all suffered a range contraction of more than 50% since 1945 and are considered to be endangered. The nase (*Chondrostoma nasus*) and barbel (*B. barbus*) have experienced a marked (80–90%) decline in numbers and probably a range contraction too since 1945. The number of sea lampreys (*Petromyzon marinus*) entering the upper reaches of the river Rhine and Meuse have also strongly declined. The brown trout (*Salmo trutta fario*), houting (*Coregonus oxyrinchus*), salmon (*Salmo salar*), twaite shad (*Alosa fallax*), grayling (*T. thymallus*), sturgeon (*Acipenser sturio*) and allis shad (*Alosa alosa*) are all thought to be extinct in the Delta now, although a few may be found as immigrants from outside the country or from artificially stocked fish.

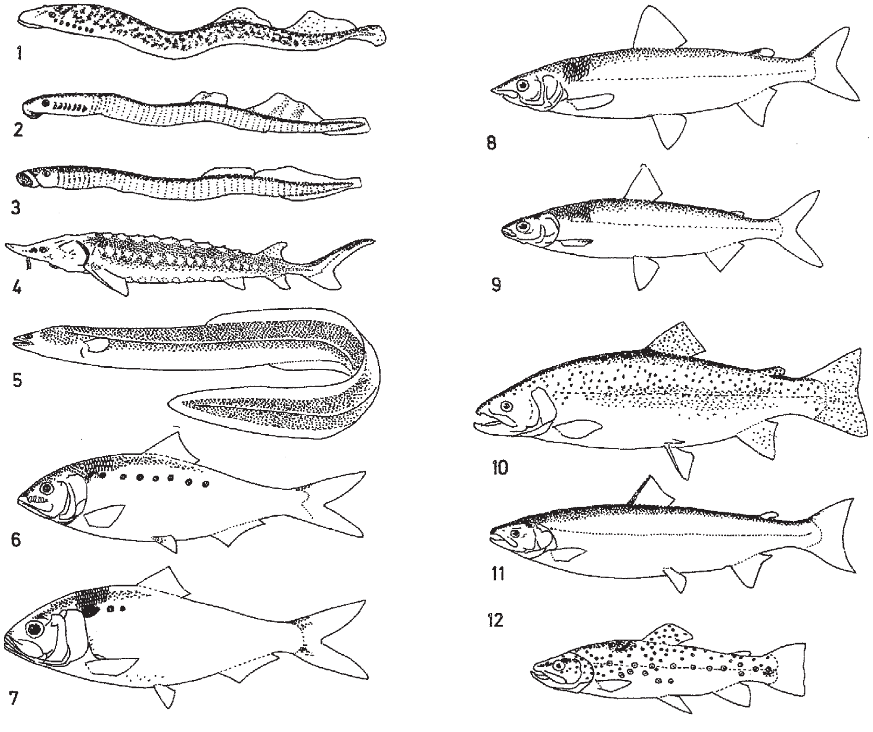

**Fig. 15.1** A number of fish species in the Delta, now (very) rare or (probably) extinct 1 = sea lamprey (80 cm); 2 = river lamprey (35 cm); 3 = brook lamprey (15 cm); 4 = sturgeon (several metres); 5 = eel (50–100 cm); 6 = twaite shad (40 cm); 7 = allis shad (40 cm); 8 = houting (50 cm); 9 = schelly (70 cm); 10 = rainbow trout (50 cm); 11 = salmon (*ca.* 1 m); 12 = brown trout (25–50 cm) (scientific names see Table 15.1; in brackets average size). Most species are rheophilic endangered or vulnerable Red list species. Eel and schelly are eurytopic species. The eel became a rare species very recently (Chapter 8); the schelly is an extinct species. Rainbow trout is an introduced species from North America, and since 1965 stocked in the Delta surface waters (Nijssen and De Groot, 1975; Aarts and Nienhuis, 2003)

Van den Brink et al. (1996) analysed the fish fauna of Rhine–Meuse Delta. Their dataset, comprising 48 species, consisted of long-term (5-year period) fish investigations in these rivers, collected by year-round sampling using various nets, electro-fishing and collecting the fish that were caught at the cooling-water intake of an energy plant on the bank of the river Rhine near Nijmegen. Non-reproducing exotic species, such as grass carp (*Ctenopharyngodon idella*), were not included in their analyses, but fully acclimatised, reproducing exotic species with self-sustaining populations were included, because they can constitute a substantial proportion of the fish stock (e.g. pikeperch [*Stizostedion lucioperca*]). Table 15.1 is composed of Van den Brink's list, and the Red list of De Nie and Van Ommering (1998). Data from Table 15.1 were subsequently used as the reference status, to evaluate the present ecological values of fish species, ecological guilds and aquatic habitats on the flood plains.

Compared with the historical situation, the diversity of fish in the main channels of the large rivers has decreased. At present, only two fish species (4% of the total) collected in the Delta Rhine and Meuse rivers occur exclusively in the flood-plain lakes and seven species (15%) exclusively in the main channel. Anadromous species, in particular, have either declined over the years, or become entirely extinct from the rivers. Since these fish species were economically important, the long-term depletion of their stocks has been well-documented (see Chapter 8). The decline of the anadromous species was already evident in the first half of the 19th century, when river engineering works resulted in the disappearance of specific spawning grounds, feeding biotopes, nursery areas and the obstruction and blockage of migrating routes. During the 1960s–1970s, fish diversity was at its lowest point, which coincided with low oxygen concentrations and high levels of micro-pollutants in the river water at that time. The fish fauna is currently dominated by euryoecious Cyprinids, such as bream (*A. brama*), silver bream (*Blicca bjoerkna*), bleak (*Alburnus alburnus*) and roach (*Rutilus rutilus*). Although still present in the Delta rivers, the densities of the characteristic rheophilous Cyprinids, such as barbel, dace, chub and nase have been strongly reduced. Pelagophils, lithophils and phytophils (for definitions see Table 15.1), and predominantly zooplanktivorous and zoobenthivorous fish species, have been reduced in diversity. This means that deterioration of spawning and feeding habitats, and obstruction of migration routes can be considered as important causes for their decline (Van den Brink et al., 1996).

The decline of fish diversity is partly obscured by the presence of exotics. Most of them have been introduced to stop the decline of fish stocks. However, only a few species, like carp and pikeperch are successful and dominant (see Chapter 8). The data presented above about the decline of the fish fauna in the Rhine and Meuse catchments are alarming. The evaluation of Stanners and Bourdeau (1995) showed, however, that the decrease in numbers of native fish species is not restricted to the Delta only. Along the upper reaches of the Rhine and Meuse a similar decline is going on. In the Netherlands 79% of the fish species are threatened in their existence, in Belgium 100%, in Western Germany 66% and in Switzerland, where the Rhine takes its rise, 38%. There are signs of hope, however. Recent estimates show a relative increase (*ca.* 25%) in the number of autochthonous fish species caught in the lower Rhine over the period 1993–2003, mainly to be attributed to diverse restoration measures, such as the digging of secondary channels and the construction of fish ladders (Section 11.5). The river Meuse lags behind: the number of fish species caught does not show a significant increase over the same period of time (De Leeuw et al., 2005; Reeze et al., 2005).

### *15.4.2 Ecological Fish Guilds*

Fish species that exploit a resource, either food or habitat, in a similar fashion can be grouped into ecological guilds or functional groups (Bergers, 1991). Studying changes in the composition and distribution of guilds in space and time can give distinctly different information on the processes and habitat availabilities for fish, than studying the presence of single species (Simberloff and Dayan, 1991). Aarts et al. (2004) have classified fish species according to their (1) flow preference, (2) reproduction ecology and (3) diet (Table 15.1). The flow preference classification used here has been developed by the Dutch Organisation for Inland Fisheries (Quak, 1994; Schouten and Quak, 1994). It can be regarded as an elaboration of the flow preference classification of Redeke (1941), and it classifies fish species into six categories (Table 15.1) based on their preference for running or standing waters and behaviour during spawning migrations. The reproductive strategies of many riverine species are adapted to the occurrence of inundations, and these species often also show clear ontogenetic shifts in their habitat requirements during early life stages. The ‘flow preference’ system explicitly incorporates these phenomena, although much work remains to be done on the specific requirements of European species (Grift, 2001). Balon (1975a, b, 1981) classified fish species according to their spawning habitats and behaviour, and Table 15.1 presents the classification of some river fishes according to Balon’s reproductive guilds. Widely used in zoology, fish species too can be grouped into guilds according to their feeding ecology. There is however no common classification system, and many authors have designed their own system. In this study the feeding guild classification of Van den Brink et al. (1996) has been followed: parasitic, detritivorous, zoobenthivorous, zoop1anktivorous, piscivorous, periphytivorous (feeding on small sessile organisms, such as algae and small crustaceans, which live attached to surfaces of plants or other objects) and phytivorous (feeding on plants) (Table 15.1).

### *15.4.3 The Transversal Flood Plain Gradient of Regulated Rivers*

A transversal succession gradient in fish community structure, resembling the longitudinal gradient found in natural rivers, can still be discerned in heavily regulated rivers like the Rhine and Meuse. With decreasing hydrological connectivity of flood-plain waterbodies the richness and diversity of fish species, particularly endangered species, and of ecological guilds decrease. Contrastingly, the biodiversity of some other aquatic biota, such as macrophytes, zooplankton and phytoplankton and macro-invertebrates, shows an opposite trend (Van den Brink et al., 1996; see Fig. 18.5), probably because those taxa are more sensitive to water quality (eutrophication) and the loss of very specific riverine habitats. The current transversal gradient is an unnatural one: flooding frequencies are controlled mainly by the heights of man-made levees in the flood plains. Furthermore, many natural habitats are lost, and replaced by man-made waters.

In Fig. 15.2 four types of waterbodies have been distinguished, on the basis of the degree of hydrological connectivity with the main river channel: (1) the main channel proper, (2) the dynamic flood-plain lakes, the former braided channels, (3) the moderately dynamic flood-plain lakes and (4) the isolated lakes, comprising the rarely inundated oxbow lakes, and isolated inland lakes (cf. Fig. 18.5). In regulated river–flood-plain systems the static, isolated lakes, driven by internal succession processes, are more numerous than the dynamic pioneer habitats of the main river channel and dynamic flood-plain lakes, which are constantly rejuvenated by reversible external succession processes. For conservation and restoration management this situation is very fortunate, because it means that habitats that are not easily regenerated by artificial measures are still present, while the habitats that are lacking (e.g. active secondary channels) can relatively easily be regenerated (Schropp and Bakker, 1998; Simons et al., 2001).

At present the anthropogenic impact on large rivers is huge, resulting in a fish fauna that is impoverished, unbalanced and unsustainable, and that departs greatly from the natural situation (Raat, 2001). For the definition of end goals of nature management programmes, aiming at the restoration of the fish fauna in large rivers, it is important to note that the exact composition of the fish fauna in the fully natural reference situation is not known in detail (Schouten and Quak, 1994; De Nie and Van Ommering, 1998), and that fully natural large rivers cannot be found anymore in Europe. The combined impact of chemical, physical and biological disturbances brought about by man in most river systems has affected the various fish species unevenly (Figs. 15.3 and 15.4): guilds of specialised species that share life history strategies, adapted to specifically riverine conditions have declined far more than generalist species that can survive in a wide range of habitats that are not characteristic of river ecosystems. Due to dams and sluices, migratory river fishes (rheophilic Al and C; see Table 15.1) have become extinct or very rare. Non-migratory river fishes (rheophilic A2 and B; see Table 15.1) have become (very) rare because their lotic habitats have disappeared or have degraded (Grift, 2001; Grift et al., 2003). Limnophilic fishes, that are dependent on clear waters with aquatic macrophytes, have become rare too, mainly as a result of eutrophication. Eurytopic fishes have become dominant everywhere, although eutrophication is disadvantageous for the phytophilic spawners within this group.

The transversal gradient in ecological properties of waterbodies and fish guilds across a natural flood plain (Fig. 15.2) resembles the longitudinal gradient that is present in large rivers from the headwaters to the mouth (see Chapter 8; Aarts and

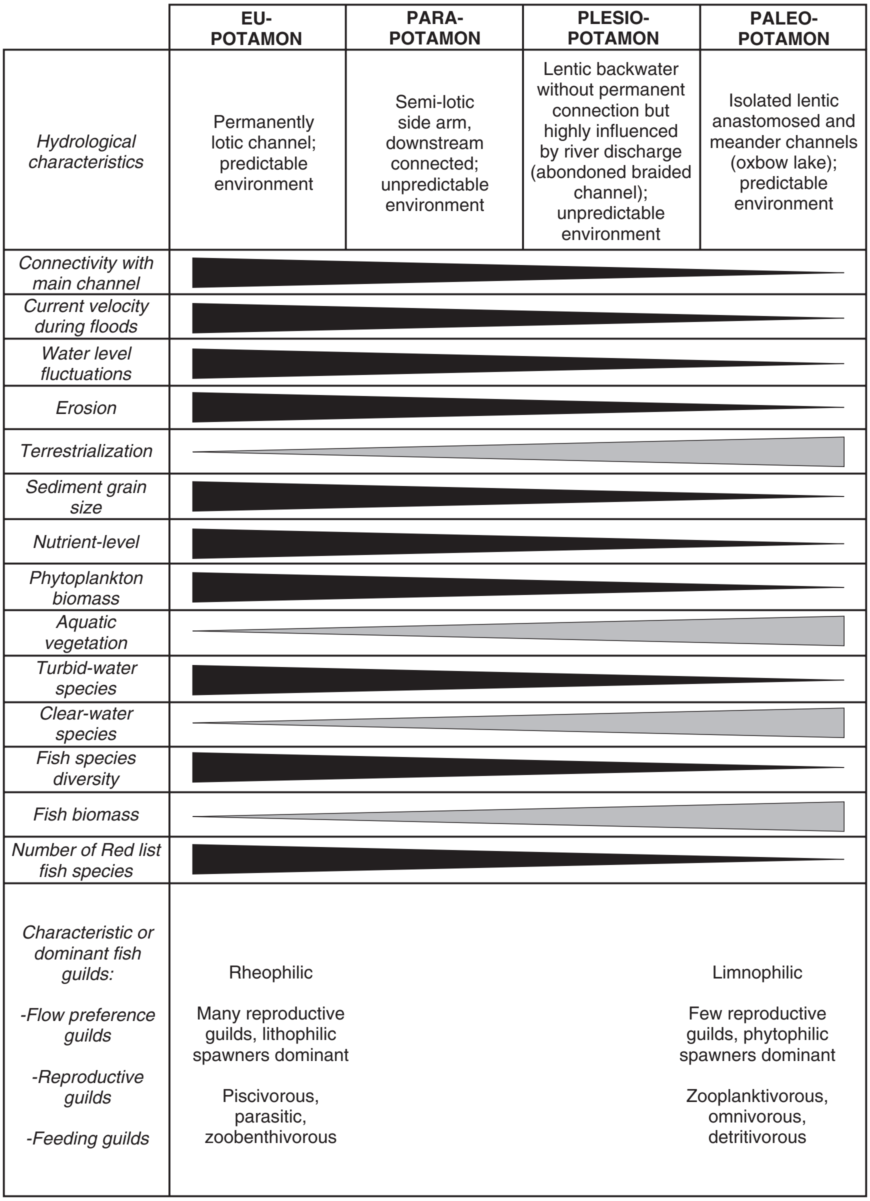

**Fig. 15.2** The transversal gradient in physical, chemical and biological characteristics of the four types of flood-plain waters (Aarts et al., 2004). The Greek terms in river science (potamology) will not be used in the text

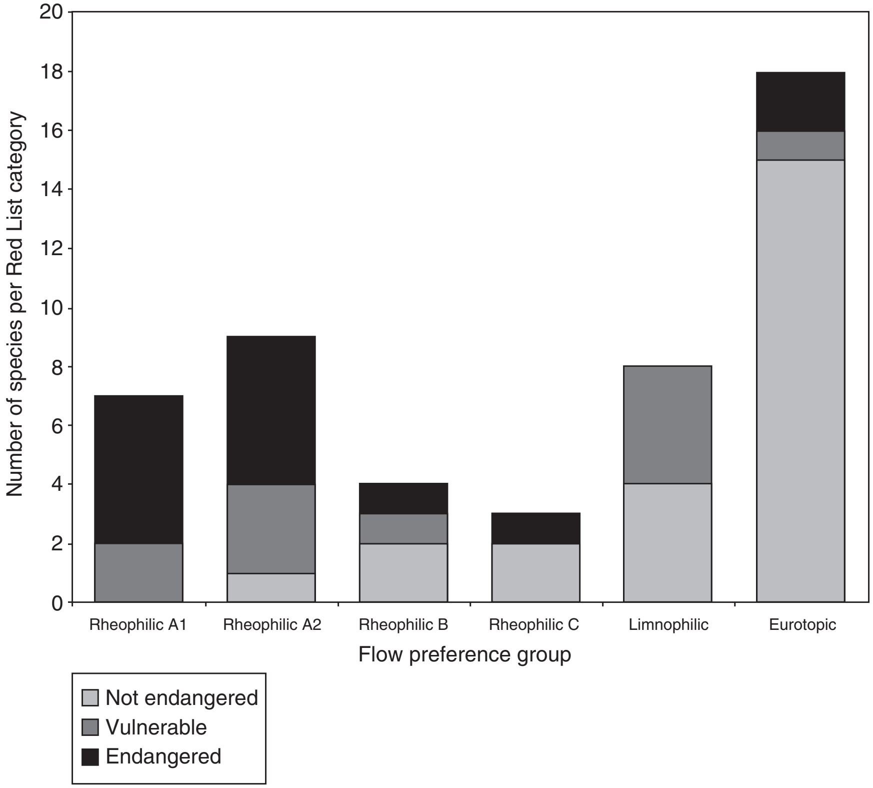

**Fig. 15.3** Red list status of flow preference groups of fish in the lower Rhine–Meuse, see also Table 15.1 (Aarts et al., 2004)

Nienhuis, 2003). Basically, both gradients comprise the transition from lotic to (semi-)lentic waters. Along its longitudinal axis a river changes from a fast-flowing, erosive, shallow mountain brook with cold, well-oxygenated water and a bottom consisting of pebbles and gravel, to a slow-flowing, deep, depositional lowland large river with relatively warm water with lower oxygen contents and a bottom consisting of sand and clay. Transversally – from the main river channel across the flood plain – the characteristics of waterbodies change from erosive running waters with relatively high oxygen content and colder water and sand/clay bottoms to standing waters with silt and organic deposits, undergoing a process of growing solid, and subjected to periodic oxygen deficits and high water temperatures. Some predictions of the River Continuum Concept (RCC; Vannote et al., 1980) can be applied to this transversal gradient, as the gradual change in ratio of external and internal processes observed longitudinally also occurs transversally within the

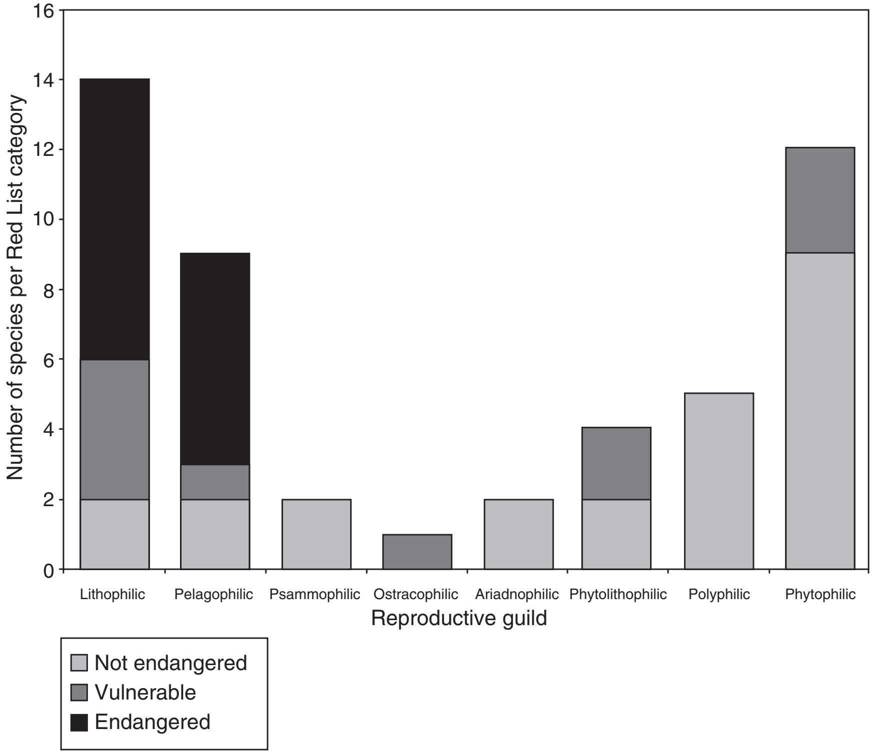

**Fig. 15.4** Red list status of reproductive guilds in the lower Rhine–Meuse. The flow preference groups (Fig. 15.3) correlate roughly with the reproductive guilds, see also Table 15.1 (Aarts et al., 2004)

flood plain, as lotic side channels, driven mainly by external processes, were cut off from the river and subjected to internal oriented processes such as eutrophication.

The fish guilds along both gradients show striking similarities (see Figs. 15.3 and 15.4): with decreasing current velocities litho- and psammophilic spawning rheophils are gradually replaced by phytophilic and polyphilic spawning limnophils and eurytopics, because the lotic habitats are characterised by clean gravel/sand bottoms and little vegetation, whereas the silted lentic habitats are characterized by the dominance of aquatic macrophytes and helophytes. In the RCC, zoobenthivorous, piscivorous and periphytivorous fish species are replaced by zooplanktivorous and phytivorous species along the longitudinal axis of a river; the same replacement pattern is also evident along the transversal axis. Connected flood-plain lakes have a much higher fish production than the main river channel (Chapter 8), which explains why piscivorous fish are relatively abundant in these lakes. The high zooplankton and macrophyte diversity in oxbowlakes is mirrored by the occurrence of several zooplanktivorous and phytivorous fish species in these lakes (Van den Brink et al., 1996).

### *15.4.4 Relation Between Current Velocities and Reproductive Behaviour*

The ecological requirements of fish species regarding current velocity and reproductive strategies seem to be correlated (Figs. 15.2–15.4): most rheophils are lithophilic, pelagophilic or psammophilic spawners, most limnophils are phytophilic spawners and most eurytopics are polyphilic or phytophilic spawners. The distribution of reproductive guilds over the flood-plain waterbodies is therefore not surprising: with decreasing flooding frequency of the lakes, the lithophilic, pelagophilic and psammophilic guilds decrease, whereas the phytophilic and polyphilic guilds increase. There is only one ostracophilic spawner, bitterling, which needs Unionids for reproduction, and this is one of the few species that was only present in flood-plain lakes and not in the main river channel. Before 1900, however, the bitterling occurred in the main channels of the Rhine–Meuse Delta (Van den Brink et al., 1996). Obviously, the occurrence of bitterling is more determined by mussel presence than by other factors (Bischoff and Wolter, 2001).

The distribution of feeding guilds is only poorly differentiated between the various waterbody types. With decreasing hydrological connectivity, parasitic, zoobenthivorous, piscivorous and periphytivorous species decrease, whereas detritivorous, zooplanktivorous and phytivorous species increase slightly (Van den Brink et al., 1996). Endangered species are predominantly found in the main river channel and in dynamic flood-plain lakes, and they are scarce or absent in the disconnected moderately dynamic and isolated flood-plain lakes. Only a few Red List species find optimal habitat in isolated flood-plainlakes, namely mainly some limnophilic specialists, such as bitterling and sun bleak (*L. delineatus*). This differentiated importance of waterbody types is mirrored in the distribution of Red List species across the ecological guilds. Nearly all rheophilic, lithophilic and pelagophilic species are endangered or vulnerable (Figs. 15.3 and 15.4). Species that are not dependent on running water habitats are mostly non-endangered, although those species that are reliant on aquatic vegetation and thus clear water (limnophils and phyto-(litho-)philic spawners) have become vulnerable.

## 15.5 River Rehabilitation

### *15.5.1 Rehabilitating River Habitats to Enhance Biodiversity Recovery*

Chemical water quality in the Large Rivers such as the river Rhine has improved markedly in the last two decades (cf. Chapter 14), yet the recovery of the biological diversity, including fish, is stagnating (Van den Brink et al., 1996; Nienhuis et al., 1998), or locally slightly improving (Reeze et al., 2005). It is evident that for the rehabilitation of sustainable populations of the most characteristic and most threatened riverine fish species (rheophilic cyprinids, salmonids, etc.) river managers should switch their attention from pursuing further water quality improvements towards restoration or redevelopment of lost habitats in the entire catchment area including connectivity between main channel and headwater streams, and the natural processes that maintain them. Fish habitats in river channels proper and dynamic flood-plain lakes (cf. Fig. 15.2) have suffered most from regulation and normalisation works and contain the highest percentage of threatened fish species. Reproductive habitats for rheophilic species, such as shallow, slow-flowing water in the main river channel and in side channels, are severely degraded or absent in regulated rivers (Grift, 2001). Free migration into smaller tributaries, that contain valuable spawning areas for many endangered rheophilic fish species, is often disrupted by dams and sluices. Natural semilotic, former braided channels have a high species richness, because they accommodate several reproductive guilds during their annual succession from lotic to lentic conditions. However, dynamic flood-plain channels are often disconnected by regulation works, resulting in relatively large losses in fish species richness.

Moderately dynamic flood-plain lakes and isolated lakes, such as abandoned braids and meander bends, are still present in regulated river–flood-plain systems, but their persistence is threatened owing to the fact that they are growing solid by peat formation, while the process of natural formation of new lakes has ceased because the river channel is immobilised. However, some man-made lakes closely resemble these natural habitats and seem to be suitable replacement habitats for fish. Especially isolated artificial 'oxbow lakes' (e.g. sand pits) contain a few endangered clear-water fish species that are not found anymore in the highly eutrophicated main river channel. However, these species are not typically bound to river systems, but live in various well-vegetated lentic biotopes. Gravel pits with permanently open connections to the main river channel can be important nursery, feeding, winter and shelter habitats for many riverine fishes, even for some rheophilic species. However, rheophilics do not reproduce in these pits, they are strictly bound to lotic habitats for spawning (Schiemer and Zalewski, 1992). Moreover, the different early life stages (fry, larvae and juveniles) of rheophilic species need different lotic microhabitats in close proximity to each other, so even if these microhabitats are present, habitat fragmentation could hamper successful recruitment of these highly adapted riverine species (Aarts et al., 2004).

## *15.5.2 Actual Rehabilitation Measures and Nature Development*

The objective of the European Water Framework Directive (www.kaderrichtlijnwater.nl; Chapters 20 and 21) is that all European surface waters, including large rivers, should have attained a 'good ecological status' by 2015. Because reproductive habitats of many critical rheophilic fish species are almost irreversibly lost, this objective will be almost impossible to meet. In Europe most flood plains are immobilised, while the majority of the river channels have become unnaturally dynamic.

It is vitally important for ecological rehabilitation of large river–flood-plain systems that more opportunities are given to their natural dynamics, thereby restoring the natural level of hydrological connectivity of flood-plain waters and the high diversity of aquatic habitats within the main river channel and on its flood plains. Large-scale restoration measures should also focus on a more natural hydrological regime, by promoting water retention in the catchments of tributaries and brooks ('natural sponge function'); the flood pulse (Junk et al., 1989) will then change from short, devastating peak discharges to lower discharges of longer duration, resulting in more contact and interaction between the river and its flood plain.

Since 1989 the possibilities to create man-made secondary channels in the flood plains of the Dutch rivers have been explored by means of literature studies and model experiments (Schropp and Bakker, 1998; Buijse et al., 2002). In1994, the first two permanently flowing secondary channels along the river Waal were created at Opijnen and Beneden-Leeuwen, and other projects followed during 1995–2006. These waterbodies should compensate for the loss of low-flow zones and connected backwaters along the lower river Rhine. Because of the experimental status of these secondary channels, the hydrological, morphological and ecological developments were intensively monitored. Grift (2001) and Grift et al. (2003) estimated the ecological value for fish populations of the new secondary channels on the basis of the monitoring surveys. Their study presents a description of the structure of the fish community that is present year-round, inferred from patterns of occurrence over time of larval, juvenile and adult fish, particularly of endangered rheophilic cyprinids.

Of the 48 species observed in the Rhine in the Delta (Table 15.1), 30 occurred in the newly created flood-plain waterbodies. Of 23 species, O-group fish were present. The waterbodies function as short-term nursery areas for rheophilic species of which densities peaked in summer. The secondary channels may also function as spawning areas for ide and gudgeon, but this could not be demonstrated unambiguously. For the lithophilic species (barbel and asp) they do not function as spawning areas since suitable substrate is lacking. Eurytopic species, like bream, roach and pikeperch, use these waterbodies both as spawning and nursery areas (Fig. 15.5). Grift (2001) and Grift et al. (2003) concluded that the colonisation of these new man-made waterbodies has been rapid, and that their functioning for fish resembles that of natural waterbodies as described for less degraded rivers elsewhere. However, stock rehabilitation of rheophilic A species (barbel, chub, nase and dace) in the lower reaches of the Rhine may be constrained by lack of suitable upstream spawning areas and the opportunities for larvae to passively reach downstream nursery areas. For some rheophilic B species (ide, gudgeon), secondary channels appeared to fulfil the requirements of all early life stages (eggs, larvae, juveniles). For all rheophilic species, the reconnected oxbow lake appeared to function as a nursery area. Restoration of lateral connectivity is probably most important for their rehabilitation, because longitudinal connectivity between spawning and nursery areas is not limiting, at least not in the rivers Waal and IJssel. Both lateral and longitudinal connectivity, in their complex interactions with hydrology, function as vital requirements for diverse fish communities and high productivity.

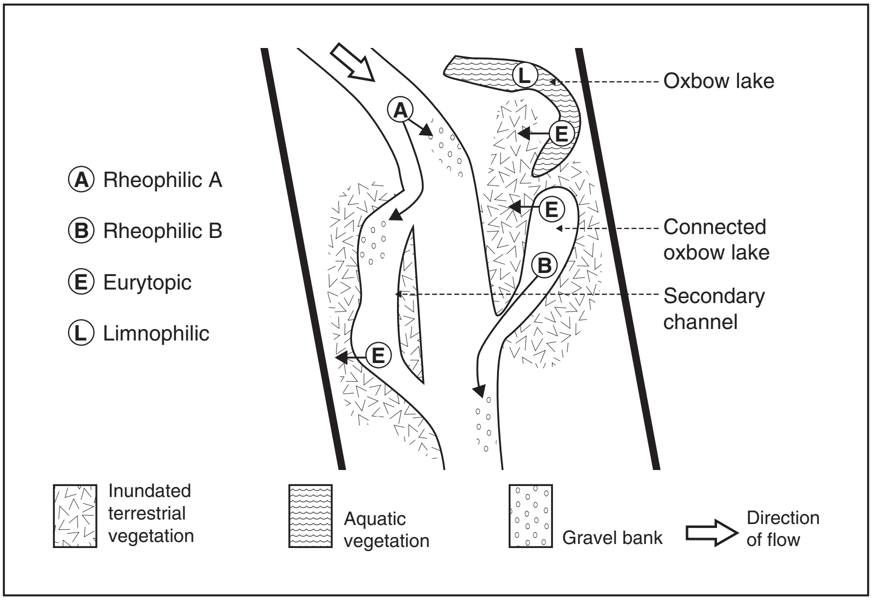

**Fig. 15.5** Differential use of habitats in flood plains along lowland rivers by four reproductive guilds. Black arrows indicate adult migration to spawning sites (Grift, 2001)

The findings of Grift (2001) showed that, on a local scale, man-made waterbodies can compensate for lost habitats along the lower Rhine. Since all rheophilic fish spawn in flowing water, their larvae face the risk of being swept away from the spawning areas, from which they need to reach suitable nursery areas. In these restricted areas, the population of O-group fish is determined by both imports and exports. Therefore, the distance between spawning and nursery areas should support early settling of the larvae, and the probability of retention in the nursery areas should be optimised. A high retention will benefit recruitment, particularly in regulated rivers such as the Rhine where nursery areas are scarce: only a restricted number of secondary channels and reconnected oxbow lakes exist at present. The other permanently connected waterbodies are up to 20 m deep sandpits and harbours with steep slopes along the shores.

At present, flood-plain management along the lower Rhine foresees the creation of more secondary channels in the framework of the flood protection measures (Reeze et al., 2005). Numbers of gudgeon, asp, burbot and nase increased significantly from 1993 to 1999, as demonstrated in a national monitoring programme, in which catches from fish-traps of professional fishermen have been recorded (Winter et al., 2000). This confirms the assumption of Grift (2001) that there is a stock of rheophilic fish present in the lower Rhine which has the ability to reproduce and grow and has the potential to profit from the new secondary channels and reconnected oxbow lakes.

## 15.6 Recruitment of the Meuse from its Tributaries

As said before, the fish fauna of the Large Rivers in the Delta is currently dominated by eurytopic species. During the last two centuries, modifications to the geomorphology of the river Meuse have resulted in a decline and isolation of flood-plain waterbodies, the presence of steep and fortified stony embankments and a severe lack of aquatic vegetation in the main channel, leading to a greatly reduced or even absent recruitment potential for limnophilic species (Vriese et al., 1994). Surprisingly, however, despite the lack of flood-plain lakes and the adverse conditions in the main channel of the Meuse, a few limnophilic species, particularly pike, tench and rudd, are still found, and although they are generally caught in small numbers, their occurrence has been quantified as common to locally common by Admiraal et al. (1993) and Crombaghs et al. (2000) respectively.

When studying riverine fish ecology, the importance of lowland tributaries is commonly overlooked, as attention is focused on the main channel and its immediate off-channel flood-plain habitats. However, in regulated rivers with reduced availability of spawning and nursery habitats, potential recruitment from tributaries may be particularly important. Lowland tributaries often harbour a diverse fish fauna, from which fishes can be recruited for populations in the main river, either through drift of larvae or through migration of juveniles. Surprisingly, however, although many researchers have studied ‘flood-plain main channel’ interactions (cf. Grift, 2001), few studies have focused on the ecology of fish in lowland tributaries, and quantitative data describing ecological links between tributaries and the main channel are largely lacking (Pollux et al., 2006).

In the Delta, the Meuse is connected to tens of tributaries, and on the western bank of the Delta Meuse these streams have an estimated total length of over 500 km, with an average width of approximately 5–10 m. These tributaries comprise an area of considerable size consisting of slow-flowing, shallow-water habitats with locally abundant vegetation, hence providing suitable spawning and nursery habitats for many species. Pollux et al. (2006) investigated the reproduction, growth and migration of fish in the Everlose Beek, a regulated lowland tributary of the river Meuse (Fig. 15.6), by biweekly sampling from January to December 2002. A total of 8,615 fishes were caught, belonging to 13 different species. The fish species were classified into three groups, namely, residents, migrants and transients, based on the presence of various life stages in the tributary. Size frequency data suggest that each group uses the Everlose Beek differently: (i) stone loach, gudgeon and three-spined stickleback were resident species using the tributary as a spawning, nursery and adult habitat; (ii) bream, roach, rudd, tench, and pike were migratory species, using the tributary as a spawning area, as well as a nursery habitat during their first year of growth, but migrating towards the river Meuse typically at a length of 5–15 cm; and (iii) bleak, sunbleak, carp, crucian carp, and perch were transient species, characterised by an absence of reproduction and very low densities, of greater than age-l juveniles and adults only (Fig. 15.6).

Pollux et al. (2006) study showed that phytophilic (e.g., rudd, tench, pike, and three-spined stickleback), psammophilic (stone loach and gudgeon) and polyphilic

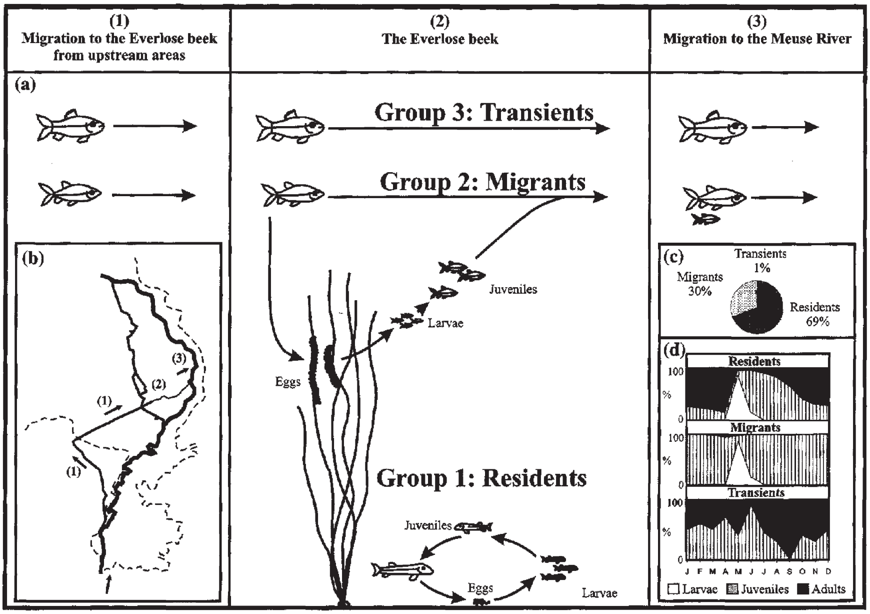

**Fig. 15.6** Schematic representation of the way in which resident, migrant and transient fish species utilize the lowland tributary streams on the western bank of the river Maas. (a) Residents complete their entire life cycle in the tributary streams, migrants are born in the tributary streams but display ontogenetic migration towards the river Maas and transients merely pass through the systems of canals and tributary streams without reproducing within the streams. (b) Adult migrant and transient fishes originate from upstream areas, migrate towards the Everlose Beek and ultimately migrate farther downstream towards the river Maas, displaying only unidirectional migration due to the presence of weirs. (c) Total catch (%) of resident, migrant and transient species in the Everlose Beek. (d) Composition (%) of life stages (i.e. larvae, juveniles and adults) throughout the year; note the absence of adults for migrant species and the absence of larvae for transient species (Pollux et al., 2006)

(roach and bream) spawners can reproduce in the streams. A few resident species spend their entire lives in the shallow streams, but migrants display ontogenetic shifts to the river Meuse. This suggests that lowland tributaries, such as the Everlose Beek, may function as important recruitment sources for phytophilic species, and that the persistence of the severely reduced populations of phytophilic species in the heavily modified river Meuse, may be attributed to recruitment from the tributaries (cf. Kestemont et al., 2002).

## 15.7 Bream and Biomanipulation

Bream (*A. brama*) is usually a dominant fish species in eutrophic lakes in Europe, particularly in the Netherlands. With increasing eutrophication of lakes, submerged vegetation has declined and new habitat for bream, i.e. turbid open water, has been created. Since the beginning of the 1970s, bream have dominated most Delta lakes and although nutrient loads have decreased significantly since the late 1980s, bream stocks have not responded by a decline, and water transparency of most lakes is still low. In terms of existing standing stocks of fish, bream was perhaps the most important planktivorous/benthivorous fish species in most shallow Delta lakes until lake restoration studies were initiated in the late 1980s (Gulati and Van Donk, 2002).

Our knowledge that fish play a major role in aquatic ecosystems has contributed to the concept of biomanipulation, synonymous with so-called biological control, which Moss (1998) has called 'the lynchpin of shallow lake restoration' (cf. Fig. 14.4). According to Gulati and Van Donk (2002) there are good reasons for assigning a key role to fish in lake restoration: the fish are a relatively easy, supplementary instrument for restoration and management. The effects of top-down manipulation are virtually instantaneous, and more tangible in shallow lakes than in deep lakes, except if the macrophytes are abundant. This is in contrast to the effects of hydrological and nutrient control measures, which need time to produce the desired results. Fish management strategies essentially involve reducing and regulating the impact of planktivorous fish by reducing their numbers or removing them entirely and restocking with piscivores. The literature relating to the European lakes, including 18 case studies from the Netherlands, shows that fish removal rates vary from 25% to 100%, although we know that most effective biomanipulation measures have involved attempting to remove 75–100% of the entire fish community (Hansson et al., 1998; Meijer et al., 1999). Continuous fish management would result in mutually acceptable changes for both fishermen and water quality managers. However, the cost-benefit aspects of such enterprises do not make almost total removal of the fish stock a practical solution (Gulati and Van Donk, 2002).

The evaluation of numerous biomanipulation cases showed that this measure can speed up the recovery process of an aquatic ecosystem, but the duration of the effect depends on the nutrient concentration in the lake. In many of these biomanipulation studies, the main species to be removed is bream and the reduction measures take only a few days to a few months depending on the size of the lake. In the Netherlands, the position of bream in the fishery market has changed considerably since the 1990s. As the demand for bream by angling clubs in Belgium has increased and at the same time the eel fishery has steadily decreased, several commercial fishermen switched to bream fishery. As a consequence, in many lakes, unintended biomanipulation is taking place, affecting the entire lake ecosystem (Lammens et al., 2002).

Commercial exploitation of bream populations can have large consequences for the water quality of shallow eutrophic lakes. The strength of the effects depends on the efficiency of the fishery, fish recruitment success and temperature conditions. When natural death and fishery together lead to a mortality of bream of more than 50%, bream populations are likely to decline, water transparency to increase and submerged macrophytes to develop. At an overall mortality of 40%, losses may be compensated by relatively high recruitment rates. Bream can then dominate the fish community and prevent zebra mussels and submerged macrophytes from establishing because of physical disturbance, enhanced internal P-loading and increased apparent sedimentation rates when resuspended sediments resettle. Conversely, when bream biomass is strongly reduced by an intense fishery, chances are high for zebra mussels and submerged macrophytes to develop, and a clear-water state to be established (Lammens et al., 2002).

## 15.8 Conclusions

- Ecological fish guilds appear to be good indicators of ecological integrity and functioning of river–flood-plain systems. A transversal succession gradient in fish communities, perpendicular to the main axis of the river, resembles the longitudinal gradient that is present in large rivers from the headwaters to the mouth (River Continuum Concept).
- Overall, richness and diversity of species and ecological fish guilds decrease with decreasing hydrological connectivity of flood-plain waterbodies with the main channels of the Large Rivers.
- Anthropogenic disturbances have affected fish species unevenly: guilds of specialised species that are highly adapted to specifically riverine conditions have declined far more than generalist species. Fish habitats in the main and secondary channels have suffered most from regulation and contain the highest percentage of threatened species.
- Rheophilic fishes have become rare in the Large River basins because their lotic reproductive habitats are severely degraded, fragmented, absent or unreachable. Limnophilic fishes have become rare too, mainly as a result of eutrophication, and eurytopic fishes have become dominant everywhere.
- For the rehabilitation of sustainable populations of characteristic and threatened riverine fish species (rheophilic cyprinids, salmonids, etc.) river managers should switch their attention from pursuing further water quality improvements, towards restoration or redevelopment of lost habitats, including connectivity between main channel and headwater streams.
- At present, flood-plain management along the Large Rivers foresees the creation of secondary channels in the framework of flood protection and ‘nature development’ measures. There is a stock of rheophilic fish present in the lower Rhine which has the ability to reproduce and grow and has the potential to profit from the new secondary channels and reconnected oxbow lakes.
- In the regulated Large Rivers with reduced availability of spawning and nursery habitats, potential recruitment from lowland tributaries may be particularly important for a wide variety of fish species, provided that obstacles that prevent fish migration will be removed.
- Bream may dominate the fish community in peat lakes in the Delta and will cause physical disturbance, enhanced internal P-loading and increased apparent sedimentation rates when resuspended sediments resettle. Conversely, when bream biomass is strongly reduced by an intense fishery, chances are high for zebra mussels and submerged macrophytes to develop, and a clear-water state to be established (biomanipulation).

# Chapter 16
# Eelgrass Wax and Wane: A Case Study

## 16.1 Introduction

A significant change in the Rhine–Meuse Delta is the substantial reduction in the longitudinal connectivity, and connected habitat diversity. The dams built to protect the hinterland against flooding, deprived the areas of their estuarine gradients. Large weirs in the rivers proper, and massive seawalls closing off the estuaries, have drastically altered mass transport dynamics and the functioning of habitats for estuarine biota. Flood peaks have been eliminated, daily discharges are more equable and temperature seasonality is partly reduced. The slowing down of upstream sediment supply and the loss of scouring flood flows, has led to storage of sediment in the IJsselmeer and the Haringvliet-Biesbosch reservoir, and constant clear water flushing downstream artificially depletes finer sediments in the tail-waters. The mixing zone between seawater and freshwater, enriched with nutrients from upstream, has been converted into freshwater or saline water lakes The estuarine gradient between the Wadden Sea and the Zuiderzee was lost in 1932, and the gradient between the North Sea and the estuaries in the SW Delta was largely annihilated between 1964 and 1986.

As stated in the River Continuum Concept (Vannote et al., 1980), the ecological gradient in the undisturbed river, from its very source to where it debouches into the sea, in functional terms the longitudinal connectivity, is essential for the life cycle of many species. The river proper and the connected estuaries form an elongated ecological entity (cf. Chapters 10 and 15). Eelgrass is a keystone species confirming this theory of longitudinal connectivity. Eelgrass is 'estuary grass'. That is the reason why the wax and wane of eelgrass, *Zostera marina*, will be treated in a book on the environmental history of the Rhine–Meuse Delta. The lowland river continuum comprises the entire dynamic marine–brackish–freshwater gradient where eelgrass thrives. Eelgrass played a dominant role in estuarine habitats of the Delta: with the disappearance of eelgrass, a complete ecosystem including algae, invertebrates, fish and bird species has vanished. The wax and wane of eelgrass in the Delta has everything to do with the presence or absence of river water, and concomitant processes like eutrophication and turbidity.

P.H. Nienhuis, *Environmental History of the Rhine—Meuse Delta,*

In this chapter the historic occurrence of eelgrass in the Wadden Sea and in Grevelingen lagoon, the main site in the SW Delta, will be dealt with. The once significant *Zostera* food web, and the considerable economic use of eelgrass will be discussed, together with the enigmatic wasting disease that presumably annihilated the crop in the Wadden Sea. The chapter will end with some ideas for the restoration of lost eelgrass beds.

## 16.2 Eelgrass in the Wadden Sea

The Wadden Sea is one of the world's largest international marine wetland reserves (*ca.* 6,000 km$^2$), bordering the coasts of the Netherlands, Germany and Denmark (Figs. 14.1 and 14.2). The dramatic decline of the once thriving and economically important eelgrass beds in the 1930s is an historic fact, which gave rise to many speculations about the causes of this ecological disaster. In the records of the 19th and the early 20th century, the total area occupied by *Zostera* in the Dutch western Wadden Sea and the Zuiderzee was estimated between 6,500 and 15,000 ha (Fig. 16.1). The position and the size of the sublittoral *Z. marina* beds obviously underwent long-term and annual fluctuations in the course of time. *Z. marina* also occurred in the former Zuiderzee, where it could stand salinities as low as 6‰. Z. *marina* penetrated into eulittoral sand and mudflats as a form with narrow leaves, where it was accompanied by *Zostera noltii* (Den Hartog and Polderman, 1975).

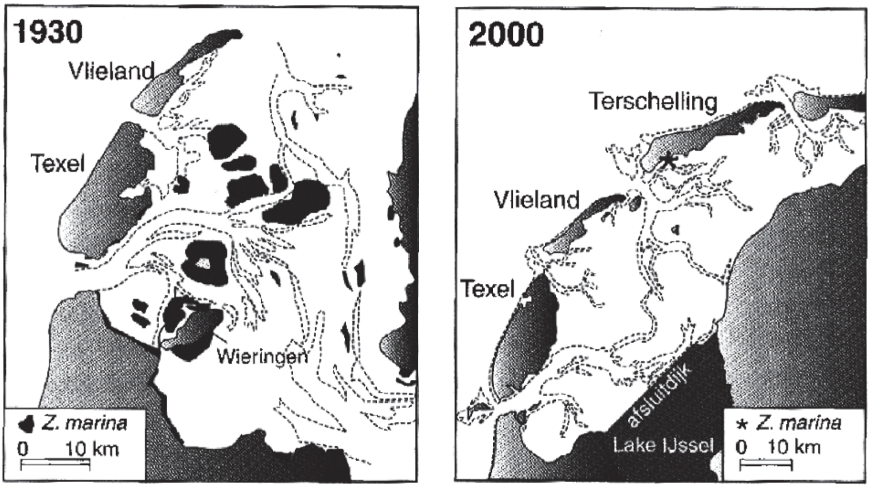

**Fig. 16.1** The Wadden Sea and the island of Wieringen in 1930 before the 'wasting disease', showing an area of *Zostera marina* of roughly 10,000 ha. The Afsluitdijk was closed in 1932, changing the Zuiderzee into the IJsselmeer (Lake IJssel). In 2000 a small intertidal eelgrass bed of less than 10 ha remained at Terschelling harbour (Van Katwijk, 2000)

A detailed mapping of eelgrass beds in the western Wadden Sea was carried out in 1869 (Oudemans et al., 1870) and another one in 1930 (Reigersman, 1939). De Jonge and De Ruiter (1996) combined the 1869 and the 1930 maps with available nautical charts by application of GIS packages, in order to estimate the eulittoral and sublittoral distribution of the eelgrass beds. It was necessary to carry out corrections because of inaccuracies both in the eelgrass mapping and in the old nautical charts. Prior to the 'wasting disease' and the closure of the former Zuiderzee, eelgrass occurred in both the intertidal zone as well as in the subtidal zone. The calculations showed that in 1869 45% of the eelgrass beds were present in the intertidal zone and 55% in the subtidal zone. In 1930 the distribution amounted to 56% in the intertidal zone and 44% in the subtidal zone. When comparing the relative distribution of eelgrass in 1869 and in 1930, it can be noticed that the total surface area covered by eelgrass was much higher in 1930 than in 1869, but the percentage of subtidal eelgrass beds in 1930 was lower than in 1869. This difference gives rise to the speculation that, over the period 1869–1930, light conditions had already deteriorated due to the closure of the Zuiderzee which was initiated in the late 1920s and was completed in 1932. Another likely factor that has reduced the presence of the subtidal eelgrass beds is the fisheries technique that, starting in the 1920s, changed from sailing vessels to propeller driven vessels with a much higher trawling capacity (De Jonge and De Ruiter, 1996).

Den Hartog (1970) suggested that hydrographic changes caused by the closure of the Zuiderzee in 1932 have prevented the re-establishment of sublittoral *Z. marina* in the Dutch Western Wadden Sea. It is speculated that erosion of the silt substrates favourable for the growth of *Z. marina*, the too strong currents for the establishment of seeds, and a rise of the average flood level by 20 cm, were the main factors responsible. An additional cause could be a considerable increase in the turbidity of the seawater, diminishing the underwater light intensities to values lower than *Zostera*'s light compensation point, as was hypothesised by Giesen et al. (1990).

Coinciding with the closure of the Zuiderzee in 1932 was the 'wasting disease' of *Z. marina*, which started in North America, reached the Netherlands and the German Northern Wadden Sea, and exterminated almost completely the sublittoral broad-leaved *Z. marina* beds. The Wadden Sea harbours two forms of *Z. marina*, the subtidal broad-leaved form is called mud-*Zostera*, and the intertidal narrow-leaved form is the sand-*Zostera* (Van Goor, 1919). Presumably the eulittoral sand-*Zostera*, together with *Z. noltii* were far less or not affected by the epeidemic: scattered eulittoral *Z. marina* stands and populations in brackish water ditches and ponds on the Wadden islands survived. From about 1940 onwards the decimated *Z. marina* populations all along the N Atlantic gradually increased in size and regained their lost grounds. In the German Wadden Sea, *Z. noltii* and *Z. marina* together cover now approximately 170 $\text{km}^2$, and in the Danish Wadden Sea *ca.* 30 $\text{km}^2$. Only in the Dutch Wadden Sea did eelgrass never succeed in re-establishing its sublittoral beds. At present, only intertidal *Z. marina* stands occur over an area of approximately 2 $\text{km}^2$. As *Z. marina* is incapable of surviving frost, its eulittoral populations are mostly annual and have to start their growth from seed each year (Van Katwijk, 2000).

## 16.3 Eelgrass in Grevelingen Lagoon

In the period 1964–1971 the Grevelingen estuary was closed off from the sea and from the river by massive seawalls, and the system became a large lake filled with clear, good quality seawater (Chapter 10). Within a period of ten years extensive eelgrass (*Z. marina*) beds developed all over the lake. It started with patches of a few hundreds of hectares, and gradually expanded into massive underwater meadows, to 5 m water depth. Eelgrass possesses two long-range dispersal mechanisms, viz. seeds and rhizomes. Uprooted rhizomes, however, were seldom found. In autumn and winter seeds occurred in large quantities in the superficial layers of the sediment within the seagrass fields. Beyond those areas no seeds were found. Since ripe seeds sink quickly to the bottom, they are only transported from the existing eelgrass beds in a very limited way, meaning that large distance colonisation could only occur by floating flowering shoots containing spathes with seeds. In summer 1978, after 7 years of colonisation by seeds and rhizomes, all potential habitats were occupied, viz. sheltered sediment areas with a water depth between 0 and 2.5 m, an area of over 4,500 ha (Fig. 16.2). Only the exposed central-western part of Grevelingen lagoon, fully open to the westerly winds, where water depths of 1–3 m potentially allow eelgrass growth, has never been colonized (Nienhuis, 1983a).

Semi-quantitative observations in 1979 revealed massive dieback of belowground biomass (dark brown/black fragmented rhizomes), coinciding with the severe winter of 1978–1979 and the opening of the sluice connection with the North Sea. In 1980 the surface area of the eelgrass beds was only 58% of the surface area in 1978, and the calculated biomass was only 39% of the 1978 biomass. After 1980 restoration of the eelgrass population took place, and the distribution map of 1983 is almost an image of the 1978 map. After 1983 and coinciding with the opening of the siphon connection with the Oosterschelde estuary, the eelgrass population declined dramatically, year after year, from 3,800 ha in 1985 to less than 100 ha in 1993, and from 1,520 t C biomass in 1985 to less than 10 t C in 1993. From 1989 onwards the vitality of the population was visibly getting worse. Substantial areas, in former years covered with a dense eelgrass mat during summer, showed black, fragmented patchy mats of rhizomes, occasionally bordered by up to 10 cm high abrasion edges. The years 1991–1993 were characterised by a shrinking population of eelgrass, consisting of isolated, perennial patches at almost predictable spots. Most plants were not vigorous and seed production was strongly reduced (Nienhuis et al., 1996). No improvements could be observed in the subsequent years, and in 2006 only a few traces remained of the once flourishing seagrass beds in the past.

The complex of external abiotic factors influencing seagrass growth and decomposition in Grevelingen lagoon left much room for speculation. For the period 1973–1980 the following hypothesis has been postulated, in which the effects of low water temperatures were combined with the effects of high salinity. The severe winter of 1978–1979 with ice-cover until March 1979 all over the shallow seagrass beds, presumably caused anaerobic conditions in the sediment and in the overlying, accumulated mass of decomposing seagrass, leading to massive die back of belowground eelgrass biomass. Moreover, anaerobiosis appears to be lethal to *Z. marina*

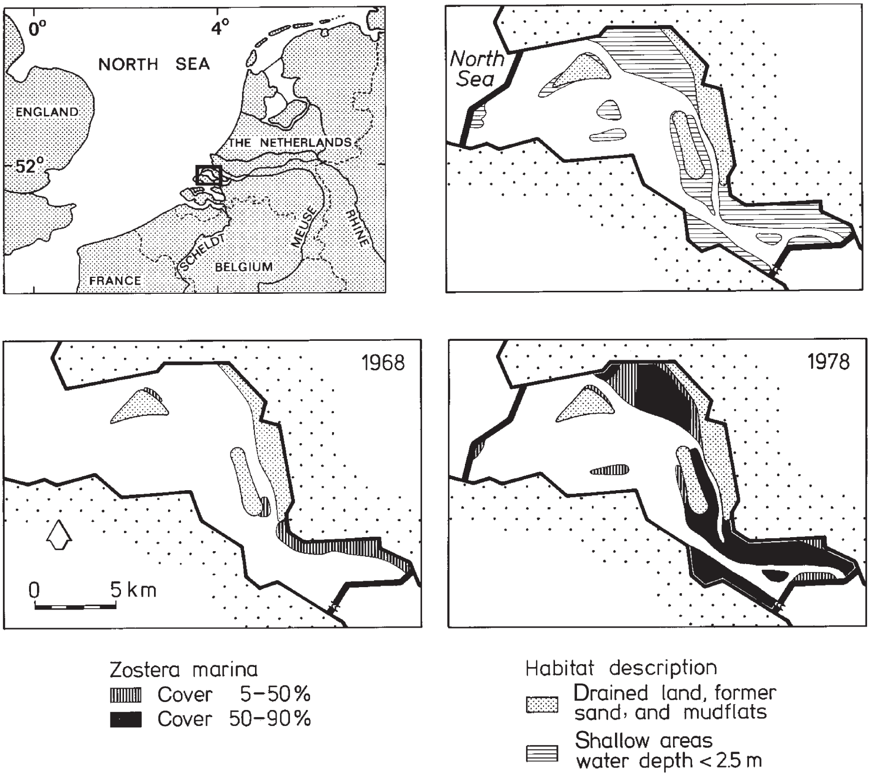

**Fig. 16.2** Distribution of *Zostera marina* in Grevelingen estuary (SW Delta) in 1968, and in 1978 after the closure of the western dam in 1971, which changed the estuary into a stagnant brackish lagoon (Nienhuis, 1983a)

seeds (Nienhuis, 1983a). The sudden increase in salinity of the water, from 24‰ total salinity in 1978 to 32‰ total salinity in 1980, could have decreased the germination rate of eelgrass seeds significantly. High salinity has been suggested as the primary factor for a decrease in germination rate (Hootsmans et al., 1987). If salinity is a determining factor, then the steadily decreasing salinity in Grevelingen in the period 1971–1978 may have notably favoured the germination of eelgrass. Moreover, the possibility exists that the seeds of the original estuarine population, genetically adapted to brackish water, demonstrated a lower germination rate under full seawater conditions.

The dramatic decline of the Grevelingen eelgrass population between 1985 and 1993 gave way for the following speculations: (1) The constantly high marine salinities were suppressing the germination process of eelgrass seeds. This argument has been elaborated above for the decline in 1980. (2) From 1984 onwards the surface water of Grevelingen lagoon contained extremely low ammonium values (on average 5 μM or less). The sediment pore water of eelgrass beds in Grevelingen lagoon (1987–1988) contained 5–100 µM ammonium, with exceptional values up to 150 µM (Van Lent, 1995). Ammonium concentrations may have been limiting eelgrass growth between 1985 and recent years. Ammonium is the preferred N-source for eelgrass growth, and both leaf- and root-uptake of ammonium is normally occurring. In theory concentrations below 100 µM are limiting growth rates of eelgrass. In experiments by Williams and Ruckelhaus (1993) leaf growth rates demonstrated a saturation-type response to sediment ammonium concentrations of more than 100 µM, providing further support for nitrogen limitation of eelgrass growth in ambient concentrations of 30–140 µM in the sediment pore-water. Moreover, among aquatic macrophytes the nitrogen requirements of the plants increase under conditions of salinity stress.

Two consecutive very cold to severe winters (1984–1985 and 1985–1986) may have stressed the below-ground biomass, presumably leading to mass mortality of the rhizome-root mat, or destruction of the vegetation in shallow water by ice scouring. The IJnsen value, an index of winter severity, indicating very cold to severe winters in 1978–1979, 1984–1985 and 1985–1986 (cf. Fig. 9.4), coincide with observations on massive dieback of rhizome mats of *Zostera* in the subsequent spring and summer period (Nienhuis et al., 1996).

Light extinction, often mentioned as a causal variable, explaining the wax and wane of eelgrass populations under turbid, eutrophicated conditions (e.g. as postulated for the Wadden Sea; Giesen et al., 1990) cannot explain the extinction of the eelgrass population in Grevelingen lagoon. The water was extremely clear and Secchi disc visibility showed a slight increase over the years (from 40 to 50 dm).

The incomplete picture emerging from data on Grevelingen lagoon is that of an extremely impoverished eelgrass population, living from 1980 onwards under oligo-mesotrophic marine conditions. Both the sexual and the vegetative modes of reproduction were severely stressed by environmental variables, most likely a combination of low temperatures, high salinity (and concomitant low dissolved silicate) and low ammonium concentrations. Eelgrass wax and wane showed a number of statistical correlations with the environmental variables mentioned, but no causal relations (Nienhuis, 2006). The most likely explanation for the decline of the population appeared to be the constant high salinity of the water. The original estuarine narrow-leaved *Z. marina* population was closed off from the sea in 1971. Favoured by a declining salinity in the 1970s the population thrived, but obviously, a constantly high salinity is experienced by the brackish water vegetation as a severe and continuous stress situation (Kamermans et al., 1999).

The work of Nienhuis (2006) and co-workers offered input for many model parameters, still in use to formulate and calculate the rules in behavioural patters of *Z. marina* populations all over the world. The research, however, was carried out in a young, instable, not resilient ecosystem. The models were able to predict the wax of the eelgrass vegetation, but not the wane. The reason for that is simply because the property of the population to react negatively to high salinity was not included in the models as a variable. And we know, models cannot deliver better predictions than the data allow. Restoration of the eelgrass vegetation might be expected when the estuarine dynamics in Lake Grevelingen will be restored. This hypothesis offers the water managers a solid argument (next to other arguments) to work on the restoration of the estuarine gradient in the lagoon.

## 16.4 The Eelgrass Food Web

The abundant production of eelgrass biomass in the western Wadden Sea and in the Danish fjords in passed centuries induced much research into the structure and the functioning of the estuarine food web. From 1883 to 1917 Danish investigators worked on the structure of the food web, the composition of organic matter produced by eelgrass, and they roughly estimated the production of phytoplankton and eelgrass in the Danish fjords and the Kattegat. Their main interest was focused on the role of eelgrass in the growth of economically important fish species such as plaice, cod and herring, and therefore they quantified (next to the eelgrass biomass) the ‘useful animals’ which serve as food for fish, viz. small crustaceans, benthic and sessile molluscs, annelid worms, and ‘useless animals’, viz. large bivalves and echinoderms.

The researchers concluded that the rich *Zostera* vegetation in the Danish waters was one of the principal supports of their fisheries, and that in more open waters plankton organism may play a subsidiary role as a source of organic matter for bottom organisms. The biomass of wet eelgrass in Danish waters in summer was estimated at 24 million tonnes, providing food for tonnes of invertebrates and ultimately fish (Fig. 16.3) (Ostenfeld, 1908; Petersen and Boysen Jensen, 1911; Boysen Jensen, 1914; Blegvad, 1916; Petersen, 1915, 1918). Petersen (1918, p. 9) finally came to the conclusion that the Danish shallow waters were dominated by an eelgrass-fuelled food web: ‘…I realised that the plankton organisms only comparatively rarely enter the stomach of oysters and other bivalves living on the bottom, the true food of these in fact consisting chiefly of the fine detritus dust which is found, either in suspension in the water, or deposited as the thin upper layer of the bottom itself, lifting and spreading at times, in stormy weather.…’ Inspired by the results of Ostenfeld and Petersen, Van Goor (1919) started his investigation into the role of eelgrass in the food chain of the western Wadden Sea already in 1912. Van Goor corroborated Petersen’s conclusions, although he was also aware of the epiphytic micro-algae and small macro-algae as potential food for invertebrates and fish.

Research of the past decades into the role of seagrass in the estuarine food chain has moderated the role of these plants. Notwithstanding the physically overwhelming biomass of *Zostera*, the rate of primary production is low compared to phytoplankton. The low quality of detritus as food, together with numerous refractory components made its dominant role in the estuarine food web unlikely. The historic contribution (up to 1932) of sublittoral *Z. marina* to the production of organic matter in the Wadden Sea can be only very roughly approximated, because neither exact biomass nor primary production measurements from that period are available. Van den Hoek et al. (1979) estimated the primary production of eelgrass during its (waning)

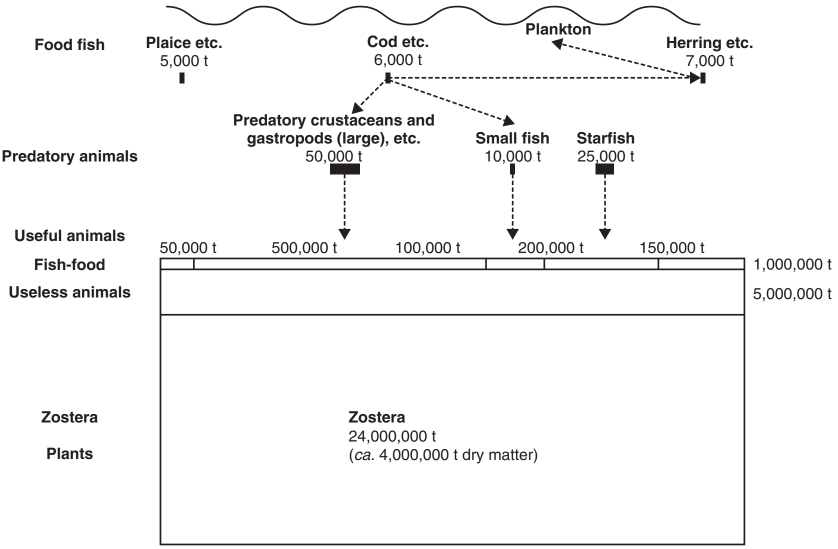

**Fig. 16.3** *Zostera* food web in Danish coastal waters supposed to be fuelled by *Zostera* detritus; for details see text (Petersen, 1918)

heydays in the western Wadden Sea (1920–1930) at 100–500 g C m$^{-2}$ year$^{-1}$ in *Zostera* stands, and calculated for the entire Dutch Western Wadden Sea at 10–50 g C m$^{-2}$ year$^{-1}$. Phytoplankton primary production measurements of the early decades of the 20th century are not available. Phytoplankton production in the western Wadden Sea ranged from 40 g C m$^{-2}$ year$^{-1}$ in the 1950s to 150 g C m$^{-2}$ year $^{-1}$ in the mid-1960s to over 500 g in 1986, and down in the 1990s to 400 g (measured with different, only partially comparable methods), e.g. stimulated by the load of dissolved inorganic phosphate from Lake IJssel, a reservoir supplied by Rhine water. Microphytobenthos production added another 100–200 g C m$^{-2}$ year$^{-1}$ to the budget (De Jonge et al., 1996). Nienhuis (1992a, b) calculated the net primary production of the eelgrass community of Grevelingen lagoon at 110 g C m$^{-2}$ year$^{-1}$, averaged over the top-years 1978 and 1979. Phytoplankton added 40 g C m$^{-2}$ year$^{-1}$ to the annual budget, and microphytobenthos another 50 g. These relatively low values for micro-algae are caused by the fact that the shallow water column (0–3 m) plays a dominant role in the calculations of primary production per unit area. Estimated for entire Grevelingen lagoon, phytoplankton dominated significantly (200 g C m$^{-2}$ year$^{-1}$), and eelgrass played only a subordinate role (40 g C m$^{-2}$ year$^{-1}$).

The prominent food link in Grevelingen lagoon, as well as in the Wadden Sea is dominated by phytoplankton to benthic filter-feeders such as mussels and cockles. The turnover rate of nutrients in these ecosystems is determined by the filtering capacity of benthic filter-feeders. Theoretically, every 5–10 days the entire volume of water of the estuaries mentioned circulates through the filtering apparatus of the suspension feeders. Filter-feeders act as natural controllers of eutrophication processes; they transfer organic material from the water column onto the bottom sediments. Moreover, they accelerate the regeneration of nutrients from the deposited particulate organic matter, thereby enhancing the primary production of phytoplankton, as was assumed for Grevelingen lagoon (De Vries et al., 1996). Phytoplankton and microphytobenthos dominate the food web of estuarine habitats, but in very dense and shallow eelgrass stands this plant is prevailing in terms of biomass and primary production. The weed, however, appears to be rather inferior as a direct food source.

Petersen (1918) and Van Goor (1919) were in fact mainly interested in the possible role of eelgrass detritus in the food chain leading to commercial fishes. Research in the dense eelgrass beds in Grevelingen lagoon led Nienhuis (1983b) to the conclusion that it is not so much the fish that feed directly on the bulk of eelgrass, but that lots of other animals are taking advantage of this biomass, viz. crustaceans and birds. It was estimated that *ca*. 10% of the eelgrass net production was directly consumed by the isopod *Idotea chelipes* (6%) and by herbivorous birds (4%). Bird numbers reflect the status of the eelgrass beds remarkably clearly. The maximum above-ground biomass of *Z. marina* in July/August, over the period 1973–1988, showed a significant correlation with the number of bird-days of herbivorous birds (*Fulica atra*, *Anas penelope*, *A. platyrhynchos*, *A. crecca*, *Branta bernicla*, *Cygnus olor*) in the subsequent autumn and winter (Fig. 16.4). Although the birds only consume 4% of the annual above-ground primary production of eelgrass, that is 11% of the peak standing crop in August, the correlation between the numbers of birds present and their obligate food source is significant. Obviously a large part of the peak standing crop is not available to the birds because it is beyond the reach of their bills, or because the timing of the birds does not match with maximum standing stock of the macrophytes: when most birds arrive later in the year, the larger part of the seagrass biomass has already decomposed. For Grevelingen lagoon it has been estimated that mallard and widgeon were the most prominent consumers of eelgrass (seeds); brent geese were far less conspicuous (Nienhuis and Groenendijk, 1986). In the literature brent geese are often associated with tidal populations of eelgrass, and it is not surprising that the numbers of brent geese in the Wadden Sea significantly decreased after the wasting disease decimated the weed population (Brouwer, 1936).

Nienhuis (1983b) traced the role of *Idotea chelipes* – eelgrass consumer preeminently – in the food chain of Grevelingen lagoon, and concluded that via the secondary consumers, the gobies *Pomatoschistus microps* and *P. minutes*, and the tertiary consumers like the eel, *Anguilla anguilla*, and the cormorant, *Phalacrocorax carbo*, less than 10% of the produced *Idotea*, and implicitly an indefinable small fraction of the original eelgrass, ends up in the top predators. The bulk of the annual eelgrass production (90%) becomes detritus, and by continuous leaching or organic substances, and by fragmentation to fine and ultra-fine particles, the particulate organic material turns into excellent nuclei for the colonisation by micro-organisms (Fig. 16.5). Indeed the ‘fine detritus dust’ (Petersen, 1918) finally fuels part of the estuarine food chain, but far more complicated and far less prominent as assumed a century ago (compare Figs. 16.3 and 16.5).

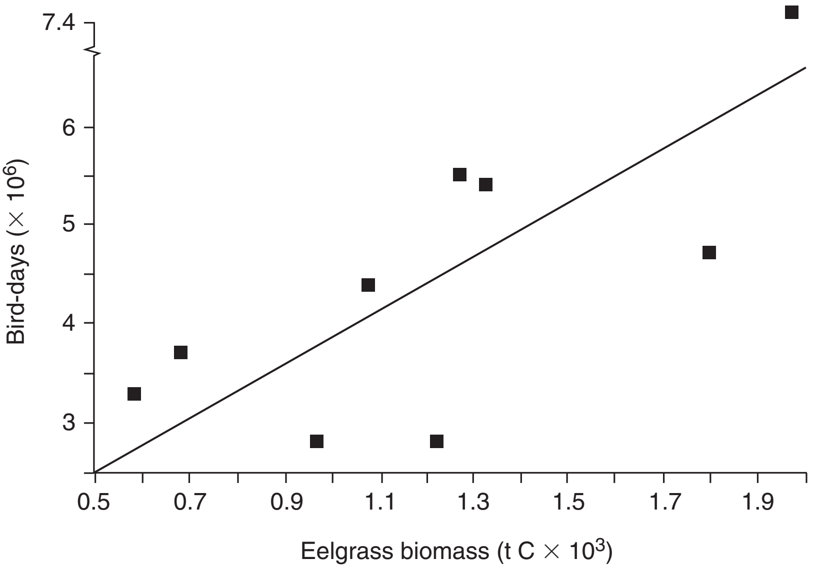

**Fig. 16.4** Relation between maximum above-ground biomass of *Zostera marina* in Grevelingen lagoon during July–August, and the number of bird-days of herbivorous waterfowl (i.e. the numbers of birds times the number of days the birds feed on eelgrass) in the subsequent autumn and winter over the period 1973–1987. $n = 9$; $r = 0.74$; $p < 0.025$ (Nienhuis, 1992b)

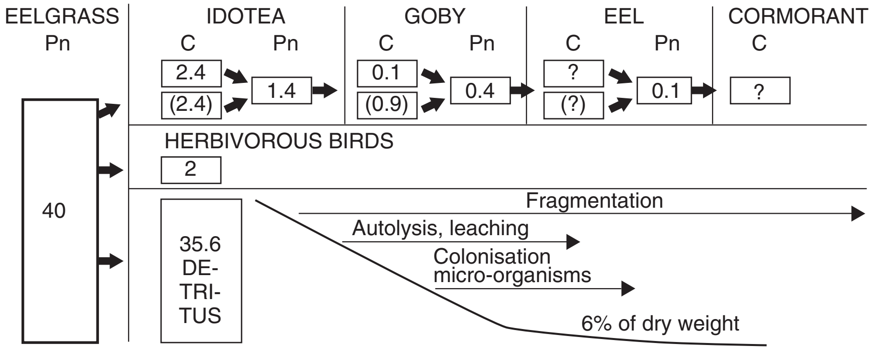

**Fig. 16.5** Average annual eelgrass food web in Grevelingen lagoon during the period 1978–1982. The production and use of eelgrass follow three major chains. The upper chain depicts the consumption by invertebrates (isopod *Idotea*), fish (gobies and eel) and birds (e.g. cormorants). The middle chain depicts the consumption by herbivorous birds. The lower chain depicts the reworking of detritus until *ca*. 6% refractory material remains. Pn = net primary or secondary production; C = consumption; data in grams ash-free dry weight per square metre per year. Data in brackets indicate other organic food sources than eelgrass (Adapted from Nienhuis, 1983b)

## 16.5 The Wasting Disease

### *16.5.1 Wasting Disease and the Eelgrass Population in the Wadden Sea*

Much has been published already about the causes of the almost total disappearance of eelgrass, *Z. marina*, from the N Atlantic coastal waters during 1930–1933. Stevens (1936) described the collapse of the sublittoral populations of the species as the most interesting biological phenomenon that he had ever observed. Numerous hypotheses have been launched to explain the fatal decrease of eelgrass, but none of them is able to explain satisfactorily the epidemic of the early 1930s. The strongest hypothesis regards an infectious disease caused by *Labyrinthula* spec., a marine slime mold (Mycetozoa), showing characteristic symptoms, viz. dark brown spots and streaks on the leaves, spreading in a longitudinal way over the leaf-blades (Muehlstein et al., 1988; Short et al., 1988). Being an historic fact, the wasting disease of the 1930s will always remain an ecological enigma. Local explanations, such as turbidity and light deficiency in the Dutch Wadden Sea (Giesen et al., 1990), may reduce the uncertainty, but the worldwide, synchronous occurrence of the eelgrass blight suggests a large-scale physical trigger.

Spierenburg (1933), a phytopathologist, wrote an early paper on the eelgrass wasting disease, in which she carefully hypothesised that bacteria might be responsible for the disease. Harmsen (1936) stressed the fact that the closure of the Afsluitdijk, a long seawall closing off a large area of tidal waters from the sea, on May 28, 1932, coincided with the outbreak of the wasting disease in the Dutch Wadden Sea, blurring the actual cause of the decline of the eelgrass population. In September 1932, A. van der Werff was asked by the director of the Netherlands Seagrass Industry to investigate the dramatic decline of eelgrass around the Island of Wieringen, and during the period 1932–1936 he did regular observations, both in the field and in the laboratory through the microscope. Van der Werff's (1938) interpretation of the causes of the disease is strongly influenced by the work of Renn (1934, 1935, 1937), who coined the epidemic as the 'wasting disease'. Renn postulated that the massive occurrence of spindle-shaped parasites in diseased eelgrass tissues from the East Coast of N. America, considered as belonging to the genus *Labyrinthula* (Mycetozoa), could be responsible for the outbreak of the blight. According to Van der Werff there was no doubt that the parasites found in *Zostera* of the American east coast were the same as those which were found in eelgrass ("attacking the chloroplasts and destroying the parenchyma") in the Netherlands during 1932.

Later on Van der Werff (1961, annotated manuscript of 1936) was more reluctant about the causes of the wasting disease. After presenting detailed photographs and drawings of *Labyrinthula* in *Zostera* cells, the final paragraph of this paper is clear enough: 'By no means I think, it is convincingly proved that the disease of *Zostera* is really caused by the described organism (*Labyrinthula*; PN). I only had in view to draw the attention to the fact that the organisms, found in 1932 by Renn and

Waksman in diseased *Zostera* plants, are also found in the same year in the Dutch eelgrass'. According to Den Hartog (1994) it is obvious that Van der Werff's original diagnosis was rather inadequate, because he and others, were unaware of the succession of micro-organisms in the diseased spots (*Labyrinthula* > bacteria > *Ophiobolus*). Momentary observations only give a static picture, and do not explain the time-dependent biological process behind the observations. Changes of 'cause' and 'effect' may thus easily creep in. This lack of knowledge caused considerable confusion and distracted the investigators from their main problem: discovering the cause of the disease (Nienhuis, 1994).

### *16.5.2 Wasting Disease in the Grevelingen Population?*

*Z. marina* found a very favourable habitat in the newly created Grevelingen lagoon, an estuary enclosed in 1971: the vegetation expanded in 8 years time from less than 1,000 ha to a population of 4,500 ha in 1978. In 1980 the lagoon experienced a major decline of the eelgrass distribution to less than 60% of the former surface area. Speculations about the cause of the dramatic decline in 1980 induced me to think that we should not overlook the possibility that the 'wasting disease' had struck again. Van der Werff, who studied the seagrass decline in the 1930s, was invited by me to come to the SW Delta in order to test the wasting disease hypothesis. He came on 2nd and 3rd September 1980. We went into the field together and we sampled specimens of *Z. marina* from various places, 'sick' material from Grevelingen lagoon, and 'healthy' plants from Oosterschelde estuary. The eelgrass material was transported in ambient water to the laboratory in Yerseke, and was kept overnight under cool conditions.

Van der Werff noticed the characteristic black spots and streaks under the binocular microscope, he prepared microscopic slides and continued his observations. I looked 'over his shoulder' through the microscope, and we discussed the observed phenomena. I quote from my notebook on September 3, 1980: 'I observed "spindles" under the microscope, but these small bodies have a too rigid structure to be amoeboid. "Amoeboid plasmodia", as Van der Werff calls them, might as well be degenerated chloroplasts, cell granulae or artefacts. In a few cells I observed something amoeboid, but I am not convinced. Van der Werff finds "spindles", "plasmodia" and "granulae" in Grevelingen eelgrass material, mainly in rhizome-cells. The eelgrass plants are "sick" and "affected". In *Zostera* from the Oosterschelde estuary "spindles" and "plasmodia" are doubtful. The process of decay from "spindles", via "plasmodia" to "granules", as sketched by Van der Werff, is in my opinion a series of separate and independent cell bodies that cannot be linked together to a time-dependent process of decomposition' (Nienhuis, 1994).

Already on 20 September I received a long letter from Mr. Van der Werff, from which I will quote some (translated) passages: 'The past 18 days were mainly dedicated to the *Zostera* research. I surprisingly discovered that we, misled by the investigations of Waksman and Tutin who indicated an infestation by Protozoa, presumably searched into the wrong direction. It has always been strange that free-living developmental stages of *Labyrinthula* were never found, in order to explain the massive attack of *Zostera* and the subsequent rapid dieback. Neither in the plankton nor on the surface of the *Zostera* plants these stages were found. The "plasmodium" and the "spindles" were in fact only found in affected and dead cells'.

Then Van der Werff unfolded a new theory, in which green algae of the Chaetophoraceae, living as epiphytes and endophytes on *Zostera*-plants are held responsible for the eelgrass decline. He gives pages-long, very detailed descriptions of what he saw under the microscope, including coloured drawings. I quote: 'Both algae, presumably belonging to one species of the Chaetophoraceae live as parasites on and in *Zostera* cells, but also in algae like *Chaetomorpha*. As far as I have been able to check my statements these Chaetophoraceae are certainly an important cause of the dieback of eelgrass, may be even the ultimate cause. Owing to lack of sufficient live material in 1932, I was not able to reach the same conclusion as I have reached now, and consequently I supported the *Labyrinthula* hypothesis. The numerous possibilities for infection and the enormous number of parasitic germ-cells of the Chaetophoraceae do explain now the rate of distribution of the disease, and hence the sudden dieback of *Zostera*. Further research is needed to explore the hypothesis that a change in environmental conditions will induce the development of the green algae. The study should preferably cover the entire life-cycle of the Chaetophoracean alga'.

The green algae belonging to the Chaetophoraceae, and growing abundantly on old and decaying parts of eelgrass, as prostrate epiphytes and endophytes. Parasitic aquatic Chaetophoracean green algae are unknown. There are indeed terrestrial Chaetophorales that live parasitic on leaves and stems of tropical plants, e.g. the 'red rust of tea' in SE Asia, one of the most serious diseases to which the tea-plant (*Thea sinensis*) is exposed (Fritsch, 1965).

### *16.5.3 Recent Ideas*

With regard to the causes of the epidemic, it has never been convincingly proved in the European literature that *Labyrinthula* was a widespread and synchronously occurring agent in *Z. marina* populations of the E Atlantic, during the wasting epidemic in the 1930s. The most likely cause in Europe has to be searched among the pathogenic bacteria (Fischer-Piette et al., 1932; Heim and Lami, 1933). The American literature gives more evidence for the *Labyrinthula* hypothesis; it was Renn (1934, 1935, 1937) who repeatedly demonstrated that a *Labyrinthula* species was closely connected to the epidemic destruction of eelgrass on the W Atlantic coast. Further studies on *Labyrinthula* in the laboratory by Young (1937, 1943) proved that *L. macrocystis* Cienkowski could easily be isolated from *Z. marina* plants. The vegetative plasmodium of the parasite comprises a mass of filaments forming an intricate lacy network of which fusiform, red to yellowish coloured cell bodies, called spindles, migrate, either as single individuals or as individuals massed in ropelike aggregates.

In the meantime, the 1930's massive wasting disease is still an ecological and historical enigma, despite several attractive theories (cf. Den Hartog, 1987, 1996). The discussion on the causes of the wasting disease among *Z. marina* continued, and obtained new momentum owing to the recent decline of the species along the E and W coast of the Atlantic (Short et al., 1986, 1988; Den Hartog, 1996). Muehlstein et al., (1991) identified *Labyrinthula zosterae* as the causative agent of wasting disease. They appear to be positive about the cause of the disease: the blackened, necrotic streaks and patches symptomatic of the 1930's wasting disease reported by Renn (1936) are identical to symptoms found on eelgrass, occurring along the Atlantic west coast. Den Hartog (1987, 1996) is far more careful in his deductions: the presented documentation of wasting-disease like patterns in *Z. marina* over a long period, prior to the outbreak of the disastrous epidemic in the 1930s, suggests that wasting disease is an inconspicuous but widespread endemic phenomenon normally occurring in eelgrass beds. However, when an eelgrass population comes under environmental stress by natural and or anthropogenic causes, this may lead to weakening of the host and create the right conditions for the parasitic organism to multiply and to expand; in extreme situations this may lead to an epidemic. Already Young (1943) came to that same conclusion: because of its wide natural host range *Labyrinthula* may be omnipresent, waiting but for the ideal ecological changes around *Zostera*, or for some physiological change within the *Zostera*-plant to permit invasion. In this context Van de Werff's new theory about the infection with Chaetophoraceae should also be taken seriously. These lines of thought may help to explain the local outbreaks of wasting disease, but not the triggering of the 1930's epidemic which struck eelgrass in the whole N Atlantic.

## 16.6 The Economic Use of Eelgrass

### *16.6.1 Wadden Sea*

The island of Wieringen, a Pleistocene boulder-clay deposit in an area of Holocene peat (Fig. 16.1), increasingly experienced flooding from the 11th century onwards. Consequently, the inhabitants were forced to build levees, in order to protect their properties. The first primitive levees were made of sods of peat and clay, later on reinforced with heaps of eelgrass (*Z. marina*). In a document dating back to 1319 a ‘dyke of weed’ is mentioned for the first time (www.pagowirense.nl). Plenty of weed was available on the tidal flats or washed ashore. The dried weed had the advantage that it compacted to a hard almost stone-like mass that was rather resistant to wave attack, but the steep wall of weed based on clay, could easily be undermined. Continuous repair and improvements were therefore necessary (Fig. 16.6).

Cross sections of the ‘Westfriese Omringdijk’ have been made, from which the history of the dyke could be reconstructed (see Fig. 4.5). In the 13th century the oldest dyke was built from sods of peat (4.5 m high). After compacting of the peat the dyke was heightened and reinforced with clay in the 14th century. In the first half of

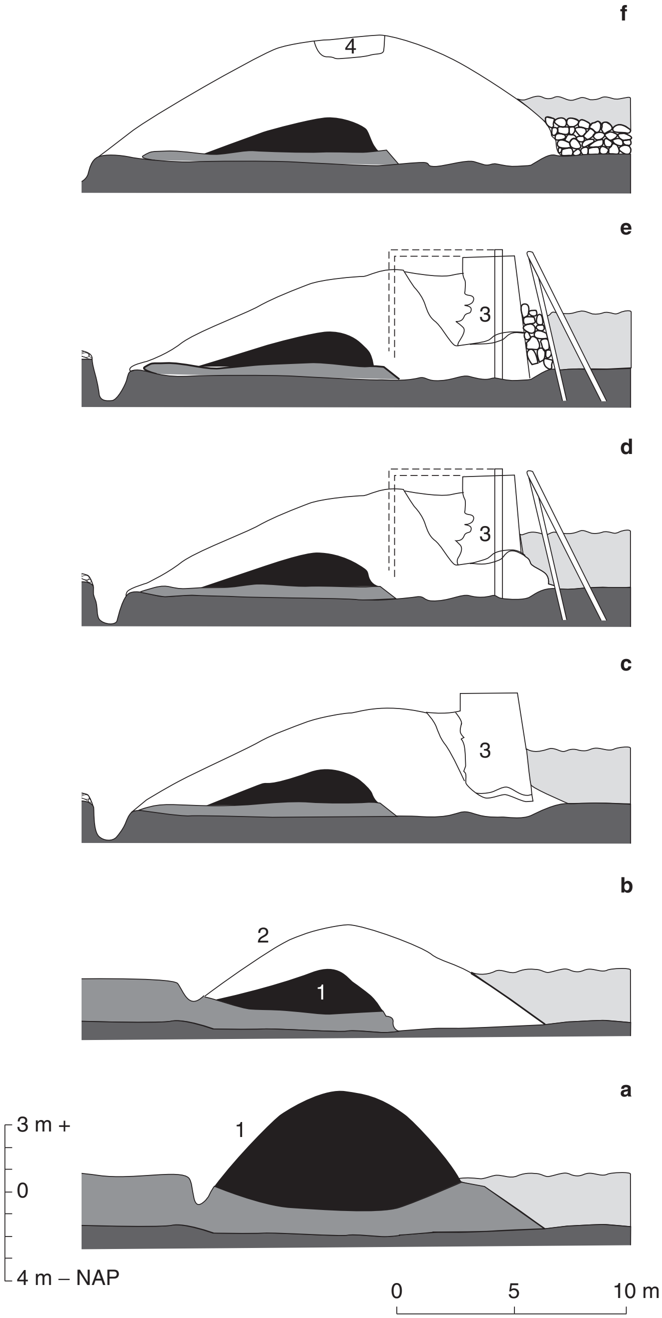

**Fig. 16.6** Development of the Westfriese Omringdijk (geographic position in Fig. 4.5). Light grey (on the right) = tidal Zuiderzee; dark grey = ground level, peat-moor; black = thrown up embankment of sods of peat, gradually subsiding and oxidising in the course of time; white = clay; 3 in white = wall of compacted eelgrass at the seaward side of the dyke, later on reinforced with wooden poles, and still later with stones. A = 13th century core of the dyke consisting of sods of peat; B = 14th century, dyke reinforced and heightened with clay; C-D-E = 15th to 18th century, embankment of compacted eelgrass, later on reinforced with poles and natural stones; F = 20th century, 4 = paved footpath in present day dyke; the clay dyke is covered with grass (Knol, 1991b)

the 16th century a 2 m high wall of eelgrass was constructed at the seaward side of the dyke, later on reinforced with wooden poles. From the 17th century onwards this wooden revetment was attacked and finally destroyed by *Teredo navalis*, the shipworm, a boring lamellibranch mollusc, which caused great damage to the wooden revetments of Delta dykes (cf. Chapter 4). Gradually the foot of the weakened dykes was protected with natural stones, which were brought in over long distances (Knol, 1991b). Now in 2007 the durability of eelgrass as building material is still visible in the field: a remnant of the original 'weed dyke' at the south side of Wieringen, at Hoelm, has survived the centuries, and is now a provincial monument.

Houttuyn (1793) rephrased a publication of Linnaeus (as cited in Van Geel and Borger, 2002), who mentioned the use of *Z. marina* along the northern European coasts as stuffing for cushions and mattresses, as manure on the fields and for gaining salt. Weed use in the Delta pointed particularly to the covering and maintaining of seawalls, and to the thatching of roofs. Historic sources indicate the usefulness of burnt eelgrass as a source of salt. Descriptions of that process from the 16th and 18th century have been handed down from Sleeswijk-Holstein (a county north of the Netherlands), but the gaining of salt from eelgrass deposits in the Rhine–Meuse Delta remains unclear. Van Geel and Borger (2002) reported the results of an excavation north of Kolhorn (at the Westfriese Omringdijk) in 1995, indicating the large-scale manufacturing of saline peat. The medieval exploitation and the subsequent compacting of the raised-bogs close to the sea made these areas vulnerable for floods from the sea (in Chapter 3 this phenomenon has been explained for the SW Delta). It is hypothesised that the rising sea gradually invaded the peat-marshes, and that subsequent marine deposits formed a good habitat for the growth of eelgrass. Holes at the Kolhorn excavation filled with burnt plant material contained also eelgrass remnants reduced to ashes.

In the past centuries eelgrass was widespread over the entire Wadden Sea, but in the Dutch Eastern Wadden Sea, and in the German Wadden Sea an eelgrass industry did not exist, apparently because extensive sublittoral *Zostera* meadows were lacking. However, in the German Northern Wadden Sea an important sublittoral *Z. marina* stand has been described for the coast of the isle of Sylt. It is likely that relatively high water transparency and the available vast shallow sublittoral flats promoted the development of the sublittoral *Zostera* meadows in the Dutch Western Wadden Sea and the German Northern Wadden Sea. The intervening stretch of Wadden Sea lacked sublittoral *Z. marina* beds probably as a result of its more turbid water, caused by the inflowing rivers, and by the larger tidal amplitudes resulting in stronger tidal currents (Nienhuis, 1996).

More to the north, in the Danish fjords and the Kategat, luxurious vegetations of eelgrass existed (Petersen, 1918). Cottam (1934) reported that eelgrass ash was found at ancient village sites in Denmark; the plants were probably burned for salt and soda, although on islands poor in wood they may have been burned merely for warmth. They provided bedding for the people as stuffing for mattresses and bed ticks, and for their domestic animals, as a substitute for straw. Coastal Danes did use *Zostera* for a tough and long-lasting roof thatch as well. Centuries later eelgrass fibres found use as an upholstery material, as packing and as a compost for fertiliser. During World War I large quantities of eelgrass have been exported to Germany for the stuffing of mattresses for soldiers and for the trenches on the battle fields as a substitute for straw; because of the shortage of genuine cotton, the Germans substituted eelgrass fibre for it in the manufacture of nitrocellulose (Cottam, 1934). In the first decades of the 20th century the United States even imported eelgrass for use in insulation for sound and temperature control. The legendary Titanic had a large cargo of Dutch eelgrass on board (Mets, 1914).

Extensive descriptions about harvesting and preparing Dutch eelgrass and its applications are known from the 18th and 19th century (Martinet, 1782; Sloet tot Oldhuis, 1855). Loose-lying and floating weed was sampled on the tidal flats, and brought ashore by everyone interested in a small additional income. Dried eelgrass was used as roofing, as packing material and to stuff mattresses and cushions. Dried eelgrass was also used as isolation material. In 2007, during the restoration of the medieval castle Waardenburg on the river Waal, a layer of eelgrass has been revealed in between the boards of a ceiling of one of the living rooms of the castle, presumably placed in position in the mid-19th century. Although the age of the eelgrass should at least be one and half century, it looked like it was dried yesterday. Eelgrass got its economic importance around the isle of Wieringen in the 19th century, when the ‘weed fishery’ systematically developed into a source of main income for fishermen; the income was unreliable because frost, which could destroy an entire bed in one winter, wind and tides decided about the size of the harvest notwithstanding the ‘Annual Prayer Day for Weed Harvest’.

In 1826 the first industrial application, i.e. the mowing of weed, started on Wieringen. The quality of the weed became an important issue: mown weed was of better quality than plant material that was sampled loose lying on the tidal flats. It was green and fresh and had far less adhered sand and silt. The harvesting of weed and the manufacturing of the stuff was labour-intensive work. From June to August the harvesters mowed the plants with an elongated scythe while standing breast-deep in the tidal water at half tide. The mown grass was sampled in nets, loaded in boats, brought ashore, and then spread in the fields to dry partially. The plants died and the colour changed then from green to dark brown. Then the harvested plants were soaked during some time in freshwater ditches, and the desalinated stuff was brought on land again. A process that required great care: a too short period in freshwater did remove the hygroscopic salt inadequately, and a too long period in the ditches turned the weed into a black stuff because of the attached iron ore. Once on land the grass was dried thoroughly, transported to warehouses where it was pressed in a specific weed-press into bales for shipment to manufacturers of the derivative products (www.pagowirense.nl; Bremer, 1980). Around 1870, the Dutch government still appreciated the importance of the plants and ordered the Oudemans Committee to map the most important seagrass beds in northern Holland (Oudemans et al., 1870). The Netherlands Weed Industry in the early 20th century comprised a considerable number of companies, providing a living to 500 families. Figure 16.7 shows the fleet of the ‘weed mowers’ in the Wadden Sea around 1900. The men are standing hip-deep in the water, armed with a scythe. In front of the troop stands the boss, fully dressed with hat, collar and tie.

From 1920 onwards preparations were made for the construction of the Afsluitdijk, and the changing tidal currents and patterns of sedimentation considerably reduced the surface area of the eelgrass beds. The closure of the Afsluitdijk in 1932, disconnecting the IJsselmeer from the marine tidal Wadden Sea, meant the end of the weed industry: the beds were largely lost and they never recovered. The official version was that eelgrass beds died owing to the ‘wasting disease’, but insiders attributed the wane to the execution of the coastal engineering works.

### *16.6.2 SW Delta*

In contrast to the situation in the western Wadden Sea there is no literature at my disposal on abundant occurrence of eelgrass in the SW Delta. *Z. marina* did occur in the estuaries but in inconspicuous amounts. Before the execution of the Delta Works the Oosterschelde and the Grevelingen harboured some hundreds of hectares of the narrow-leaved form of eelgrass. The broad-leaved form, so common in the subtidal northern localities, has only been described from a very small local population in the SW Delta. It can be hypothesised that the potential subtidal habitats in the SW Delta for the broad-leaved form were too exposed and too instable to allow the growth of the mud-*Zostera*. What about pre- and proto-historic use of eelgrass in the southern delta? Leenders (www.bart.nl/leenders) published an extensive survey of peat exploitation and the gaining of salt from freshwater peat that became saturated with saltwater (cf. Chapter 2). But nowhere in his report he mentioned the occurrence or use of eelgrass (cf. Van Geel and Borger, 2002 in the NW Delta).

**Fig. 16.7** Fleet of ‘weed mowers’ (*Zostera marina*) in the Wadden Sea around 1900. (Photograph Zuiderzeemuseum Enkhuizen in Van der Werff, 1961)

A unique population of eelgrass in the Delta waters occurred for a very short time in the newly created Grevelingen lagoon, comprising a production of tens of thousands of tonnes per year (see Section 16.3). The developing ecosystem was appreciated by nature conservationists, but the amount of eelgrass piling up along the shores of the lagoon was seen as a mere nuisance. Eelgrass is a slow decomposer, and the decaying plant mass piled up in autumn along the shores of Grevelingen lagoon, a stinking heap of weed, driven together by the prevailing westerly winds in the eastern part of the lagoon. Partly anaerobic accumulations of eelgrass, with a core of compacted, refractory plant parts, lead to the formation of some hectares of marshland, and became gradually overgrown with higher plants. Tourists, recreation employers and fishermen experienced the piling up of eelgrass as a nuisance. Tourists simply hated the stench of rotting organic debris. Recreation entrepreneurs had to face the problem that the gullies towards their yachting harbours filled with eelgrass detritus, which had to be scooped out from time to time. Fishermen complained about the streamers of eelgrass clogging their nets. Among tourists and fishermen, however, the masses of eelgrass evoked double feelings. Scuba-divers enjoyed the exciting underwater world of gobies, sand-smelts, nesting three-spine sticklebacks, grazing isopods and amphipods, tunicates, and many other invertebrates. Fishermen soon discovered that the seagrass beds harboured plenty of (expensive) eel. In contrast to the 18th and 19th century in the northern Wadden Sea and Zuiderzee, there was no economic interest at all in the seagrass itself. I remember that in the late 1970s a Belgian manufacturer of traditional lace pillows needed an annual supply of 2,000 kg per year. His needs could be easily satisfied, free of charge. The ‘problem’ resolved itself: concomitant with the vanishing eelgrass ecosystem the piled up detritus also disappeared.

## 16.7 Restoration of Lost Eelgrass Beds

The Dutch government is currently aiming at restoration of seagrass beds in the Wadden Sea, in order to ‘restore natural values’. Seagrass beds form a specific estuarine ecosystem, and are important as a nursery, shelter and feeding area for many fish and invertebrate species (e.g. van Goor, 1919; Van Katwijk, 2000). The availability of potential seagrass habitats is the first condition for successful restoration. In the Wadden Sea, a distinction can be made in a high intertidal and a low intertidal and subtidal zone of potential habitats along the tidal gradient, each suitable for differing forms of *Z. marina*. The higher zone is inhabited by dominantly narrow-leaved annual plants. When emerged, the plants lay flat on the moist sediment, in this way protected from desiccation. The lower zone (that disappeared during the 1930s) was inhabited by broad-leaved perennial plants, with their stiff upright sheaths being vulnerable to desiccation during low tide, but more resistant to high water dynamics than the narrow-leaved form. Between the two seagrass zones, a bare zone existed, where the habitat was too dynamic for the narrow-leaved form, and the periods of emergence last too long for the broad-leaved form. The upper limit for *Z. marina* growth in the high zone is delineated by the degree of desiccation, whereas the low zone is limited by light availability and/or strong currents due to the presence of tidal channels.

Important factors influencing the occurrence of *Z. marina* are: turbidity of the water leading to a low level of available sunlight, water and sediment dynamics, degree of desiccation during low tide, nutrient level and salinity. High nutrient loads negatively effect *Z. marina*; high salinity stresses the plants (cf. Grevelingen), which will aggravate the negative effects of high nutrient loads. Disturbance by fisheries activities, in the Wadden Sea mainly caused by shellfish exploitation, acts locally and indiscriminately in both *Z. marina* zones (e.g. de Jonge and De Jong, 2002).

In the Wadden Sea, physical dynamics, disturbance by humans and nutrient loads have all increased during the 20th century, whereas the overall salinity has remained equal. As a result, the area suitable for re-establishment of *Z. marina* has decreased. However, since the end of the 1980s, turbidity levels in the Wadden Sea have decreased, nutrients loads have decreased or stabilised, and shellfish fisheries are prohibited in some areas, which makes restoration of *Z. marina* beds now more feasible than 20 years ago.

Ecosystems in a natural coastal gradient often protect each other: sublittoral *Z. marina* beds can protect mussel beds against storms, mussel beds can provide shelter to mid-littoral *Z. marina* and *Z. noltii* populations (Fig. 16.8), as is evidenced by the extension of *Z. marina* beds towards the mussel beds at low water level. The shelter that is provided by mussel beds will additionally stimulate the accumulation of fine sediments and a lesser degree of desiccation of the sediment, which is favourable to *Z. marina*. Inturn, the presence of mid-littoral *Z. marina* and *Z. noltii* beds can reduce erosion of salt marshes, as they accumulate sediments, in this way providing a natural barrier in front of the salt marsh edge (Van Katwijk, 2000).

The coherence of these zones makes restoration of one of the separate zones less feasible than simultaneous restoration of the complete zonation. However, restoration of the sublittoral *Z. marina* beds is complex, as the broad-leaved form that is suitable for this zone probably has become extinct or very rare in the Wadden Sea. A practical solution would be to first restore stable mussel beds, as these can maintain themselves without sublittoral seagrass. Secondly, mid-littoral *Z. marina* and *Z. noltii* can be transplanted, which will probably reduce salt marsh erosion. Finally, to complete the gradient, sublittoral *Z. marina* can be transplanted, provided a suitable donor population has been found. Recently experiments have started to test the hypotheses formulated above (Bos et al., 2007).

## 16.8 Conclusions

- The estuarine gradient between the Wadden Sea and the Zuiderzee was lost in 1932, and the gradient between the North Sea and the estuaries in the SW Delta was largely annihilated between 1964 and 1986.
- The disappearance of the vast sublittoral *Z. marina* beds in the western Wadden Sea and in Grevelingen lagoon is an interesting example of large-scale effects on estuarine ecosystems by human interference. Eelgrass played a dominant role

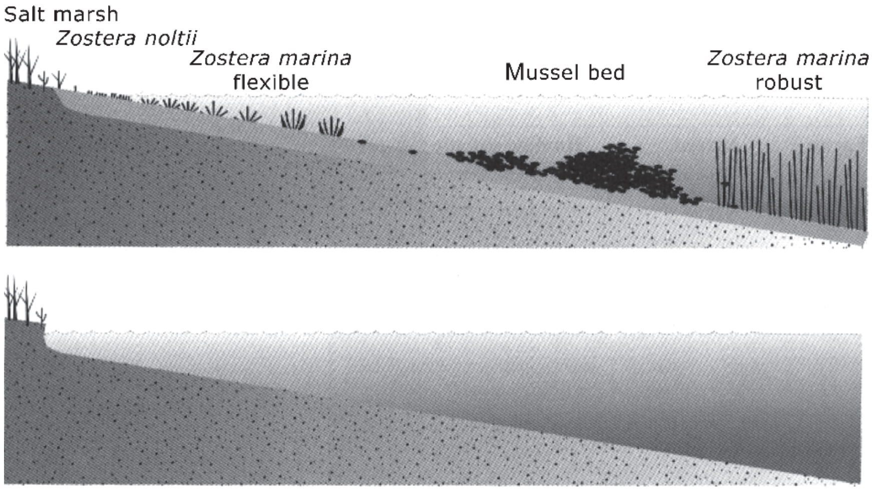

**Fig. 16.8** Upper panel: zoning of communities protecting each other from deep to shallow localities against water dynamics and erosion. Lower panel: disappearance of the intertidal and subtidal communities will cause erosion of sand- and mudflats sediments and salt marsh edges (Van Katwijk, 2000)

in estuarine habitats of the Delta: a complete ecosystem including algae, invertebrates, fish and bird species has vanished.

- A comparison of the views on the role of eelgrass in the estuarine food web in the early 20th century, and the present-day field and experimental evidence, demonstrates the changed views on food web functioning, and particularly on the role of detritus.
- It has never been convincingly proved that *Labyrinthula* was a widespread and synchronously occurring agent in *Z. marina* populations of the E Atlantic, during the wasting epidemic in the 1930s. Lack of knowledge in the 1930s in the eelgrass case in the Wadden Sea demonstrates that changes of 'cause' and 'effect' could easily blur scientific conclusions.
- From the Middle Ages onwards eelgrass biomass in the Wadden Sea was used for the building of embankments and for many other purposes. The large eelgrass biomass in the Grevelingen lagoon in the period 1970–1990 was economically considered as a nuisance. This illustrates the changed views on the economic use of a water-plant in environmental history.
- Notwithstanding the considerably increased scientific knowledge, the causes of the extinction of eelgrass in Grevelingen lagoon, after two decades (1971–1991) of wax and wane, are not clear. The most likely causal factor that annihilated the ecosystem was the constant high salinity of the water, and the associated low concentrations of silicate and ammonium as limiting factors for growth.
- Rehabilitation of eelgrass beds demands 'old fashioned' estuarine conditions: low turbidity, moderate nutrient load, fluctuating salinities, and the cease of specific disturbing fisheries activities.

# Chapter 17
# Exotics and Invasions of Plants and Animals

## 17.1 Introduction

Biological invasions, associated with human activities, are recognised as one of the major elements of global changes in biodiversity. In the course of millennia many natural dispersal barriers for both terrestrial and aquatic species have been lifted by man, resulting in global mixing of previously isolated biota. The ecological history of the Rhine–Meuse Delta cannot be documented without ample attention for the significance of alien species. To some extent, ecological history is the history of biological invasions, the story of constant change in biodiversity. Consequently, besides in this chapter, in several other chapters (e.g. Chapters 15, 18 and 19), the issue of exotics and biological invasions will be dealt with.

Invasive species are topical subjects, if we consider the number of publications appearing on the market as standard for the public interest. Starting with Elton's classic milestone in 1958 (fifth reprint in 2000), the number of books on invasive species hardly increased over the decades, until in the late 1980s the number of publications grew to 6–8 per year, followed by a steady increase until in recent years a flood of issues appeared. In the period 1999–2002 annually 23 to 27 books were published (in English, I presume) on biological invasions (Simberloff, 2004). The apparently unpredictable nature of some invasions intrigues scientists and lay citizens alike. But it is not so much the changes in natural ecosystems that water managers care about, but rather the enormous economic costs associated with biological invasions.

The aim of this chapter is to provide an overview of the invasions of exotic biota to the Rhine–Meuse Delta. Invasions of non-native plants and animals to and from western Europe have occurred from prehistoric times onwards, and consequently drastic restrictions in the framework of this chapter are necessary. The focus is on recent (19th and 20th century) invasions in freshwater ecosystems. Estuarine-marine invasions are mainly left out, except for those species that penetrate the brackish environment from the freshwater habitat. Massive marine invasions changing the outlook of complete estuarine ecosystems, such as the Japanese oyster, *Crassotrea gigas*, and the American razor clam, *Ensis americanus*, belong to the domain of the environmental history of marine ecosystems (cf. Lotze et al.,

P.H. Nienhuis, *Environmental History of the Rhine—Meuse Delta,*

2005). The question, what makes invasions successful, is particularly intriguing because disturbed river basins are coined as ecosystems most susceptible to the introduction of exotics. The evidence for causal factors underlying invasion phenomena is scanty, however, and only recently substantiated. Climate change has all too eagerly been coined as explanatory for various invasion patterns, induced by the recently aroused interest for that phenomenon. In this chapter data are given on migration routes and range extensions of tens of species, invertebrates and higher plants. The Ponto-Caspian connection will be highlighted, along which a considerable number of southeastern European and Asian invertebrates entered the western European lowland rivers. The chapter comprises four case studies, two bivalve mollusc species from the Black Sea and the Adriatic Sea, and two plant species from America. The contrast between two historic introductions from the 19th century, and two recent invasions, is worked out.

## 17.2 The History of Invasions

Europe is known as the source continent for many invaders all over the world, as well as a recipient continent for thousands of non-indigenous species from the four winds. Since prehistoric times, European inland and coastal waters have been exposed to invasions of aquatic plant and animal species. Non-native plants can be divided into two categories: archaeophytes, imported before the end of the Middle Ages, and neophytes, introduced after the year 1500. This time limit fits roughly also for aquatic non-indigenous species. The term ‘native’ is used for organisms which have been native to a particular geographical area in historical times. However, the concept of ‘historical times’ itself is rarely defined in the literature. For most non-indigenous species, there is evidence of their origin, either from archaeological, historical, ecological or biogeographical sources. It is often difficult, however, to determine whether a species is native or introduced. Perhaps thousands of introductions date far back in time and their invasion history will be unclear forever. The early intentional transfers at the dawn of agriculture and stocking of waters with edible species remain unknown and nameless. The numbers of transfers of species has increased dramatically over time, and in the 20th century the introduction of non-indigenous species became a global issue (Leppäkoski et al., 2002).

It is often said that invasions are less of a problem in Europe (and China) than in America, because agriculture started in the Old World, and many, but far from all, invasive problems follow the introduction of European agriculture and fisheries practice. What is undoubtedly true is that invasions are seen as much more of a threat in the USA than in Europe. Next to imperilled species, invaders are indeed considered as the second threat to biodiversity in the USA (Wilcove et al., 1998). In Europe pollution, agricultural practices, urbanisation and other threats are probably at least as important (Williamson, 1999). The perception of an invasion obviously differs between the USA and Europe, because Europeans are familiar with invasions for thousands of years. In semi-natural landscapes in river basins, where man dominates the scene, the high ‘invasibility’ of disturbed areas, the inherent susceptibility to invasions, has become an accepted cultural-historic phenomenon. It is often depending on the definition of ‘exotic’ whether a species should be seen as alien or invader. The rule of 10:10 of Williamson (1996) is illustrative in this context. According to this rule only 10% of the introduced species will maintain itself in the newly colonised habitat, and of these 10% only 10% (i.e. one in a hundred) will develop into a real pest. But this rule of thumb is debatable; other data suggest that introduced species increasingly establish populations in man-dominated landscapes (Kowarik, 1995). European river basins in particular have a long history of human disturbance, and it might be that river managers have become laconic with regard to newcomers, until the societal costs to fight or to eradicate the intruder become unacceptably high.

## 17.3 What Makes an Invasion Successful?

Invasive populations are favoured by a combination of environmental factors, like the presence of vacant ‘Eltonian’ niches, habitat modification and disturbance before and during invasion. Environmental disturbance is coined as a major factor in mediating invasions, and the possible linkage of ecosystem resistance to invasive species merits serious attention. Decreasing levels of ‘disturbance’ may decrease chances of invasions. However, there is also some evidence that lack of disturbance does not preclude invasions, and that ‘undisturbed’ ecosystems are also invaded. Decreasing water pollution resulting in lowering of disturbance may actually make coastal systems and rivers more prone to invasions. The link between the biodiversity of communities and their susceptibility to invasions remains to be proved, but invasive abilities are known to increase in case a community lacks certain species, which ought to be present under optimum conditions (Van der Velde et al., 2002, 2006b).

Range extensions by non-indigenous species can be sustained by anthropogenic modification of habitats as well. Pollution calamities in rivers, for example, can create empty niches, giving invasive species an opportunity to colonise, and persistent river pollution may create such empty habitats. On the other hand, water quality improvement may also give newcomers the opportunity to settle. In fact, new species may be pre-adapted because of the similarity between their ancestral habitat and the new habitat to be colonised, resulting in relatively quick invasions. Indigenous species, however, may be simultaneously weakened by the modifications occurring in their habitats. Sometimes new niches are exploited because equivalent indigenous species are simply not present (Bij de Vaate et al., 2002).

The introduction of a species will be successful if all abiotic and biotic factors in its new environment are appropriate to receive the species. This means that the species has to arrive in sufficient numbers at the right time. Successful invasions usually proceed through a number of successive stages. After the first introduction most species need time to establish populations before a shift in growth rate opens the opportunity to a more expansive phase of invasion. During the initial lag phase, an invasive species should be able to adapt to its new habitat, to reproduce and complete its life cycle. Finally, it will disperse within the new range, usually through gradual local dispersal, but sudden secondary introductions by human transport are also possible. Typically, the invader will exhibit exponential population growth, often to densities higher than those in its native range, followed by somewhat lower steady-state numbers (Kowarik, 1995; Bij de Vaate et al., 2002).

The hypothesis that invaders prefer simple or disturbed habitats cannot be tested anymore in river catchments in western Europe, where all ecosystems have been distorted by anthropogenic impact, already for centuries. Research in Australia, recently suffering from aggressive invaders, shows that indeed natural ecosystems without disturbance are not susceptible to invasive exotics (Lake and Leishman, 2004). In Europe the river Rhine illustrates perfectly the relation between ecosystem disturbance and biological invasions. The pollution of this open sewer by the Swiss and German chemical plants, the French potassium mines, and the pan-European agriculture was worst in the second half of the 20th century, (Chapters 12 and 13) and this have led to the disappearance of a considerable number of autochthonous species, which left open niches for invaders.

A major disturbance like the Sandoz accident in 1986 subsequently led to invasions by many new species, which reached unprecedented densities. The fact that filter-feeders are particularly abundant can be attributed to intense phytoplankton blooms due to eutrophication. In the turbid Rhine channel hardly any macrophyte vegetation is present, to compete with phytoplankton for nutrients. Water quality improvement led to a partial recovery of the original communities together with the establishment of previously disappeared and new invaders. Recolonisation after partial reduction of pollution in rivers modified by human activities seems to favour invaders more than indigenous species. These invaders then suppress the development of populations of indigenous species, although biodiversity will increase. Smaller water bodies are also subject to invasions mostly related to changes in water quality like eutrophication and organic pollution, or acidification in the case of moorland pools (Van der Velde et al., 2002)

Rivers and canals, as well as artificial lakes, are most prone to invasions. These systems are continuously subject to environmental stress and they offer empty niches for colonisation and/or re-colonisation. Man-made canals connect the large rivers with the ports of Amsterdam and Rotterdam; they link the rivers Meuse and Rhine and form a network all over the Delta, transporting river water towards areas outside the Rhine basin (Fig. 14.2). Consequently, the water quality of all these waters is very similar to that of the main rivers, and invaders adapted to these conditions have opportunities to spread all over the country. Many species have taken advantage of the stone banks and groynes constructed along rivers, where hard substrate was originally lacking (Van der Velde et al., 2002).

The correlations discussed above between invasibility and environmental factors do seldom reveal causal relations. Up to 95% of the research on invasive species is restricted to a description of their distribution and ecology, and only 5% is dealing with the underlying mechanisms. The questions remain: why do invaders prefer simple or disturbed habitats; why are generalists better invaders than specialists? Recent evidence suggests that the invasion success of exotic aquatic organisms, among other explanations, should be attributed to chemical communication between the invader and its environment, or the absence of plant-specific water-borne pathogens. About the role of plant-specific water-borne diseases very little is known, but they may as well decide about the potential for expansion of an exotic, as they do on land. A further possible explanation for the initial success of an invader could be that the escape from natural pathogens gives the invader a competitive advantage (Van der Putten, 2004).

Evidence that info-chemicals, chemicals secreted by a specific organism, resulting in a reaction in another organism, play an important role in aquatic ecosystems is increasing (Van Donk, 2002). It is known from land plants and saltwater plants that they can defend themselves against degradation by animals. Some land plants become toxic when they are consumed by herbivores, and this is considered a direct defence mechanism (Agrawal and Karban, 1999). Bolser et al. (1998) described a case of chemical communication between water plants and their potential consumers. Some freshwater plants are able to produce toxic substances, which make them less palatable for freshwater crawfish (*Procambarus clarkii*). It is, however, not clear whether this is an induced defence mechanism. Some water plants are able to eliminate their direct competitors for light, such as floating algae. This can be observed in the field: around specific water plants, like the water soldier, *Stratiotes aloides*, and stonewort (*Chara*) species the water is often remarkably clear and devoid of algal growth. Most likely chemicals secreted by the water plants are responsible for the elimination of algal growth. This phenomenon is called allelopathy (Van Donk, 2002).

## 17.4 Invasions of Invertebrates

### *17.4.1 Migration and Range Extensions*

The European seas and inland waters have been invaded by non-indigenous species belonging to several major biogeographic groups. The principal sources are (1) the Mediterranean fauna and flora expanding to the north, (2) the Ponto-Caspian element mainly from the Black Sea and the Caspian Sea, and (3) transoceanic or transcontinental invasions originating from remote areas, e.g. Southeast Asia, New Zealand, North and South America. There are examples of both deliberate and unintentional introductions among all these groups (Leppäkoski et al., 2002).

The introduction of non-indigenous aquatic organisms to Europe has resulted in populations of many species being established in self-sustaining communities outside their native ranges. Whilst some species are introduced deliberately to new areas for aquaculture and stocking purposes, shipping is often regarded as one of the main vectors for the accidental transfer of aquatic organisms. While intentional introductions are controlled more effectively than before through guidelines, national legislation and international conventions (Anonymous, 2002), the unintentional ones seem to be in steady increase as a result of the progressive globalisation of trade. The transport of large quantities of water in ballast tanks from one biogeographical region to another is considered to be one of the most important sources of unintentional intercontinental introductions. It has been estimated that the world's major cargo vessels transfer 3–12 billion tonnes of ballast water per year, and that on average 3,000–4,000 species are transported by ships each day (Gollasch, 1996).

However, not only transport of plants and animals by sea-going vessels is important for their spread, but also the construction of canals, connecting previously separated biogeographic regions. The interconnection of river basins has facilitated the range expansions of many species in Europe. Numerous canals have been constructed during the last two centuries in Europe as a result of industrial and economic activities. In Germany for example, approximately 1,770 km of all inland waterways are man-made (Tittizer and Krebs, 1996), and intentionally released or escaped specimens have taken advantage of the interconnected river basins.

Invaders have been and are entering western Europe in several ways and along various routes. In 1986 12% of the benthic animal species of the 850 km Rhine shipway were exotics. In terms of biomass, these species are even more important. The zebra mussel (*Dreissena polymorpha*) had the highest production rate among the invaders in 1986, followed by the snail *Potamopyrgus antipodarum*, the amphipods *Gammarus tigrinus* and *Orchestia cavimana*. This range has since changed. In 1994 the clams *Corbicula fluminea* and *Corbicula fluminalis* are on top, followed by the amphipods *Corophium curvispinum*, *G. tigrinus* and *Gammarus ischnus* (Kinzelbach, 1995).

Van der Velde et al. (2002) estimated the status of invasions in Delta freshwater systems, and gave some statistics. In freshwater ecosystems in the Netherlands 85 species have been identified as exotics, including 20 macrophytes, 40 macro-invertebrates and 25 fishes, amphibians and reptilians. The statistics date back to roughly 1800, and it is remarkable that the majority of the species have been reported recently, i.e. after 1950, from the lower Rhine and Meuse basins (see Table 17.1 for a selection of macro-invertebrates as listed by Bij de Vaate, 2003). Among the invaders a number of escapes from aquaria, aquaculture set-ups, botanical gardens and garden ponds are known, including intentional introductions, some as fish food (*G. tigrinus*), as human food or for angling (*Cyprinus carpio*, *Stizostedion lucioperca*) and some for the control of aquatic macrophytes, such as the grass carp (*Ctenopharyngodon idella*). All these categories together include 55 species (mostly plants, snails and vertebrates). Nine species (especially crabs and bivalves) have been transported by the timber trade or in ballast water, mostly as larvae that managed to invade freshwater bodies via international trade ports and dispersed upstream into the rivers. The remaining 21 invading species (20 macro-invertebrate species of which 12 from the Ponto-Caspian region) reached western Europe especially from the southern and eastern parts of Europe travelling via canals, either through dispersal by flow or attached to ship's hulls. Of the 85 species referred to above, 65% were introduced or escaped, 25% invaded via canals and 10% by the aid of sea-going ships. Of the invaders 34% originated from North America, 27% from eastern Europe and 14% from East Asia, hence from areas with a climate similar to that of western Europe. The remaining 25% originated mainly from southern Europe and South America. According to Van der Velde et al. (2002), approximately 20% of the invading species can be regarded as successful, either for a short period or for many years (compare the 'rule of ten'; Williamson, 1996).

**Table 17.1** Non-indigenous macro-invertebrates after 1950 reported from the Rhine–Meuse Delta (Bij de Vaate, 2003 and references therein)

| Species | Origin | Rhine Delta | Lower Meuse |
|---|---|---|---|
| **Tricladida** | | | |
| *Dendrocoelum romanodanubiale* | Eastern Europe | + | |
| *Dugesia tigrina* | North America | + | + |
| **Bivalvia** | | | |
| *Corbicula fluminalis* | Eastern Asia | + | + |
| *Corbicula fluminea* | Eastern Asia | + | + |
| *Musculium transversum* | North America | + | |
| **Gastropoda** | | | |
| *Helisoma nigricans* | North America | | |
| *Menetus dilatatus* | North America | | + |
| *Physella heterostropha* | North America | | + |
| *Potamopyrgus antipodarum* | New Zealand | + | + |
| **Annelida** | | | |
| *Branchyura sowerbyi* | Eastern Asia | + | + |
| *Caspiobdella fadejewi* | Eastern Europe | + | |
| *Hypania invalida* | Eastern Europe | + | |
| *Limnodrilus maumeensis* | North America | + | + |
| **Acari** | | | |
| *Caspihalacarus hyrcanus danubialis* | Eastern Europe | + | |
| **Crustacea** | | | |
| *Astacus leptodactylus* | Eastern Europe | + | |
| *Atyaephyra desmarestii* | Southern Europe | + | + |
| *Bythotrephes longimanus* | Northern and Eastern | + | + |
| *Chelicorophium curvispinum* | Eastern Europe | + | + |
| *Crangonyx pseudogracilis* | North America | + | |
| *Dikerogammarus villosus* | Eastern Europe | + | + |
| *Echinogammarus ischnus* | Eastern Europe | + | |
| *Echinogammarus trichiatus* | Eastern Europe | + | |
| *Gammarus tigrinus* | North America | + | + |
| *Hemimysis anomala* | Eastern Europe | + | |
| *Jaera istri* | Eastern Europe | + | |
| *Limnomysis benedeni* | Eastern Europe | + | + |
| *Orconectes limosus* | North America | + | + |
| *Procambarus clarkii* | North America | + | |

A considerable number of species in the river Rhine is euryhaline and/or thermophilous, and the animals belong to three trophic functional groups, viz. filter-feeders, omnivores and predators. Thermophilous organisms thrive in Rhine water because water temperatures in the river have increased some degrees centigrade over time as a result of thermal pollution, mainly by large by power plants (cf. Chapter 14). The salinity of Rhine water has considerably increased over the past decades (cf. Fig. 12.7), and this opened opportunities for brackish water invaders. The Ponto-Caspian macro-invertebrates which have expanded their range in Europe are euryhaline with an oligohaline preference. These species are endemic in estuarine areas of the Black Sea and the Caspian Sea with relatively low salinity (0.5–5‰). The colonisation success of the Ponto-Caspian macro-invertebrates that have invaded regions of Europe beyond their native range can be attributed to several biological features, viz. their tolerance for euryhaline conditions, their non-specific food preference and their protection of juveniles (Crustaceans). Relatively most successful in extending their territory in westward direction were the Crustaceans, and their expansion is considered to be attributable to their ease of mobility. Because of this, they easily can colonise a ship's hull to use it as a transport facility. This mechanism of spread is considered to be important in rivers for upstream migration. Once having arrived in a new area, their mobility enables them to spread quickly (Bij de Vaate, 2003).

### *17.4.2 The Ponto-Caspian Connection*

In the recent history of newcomers in the lower basins of the rivers Rhine and Meuse the Eurasian migration routes from east to west are the most interesting ones. In general, the interconnection of river basins in Europe resulted in corridors for aquatic animals to migrate actively or passively (e.g. by vessels in humid places or attached to the ship's hull) from one geographical region to another. Three important corridors for the range extension of Ponto-Caspian species can be identified (Fig. 17.1), the Northern corridor from the Volga River to the Baltic Sea, the Central corridor from the Dniepr River crossing central Europe to the Rhine basin, and the Southern corridor from the Danube River to the Rhine River via the interconnecting Main-Danube Canal (Bij de Vaate, 2003). Table 17.1 shows a number of macro-invertebrates that successfully colonised the Rhine basin along the three corridors mentioned. The Southern corridor appeared to be the most effective connection between the Black Sea and Caspian Sea and the Rhine basin.

Attempts were already made in the 19th century to connect the rivers Danube and Main (Rhine basin), but these largely failed. The Main-Danube Canal was opened in 1992, connecting the Rhine and Danube basins, and is today the most important link between the Black Sea area and western Europe for the immigration of Ponto-Caspian species. This corridor has served as a passageway for at least nine Ponto-Caspian macro-invertebrate species to the Rhine basin, which has led to dramatic changes in benthic communities in this river basin. Bij de Vaate (2003) estimated

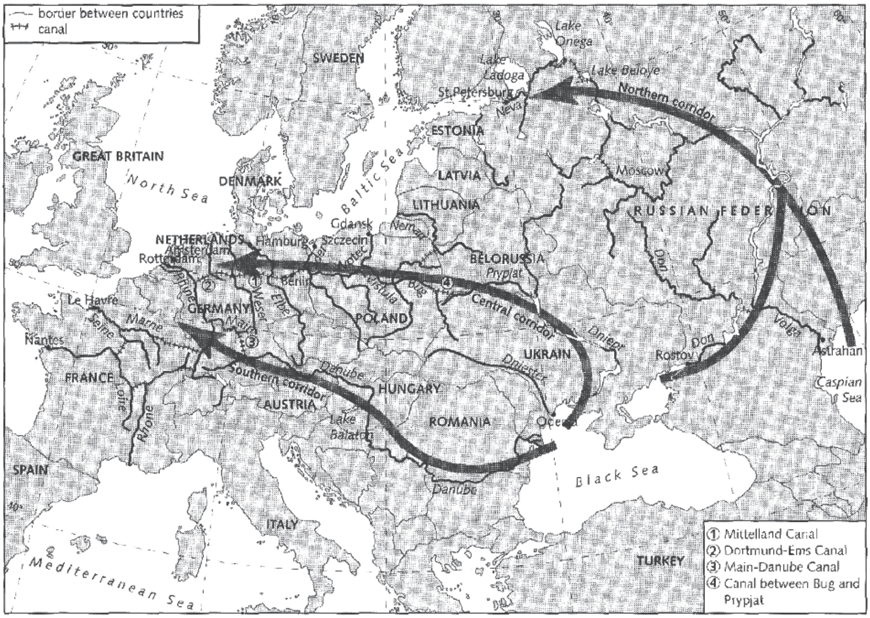

**Fig. 17.1** The migration corridors of Ponto-Caspian species in Europe; explanation see text (Bij de Vaate, 2003)

that in 1990 more than 95% of the maco-invertebrate density in the main distributaries of the Rhine Delta consisted of non-indigenous species of which the major part originated from the Ponto-Caspian area.

Field research by Van der Velde et al. (2002) from the 1980s onwards revealed the successive waves of colonisation on stones, the man-made riprap revetments and groynes along the banks of the river IJssel, one of the Rhine branches, and on artificial substrates along the banks of the river Rhine. The Ponto-Caspian bivalve *D. polymorpha*, a filter-feeder, and the North American flatworm *Dugesia tigrina*, a predator became the dominant species. These were later joined by the North American omnivorous Crustacean *G. tigrinus*. This community collapsed during the Sandoz accident in 1986, but later restored itself. In 1987, the Ponto-Caspian Crustacean species *Chelicorophium curvispinum*, a filter-feeder, started to grow and reached considerable densities from 1990 onwards, far into the Delta of the river Rhine (Platvoet and Pinkster, 1995). The amphipod has dominated the communities on the stones since then in densities of hundreds of thousands per square metres. It has radically altered the ecosystem by covering the stones with a layer of muddy tubes up to 4 cm thick, changing the conditions for colonisation completely. It caused a severe decline of *D. polymorpha* by smothering them under layers of mud and depriving their larvae of the bare stone surface they need (Van den Brink et al., 1993). Since 1995 a new Ponto-Caspian gammarid has appeared, *Dikerogammarus villosus*, showing various pigmentation patterns, consequently camouflaging its individuals between those of *D. polymorpha. D. villosus* turned out to be a predatory species, preying on the other macro-invertebrates inhabiting the stones, such as *G. tigrinus* and *C. curvispinum* (Van Riel et al., 2006). Since that time the densities of *C. curvispinum* have greatly decreased, although it remains the most numerous macro-invertebrate species on stones. The addition of bare stones to the river bank increased the biodiversity of the habitat. A species that benefited from the additional substrates is the Ponto-Caspian grazing isopod *Jaera istri*, discovered in 1997. In 1999 the stones were invaded by the triclad *Dendrocoelum romanodanubiale*, a predator, which completely replaced *D. tigrina* (Van der Velde et al., 2002).

The developments along the banks of the river IJssel roughly mirrored the picture described for the upper and middle Rhine in Germany (Haas et al., 2002). Figure 17.2 shows a semi-quantitative, schematic overview of the sudden and fast changes in abundance of a number of exotics over the period 1993–2001. Obviously, along the river continuum the connectivity for invaders is maximal, and the phenomena described for the lower Delta Rhine, appear also to be valid for sections of the upper and middle Rhine. There are, however, considerable differences between the invasibility of the river Rhine (at Lobith) and Meuse (at Grave): (1) The absolute numbers of macrofauna individuals over the period 1992–2003 in the Meuse were only one third of the numbers in the Rhine, notwithstanding the same method of sampling. (2) The share of indigenous species in the Meuse samples is considerably higher than in the Rhine. (3) The peak of *Cheliocorophium curvispinum* was considerably retarded in the river Meuse (1999–2003), compared to the Rhine (1991–1996). (4) The occurrence of *J. istri* in the Meuse is insignificant compared to the major peak in the Rhine (Greijdanus-Klaas and Reeze, 2005).

Invasions of exotics not only occurred on the stony revetments of the rivers, but also on the sandy and muddy bottom sediments. Following the improvements of the water quality of the Rhine, the Rhine sediments gradually became cleaner, and the improved habitat quality led to the introduction of two coexisting Asian clam species (*C. fluminalis* and C. *fluminea*) in *ca.*1990. These two bivalves have dominated the benthic communities in the main Rhine branches since then. The polychaete *Hypania invalida* was the next Ponto-Caspian invader to become very numerous in the sandy sediment. New species have also invaded the nekton of the river Rhine including fish species like *Aspius aspius* and the Ponto-Caspian mysids *Hemimysis anomala* and *Limnomysis benedeni*, which also invaded lakes. Fish species in the Rhine adapted their diet to this rapid turnover of invading species (Kelleher et al., 2000).

The drastic environmental changes caused by the enclosure of the Zuiderzee, now called IJsselmeer, the Volkerak-Zoommeer and the Haringvliet, changing saltwater and brackish estuaries into river-fed freshwater lakes, were very favourable for new invaders originating from the river Rhine. *D. polymorpha* presented a valuable food source for predator gammarids like *G. tigrinus*, for freshwater fish, like eel, and for waterfowl, like diving ducks. Recently, *D. villosus* invaded lake IJsselmeer, exterminating *G. tigrinus* as well as *Gammarus duebeni*. Gravel, clay and sand extraction pits, which have been excavated along the rivers, have also

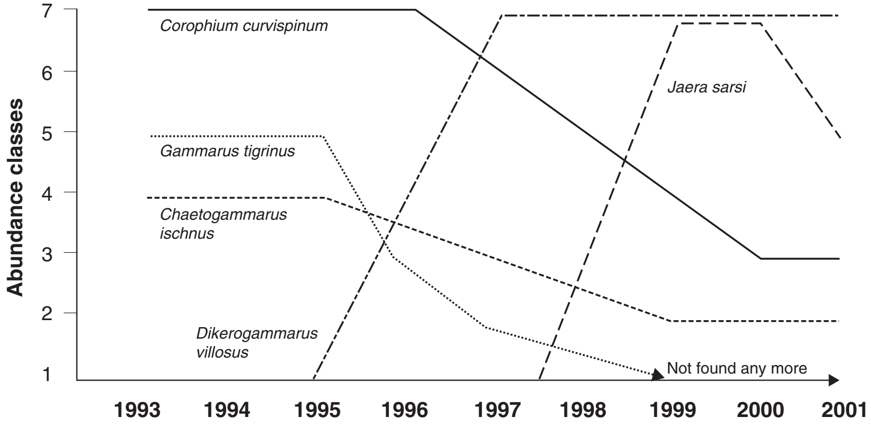

**Fig. 17.2** Schematic overview of changes in abundance classes of four exotic amphipod and one isopod species (*Jaera sarsi*) in the upper and middle Rhine, during the period 1993–2001. Abundance classes: (1) = very rare (<2); (2) = rare (2–10 $m^{-2}$); (3) = moderate (11–50 $m^{-2}$; (4) = regular (51–200 $m^{-2}$); (5) = common (201–500 $m^{-2}$); (6) = frequent (501–1,000 $m^{-2}$); (7) = abundant (>1,000 $m^{-2}$). Data based on animals collected from riprap, regularly sampled from 16 stations in the channel of the Rhine, between Mannheim and Koblenz (Haas et al., 2002). From the discussion among taxonomists (www.macrofauna.web-log.nl) I conclude that *Jaera sarsi* is the same species as *Jaera istri*

created new opportunities for rapid colonisers like the molluscs *D. polymorpha* and *P. antipodarum*. The construction of large drinking water reservoirs in the Biesbosch area, storing river water from the Meuse, has also led to invasions of various crustacean macro-invertebrates (Van der Velde et al., 2000).

## 17.5 Case Studies of Introduced Bivalve Species

I will deal with two case studies into an eco-historic context, the zebra mussel, *D. polymorpha*, introduced in 1826, and the Asiatic clam, *Corbicula*, introduced in 1990. Both molluscs are freshwater species with a slight tolerance for brackish conditions.

### *17.5.1 Dreissena polymorpha*

The zebra mussel, *D. polymorpha*, is a well-known historic invader. This bivalve, formerly endemic to the Ponto-Caspian region, reached western Europe along several routes. Its native range includes the Black, Caspian and Azov seas. It extended its area northwards in the 18th century via the river Volga by means of shipping routes and canals linking the rivers to Lithuania. From there it was dispersed by the Baltic timber trade to the harbours of northern Germany, London (1824) and Amsterdam (1826), from where it dispersed land inwards. The species was recorded for the first time in the Netherlands in 1826. At the same time, westward dispersal from the Ponto-Caspian area also took place via a central corridor connecting the rivers Dnieper, Vistula, Oder, Elbe and Rhine. *D. polymorpha* was able to spread across Europe, due to the expansion of canal networks. At present, the zebra mussel is one of the most commonly occurring mussel species in the large rivers, lakes and canals of large parts of Europe. It is common in the entire country of the Netherlands, particularly in river catchments, in running water and stagnant water. It does not occur in the brackish southwestern estuarine area and on the Wadden Islands. The zebra mussel is a quick coloniser: when the habitat is suitable, the species will invade it within a few years, as was demonstrated after the closure of the IJsselmeer in 1932, the Brielse Meer in 1950 and the Volkerak-Zoommeer in 1987 (Gittenberger et al., 1998).

Who is *D. polymorpha*? A small bivalve, up to 35 mm in length, living in clumps, firmly attached to the substrate with byssal threads in estuarine and lacustrine environments, *D. polymorpha* usually inhabits littoral and sublittoral zones in localities where substrata and food are available, and ice abrasion is absent. Mesotrophic and eutrophic waters, particularly freshwater lakes are the preferred habitat, although slightly brackish conditions can be tolerated. The availability of suitable substratum appears to be one of the principal factors affecting the spatial distribution of *Dreissena*. Abundant zebra mussel populations have been recorded on stones and gravel, but also on plants (reeds, flooded forests, submerged aquatic plants), shells and valves of molluscs. Other living organisms like bivalves and crustaceans can also be colonised by *Dreissena*. The greatest abundances of the mollusc have been observed on artificial substrata; abundances on water pipes of power plants can reach hundreds of thousands of individuals per square metres (Schloesser et al., 1994).

Thanks to the extensive literature *D. polymorpha* has a well-defined ecological profile. The species lives at water depths of 0.1–60 m, at salinities of 0–6‰ and at an oxygen saturation of 50–100% (Schloesser et al., 1994). It is an obligate seston-feeder, filtration normally occurs at a temperature of 5–30°C, and at a pH of 8–9. The most preferable suspension concentration is 3–15 mg $l^{-1}$, and the most preferable particle size is 4–50 mm. Filtration rate is strongly dependent on body weight and can be described by the equation $F = 85.5 W 0.6$, where $F$ = rate of filtration (water clearance) expressed in millilitres per individual per hour; and $W$ = wet weight of body in grams. The net result is a sedimentation of previously suspended organic matter in the form of faeces and pseudofaeces, shifting energy and nutrient balances from the pelagic to the benthic zone. Increase in water clarity favours increased photosynthesis by rooted aquatic macrophytes. Removal of green algae gives Cyanobacteria a competitive advantage, as zebra mussels will stop filtering in the presence of Cyanobacteria. Besides rejecting blue-green algae, mussels usually reject mats of diatoms, big-sized colonies of green alga, and emulsions of organic liquids. Under the most favourable living conditions (e.g. heated reservoirs), annual production of over 2 kg $m^{-2}$ have been found, and production can exceed biomass (P/B ratio) by 2–6 times (Schloesser et al., 1994; McMahon, 1996).

The zebra mussel was introduced in the USA, into lake St. Clair probably in 1985. The species spread quickly over North America, where it is found now in the Great Lakes and all of the major river drainages east of the Rocky Mountains. In the past 25 years the biology of *D. polymorpha* has been studied by hundreds of biologists, and symposium volumes and bibliographies (e.g. Schloesser et al., 1994; Mackie et al., 1989; McMahon, 1996; Nalepa and Schloesser, 1993) reveal an ecological profile of the zebra mussel that is far more clear than the profile of *Corbicula* species (see Section 17.5.2).The avalanche of data indicates the enormous public interest in the bivalve that became in 10 years time one of the most serious biofouling pests in the USA (Claudi and Macki, 1994). This species has been nominated as among 100 of the 'World's Worst' invaders. The economic loss in the USA from zebra mussel invasion by 1991 alone was estimated at over three billion dollars (Williamson, 1996). Over the years it became clear that the sudden and major impact of zebra mussel had devastating economic consequences. Great losses of revenues were calculated from industries during closure for cleanout of intake pipes, cost of control in municipal water treatment plants and power plants and local cost of removal of biofouling from docks and boat hulls. Particularly in the American literature (Claudi and Macki, 1994) numerous control methods are displayed to remove mussels from substrates or kill them within infested water intakes or on fouled man-made substrates; none of these methods is useful for control in the wild.

This is indeed different from Europe, where the impact of this invader is negligible (Williamson, 1996). Certainly, there are biofouling impacts mentioned in Europe also, concerning clogging of water intake pipes, industrial plants and power plants, and fouling of ships' hulls and navigational constructions. But it is remarkable that in the lower basins of Rhine and Meuse *D. polymorpha* in fact never is considered as a 'pest', as it is in the USA. In contrast, in the recent Dutch literature the favourable characteristics of the zebra mussels get ample attention instead of the negative ones. I will come to that later.

After the zebra mussel invasion in the lower Rhine and Meuse catchment in the early 1800s, the species became a common bivalve in most large rivers, lakes and canals. Suitable habitat increased considerably during the 20th century because several estuaries were converted into freshwater lakes by damming them from the sea. For example, the IJsselmeer was created in 1932 by closing off the former Zuiderzee from the sea. Chloride concentrations gradually dropped from 6 g $l^{-1}$ in 1932 to 0.6 g $l^{-1}$ in 1935 and to 0.4 g $l^{-1}$ in 1936. Prior to 1932, zebra mussels, which commonly occurred in the river Rhine, were restricted to the river IJssel delta where it emptied into the Zuiderzee. Zebra mussels were recorded in IJsselmeer in 1936; by 1937 zebra mussels were found in the northern part of the lake and by 1938 they were distributed throughout the lake (Fig. 17.3; Smit et al., 1992).

Severe pollution probably caused the disappearance of zebra mussels from the lower Rhine in the late 1960s (Wolff, 1969). Annual monitoring of macrozoobenthos on stone blocks of the river Rhine IJssel, one of the branches of the river Rhine, has given insight into the re-colonisation by zebra mussels, which started in the second

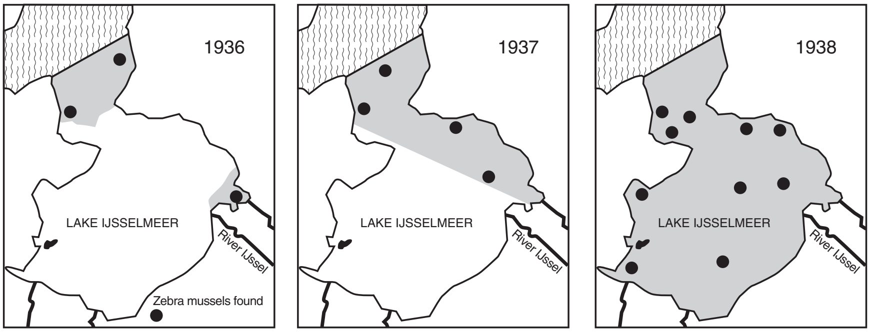

**Fig. 17.3** Colonisation of lake IJsselmeer by *Dreissena polymorpha* after the closure of the Zuiderzee in 1932 (Smit et al., 1992, based on data from Van Benthem Jutting, 1954). For the position of IJsselmeer see Fig. 5.7)

half of the 1970s. While the zebra mussel was absent from the lower Rhine, a considerable reproductive population was present in Lake Constance at the Swiss–German border. Re-colonisation took place the same time (late 1970s) that improvements in water quality of the river Rhine occurred (Smit et al., 1992) (cf. Chapter 12).

The population of *D. polymorpha* in IJsselmeer in the 1980s reached densities to about 10,000 individuals per square metre. Their distribution was strongly related to the amount of solid substrate available; stones and riprap, but also water plants and other bivalves (*Anodonta cygnea*) served as substrate. In IJsselmeer almost all these materials were overgrown with zebra mussels, which means that substrate was the limiting factor in the distribution and density of the species (Bij de Vaate, 1991).

Van Eerden (1997) studied the impact of wintering diving ducks on their food supply in the IJsselmeer during the period 1975–1995. The IJsselmeer is a major foraging site on the trans-European flyway of migratory birds, harbouring a total winter maximum of more than 300,000 birds. Zebra mussels are common in the lake at depths of 1–6 m, with an average biomass of 400–700 g fresh weight per square metre, all within potential reach of the avian predators. Four species of benthivorous diving ducks, tufted duck (*Aythya fuligula*), pochard (*Aythya farina*), scaup (*Aythya marila*), and goldeneye (*Bucephala clangula*), and to a far lesser extent the coot (*Fulica atra*), almost completely depend on the zebra mussel as a food source. The overall biomass reduction owing to diving ducks predation was 5–22%. Locally diving ducks were able to remove more than 80% of the mussel stock.

The establishment and expansion of *D. polymorpha* in western Europe during the second half of the 19th and the 20th century has had a marked positive effect on the number of wintering diving ducks, not only in the IJsselmeer. Predation can be very substantial with the highest values of more than 95% of the mussel population consumed in the river Rhine area in Switzerland, but winter losses are often considerably lower (Suter, 1982).

Smit et al. (1992) investigated the fast zebra mussel colonisation in lake Volkerakmeer and Zoommeer, waters that were dammed from the Oosterschelde estuary in April 1987 (Fig. 10.6). As a result of the enclosure, chloride concentrations dropped from 10 g $l^{-1}$ in April 1987 to 0.8 g $l^{-1}$ in September 1987. The main source of zebra mussel veliger larvae entering lake Volkerakmeer, was water from the rivers Rhine and Meuse that reached the lake through the Volkerak sluices. The first adult mussels were reported in lake Volkerakmeer in October 1987. Colonisation probably occurred in September, because veligers only occur in plankton of both rivers between May and September. In January 1988 *Dreissena* had spread throughout lake Volkerakmeer. Lake Zoommeer, which had somewhat higher chloride concentrations (0.7 g $l^{-1}$) compared to Lake Volkerakmeer (0.3–0.4 g $l^{-1}$) was colonised 2 years later; these higher chloride concentrations probably slowed the colonisation process. Monthly monitoring of nine sampling sites indicated that both density and biomass increased to peak levels 2 years after settlement, bridging a distance of more than 50 km. Gradually, however, the numbers of zebra mussels decreased over the years: serious eutrophication resulted in smothering of all hard substrates.

The Veluwerandmeren, which originated after the reclamation of the Flevopolders in the period 1957–1968 (Fig. 5.7), were invaded by the zebra mussel in a few years time – the common pattern – and the mussels became a common component in the new lakes. But at the end of the 1960s the mussel drastically decreased in numbers, caused by the increasing eutrophication of the lakes. All solid substrates became burrowed under a layer of died off algae, detritus and silt, and oxygen concentrations close to the bottom dropped dramatically. In the meantime the favourable characteristic of the zebra mussel to clean polluted water was discovered in the Delta. Zebra mussels' filtering capacities cause an increase of water transparency due to elimination of seston and, as a result, create more favourable conditions for benthic plants. Because the availability of hard substrates is essential for the settlement of zebra mussel, experiments were done in the Veluwemeer to add new substrate – dead shells of bivalves – to the bottom of the lake. These experiments, however, were not successful, mainly because the new substrates were in no time covered with organic material. Around 1994 *Dreissena* spontaneously returned to the lake, as a result of the improvement of the water quality, owing to a drastic decrease of the discharges of eutrofied and polluted water, and hence less deposition of organic material on the bottom. In the Volkerak-Zoommeer the same type of experiment was done in 1990 and later years, and tonnes of shells were dumped into the lake in order to enlarge the area suitable for zebra mussel colonisation. But here the same phenomena were noticed as in Veluwemeer: continuing eutrophication, deposition of fine material on hard substrates, hampered the come back of *Dreissena* (Noordhuis et al., 1994).

As said before, *D. polymorpha* was already introduced in the Netherlands in the early 19th century. It is possible to make a reconstruction of the past distribution of the species, and, moreover, early authors made notice of the nuisance caused by the zebra mussel. The oldest records are from Waardenburg (1827), as cited by Van Benthem Jutting, 1943), who described the mollusc from the Haarlemmermeer and the Oude Rijn at Leiden, and from Herklots (1859), as cited by Van Benthem Jutting (1943) who mentioned that the mollusc abundantly occurred in rivers and water courses. Obviously, in the late 19th century *Dreissena* became a nuisance for water companies. Hugo de Vries (1890) observed zebra mussels in the dark depots of the Rotterdam waterworks. In those days zebra mussel growth caused a great deal of trouble in plants for the supply of drinking water, where large numbers grew attached to the inner side of water transport pipes for unfiltered water (review of the literature by Van Benthem Jutting, 1943). Later on Van Benthem Jutting (1952) toned down earlier statements from the literature: ‘Damage by bivalves has never been recorded in the Netherlands. It must be admitted that in some waterworks now and than some nuisance is caused by *Dreissena polymorpha*, when this mussel attaches itself in large clumps on the filters or in the transport pipes of the unfiltered water. With the use of a rake or a scoop the trouble is to be remedied’ (p. 128). In his famous treatise of freshwater hydrobiology in the Netherlands, Redeke (1948) characterised *D. polymorpha* as that ‘pretty little mussel’, common in rivers and large inland waters, and rare or absent in brooks and ditches, tolerating slightly brackish conditions. Hana (1952), a field biologist, who did many observations along the shores of the IJsselmeer in the 1940s, made a few notes on the zebra mussel. He is surprised by the quick invasion of *D. polymorpha* in the new freshwater lake, as witnessed by dark flood-mark of the shells of the newcomer, the zebra mussels, separated from the washed ashore zone of snow-white shells of the original inhabitants of the Zuiderzee, the large bivalves.

No panic in the older Dutch literature. No ‘devastating economic consequences’ (as mentioned in the American literature). The reverse is true. The slightly negative to neutral attitude against the zebra mussel in the past, has changed into a positive attitude nowadays. The zebra mussel is a well-respected mollusc in Dutch freshwaters, from the viewpoint of nature conservation (feed for Red List birds), and as a fighter against eutrophication, resulting in increased transparency of the water, and enhancement of benthic ecosystem development.

### *17.5.2 Corbicula fluminalis and C. fluminea*

Asian clams of the genus *Corbicula* naturally occur in SE Asia, from southern Russia, via Korea, South China and Indonesia to Australia; the clam also occurs in tropical Africa. The date and means of introduction of the Asian clam in America is not known. Generally, the introduction of this species is attributed to Chinese immigrants who used Asian clams as food. The earliest verifiable record of this species in North America dates back to 1924 (Vancouver Island, British Columbia). From 1938 onwards *C. fluminea* was found everywhere in North America. Asian clams have had one of the most rapid range expansions of any non-indigenous species in North America. The species is now found in freshwaters throughout the USA. Estuarine populations have been reported for both west- and east coast bays. Because of their reproductive success and high infestation rate the species has become a serious pest throughout the USA, especially in irrigation and drainage canals as well as water distribution systems and industrial water use systems. The Asian clam is found in densities of thousands to tens of thousands of individuals per square metres (Lachner et al., 1970; Sinclair, 1971). In the USA *Corbicula* rouses from time to time apocalyptic headlines in the newspapers: ‘Here come the clams’. Kinzelbach (1995) a German expert on invasive species, is of the opinion that immigrating species should not be stigmatised by defending a pure autochthonous fauna. A plea for an unchangeable flora and fauna is an untenable viewpoint in an open society.

One of the main reasons of the fast distribution over the American continent is most likely the transport on barges containing river gravel. Such cargo is often shipped great distances and maintains sufficient humidity to allow the clams to survive. Other causes for the quick distribution are the intentional or accidental releases by recreational aquarists or fishermen who used the clam as bait (Lachner et al., 1970). *Corbicula* presumably entered Europe in ballast water of trade ships. The clam is expanding its range stream upwards, via the estuaries, and is known already in the early 1980s from Spain, Portugal and main rivers in France, and more recently from Germany (Rhine and tributaries). Records from Belgium and England are also known now (Gittenberger et al., 1998). Morphological and genetic data indicated that there are two distinct species, *C. fluminalis* and *C. fluminea* in material from the Rhine basin and the Rhone basin. In the Rhone basin a third species was recognised solely on genetic grounds (Renard et al., 2000). In 1990 *Corbicula* was recorded for the first time in the Netherlands (Bij de Vaate and Greijdanus-Klaas, 1990), followed by an avalanche of records in the river Rhine and river Meuse basins.

Obviously, among American specimens no distinction is made between *C. fluminalis* and *C. fluminea*. *C. fluminea* in America can tolerate salinities of up to 13‰ for short periods of time. In nature, in North America, Asian clams occur mostly in freshwaters, however, they have been reported from brackish and estuarine habitats, but are typically not as abundant in such habitats as in freshwater. Concerning specimens from the lower Rhine and Meuse, Gittenberger et al. (1998) distinguish between *C. fluminalis* and *C. fluminea* on morphological characteristics, but also on their salinity tolerance. Both species occur in running water, in sandy substrates, and *C. fluminalis* may also occur under brackish conditions, making its distribution most likely via ballast water of sea-going ships; from the estuaries the species should be able to migrate upstream. *C. fluminea* has a lower tolerance for elevated salinities, but incidental salinities of 13‰ (derived from American data) can be survived.

The Asian clam in America appears to tolerate low temperatures of 0–2°C over winter. Reproduction, on the other hand is limited by low temperatures, since veliger larvae are typically released at temperatures of 16°C and higher. Transposition of the temperature requirements of the Asian clam to the situation in European rivers means a serious restriction with regard to the northern distribution of *C. fluminea*. On places were cooling water is discharged into the river the species can maintain itself during winter. Very small individuals of several millimetre long are able to attach themselves with byssus threads to hard substrates, but when the bivalves have grown to young adults the byssus threads lose their function. Animals larger than 10 mm do not attach to hard substrates; they live burrowed in instable sand – and gravel sediments, in quickly running waters (Gittenberger et al., 1998). From observations in North America it is known that the sediment in *Corbicula*'s habitat should be aerobic, the animals are susceptible to low oxygen contents. Population densities may be strongly reduced by flooding, periods of low water, when the sediment is exposed to the air, and extreme fluctuations in temperature. The lethal maximum temperature is 33–34° C (McMahon, 1983).

Before 1990 *Corbicula* was only known from the Netherlands as fossil material from Pleistocene interglacial deposits, in cores from bore holes spread over the country, and washed ashore along the Westerschelde and at the beaches of Walcheren. The Dutch fossil material cannot easily be classified to one of the present species, and will as yet be identified as *Corbicula* species (Gittenberger et al., 1998). Now, in the early years of the 21st century, *Corbicula* is a very common genus in almost all Dutch rivers and in some canals. Gittenberger et al. (1998) stated that both species are equally common in river sediments. Along the river Waal this is certainly not the case. Here *C. fluminea* is far out the dominant species. On November 7, 2004 I took three random samples of 10 by 10 cm each from a dense layer of *Corbicula* shells washed ashore on a river beach (Waal near Rossum; location Fig. 5.5). The samples contained respectively 78, 76 and 81 *Corbicula* shells, and among them were respectively 3%, 4% and 6% shells of *C. fluminalis*. From those three samples the shells of *C. fluminalis* (maximum height 19 mm; maximum length 18 mm) are smaller than those of *C. fluminea* (maximum height 32 mm; maximum length 35 mm). In America, *C. fluminea* may grow to between 50 and 65 mm in shell length. However, individuals above 25 mm are typically uncommon (Lachner et al., 1970). The Dutch individuals do not reach the American dimensions: the largest specimen found by me had a length of 39 mm (Waal, April 2004). Gittenberger et al. (1998) give as maximum length 33 mm.

*C. fluminalis* and *C. fluminea* are suggested to occur as sympatric species in the same habitat, the sandy sediments in between the groynes. The dominance in numbers of shells, and the far greater range in sizes of the shells of *C. fluminea* washed ashore along the river Waal suggest at least a quantitative difference in occurrence in their joint habitat. Theoretically, coexistence of closely related species may occur through resource partitioning. Rajagopal et al. (2000) studied the reproductive biology of the two Asian clam species in the lower Rhine. Their observations show clear differences between the two *Corbicula* species with respect to reproductive strategy, spawning period and possibly food resources, which may explain their coexistence in the river Rhine. Rajagopal et al. (2000) hypothesised that other factors, like sediment preference and temperature and salinity tolerance, may also cause niche differentiation.

When we project the habitat requirements of the American populations of *C. fluminea* on the present distribution in the lower reaches of Rhine and Meuse, the species will have a bright future in the Netherlands. The full stretches of Rhine and Meuse, including the estuarine river mouths in the SW Netherlands (particularly for

**Fig. 17.4** A recent immigrant, the Asian clam is now the most dominant bivalve washed ashore along the river Waal (size of larger shells on average 25 mm). The mollusc lives in bottom sediments of the river channel (Photograph P.H. Nienhuis, November 7, 2004, Rossum, river Waal)

**Fig. 17.5** Long girdles of stranded shells of the Asian clam, marking high water levels and wave surge levels along the river Waal (Photograph P.H. Nienhuis, November 7, 2004, Rossum, river Waal)

*C. fluminalis*), are potential habitats for the clam. *Corbicula* already has completely changed the appearance of the beaches of the river Waal within 10 years. The Asian clam is far out the most dominant bivalve living in the bottom sediments, as evidenced by the billions of shells washed ashore (Fig. 17.4). Long girdles of stranded shells are marking high water levels and wave surge levels between the groynes (Fig. 17.5) and tens of metres long banks of shells, up to 30 cm high, are formed in shallow corners.

## 17.6 Invasions of Higher Plants

### *17.6.1 Migration and Range Extensions*

Pot (2002) classified roughly 470 species of higher plants as water plants and shore weeds, occurring in aquatic or semi-aquatic habitats in the Netherlands. Among them are 27 exotics defined as non-indigenous in Europe, and having a fast range of expansion (Table 17.2). Specific plant families like the Lemnaceae and Hydrocharitaceae, with many floating or submerged representatives, have a relatively high share in the number of invaders. Among the exotics are no grasses, sedges or rushes. The river environment is very susceptible to invaders. Almost all plant exotics that arrived here in the last 150 years occur in (very) eutrophic waters, preferably ditches, canals, small lakes, and rough herbage and brushwood vegetations along rivers and brooks. They seldom occur in the fast flowing water of the large rivers proper, but they flourish in the smaller backwaters connected to the rivers. A number of exotics mainly occur in relatively warm water, such as cooling water outlets of power plants, and garden ponds; they cannot stand frost during winter, and consequently they will never develop into a real nuisance. A number escaped from aquaria and garden ponds, either accidentally or on purpose. Among the plants classified by Pot (2002), 84 are on the Red List (2000) of rare and threatened species, and 18 species are protected by the Dutch Flora and Fauna Act. This indicates the enormous shifts in the natural flora over time. A species that was considered as ‘common’ in former centuries might now be ‘rare’ or ‘endangered’. Habitat loss and the deterioration of remaining habitats are most likely causes underlying this phenomenon.

The problem of invasive plants is taken far more serious in the Netherlands than the introduction of invasive animals. Polders and other low-lying areas in the Netherlands have been drained by an extensive system of ditches and water courses. A number of important functions of the surface water systems, such as drainage, fishing and navigation can all be seriously hampered by excessive plant growth and counteracting mechanical control has to be carried out once or twice a year. Since 1977, grass carp (*C. idella*) have been released to control macrophyte growth in the ditches. The Dutch fauna lacked such a herbivorous fish and the introduction of grass carp apparently fills an empty niche (see Chapters 8 and 15; De Nie, 1996).

**Table 17.2** Exotics among water plants and shore weeds in the Netherlands, derived from Pot (2002). Some details on country of origin from Van der Meijden (1990)

| Species | English name | Characteristics |
|---|---|---|
| *Lemna minuta* | Least duckweed | Since 1988; competitive |
| *Lemna turionifera* | | Since 2002 |
| *Azolla filiculoides* | Water fern | Early 20th century; North America |
| *Azolla mexicana* | Lesser water fern | End 19th century; North America |
| *Salvinia molesta* | | Warm water |
| *Pistia stratiotes* (W;P) | Water lettuce | Warm water; no frost |
| *Eichornia crassipes* (W;P) | Water hyacinth | Warm water; no frost |
| *Ludwigia grandiflora* | Water primrose willow | Since 1990 |
| *Ludwigia peploides* | | Recently in Belgium |
| *Hydrocotyle ranunculoides* | Floating pennywort | Very competitive; no import |
| *Nymphaea marliacea* (P) | | Pond weed |
| *Elodea nuttalli* | Nuttall's waterweed | Since 1941; common |
| *Elodea canadensis* | Canadian pondweed | Since 1859; North America |
| *Egeria densa* (P) | Greater pondweed | Pond weed; South America |
| *Lagarosiphon major* (P) | Curly waterweed | Pond weed; South Africa |
| *Crassula helmsii* | New Zeal. Pigmy weed | Rec. expanding; New Zealand |
| *Myriophyllum aquaticum* (W) | Parrot feather | Warm water; no severe frost |
| *Cabomba caroliniana* (W;P) | Fanwort | Warm water |
| *Potederia cordata* (P) | Pickerelweed | Pond weed; Africa |
| *Impatiens glandulifera* | Indian balsam | *ca.* 1930; India, Himalaya |
| *Bidens frondosa* | Beggar-ticks | North America |
| *Bidens connata* | Swamp beggar-ticks | North America |
| *Epilobium ciliatum* | American willow herb | North America |
| *Fallopia japonica* | Japanese bindweed | Japan |
| *Cotula coronopifolia* | Button weed | Since 18th century; S Africa |
| *Angelica archangelica* | | Since 1934 |
| *Oxycoccus macrocarpos* | American cranberry | North America |

Under 'characteristics' the year of introduction in the Netherlands, and country of origin.
W = prefer warmer water; P = escaped on purpose

Some of the exotic aquatic macrophytes grow to great densities. They profit from eutrophication, being adapted to a quick uptake of nutrients necessary for growth, and avoid turbidity by covering the water surface suppressing all other macrophyte growth. This type of vegetation consists of *Lemna*, *Salvinia* and *Azolla* species, particularly *A. mexicana* and *A. filiculoides*. The first species is an inhabitant of less polluted freshwater, and no fertile specimens have been recorded for the last century. It is nowadays so rare that it is on the Red List of endangered plant species in the Netherlands (Pot, 2002). *Azolla filiculoides* actually returned from extinction during the Pleistocene, a period in which European biodiversity impoverished. *A. filiculoides* is an inhabitant of fresh and slightly brackish eutrophic water and colours most ditches red in late summer and autumn, overgrowing duckweed covers. The species is thermophilous and therefore restricted to an Atlantic climate. It builds its population later in the year than the duckweed species. *Azolla* species live in symbiosis with a nitrogen-fixing Cyanobacterium

*Anabaena azollae* and are therefore efficient phosphorus removers in the absence of nitrate. Other thermophilous macrophyte species originate from the tropics, such as *Egeria densa*, *Eichhornia crassipes*, *Pistia stratiotes* and *Salvinia molesta*. In 1976 an invasion of a species that is a nuisance in many tropical areas, the water lettuce (*P. stratiotes*), was reported from the western part of the Netherlands. One night with temperatures below zero, however, killed all those plants over a distance of 17 km (Van der Velde et al., 2002).

*Myriophyllum aquaticum* is an exotic from South America; it grows in eutrophic, shallow water, and it may explosively expand in the warm late summer months. It cannot stand severe frost. *Myriophyllum spicatum* is the Eurasian water milfoil, living in eutrophic conditions, but also surviving in waters poor in phosphate. It is illustrative in this context that *M. spicatum* has become a nuisance in the USA, while it is not common in the Netherlands. The moss *Octodiceras fontanum*, growing on stone and wood is expanding its area in the large nutrient-rich rivers, canals and lakes. It grows from the water surface to depths of about 60 cm and is usually totally submerged in the same zone as *Dreissena polymorpha* (Pot, 2002).

### 17.6.2 Giants Among the Shore Weeds

In Chapter 18 a survey will be given of the vegetation of rushes, reed marshes and osier fields in the Biesbosch (location Fig. 5.5), until 1970 part of the freshwater tidal area of the rivers Rhine and Meuse. It was an inaccessible area, partly opened up and exploited by hard labour. Nowadays it is a National Park, many tourist come to the Biesbosch Museum in Werkendam, and make a tour by boat through the former tidal gullies. A walk through a former willow coppice, over neatly mown footpaths, provided with educational displays, gives you an idea 'how it must have been', without tidal movements, of course. The willows are regularly pollarded, the foot paths are bordered by a dense vegetation, dominated by a number of more than man-sized herbs. Invasive exotics, certainly not known to our ancestors, are *Angelica archangelica*, *Heracleum mantegazzianum* with its impressive white umbels, up to half a metre in diameter, and *Impatiens glandulifera*, showing a wealth of pink flowers. Literally hundreds of metres of tracks are fringed with the Indian balsam.

Another giant is *Urtica dioica*, the stinging nettle with its obnoxious stinging hairs, not to be touched without gloves. In flower guides the stinging nettle is identified as a plant that even non-botanists must learn to recognise so that they can give it a wide berth (Fitter, 1957). The contrast between the river landscape centuries ago, and the present-day view could not be sharper. Also the use of plants has dramatically changed over the centuries. In the past, trees and herbs from the Biesbosch, like willows, reed and rushes, had a considerable economic value, and the stinging nettle was literally used for every ailment (cf. Chapter 18).

Every plant may meet its match: even bigger than *A. achangelica* is the giant hogweed, *H. mantegazzianum*, that reaches a height of 3–4 m. Originally from Asia, and introduced to western Europe during the 19th century as an ornamental plant, giant hogweed, has become a persistent invasive weed along waterways, road verges, and footpaths, both in open land and forest gaps. The problem with this plant is that it evokes double feelings. Its most impressive characteristic is its massive size, and it is nice to see such an ornamental giant in your garden, growing and growing. But on the other hand it is considered as a public health hazard, at least in America (e.g. www.metrokc.gov/hogweed). Hogweed stems contain a clear, watery sap that squirts out when stems are broken or cut. This fluid has toxins that cause photo-dermatitis to people who are allergic to these chemicals. Skin contact followed by exposure to sunlight can produce painful, burning blisters that may develop into purplish or blackened scars. Horrendous pictures show burnt and deformed body parts. The Dutch information on the internet is more moderate. Giant hogweed is classified among the garden plants that may irritate the skin, and when exposed to sunlight this may cause local skin burning. Hogweed is in a list together with *Euphorbia*, *Ranunculus* and *Primula* species and many other skin irritating plant species (www.tuinkrant.com). Is it the American overreaction to public health threats, or is giant hogweed in reality more aggressive to human health in the USA than in Europe?

Anyway, also in the Netherlands giant hogweed has a bad reputation. That is the reason why the plant is sometimes removed from parks and green space areas used by children to play (e.g. www.biosnoord.amsterdam.nl). Most European countries, including the Netherlands, are now banning or severely reducing the use of chemical pesticides in certain habitats such as waterways and nature reserves, which seriously hampers the quick and cheap control of giant hogweed. At these sites, the most common practice to handle the weed is annual mowing. However, this method seems almost contra-effective, because the plants return more numerous every year.

What to do next? The search for new methods for local eradication of the unwanted alien is ongoing. The efficacy to control giant hogweed with a new bioherbicide was studied in experiments in the river IJssel basin in 2002 and 2003. Mycelium of the fungus *Sclerotinia sclerotiorum* was applied as a liquid suspension, spread over the plants in early spring, before leaves were unfolded. The fungus penetrates the roots of giant hogweed and weakens the plant, resulting in dieback of the vegetation. Within 1.5 years its root system is almost completely exhausted. The open spot was taken over by several herbs, indicating that treatment was not detrimental for other dicotyledonous plants (De Voogd et al., 2003).

### *17.6.3 Case Studies of Introduced Water Plants*

Two case studies will be analysed, the Canadian pondweed, *Elodea canadensis*, introduced in 1859, and floating pennywort, *Hydrocotyle ranunculoides*, discovered in 1994. Both species have their homeland in America. The contrast between an early, well-documented case, and the recently discovered, successful invader is remarkable: after a turbulent rise and fall, *E. canadensis* is recently placed on the Red List of endangered species, while *H. ranunculoides* is presently violently combated.

#### 17.6.3.1 Elodea canadensis

The earliest well-documented case of an accidentally introduced species of water plant becoming a major economic problem is that of the North American *E. canadensis*, first in Europe and later in other parts of the Old World. This case is of particular importance as it is the only one as yet in which the history can be followed over a long period, and in which that history was not complicated by the use of herbicides (Sculthorpe, 1967).

Historically there has been much confusion in the classification of the species *Elodea*, and moreover, *Elodea*, *Egeria*, *Hydrilla* and *Lagarosiphon* have been much confused in the literature, mainly because of similarities in appearance and habitats. They are all submersed water plants, with leaves usually in whorls of two to eight. The number of leaves in a whorl is an important vegetative diagnostic feature, but there is a large overlap between genera. *Elodea canadensis*, *E. nuttallii*, *Egeria densa*, *Hydrilla verticillata* and *Lagarosiphon major*, all belonging to the familiy Hydrocharitaceae, are submerged, perennial species that usually root in mud. They are similar in appearance, and have all been recorded as weedy, although usually not in their country of origin (Bowmer et al., 1995).

*E. canadensis* is native to temperate North America. It frequently appears in reports of weed control practice, but generally only as a minor component of a submerged flora. *E. canadensis* is well known because it aggressively invaded the waterways of Europe in the 19th century. After spectacular vigour and dispersal, there was a subsequent decline, but new invasions and explosive growth are still occurring in Norway and Czechoslovakia. This is especially evident in mesotrophic to eutrophic lakes. It is also now considered a noxious weed in many regions of Asia, Africa, Australia and New Zealand. Canadian pondweed is able to grow slowly under ice cover and can survive inside ice. In Australia and Ireland only male flowers have been recorded, whereas in New Zealand and Europe only female flowers have been found. Ripe seeds have rarely been recorded (Bowmer et al., 1995).

It seems that spread by fruit is not particularly important in areas where *Elodea* has become a weed. Introduction into a country has almost certainly been via the trade in live aquarium plants, legal or otherwise. Once plants have become established in the wild, probably most frequently from discarded aquaria contents, dispersal has mostly been by stem fragments floating downstream. Dispersal between catchments is likewise by stem fragments. In the Netherlands flowers are rare; owing to lack of male plants pollination and the setting of fruit fails to come. Distribution solely occurs vegetative, by stem fragments (Bowmer et al., 1995).

*E. canadensis* seems to have been first found in Ireland in 1836, and it perhaps appeared in England in 1841.The next records, in 1847, were from two localities in SE England, where it may have been accidentally imported into an isolated basin or a pond. The story goes that specimens from that unknown water plant were sent to a botanist at Cambridge University, and that living plants from that collection were put into a brook in Cambridge. From this brook they could easily have reached the River Cam, either in floodwater or conveyed by ducks over a very short distance, into a stream tributary to that river. Once in the Cam the species rapidly multiplied and spread into the great system of drainage canals of the Fenland. At this time transport of goods by horse-drawn barges was an essential part of the economy of Britain. It is recorded that extra horses had to be used to pull the barges through the mass of *Elodea* in the Cam. About the same time the Trent was invaded, and soon also became full of the weed. Not only was barge traffic greatly impeded when the weed appeared in a new waterway, but water levels rose and fishing and boating became impossible. This happened over most of England as the plant spread. Fortunately, after about 5–7 years in any locality the populations declined. By 1912 few were still expanding and many were greatly reduced. At the present time *E. canadensis* is no particular problem in Britain (Hutchinson, 1975).

The same sort of story happened in continental Europe; the species entered France in 1850 and finally reached western Siberia in the 20th century. Throughout the enormous Old World range now occupied by *E. canadensis*, the flowers are almost all female and seeds are never set. The decline in the population of *E. canadensis*, which has fortunately occurred since its rapid 19th-century spread, was early attributed to a loss of vitality owing to lack of sexual reproduction, but according to Hutchinson (1975), it cannot conceal a valid genetic explanation because the asexually produced propagules were still vigorous when they entered a new territory.

The Canadian pondweed mythology shows an interesting parallel between the introduction in England and in the Netherlands. Heimans and Thijsse (1928) described vividly the introduction of *E. canadensis* in the Netherlands in 1859. It is suggested that a professor from Utrecht University has deliberately planted a strain of the water plant in an open canal, knowing the miraculous capacity for growth in England. And once the weed was planted, there was no stopping it. Ditches and canals became overgrown, and inland navigation was seriously hindered by the expanding vegetation. Until the end of the 19th century *Elodea* had conquered large parts of continental Europe, and in the Netherlands it was one of the most common water weeds. But already then the invasive behaviour of the weed slowed down, particularly in waterways that were not regularly cleaned. In the course of the 20th century *E. canadensis* gradually became a rather common to rare species, an indicator for good water quality. The name ‘water pest’ was no longer appropriate. At present Canadian pondweed is growing in isolated ponds and polder waterways were seepage is prevailing, away from inlets of eutrophic river water (Weeda et al., 1991). The invasion circle of *E. canadensis* is complete: the species is on the Dutch Red List now (Pot, 2002). Whereas for the wax and wane of most invasive species there is an (at least hypothetical) explanation, Simberloff and Gibbons (2004) consider the rapid expansion followed by the repeated collapse of the Canadian pondweed as an unexplained phenomenon.

*Elodea nuttallii* is the successor of *E. canadensis* in shallow, stagnant or flowing freshwater or slightly brackish watercourses. It appeared in the Netherlands in 1941.The species is tolerant to eutrophic, slightly polluted river water, and is particularly competitive in cleaned ditches. Probably the disappearance of Canadian pondweed has favoured at many places the expansion of Nuttall’s waterweed.

Barrat-Segretain and Elger (2002) studied growth and possible competition between *E. canadensis* and *E. nuttallii*. In monocultures the growth rates of the two species were similar. In competition experiments under eutrophic conditions *E. nuttallii* definitely displaced *E. canadensis*. Presumably the deteriorating water quality in the 20th century has favoured the expansion of *E. nutallii*, which is now the most common species of the two. The success of *E. nuttallii* might also be explained by its preference for slightly higher water temperatures than *E. canadensis*, at least in its homeland (cf. Hutchinson, 1975).

#### 17.6.3.2 Hydrocotyle ranunculoides

A new successful macrophyte is *H. ranunculoides*, floating pennywort, a native water plant species on the American continent, where it is not considered as a nuisance. The species first showed up in Dutch surface waters in 1994 and has rapidly expanded its range ever since. In 1998, it has become a prominent nuisance in N Brabant (river Dommel). The plant, commercially available in the Netherlands as an ornamental plant, has probably escaped from garden ponds. It grows on shores and forms large floating mats on the water surface. The mats form floating rhizomes with roots which reach down half a metre into the water column and can penetrate 15 cm into the sediment. The leaves can lift themselves 30 cm above the water surface. The rhizomes spread from the banks over the water surface, so that it is unaffected by turbid water. It survives cold winters and is expanding its area everywhere, mostly by clonal reproduction, though flowering and seed formation have also been recorded. The sites where *H. ranunculoides* grows are mostly eutrophic, with mostly flowing water strongly influenced by sewage from cities and agriculture (www.stowa.nl/waternavel).

Mass growth of *Hydrocotyle* and similar water plants have an serious negative impact on freshwater communities, by creating anoxic conditions underneath them. They shade the water column, suppressing submersed vegetation, impeding the diffusion of oxygen from the atmosphere and creating anoxic conditions by decomposition of organic matter. Toxic compounds like $H_2S$, $NH_3$ and $NO_2$ accumulate under the vegetation and the water becomes malodorous. The result is an impoverished biodiversity of the communities. The water is not even drinkable for cattle without health risk. These plants also impede the drainage function of the ditches by reducing the flow, while floating biomass causes problems by blocking culverts. Dense fields pose a problem for recreational users and have a potentially large impact on the ecosystem (Van der Velde et al., 2002).

The recent invasion of floating pennywort is taken very seriously in the Netherlands. The plant was discovered in 1994 in a watercourse near Utrecht. In 1995 the watercourse was fully overgrown over a distance of 2 km. In 2004 the plant had spread all over the country in ditches, canals, brooks and smaller rivers, except in brackish localities. Until a few years the free trade of the water plant via garden centres and aquarium shops was allowed, and this may explain its quick spread. On January 9, 2001 a decision was published in the framework of the Dutch Flora- and

Fauna Act in which floating pennywort is designated as a plant for which planting and distributing is prohibited, and possession, trade and transport are also prohibited. The Foundation for Applied Research in Water Management (STOWA) has opened an internet site (www.stowa.nl/waternavel), and is publishing a brochure on distribution, ecology and abatement. Observations of new localities are published on the Internet. One observation of a considerable vegetation spot at a recent restoration site of a nature-friendly river bank, where water plants have been planted, suggests that the water managers themselves are jointly responsible for the invasion.

A proper means to fight the water plant is not available. Eradication of the plant seems to be difficult because each part can grow out to a new plant, which also occurs when banks are cleared of vegetation. The classic measure, the cleaning of waterways with grabs is not effective. In flowing water of normalised brooks (Dommel) the species may distribute downstream tens of kilometres per year. The vegetation may block narrow waterways and culverts, and is thus impeding the free discharge of rainwater and river water. As is known, the Dutch have a serious allergy for the obstruction of water discharge of rivers and brooks. The species is

**Waternavel plaag**
**voor De Dommel**

- **Met een grijper wordt de waternavel uit de Dommel bij Den Bosch 'geoogst'.** Foto Joep Lennarts

**Fig. 17.6** 'Floating pennywort nuisance in river Dommel', headline from a regional newspaper (Brabants Dagblad, October 27, 2004). A shallow boat equipped with a grab is removing 50–100 t wet weight of water plants from the riverbed not hardy, and the only hope is that a severe winter will kill, or at least set back the spread of the vegetation. Strains may survive frost at cooling water outlets, or covered by a blanket of decaying shore weeds (Baas and Duistermaat, 1998).

In Fig. 17.6 a headline from a regional newspaper is shown: 'Floating pennywort nuisance in river Dommel', The picture shows a shallow boat equipped with a grab, removing 50–100 t wet weight of floating pennywort from the riverbed. Interesting detail is that floating pennywort is considered as industrial waste, because it accumulates heavy metals from the water column and the sediment. This fact is considerably increasing the costs of destruction, and other water plants that become a nuisance may be composted at a far lower fare.

## 17.7 Conclusions

- Ecological history is for a considerable part the history of biological invasions, the story of constant changes in biodiversity. The focus is on recent (19th and 20th century) invasions in freshwater ecosystems.
- The perception of an invasion differs between the USA and Europe, because Europeans are familiar with invasions for thousands of years. In the semi-natural landscapes of river basins the inherent susceptibility of disturbed areas to invasions, has become an accepted cultural-historic phenomenon.
- The exotics' profile: euryhaline, thermophilous, trophic generalists, invading open niches in disturbed or simple habitats, more or less independent of climate change; their fast distribution is strongly facilitated by the interconnection of river basins.
- The evidence for causal factors underlying invasion phenomena is scanty. Recent findings suggests that the invasion success of exotic aquatic organisms might be attributed to chemical communication between the invader and its environment, and it is possible that in the pioneer stages the escape from natural water-borne pathogens gives the invader a competitive advantage.
- Descriptions are given of migration routes and range extensions of tens of species of invertebrates and higher plants, and among them the Ponto-Caspian connection is highlighted, along which a considerable number of southeastern European and Asian invertebrates entered the western European lowland rivers.
- Four case studies have been worked out, two bivalve mollusc species from the Black Sea and the Adriatic Sea (*D. polymorpha* and *Corbicula* species), and two water plant species originating from America (*E. canadensis* and *H. ranunculoides*). The inherent contrasts between the two historic, well-documented introductions from the 19th century (*Dreissena* and *Elodea*), and the two recently discovered successful invaders (*Corbicula* and *Hydrocotyle*) have been highlighted.
- The slightly negative attitude against the abundance of the zebra mussel in the 19th century has changed into a positive attitude nowadays. *D. polymorpha*

almost disappeared from the Rhine basin owing to the severe water pollution in the 1960s and 1970s, but the species returned, and is now a valued feed for waterfowl, and applied as filter-feeder to fight eutrophication. This is in sharp contrast with the 'devastating economic consequences' the zebra mussel has in the USA.

- After its discovery in 1990 *Corbicula* species have completely changed the appearance of the beaches of the river Waal. The Asian clam is presently the most common bivalve in the main rivers, living in the bottom sediments.
- The problem of invasive plants is taken far more serious in the Netherlands than the introduction of invasive animals, mainly because the mass development of these plants forms a severe threat to the polder drainage systems.
- *E. canadensis* aggressively invaded the waterways of Europe in the 19th century (Delta in 1859). After spectacular vigour and dispersal, there was a subsequent decline in the course of the 20th century, and its common name 'water pest' became no longer appropriate. In 2000 the invasion circle of Canadian pondweed is complete: the species is on the Dutch Red List of vulnerable species now.
- The floating pennywort, *H. ranunculoides*, discovered in 1994, became a public nuisance in many water courses and small rivers, and is presently violently combated by water boards.

# Chapter 18
# Changes in Biodiversity: Lower Organisms, Vegetation and Flora

## 18.1 Introduction

Biodiversity is a framework concept, referring to the variety of life on Earth, and in this sense the concept is neither measurable nor quantifiable. However, specific features of biodiversity, e.g. species richness of taxonomic groups can be quantified. Circa 2% of the total number of identified species on Earth, roughly 35,000 species of plants and animals, live in the Delta, comprising roughly 25,000 species of animals (and among them 18,000 insects), and more than 10,000 plants, and among them *ca*. 1,400 higher plants (seed-plants or Spermatophyta). For a few hundreds of species the Delta has a (great) international significance, and this counts in particular for waterfowl (Chapter 19) (www.mnp.nl/natuurcompendium).

After the last ice age northwestern Europe has been exposed to the natural and man-induced introduction of numerous biota, and whether a plant or animal in the present Delta is considered as native or non-native fully depends on the definition (cf. Chapter 17). Most knowledge in the old literature pertains to higher plants, because of their profitable traits for human use. The systematic description of many taxonomic groups started only in the late 19th century, and the exponentially increased interest in biodiversity developed after World War II. Slight fluctuations in temperature (e.g. medieval warm period and little ice age), and annual weather extremes, such as severe winters and hot dry summers, have always been coined as causative for the (often temporary) introduction or disappearance of specific biota. The wax and wane of biodiversity is masked by a multitude of human-induced habitat changes. The historic period of reliable scientific observations is simply too short to point to climate change, assumed to be caused by the enhanced human-induced greenhouse effects, as a factor responsible for changes in biodiversity.

Scanty data are available on ‘lower organisms’, such as plankton and benthos, although sediment deposits have revealed quite some information on fossilising species. In the 20th century systematic interest in taxonomy, concomitant with improved identification techniques, has greatly improved our knowledge of river biota. Habitat changes, e.g. from the dominance of snags and wood debris in the riverbed in the past to the present petrification of the river shores, have had great consequences for the biodiversity of macro-invertebrates, mainly insects, and

P.H. Nienhuis, *Environmental History of the Rhine—Meuse Delta*,

exotic crustaceans. The annihilation of environmental gradients from nutrient poor to nutrient-rich habitats, triggered by the introduction of artificial fertiliser at the end of the 19th century, has led to the levelling down of the terrestrial vegetation.

In this chapter data will be given on the historic changes in the biodiversity of aquatic and terrestrial organisms, mainly plankton, aquatic macro-invertebrates, aquatic macrophytes and terrestrial vegetation of higher plants. The changes in the vegetation of the Biesbosch wetland are highlighted in a case study, because this national park is one of the few areas in the Delta where the flood-plain vegetation is allowed to flourish unrestrained, hence mimicking a semi-natural succession of flood-plain vegetation, developing under almost non-tidal conditions. Some notes on the human use of rushes, reeds and willow trees will close this chapter.

## 18.2 Changes in Biodiversity, Lower Organisms

### *18.2.1 Plankton*

Unlike other plant and animal groups, the diversity of plankton taxa in the lower Rhine and Meuse seems to have increased during the 20th century. However, this might be an artefact of improving identification techniques over the years: systematic description of planktonic and benthic micro-organisms only started in the late 19th century. In recent samples benthic and epiphytic species in particular have been found abundantly in flood-plain lakes, and only sporadically in the main channels. In contrast, benthic and epiphytic species of micro-algae showed a higher diversity in the main channels before river regulation took place, i.e. before the 19th century. At that time, snags in the riverbed, water plants and shallow sandy river stretches provided natural habitats for these species, as evidenced by palaeo-limnological studies of sediment cores from the Rhine area. These studies show that epipsammic and epiphytic pennate diatoms dominated the spectrum of diatom frustules in the sediment deposited during the 19th century, whereas planktonic centric species were numerically dominant in sediment layers deposited in the 20th century (unpublished data of A. Klink as reviewed by Admiraal et al., 1993). This means that a complex of lotic and lentic communities with snags, macrophytes and undisturbed sandy banks and river islands as habitats for benthic diatoms have vanished, due to regulation and normalisation works and shipping traffic.

Despite hydrological and chemical differences between the two rivers Rhine and Meuse, many species, predominantly diatoms and green algae, were shared. The occurrence of the diatom *Skeletonema subsalsum* in the Rhine and the green algae *Neodesmus danubialis*, *Micractinium pusillum* and *Pseudotetrastrum punctatum* in the Meuse (1992, but not 1996) was interpreted as a feature related, respectively, to the high salinity of the Rhine and specific riverine conditions of the Meuse. In general the potamoplankton was characterised as an opportunistic assemblage exploiting the high nutrient contents and disturbed hydrology of both rivers. As a consequence of differences in hydrological regimes, differences in phasing of phytoplankton and zooplankton development of the two rivers have been observed. Succession of algae, rotifers and crustaceans evolves faster in the middle course of the Meuse. A more mature plankton community enters the Netherlands at Eijsden (Meuse) than at Lobith (Rhine). Residence time of the water is an important decisive factor, but over a longer time span (decades), it is clear, however, that phytoplankton density of the Rhine and Meuse has increased in response to an increased availability of nutrients (Ibelings et al., 1998).

In addition to the rate of succession, temporal variation in phytoplankton development, which is often predominant in lentic systems (lakes), spatial variation, i.e. changes during downstream transport, is vital to describing phytoplankton in lotic systems (rivers). The decrease in phytoplankton biomass in the Delta stretches of the lower Rhine, i.e. comparison of Rotterdam with Lobith, seems to be attributable to grazing and sedimentation losses, not to a deterioration of growth conditions. The important role of grazing by a diverse zooplankton community in the lower stretches of the Rhine indicates that a transition from a pure riverine system to a more stagnant system is taking place (Ibelings et al., 1998).

Although not occurring in fast-flowing river sections, zooplankton is best developed in the highly regulated river Meuse with its many weirs, and in the more stagnant downstream areas of the Delta Rhine, as well as in the flood-plain lakes of both rivers. In 1977 the *Daphnia* toxicity test showed that Delta Rhine water was acutely toxic, and consequently, it seems likely that the zooplankton development in the river must also have suffered in that year. It has been indicated that the pollution of the Rhine in the early 1990s was still affecting the growth of bacterioplankton and the photosynthesis of the phytoplankton (Admiraal et al., 1993; Van den Brink et al., 1994).

### *18.2.2 Aquatic Macro-Invertebrates*

The Large Rivers in the Delta have lost most of their characteristic macro-invertebrate species, although a relatively rich fauna was present until 1940 (Redeke, 1948). Figure 18.1 shows that even before 1940 the numbers of insect species in the Rhine had decreased strongly; this can be attributed to canalisation, regulation, increased shipping and input of organic wastewater. As with aquatic macrophytes, the diversity of aquatic macro-invertebrates in the Delta Rhine and Meuse main channels was rather poor in 1996 (Van den Brink et al., 1996), and the most recent survey does not show much improvement of the macrofauna diversity either (Reeze, 2005). A clear difference between lotic and lentic river sections is expressed in the (former) presence of predominantly rheophilous taxa in the lotic channels, and the presence of taxa preferring stagnant water (e.g. most Coleoptera and Heteroptera) in the flood-plain lakes. Mainly rheophilous insects, such as Ephemeroptera, Plecoptera, Simuliidae and Trichoptera species, have disappeared over the years. Among these were many species inhabiting snag and vegetation, which significantly declined in the Large Rivers. Although the decline occurred among species with a variety of feeding modes, the strongest decline occurred in taxa with scraping and shredding feeding modes. This means that biotopes containing benthic algae and coarse particulate organic matter, provided by leaf litter, have diminished. With the deterioration of aquatic vegetation and the removal of snag and flood-plain forests from the rivers,

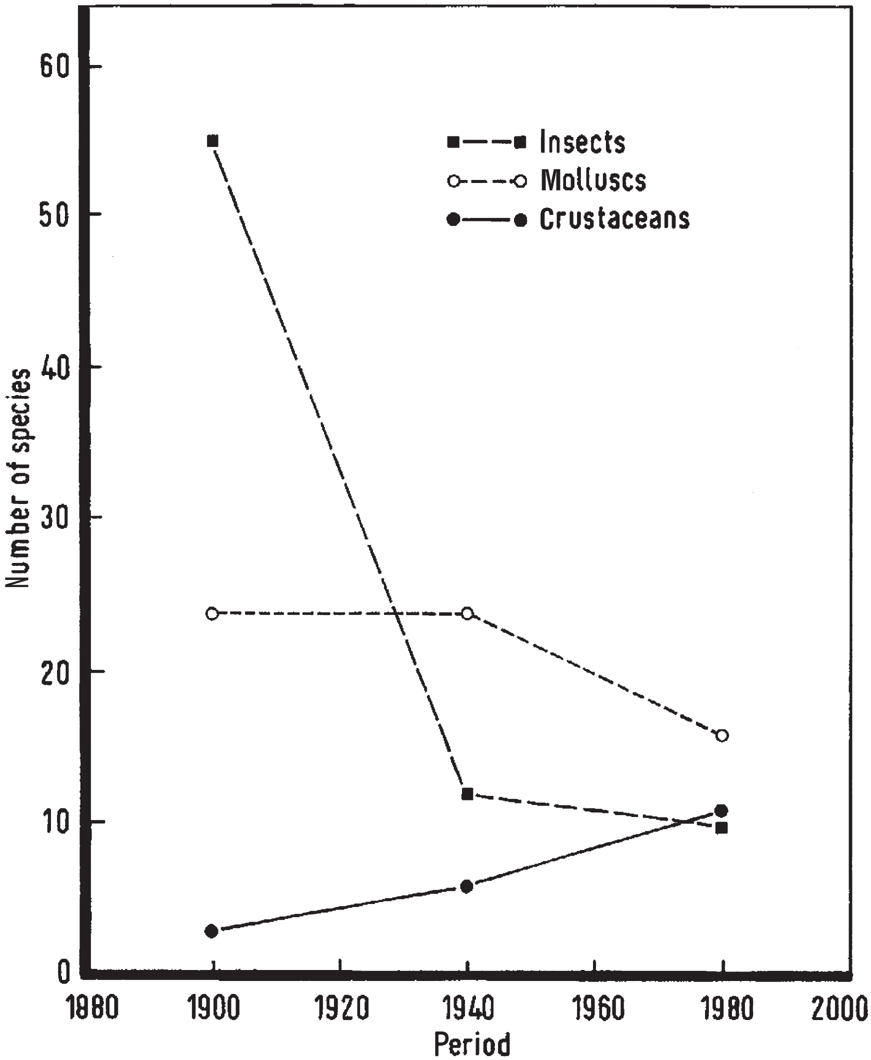

**Fig. 18.1** Changes in the numbers of macro-invertebrate species in the lower Delta Rhine between 1900 and 1980. Number of insect species excluding chironomids (Admiraal et al., 1993, based on data of Van den Brink et al., 1990)

the suitable sites for larval development and oviposition of many insect species have become scarce (Van den Brink et al., 1996).

Unlike aquatic insects, the biodiversity of snails, mussels, and especially, macro-crustaceans is at present higher than during the start of this century (Fig. 18.1). This is mainly the result of the invasion of exotics from all over the world (see Chapter 17). The macro-invertebrate communities in the main channels and connected flood-plain lakes are nowadays dominated by exotics, which all are very well adapted to the presently increased chlorinities and elevated water temperatures in these rivers (Van den Brink et al., 1996). Discharge of industrial waste and organic pollution have caused low oxygen concentrations and high levels of toxic substances. Thick layers of contaminated silt have been deposited on the riverbed in the lower reaches of the Rhine and Meuse, leading to a further decline of characteristic zoobenthos species. At present most rheophilous insect species only occur on the stones of the groynes (Fig. 18.2). Figure 18.3 shows that in the period 1850–1975 the habitats along the river IJssel have changed drastically. In the 19th century the river banks, i.e. where the river foreland borders the summer-bed of the river, mainly consisted of vegetated areas, and sandy foreshores. River regulation led to erosion of the foreshores, and consequently the river banks grew steeper. To avoid further deterioration of the flood plains, most banks are now protected with stone revetments and stone groynes perpendicular to the river channel (Van den Brink, 1994).

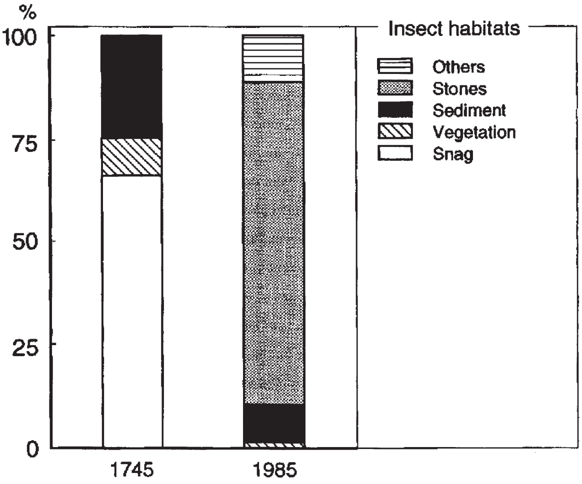

**Fig. 18.2** Changes in the aquatic insect fauna in the Delta Rhine over the period 1745–1985. The number of taxa associated with a particular habitat is plotted as a percentage of the total number of taxa (Data compiled by Van den Brink (1994) from palaeological sources (sediment cores) and from recent surveys)

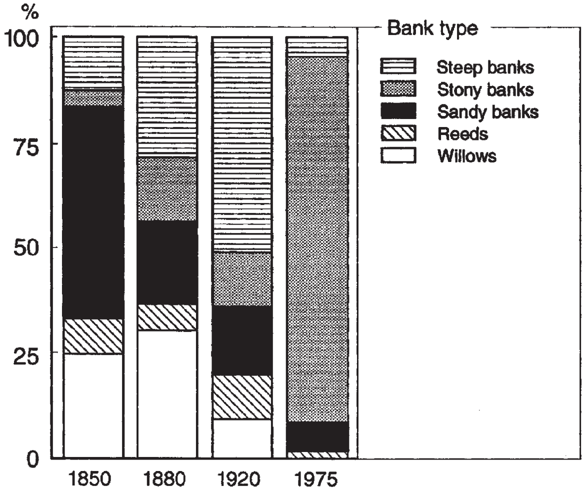

**Fig. 18.3** Changes in habitats along the banks of the river IJssel in the period 1850–1975. Bank length comprising a particular habitat is plotted as a percentage of the total bank length. Figure borrowed from Van den Brink, 1994)

## 18.3 Ecological Connectivity in River Flood Plains

River normalisation measures have greatly altered the bed forms of the Large Rivers. In the Waal, for example, these were downstream moving sandbars which were removed during the channel regulation works. Today there is still considerable bed material transport and 'dune' bed forms of about 1 m high and some 10 m long can be found. Near the banks, the bed configuration is largely determined by the 19th century groynes. The flow pattern in groyne-fields is dominated by eddies causing localised bed scour. When large vessels, especially push tows, pass by, the flow pattern around the groynes may change and the flow near the head of the groyne may even be reversed. Furthermore, the waves produced by large vessels cause considerable local erosion of the banks, and in many places the banks had to be protected by stones (Fig. 18.3). Today, the bed material in a groyne-field usually consists of well-sorted medium sand, *ca.* 70%, wet weight between 250 and 500 μm. At sites which are more exposed to the current, the bed material is less well sorted and an armour layer of gravel may be found. At these sites, over 25% of the sediments are coarser than 2.0 mm and about 60% is between 125 and 500 μm. The amount of clay and silt in the riverbed is insignificant along the river Waal; the sediments contain neither coarse organic material nor any significant amounts of fine detritus (Van Urk and Smit, 1989).

River engineering works not only had a marked influence on the characteristics of the mineral substrates in the riverbed, but also on the distribution of organic matter.

The supply of organic matter is a key factor in the development of benthic communities in running waters. The 'River Continuum Concept' (Vannote et al., 1980) suggests that benthic communities in large lowland rivers should thrive mainly on phytoplankton and fine detritus from upstream. At present in the Delta Rhine, the amount of macrophyte debris, either from terrestrial or aquatic sources, is insignificant. This situation must have been different in the past; the presence of large amounts of macrophyte debris in various types of older deposits in the Nieuwe Merwede-Hollandsch Diep area, suggests an important role for this type of detritus in the river food web. Coarse organic material is a scarce food source for benthic invertebrate communities in the river today. As the gravel and sand substrates contain little fine-grained organic matter, the only available food source for non-filter-feeding animals inhabiting such substrates would be benthic algal production. The fairly uniform depth of about 3 m at low water levels prevents light from reaching the river bottom, except near the banks, but there high suspended matter concentrations, and high turbidity may prevent the growth of micro-algae. On the riverbanks the forces exerted by the wash of the waves, mainly caused by ships, can be very strong. Wave dynamics together with water level fluctuations make the river channel a severely stressed habitat, harbouring only an impoverished benthic community (Van Urk and Smit, 1989). Figure 18.4 shows that the relative number of macro-invertebrates in the river channels indeed decreased, and that the relative share of the species in flood-plain lakes significantly increased.

Van den Brink et al. (1996) schematised the transversal zonation pattern, perpendicular to the main axis of the river channel, showing a dominant relation with flood pulse duration (Fig. 18.5). The changes in physical, chemical and biological factors are indicated. The main factor characterising the types of flood-plain lakes distinguished is their hydrological connectivity, as expressed in flooding frequency, determined by the altitude of their position on the flood plain and the height of the embankments separating them from the main river channel. Because the water of

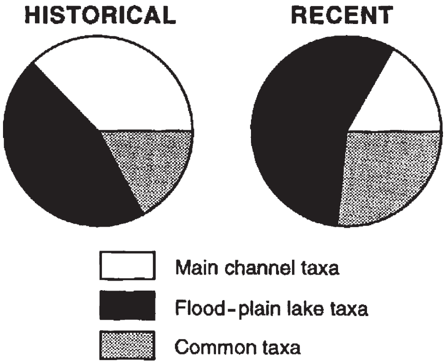

**Fig. 18.4** Relative shares of macro-invertebrates taxa in the lower Rhine and Meuse main channels and their associated flood-plain lakes in the Delta, as compiled by Van den Brink (1994). Total number of taxa is 100%. Historical data are based on analyses of sediment cores and recent literature

the rivers Rhine and Meuse is still highly eutrophic, high flooding frequency will cause flood-plain lakes to become eutrophic too, resulting in turbid water, the decline of macrophytes, and the increase of phytoplankton biomass. Isolated lakes, that are almost never flooded, have clear water and dense submerged vegetation. The species richness of phytoplankton and zooplankton, aquatic and semi-aquatic macrophytes and macro-invertebrates increases with a decreasing degree of connection with the main channel.

Four types of habitat have been distinguished in Fig. 18.5 (cf. Fig. 15.2) on river fish distribution):

- Main river channels (natural secondary channels are not present anymore in the Rhine–Meuse Delta) are dynamic, turbid systems fuelled by phytoplankton and detritus of flood-plain vegetation. Aquatic macrophytes are virtually absent, and the densities of macro-invertebrates living in sediment are low. The main invertebrate communities thrive on the artificial stone embankments (Van Riel et al., 2006).

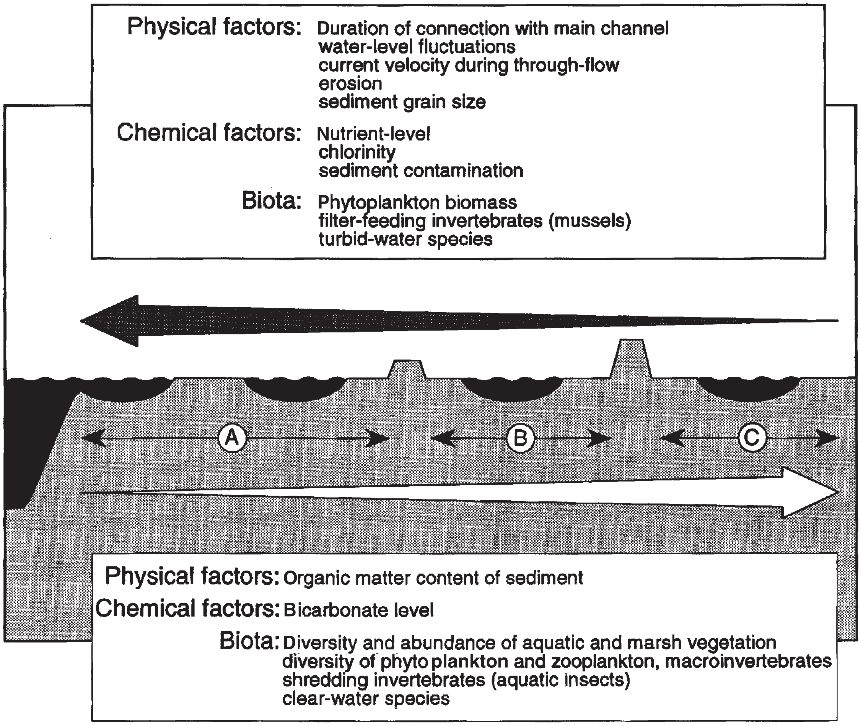

**Fig. 18.5** Schematic view of the present-day transversal zoning pattern of Delta flood-plain lakes and the directions of change of physical, chemical and biotic parameters (Van den Brink, 1994; Van den Brink et al., 1996). Main river channel on the left. A = dynamic, frequently flooded flood-plain lakes; B = moderately dynamic, infrequently flooded flood-plain lakes; C = isolated, non-flooded or seepage lakes

- Dynamic flood-plain lakes are in open connection with the main river channel for more than 20 days per year on average. Because of the high hydrological connectivity, the plankton communities in these lakes resemble those of the main channel. Nutrient levels are high, and therefore the densities of phytoplankton and zooplankton are high too. Aquatic macrophytes and helophytes are scarce. The macro-invertebrate community is numerically dominated by filter-feeders.
- Moderately dynamic flood-plain lakes are in connection with the main channel via floods during 20 or less days per year on average. Nutrient levels and chlorophyll-a levels are much lower than in the more dynamic lakes. The phytoplankton community is dominated by epiphytic diatoms. Aquatic vegetation is well developed and consists of large stands of Nymphaeids; the helophyte zone is also well developed. The macro-invertebrate community is numerically dominated by deposit-feeders.
- Isolated lakes are situated in the ancient flood plain, on the landside of the dyke outside the presently active river forelands, and are influenced by the river channel via seepage through the main dyke. The water is clear, nutrient levels are lowest here, as are phytoplankton densities. Flood-sensitive species among the aquatic vegetation and helophytes are well developed. The macro-invertebrate community is numerically dominated by shredders.

## 18.4 Changes in Vegetations of Higher Plants

### *18.4.1 Impediments to Fieldwork*

Deforestation, the thinning, changing and elimination of forests, is as old as the human occupation of the earth, and one of the key processes in the history of our transformation of its surface, and the clearing of woodland is probably the most important single factor that has changed the European landscape (Williams, 2003). In the Rhine–Meuse Delta already in the late New Stone Age deforestation gave rise to the origin of large open spots in the overall forested landscape. During the later Middle Ages closed forests became rare, and grassland started to dominate the fluvial landscapes (Bitter, 1991a). This phenomenon together with the underlying causes have amply been discussed in previous chapters.

Although higher plants enjoyed much interest through the ages, reliable but still incomplete taxonomic and ecological information came only available in the second half of the 19th century. Systematic knowledge of the wild flora of the Delta was only gathered from the early 20th century onwards. Witte (1998) classified the inventories of the wild flora in the Delta over the period 1902–1950, and he found out that inventories of water vegetations of stagnant, fresh, nutrient-rich waters are underrepresented. One explanation is that nutrient-rich ecosystems have never been given special attention by florists, as they were mainly interested in rare species. Another explanation is that florists disliked wet feet. The fact that there exist relatively few publications on former water vegetations is an indication for the latter explanation. Support can be found in the large picture library of the National State Herbarium of the Netherlands. On the photographs from the first half of the 20th century mainly florists can be seen (often gentlemen wearing a suit and a top hat), safely inspecting the land, whereas florists who venture out into the water are seldom seen. The reason for this might be that proper boots were scarce and expensive those days. It was not until the 1950s that affordable, mass-produced synthetic boots were available on the market. Before that time there was nothing but expensive, hand-made footwear available. Following Witte (1998), this explains why we never see florists wearing boots on old fieldtrip photos. However, occasionally we do see them with bandages swathed around their legs. It goes without saying that these bandages are not suitable to stand in the water with for long, or to venture out on soggy terrain with. According to Witte (1998) the absence of adequate footwear is likely to be the explanation for the absence of early 20th century inventories of aquatic plants. A parallel is to be seen in the availability of inventories of benthic underwater biota, which increased exponentially after the introduction of scuba-diving in the 1960s.

### *18.4.2 Aquatic Macrophytes*

Historically, the vegetation in the river flood plains has been determined by land use. In and around settlements and villages, situated on elevated sandy levees and channel belts, the land was intensively used for many purposes, such as gardens, orchards, arable fields, jetties. Until the 18th century cultivation of remote flood plains, particularly areas that were difficult to access, was minimal, and much low-lying land between the main river channel and abandoned channels was forested marshland. The area of willow coppice increased downstream, concomitant with the increase of the tidal range of the rivers. The fixation of the channels from the 19th century onwards facilitated the cultivation of the river forelands. In order to create meadows or hayfields, areas of flood plain were enclosed by low dykes to prevent summer spates. Flood plain forests were increasingly considered as obstacles at peak discharges, and that became a plausible reason to cut them systematically. But there were other reasons to keep the flood-plain trees low: particularly along the Nederrijn–Lek it was necessary to keep a towpath free from obstacles, as this was the main trade route from Amsterdam to Cologne (Van Urk and Smit, 1989).

Although historical data on the distribution of aquatic macrophytes in the Large Rivers and their flood-plain waters are far from complete, it is beyond doubt that many species have disappeared (e.g. Characeae) or became rare. The present diversity of aquatic macrophytes in the main channels of the Delta Rhine and Meuse is rather poor as compared with the situation in the past, or in comparison with the present diversity in flood-plain lakes. At present, about 70% of the species recorded have been found exclusively in the flood-plain lakes. The other 30% can be found both in the main channel and flood-plain lake biotopes. The more frequent the flooding, the lower the number of species of water plants. Historical records proved the presence of underwater meadows in the main channels of the Delta Rhine and Meuse, e.g. consisting of *Ranunculus fluitans*, *Potamogeton nodosus* and *Potamogeton perfoliatus*. Deterioration of aquatic macrophytes in these regulated rivers is probably caused by increased river dynamics, i.e. increased fluctuations in water level and the increased turbulence of the water (shipping), increased current velocities and a higher incidence of summer spates. Present-day minimum water levels in the river Waal itself are lower than the 19th century levels, partly owing to bed degradation and partly to varying discharge characteristics. Marsh vegetation, such as rushes and reed, are particularly sensitive to water level changes, and the cease of the tidal movements, before 1970 noticeable until Tiel along the Waal (location Fig. 5.5), is surely one of the causes of the impoverishment of these plants in large parts of the Rhine–Meuse Delta. Only in the most seaward river reaches, a small zone of emergent vegetation is still found along the banks. Due to bank erosion, the banks of the Waal are, for the greater part, not grown over, and most of the man-made banks of the Rhine and Meuse are now totally unsuitable for macrophytes (Van den Brink et al., 1996).

Not only the number of species indicating oligotrophic and mesotrophic conditions has been reduced owing to eutrophication, but also the number of eutrophic species declined, and that should be attributed to the physical disturbance of macrophyte habitats. The increased salinity of the river Rhine water has also contributed to the decline of formerly common species, such as the characteristic pondweed, *P. nodosus*, in favour of *Potamogeton pectinatus*. But recently the area of *P. nodosus* is increasing again, together with other species, mainly in the low dynamic Biesbosch-Hollands Diep-Haringvliet and IJssel (Reeze et al., 2005).

### *18.4.3 Terrestrial Vegetation*

The terrestrial vegetation in the Rhine–Meuse Delta was – and still is – the domain of the farmer: for centuries the river polders of the Large Rivers and the Central Delta have been dominated by grassland and arable fields (see Chapter 7). In the remote past manure was scarce and only the arable fields close to the human settlements in the river polders were fertilised and exploited. The hay fields farther away from the farms were not fertilised; they comprised grasslands rich in slowly growing flowering plants, which were harvested only once, late in the season. After the harvest the hay was transported to the farms; there it was fed to the cattle, and their dung was used to fertilise the arable fields. This habit, maintained over the centuries, intensified the spatial ecological gradient from the remote, not fertilised soils to the enriched fields close to the farm. This gradient manifested itself also from the clear and clean nutrient-poor water in the ditches separating the remote meadows, to the eutrophicated surroundings of the farm. The introduction of artificial fertiliser at the end of the 19th century has abruptly changed this situation; it stimulated the growth of grass and the flowering plant were out-competed, a process often completed with chemical destruction of the unwanted weeds. Mowing is fixed at an earlier date, in the middle of the breeding season. The spatial variation in habitat types has declined, and intensified land use resulting in eutrophication is still one of the major environmental problems at the countryside. These rigorous changes in agricultural habits are considered as major negative impacts on the semi-natural landscape of the 19th century (Westhoff et al., 1970, 1971).

The low-lying grasslands in the basins of the river polders had a very erratic water household: dry in summer and flooded during winter. The poorest soil consisted of compacted clay, acid and poor in lime, where horsetails and rushes dominated. The less compacted hay fields were rich in abundantly flowering higher plants (see Section 7.6.1). The production of grass on those fields, however, was poor, and the quality of hay was low; it was mainly fed to horses. Much of these hay fields have disappeared after World War II, owing to re-allotment measures, drainage and fertilisation, and only small remnants have survived, thanks to specific management measures, such as an artificial water table, and inlet of nutrient poor surface water.

The meadows-on-peat in the Central Delta harboured once thousands of hectares of unfertilised nutrient-poor hay fields, blue-grasslands with a great diversity of flowering plants. This habitat already became rare in the 1930s. Although many areas have escaped from re-allotment practice, intensification of the dairy farming, using large quantities of artificial fertiliser, has been the fatal blow for the ecological values of grassland and adjoining wetlands in the 20th century. Blue-grass fields have almost all disappeared, and only remnants have survived.

The grasslands in the river forelands, the so-called river-corridor vegetations (‘stroomdalgraslanden’), provided the best hay; these fields were frequently re-fertilised by the deposition of river silt during floods. The ‘outer hay’, from the flood plains, had a better quality than the ‘inner hay’, harvested from the fields on the landside of the dyke. The hay from the flood plains with its higher lime and nutrient content was dominated by lime-preferring grasses. Grasslands on the drier and warmer river dunes, still lower in nutrients but rich in lime, were characterised by a rich flora. Flowering plants like *Salvia pratensis*, *Ononis spinosa* and *Chrysanthemum leucanthemum* and many others, in the 19th century seen as ‘weeds’, i.e. unwanted herbs (Roessingh and Schaars, 1996), are nowadays appreciated plant species.

Changes in water levels during periods of low river discharge are of particular importance to the natural functioning of river flood plains. All flood plains of the Delta rivers have now an artificially created water regime maintained by a system of pumping engines, weirs and culverts, and this has greatly diminished the natural connectivity between the main channel, and secondary channels, oxbows and flood-plain lakes, especially during periods of low river discharge. The reduction in seasonal variation in water levels and in peak flows has negatively influenced the diversity of the entire flood-plain inundation fields. The artificially stabilised water levels in the main channel and adjacent flood-plain waters has led to an almost cease of seepage and flooding, through surface connections with the main river channel, and hence to interruption of the natural succession, decline in overall plant species richness and loss of characteristic river-bound species (Van Geest et al., 2005).

The unnatural water table (high in summer low in winter) maintained in the wetlands of the Delta is detrimental to the rehabilitation of the ‘natural’ vegetation. The creation of high water tables throughout the year as a measure against desiccation appeared not to be a good solution for this problem, e.g. as could be estimated for alder carrs in former river meanders of the river Meuse. Even within the first growing season after the introduction of this measure, the surface water had become completely covered by *Lemna* spp., while characteristic species such as *Caltha palustris*, *Calla palustris* and several *Carex* spp. had been literally drowned. Phosphate concentrations had increased several fold as a result of prolonged anoxic conditions and accumulation processes. *Alnus glutinosa* even started to die at these locations. It may be clear that this artificial hydrological regime of ‘over-rewetting’ is very detrimental and undesirable. The same holds for other types of wetlands, such as fen meadows. Aerobic conditions are needed in summer, presumably also to stimulate nitrification. Plants characteristic of this type of habitat show a strong preference for nitrate as an N source, while the accumulation of ammonium leads to toxic conditions. The re-establishment of a more natural water regime, with higher water tables during winter and tables below the hydraulic level of the nutrient-poor seepage groundwater in summer, allowing adequate nutrient efflux, have been shown to offer better prospects. A positive effect of water table fluctuation on biodiversity was also found for flood-plain lakes along the Delta Rhine branches (Lamers et al., 2006).

Although the deterioration of the flora of river flood plains and levees was already being reported in the early decades of the 20th century, until the 1960s an extensive, flower-rich grassland vegetation containing many species rare in the Delta used to be common on river dykes and in river forelands. In the aftermath of the flood disaster of 1953, large-scale reinforcement works of the dykes along the Rhine, Waal, Lek and IJssel were executed (Chapter 9). Between 1968 and 1992 as much as 89% of the locations with a dry flood-plain grassland vegetation in the Delta disappeared. In 1992 the vegetation of over 90% of the river dykes consisted of species-poor grassland grazed by sheep, or mown for haymaking. Only about 7% of the surface area of the river dykes was still covered by relatively species-rich grasslands, dominated by *Arrhenatherum elatius*, and speckled with herbs like *Lotus uliginosus*, *Lychnis flos cuculi*, *Galium uliginosum*, *Heracleum sphondylium*, *Tragopogon pratensis*, *Pastinaca sativa*, *Geranium pratense* and others. Only 1% was still covered by the typical species-rich dry grassland, dominated by *Avenula pubescens*, *Medicago falcata*, and conspicuous herbs like *Salvia pratensis*, *Verbascum lychnitis*, *Eryngium campestre* and others. The last remnants of these grasslands are in imminent danger of disappearing (Liebrand, 1999).

The deterioration in the semi-natural vegetation on the river dykes and embankments has mainly been caused by the fact that the slopes of the dykes were increasingly being used in agricultural practice, comprising intensive fertilisation, overgrazing and the use of herbicides. The botanical values of the dykes also diminished, because ecological features were insufficiently taken into account while reinforcing the dykes. On the basis of his work with numerous manipulated permanent plots, Liebrand (1999) showed that the deterioration of the river-dyke flora is a reversible process. In his experiments 98% of the plant species found before the reconstruction works of the dykes, reappeared after reconstruction. The best way to assure maintenance of species-rich grassland vegetation on reconstructed river dykes is to spare a strip of this vegetation during the reconstruction. Plant species will disperse from here to other parts of the dyke and the redevelopment of the vegetation is thus stimulated. To ensure optimal results, the soil composition of those new parts should resemble the soil composition of the spared zone as much as possible. If it is not possible to save part of the original vegetation, the upper soil layer can be set aside in the form of grass-sods or as topsoil. Replacing the original topsoil after the reinforcement provides a top-layer of similar composition to that before the reinforcement, containing the necessary seeds needed to stimulate plant succession, sustained by the application of additional seed mixtures. The application of the under-layer of clay as the new top layer, and the use of imported clay as the new top layer both prevent a quick restoration of botanically valuable, semi-natural, species-rich grasslands, because seed might be very rare or even absent in these imported soils.

Management is essential: a species-rich vegetation only develops when managed properly. On the basis of ecological features such as species-richness, number and proportion of rare species, and additional properties, the best management practices appeared to be traditional historic measures: grazing in June in combination with haymaking in September, haymaking in June in combination with grazing in September or haymaking twice a year. Haymaking once every 2 years, burning or no management at all, appeared to be insufficient management practices (Liebrand, 1999). This proves once again that the man-made semi-natural river landscape can only be maintained when the old-fashioned management practice is continued.

### *18.4.4 Changes in Habitat Structure and Vegetation*

In the process of continuous regulation of the river Rhine, in the 19th century channel constriction was the solution finally adopted to increase the discharge capacity for water and ice, and to enhance navigation. The consequences of this method of canalisation for the river vegetation can best be demonstrated in a series of maps of a stretch of river which was relatively unaffected before the works started (Fig. 18.6). Because the wide river Waal has a stronger tendency to form multiple channels than the much narrower, strongly meandering river IJssel, the effects of channel constriction on the Waal have been impressive. The oldest map of a stretch of the river Waal depicted in Fig. 18.6, reproduced in Van Heiningen (1971), dates back to 1572, but lacks sufficient detail. A 18th century map made by triangulation, gives a clear picture of the unregulated river with multiple channels separated by sandbars which were partly overgrown with trees, probably willows. Around 1750, several channels can be recognised in the forelands, one of them was still in open connection with the main channel, others were isolated at average discharges. The channels that ran parallel to the river must have been formed by moving sandbars

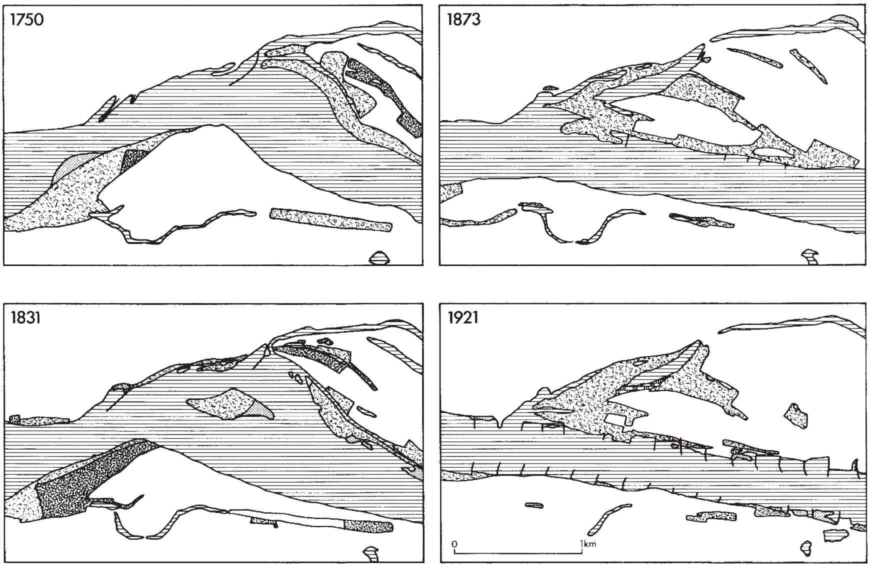

**Fig. 18.6** Waal at river 899–901 km west of Nijmegen, showing channel changes over a period of about 170 years, between 1750 and 1921.White = flood plain, probably grassland; horizontally hatched = water; lightly stippled = sand, reed, rushes and willow coppice; densely stippled = wood (Van Urk and Smit, 1989)

in the riverbed. The forelands were only partly cultivated: large areas were covered with marsh vegetation, reed and rushes and willow coppices, and stands of wood consisting of larger trees. Between 1750 and 1831 a sandy island showed up in the main channel, overgrown with rushes and willow coppice. Moreover, the wide main channel had been diverted southward, and a few groynes were built to protect the northern foreshore. By 1873 the main channel was more or less regulated: the island was integrated in the northern flood plain, and the narrow northern channel had been dammed up; behind the dam, protected by short groynes, large areas had silted-up and were occupied by willow coppices. During the same period 1831–1873 the southern bank was straightened, and most wood was cut. By 1921 the normalisation was completed, the constricted river channel was provided with numerous groynes, a few hundreds of metres apart. The open water area had decreased, older willow coppices had been removed, and remains of former meanders and channels were left as rudiments in the flood plain.

Wolfert (2001) calculated the area of ecotopes (landscape units), for 1750 and 1840 based on existing maps, and for 1990 based on Silva and Kok (1996) (Table 18.1), for the upper IJssel, the stretch from Arnhem to Zutphen (geographic names in Fig. 3.7), and for the middle Waal is the stretch from Nijmegen to Tiel (geographic names in Fig. 3.7). Wolferts' data suggest a considerable degree of accuracy, but it has to be taken into account that the old maps are not reliable, and that the ecotope classification is a subjective one. Notwithstanding these objections, Table 18.1

**Table 18.1** Historical and present-day occurrence of ecotopes (landscape units) in the flood plains of the upper IJssel and middle Waal River reaches; explanation see text (Wolfert, 2001)

| | Upper IJssel | | | Middle Waal | | |
|---|---|---|---|---|---|---|
| Ecotope | 1750 | 1840 | 1990 | 1780 | 1830 | 1990 |
| | (%) | (%) | (%) | (%) | (%) | (%) |
| Deep/shallow channel | 10.42 | 10.36 | 10.04 | 29.18 | 32.56 | 24.66 |
| Secondary channel | 0.16 | 0.00 | 0.00 | 0.99 | 3.55 | 0.00 |
| Slough | 2.40 | 0.56 | 2.62 | 3.29 | 1.40 | 4.67 |
| Sandbar/shoreface | 0.40 | 0.25 | 0.23 | 4.17 | 1.25 | 4.19 |
| Levee/dune dry ruderal vegetation | 3.03 | 2.88 | 0.30 | 0.90 | 1.29 | 0.34 |
| Levee/flood plain softwood forest | 3.27 | 2.20 | 0.60 | 8.50 | 7.69 | 1.17 |
| Levee/flood plain hardwood forest | 0.10 | 0.10 | 0.10 | 0.00 | 0.00 | 0.00 |
| Flood plain softwood timber forest | 0.71 | 0.76 | 1.36 | 2.19 | 0.56 | 0.28 |
| Flood-plain grassland | 63.05 | 66.53 | 0.20 | 44.90 | 47.43 | 0.00 |
| Flood-plain pasture | 0.00 | 0.00 | 64.07 | 0.00 | 0.00 | 48.07 |
| Flood plain moist ruderal vegetation/macrophyte marsh | 0.24 | 0.31 | 0.50 | 4.71 | 1.48 | 0.98 |
| Abandoned channel with aquatic vegetation | 1.43 | 1.45 | 0.97 | 0.09 | 1.30 | 0.12 |
| Gravel-pit lake | 0.06 | 0.06 | 8.19 | 0.19 | 0.94 | 9.48 |
| Arable flood-plain land | 14.22 | 14.12 | 8.55 | 0.77 | 0.40 | 1.78 |
| Built-up area | 0.36 | 0.42 | 2.38 | 0.13 | 0.18 | 4.23 |

allows for some interesting conclusions. During normalisation works all secondary channels disappeared. The present river ecosystems lack sandy islands, recently deposited sandbars, and levee dunes with dry river-corridor vegetation, but on the other hand the foreshore ('slough and shoreface' in Table 18.1) of the main channel is more dynamic now, which is reflected in the wide sandy beaches in between the groynes and the local presence of wind-driven river dunes and small sandy, natural levees along the river Waal. The narrow IJssel river basin contains relatively more vegetated flood plains than the wide Waal: deep and shallow channels occupy 10% of the IJssel riverbed, and roughly 25–33% of the Waal. The main occupation of the vegetated river forelands was, and still is grassland. For the river IJssel that is 70%, and for the river Waal the grassland area fluctuated over time between 55% and 70%. The intensified use of flood-plain land, however, resulted in a decrease in area of natural grasslands. The semi-natural river-corridor grassland of the past, the meadows and hay fields, made completely room for intensively fertilised and (over)grazed flood-plain pastures.

The arable flood-plain land decreased considerably along the upper IJssel, but increased along the Waal, resulting from the change of agricultural habits, in this case presumably the change from grassland into maize fields. The semi-natural flood-plain softwood forests decreased in area, the flood-plain hardwood forests were already gone along the Waal in 1750, and along the IJssel fragments remained. The area of planted flood-plain softwood timber forests (o.a. poplars) fluctuated over time. Sand and gravel mining resulted in a sharp increase in the number of deep pits and excavated areas, and the built-up lots continually increased in surface area (Wolfert, 2001).

## 18.5 The Biesbosch Wetland: A Case Study

### *18.5.1 The Vegetation of the Biesbosch*

Before 1971 the Biesbosch was the largest freshwater tidal area in western Europe (Fig. 5.5). The vegetation of this unique tidal landscape in the Rhine–Meuse Delta has been very well documented, during the period when man managed and exploited the reed and bulrush fields and willow coppices (Chapter 7). That is the reason why I pay ample attention to this area. The most detailed observations on changes in the tidal vegetation were published by Zonneveld (1959; 1999). He sustained his research on changes in the environment, mainly soil and vegetation of higher plants for 50 years from 1948 to 1997. A rarity indeed in the present-day short-term financed projects and consequently changing, fashionable interests of scientists. Zonneveld made an elaborate study of hydrology, soil genesis and vegetation composition and development in the tidal Brabantse Biesbosch before the closure of the Haringvliet (Zonneveld, 1959), and during the decades after the cease of the tidal movements (Zonneveld, 1999) (cf. Chapter 10). Figure 18.7 shows the succession of the vegetation before 1959 in detail, starting from the low-lying sand flats around low water, the silting-up process in the course of time, the sandy natural levees and the muddy back swamps covered by reed and willow beds, to the final stage where man had cultivated the grounds above mean high water level, and used them as hay meadows and arable land. Figure 18.7 not only shows the vegetation succession in time, but since all succession stages may occur simultaneously, it also shows the variety of vegetation types that occurred in the Biesbosch.

- Stage I shows the bare sandy shoals exposed at low water, a tidal gully is indicated. Isolated pools and gullies, separated by thresholds from the main tidal channel at low water, harboured a plant community dominated by *Nuphar luteum*, *P. perfoliatus* and *P. pectinatus*.
- Stage II shows the progression of the silting-up process. Natural levees were formed, consisting of (coarse) sand, and alternating layers of clay and sand. From almost low water upwards, the typical pioneer plant community, dominated

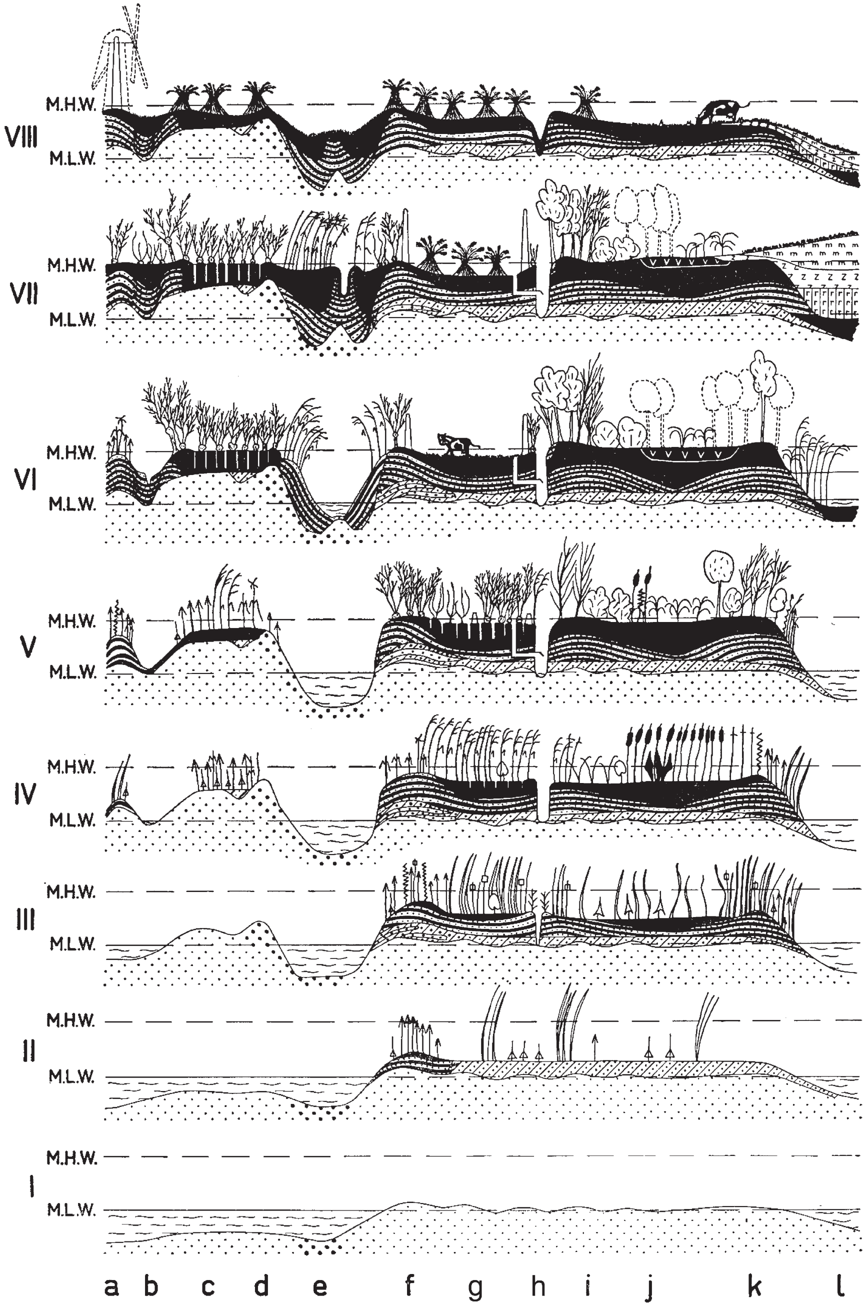

**Fig. 18.7** The figure indicates mean low water (MLW) and mean high water (MHW), the tidal difference is approximately 1.8 m. The following stages of land accretion and vegetation succession can be recognised: bare sand flats (I); rough herbage vegetation, including bulrush marshes (II, III and IV); reed marshes, and the vegetation on natural levees and in back swamps (IV, V and VI); osier fields (V, VI and VII), and polders drained by windmills and (since *ca.*1900) by steam engines (VIII). See text for further explanation (Zonneveld, 1959)

by *Scirpus maritimus* and *Scirpus triqueter*, with patches of *Scirpus lacustris*, overgrew the young sand flats, and the gently sloping banks of the gullies.

- Stages III and IV sketch the result of the ongoing silting-up process. The community of *S. maritimus* and *Phalaris arundinacea* occurred at average water level, the optimum habitat for *S. maritimus*, particularly at sites exposed to waves and currents, extensive areas were covered. Higher up this vegetation was grading into the community of *Senecio paludosus*, *Lythrum salicaria* and *S. maritimus*, optimally thriving on the natural levees. The combination of the more than 2 m tall, richly flowering yellow umbels of ragwort, together with the violet plumes of purple loosestrife composed a splendid vegetation. Still higher up the levee, around high water, a community dominated by *P. arundinacea*, with local patches of *Epilobium hirsutum* and other herbs, was growing. On the banks of narrow gullies, with gently flowing water, without competition of the larger herbs, a community dominated by the small herbs *Veronica anagallis-aquatica* and *Polygonum hydropiper* occurred. In the sheltered back swamps an open vegetation of (*Schoenoplectus*) *S. lacustris* and *Sagittaria sagittifolia* could be seen; at low tide the plants were covered with a thin layer of silt. This vegetation graded into the higher situated community of the common bulrush or club-rush, *S. lacustris* and *S. tabernaemontani*, and *L. salicaria*, the optimum habitat for the mat-rush.
- In stage IV, higher up in the intertidal zone, the community of *Typha latifolia*, *Typha angustifolia* and *Sparganium erectum* was to be found in muddy back swamps where reed, *Phragmites australis*, did not develop optimally. Close to high water mark this vegetation graded into the community of *Stachys palustris*, *Typha latifolia*, *S. erectum* and many other herbs. From mid-tide level upwards to above mean high water *Phragmites communis* formed a dominant, monotonous community, covering large areas. Around mid-tide levels and higher up, the reed marsh without herbs dominated, and *Caltha palustris* and *Myosotis scorpioides* entered the reed vegetation. Still higher up, on the natural levees around mean high water, other herbs like *Ficaria ranunculoides*, the grass *Poa trivialis*, *Anthriscus sylvestris* and *Heracleum sphondylium* became conspicuous elements.
- The stages V, VI and VII comprise the osier fields, the willow beds, the tidal forests that grow from 0.5 m below high water unto 0.5 m above, dominated by *Salix* species. In the low-lying osier fields *Salix purpurea* dominated, together with herbs like *Alisma plantago-aquatica* and *Sparganium erectum*. At higher localities a number of *Salix* species were conspicuous (*S. alba*, *S. triandra*, *S. viminalis*, *S. fragilis*), with *Rumex obtusifolius* and *Apium nodiflorum*, and algal mats of *Vaucheria* in between. Around high water *S. alba* and several tall herbs, like *Anthriscus sylvestris* and *H. sphondylium* dominated the scene. The contrast between the seasons was outspoken. In winter the swamps were grey and gloomy, the trees were bare, or covered with a layer of silt. In early spring before the willow leaves have set, the yellow flowers of *Ficaria ranunculoides* and *C. palustris* dominated the scene, soon followed by the white spots of *Cardamine amara*, a typical flood-forest plant. Around May the exuberant white flowering of the often more than 2 m tall *A. sylvestris* took over. During summer

tall herbs like *Symphytum officinale*, and *H. sphondylium* were conspicuous. On the stems of the trees a clear zoning of algae and mosses became visible (Fig. 18.8). Above mean high water, *Salix* species and other trees like alder (*Alnus glutinosa*) are dominating, and elm, oak, ash, and herbs like *Carex remota* and *Circea lutetiana* were joining the willow coppice.

- Stage VIII shows the pastures and the arable field drained by watermills, a patchwork of very small, independent polders, situated around mean high water, under the tidal regime. The embanked polders were exposed to frequent flooding, and to iron-rich seepage water. The discharge of water occurred during low water via a system of culverts. Some polders had a wind-watermill, other had a steam-pumping station, necessary after the digging of the Bergse Maas (Chapters 5 and 13), which resulted in an elevation of the average water levels in the Biesbosch. Two thirds of the Brabantse Biesbosch consisted in 1959 of arable land and pastures, and most businesses were mixed farms. In former centuries, when the levees were absent or primitive, hay meadow and pastures predominated. Large reservoirs for drinking water, altogether covering one third of the present Biesbosch area, were constructed in the 1970s (Zonneveld, 1959).

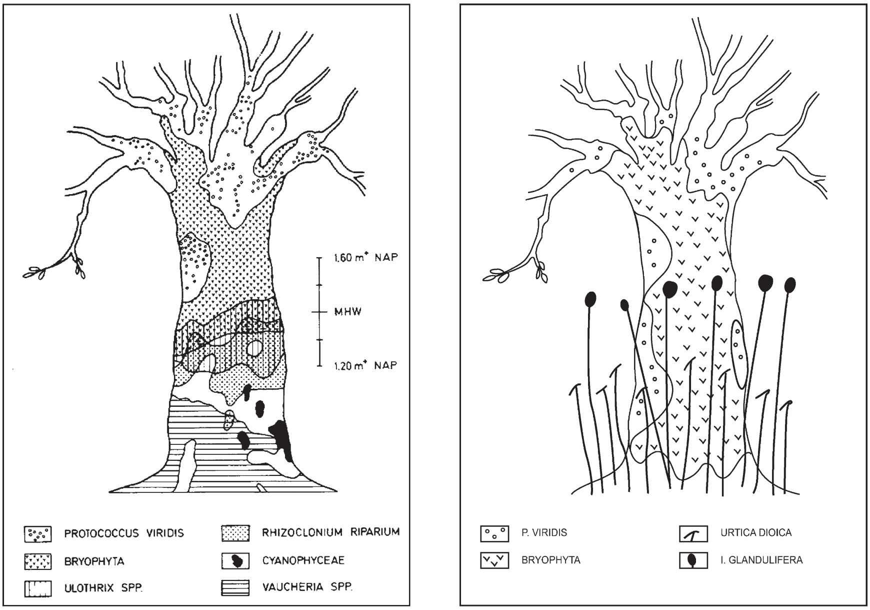

**Fig. 18.8** Growth of algae and mosses on the stem of *Salix purpurea* in a low-lying willow bed in the Biesbosch in summer 1966 (left panel) and summer 2006 (right panel). In 1966 a characteristic intertidal zoning pattern was to be observed (Nienhuis, 1980). In 1970 the tidal movements ceased and the water level was fixed at NAP ± 15 cm; in 2006 willow trees (at the same level as in 1966) were overgrown with higher plants, mosses and patches of lichens (Drawing P.H. Nienhuis)

### 18.5.2 Changes After 1970

Before the enclosure, freshwater tidal marshes were characterised by a zonation of vegetation, which was primarily associated with tidal inundation and exposure to tidal currents. In the low intertidal areas, *Scirpus* marshes with *S. lacustris*, *S. tabernaemontani*, *S. maritimus* and *S. triqueter* dominated, on higher elevations succeeded by reed marshes, ruderal vegetation and alluvial forests with characteristic understory elements. The closure of the Haringvliet estuary in 1970 abruptly ended the estuarine geomorphologic processes, and the estuary changed into a lagoon-like system with only very low currents and strongly eroding sand- and mudflats. The tidal movements were strongly reduced to a few decimetres, and thus a crucial ecologically important factor in the existence of the vast fresh and brackish water tidal marshes was eliminated (see Chapter 10). As a consequence, the vegetation changed drastically after 1970: the intertidal sand flats gradually disappeared under water, and lost their vegetation. The *Scirpus* zone gradually deteriorated throughout the enclosed Rhine–Meuse Delta: between 1970 and 1990, the *Scirpus* stands in the Haringvliet and Hollandsch Diep declined from several hundreds of hectares to less than 0.1 ha (Smit and Coops, 1990). A similar decline occurred in the Biesbosch. The reduction in area was caused by continuing erosion of the sand flats, permanent inundation of the *Scirpus* stands, and heavy grazing by geese. Figure 18.9 shows a *S. maritimus* vegetation on a sand flat that degraded after 1970 and vanished in 1985. *S. maritimus* is accompanied by an erratic undergrowth of various herbs, after 1970 particularly dominated by *E. hirsutum*, *Lycopus europaeus*, *Urtica dioica* and *Angelica archangelica*.

Within a year after the closure of the Haringvliet the reed (*P. australis*) vegetation on the sand flats changed into a dense canopy of great hairy willow-herb (*E. hirsutum*) and common nettle (*Urtica dioica*; see Box 18.1). The lack of inundation led to oxygen penetration into the soil and hence to an increased availability of nutrients. Just as was the case with the *Scirpus* stands, wave attack seriously affected the reed vegetation. Locally, this led to the formation of steep, eroding shoreline cliffs without emergent vegetation at the water's edge. It was only after the construction of protective wave breaks during the 1980s that this retreat did stop. Field studies were already undertaken in the late 1980s to study possibilities to replant *Scirpus* species using vegetatively propagated material (Clevering, 1995). Along the Haringvliet, some characteristic brackish marsh species disappeared (e.g. parsley water-dropwort [*Oenanthe lachenalii*]) or decreased significantly (e.g. wild celery [*Apium graveolens*]), while others persisted over decades (e.g. marshmallow [*Althaea officinalis*]) and common scurvy-grass (*Cochlearia officinalis*). The lower current velocities and increased transparency favoured the establishment of extensive stands of fennel-leaved pondweed (*P. pectinatus*) and perfoliate pondweed (*P. perfoliatus*) in shallow water. Between 1970 and 1995, almost all areas not embanked have become nature conservation areas. Regular mowing and grazing transformed large parts of the former reed marshes into grassland, dominated by *Poa trivialis* and *Agrostis stolonifera*, expanding the foraging terrain for wintering

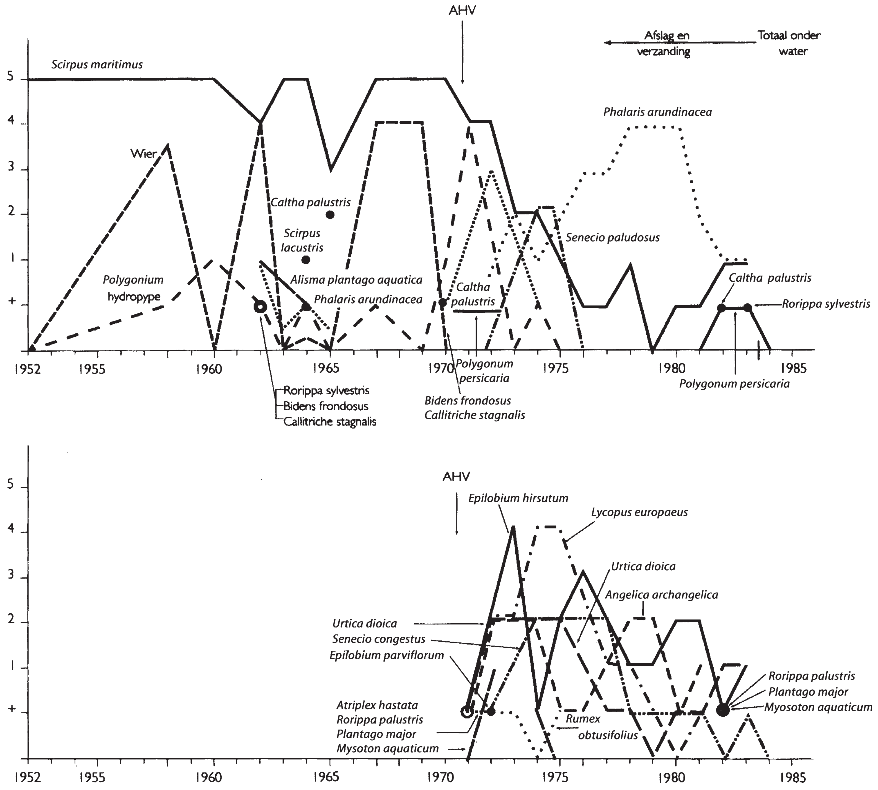

**Fig. 18.9** Sequence diagram of the plant species in permanent quadrate (PQ) 2, in the period 1952–1985 (horizontal axis), using the combined abundance-cover estimate scale of Braun-Blanquet, (vertical axis) in which + = less than 1% cover; 1 = very sparse, 1–5% cover; 2 = sparse, 6–25% cover; 3 = not numerous, 26–50% cover; 4 = numerous, 51–75% cover; 5 = very numerous, 76–100% cover (Shimwell, 1971). PQ2 was situated in 1952 *ca.* 60 cm above NAP. Mean high water was at 100 cm + NAP, MLW at *ca.* 100 cm – NAP. Haringvliet sluices closed at 55 cm + NAP, just above the level of PQ2 (Zonneveld, 1999)
The plot was fully dominated by a homogeneous vegetation of *S. maritimus* from 1952 onwards until 1971, the closure of the Haringvliet (AHV). The tidal movements ceased completely, and this shock drastically changed the vegetation pattern. *S. maritimus* shrunk to insignificant proportions, waves of *E. hirsutum*, *Lycopus europaeus*, *P. arundinacea*, *Urtica dioica*, and later *A. archangelica* came up and went down again. Additional higher plants followed: species diversity increased from 2–6 species during 1951–1970 to 11–26 species in the period 1971–1983. Erosion and sedimentation processes accentuated the instable physical circumstances of PQ2, so close to the waterline. Continuous wave attack led in 1984–1985 to the complete disappearance of the plot underwater, and only a sparse growth of the water-plant *Potamogeton pectinatus* could stand these physical forces (Zonneveld, 1999)

geese, viz. barnacle goose (*Branta leucopsis*) and greylag goose (*Anser anser*) (Smit et al., 1997; Zonneveld, 1999).

Willow trees reacted positively to the decreasing flooding frequency and the accompanying soil ripening after 1970, and gradually increased in diameter and

**Box 18.1** Praise and despise of the stinging nettle

In former centuries everything nature provided was used by humans, and this is one of the most pregnant differences with the present-time appreciation of nature. The use of artificial, chemical medicines and the squandering of food provided by our supermarkets has distracted humans from the healing powers of the plants surrounding them. Take the stinging nettle (*Urtica dioica*), nowadays seen by gardeners as one of the most unwanted weeds. The gigantic growth of the stinging nettle in the Biesbosch, thriving on the rich nitrogen sources in the soil, makes large parts of the marsh inaccessible. In olden times the stinging nettle was an appreciated medicine, as described in Dodoens' 'Cruydt-boeck' published in 1554 (Schierbeek, 1954): A medicine prepared from nettle leaves cooked together with mussels improves regular bowel movements. A mixture of nettle leaves cooked with hulled barley, or a draught of nettle juice and honey are medicines against lung diseases. Seeds of the stinging nettle mixed with vinegar function as a plaster against pustules, and various inflammations of the skin, and plasters of crushed leaves cure gout. The juice from crushed leaves staunch nose bleeding. In short, the stinging nettle was a remedy against many ailments, from affection of the lungs and kidneys, to skin diseases and gout. So far Dodoens in the 16th century. Widely applied knowledge that was transferred from one generation to the other is nowadays restricted to the domain of naturopathy, which praises the stinging nettle for its diuretic and allergy treating qualities (e.g. www.allnatural.net/herbpages).

height (see Fig. 18.8). The 'nettle forests' were gradually overshadowed by tree growth. Hardwood flood-plain forests developed at mature soil; the most important tree species are *Fraxinus excelsior*; *Ulmus minor (campestris)*, *Prunus padus* and *Quercus robur* together with still some *S. alba*, *S. fragilis* and *Populus nigra*, and as shrub *Crataegus monogyna*.

Neophytes were already on their way before the closure of the Haringvliet, but their growth was stimulated by disturbances evoked by the Delta project (cf. Chapter 17). The large invasion 'wave' of the giant *A. archangelia* even inspired engineers to suggest eradication measures. After several years in which this colourful plant dominated large parts of the former sand- and mudflats, it faded away and now takes a modest place among other rough herbage plants. In the meantime *Solidago gigantea*, a neophyte from America, and especially the giant *Impatiens glandulifera*, a colonist from the Himalaya's, expanded their area. Circa 25 years after the closure of the Haringvliet hundreds of hectares of the Brabantse Biesbosch are dominated by the giant *Impatiens*, including parts of the initial nettle forests (Fig. 18.8). The river Rhine is the main carrier of the diaspores of these newcomers as well as of the species of the hardwood flood-plain forests (Zonneveld, 1999).

### *18.5.3 Human Use of Trees and Herbs*

In former centuries everything nature provided was used by humans in one way or another (see Chapters 6 and 7; Box 18.1). Three groups of plants from the tidal freshwater habitats in particular were economically highly valued, rushes, reed and willow trees. Mat-rushes flourished in the lower half of the intertidal zone, reed had its favourite habitat from mid-tide level up to above mean high water, and willow forests, osier fields thrived around mean high water. The mat-rush cutters hated the numerous herbs that grew in between the rushes, and skilful exploitation of the marshes eventually exhausted the vegetation of herbs, while the rushes do not suffer under this regime. A well-managed mat-rush field was characterised by the almost absence of herbs. The rushes were harvested during midsummer, and in early autumn the rush vegetation had regenerated completely, but they did not flower for a second time that year. The cutting of rushes should best occur once in 2 years, because a more frequent harvest could negatively influence the vitality and the quality of the rushes. The culture of the mat-rush went down after World War II, and only some minor traditional trades are customers of small quantities of rushes.

Reed is extremely competitive, and only very muddy soft bottoms and too exposed places were avoided. Under optimum conditions reeds may reach a length of 3.5–4 m, sometimes even 5 m. Reed marshes were dominating the Biesbosch landscape, and that was mainly caused by human actions. Since olden times man had harvested reed, and particularly in the Biesbosch, because of the excellent qualities of the crops. The combination of the available genotype (*P. australis var. latifolia*), and the rich eutrophicated conditions under the tidal regime, made the reed flourishing. Shortly after the origin of the Biesbosch (1421) man started to cultivate reed. The species preferentially grew on the firmer parts of the soil of the back swamps, and one of the preconditions of a successful reed culture was that trenches had to be dug through the marshes, to enhance the dewatering of the soil, separated *ca.* 5 m from each other, and only several decimetres deep. Regular harvest was also favourable for maximum growth. Dense layers of decomposing above-ground parts of reed may suffocate the vegetation, aggravated by strong winds and ice drift in winter. The reed-cutter removed these plant parts during the harvest, hence consolidating the conditions of the soil, and stimulating the vigour of the plants. When reed marshes were not harvested during one or more seasons, the vitality of the reed plants was negatively affected. Eventually, when the silting-up progressed, the habitat became suboptimal, and ‘worn out’ and had to be abandoned.

The cultivation and reworking of reed had quite some socio-economic significance for the human population in and around the Biesbosch. Most of the work could be done by untrained labourers, in contrast to work in the willow coppices which asked for more skills. Reed is harvested during winter, when there is shortage of labour for farm workers. The work consisted of harvesting by hand with the scythe, transport to the wharf, maintenance of the drains and removing competitive herbs from the reed marsh. Skilled labourers did the cleaning and sorting of excellent reed to ‘matriet’ for reed bottoms in furniture and other wattle-work, and less tall and hard ‘dekriet’ for thatched houses, and numerous other applications (cf. Chapter 7). The quality of the reed differed greatly from place to place, depending on the genetic characteristics of the clone; one individual could cover several thousands of square metres. Centuries ago the reed-cutters were already aware of these differences in vitality and vigour of the clones. There are old stories of theft of the better reed rhizomes from neighbouring reed marshes, to plant them on their own lots. In contrast with the use of mat-rush, the use of reed is nowadays still of economic significance, e.g. for thatched houses, and as reed-mat boundaries between private properties.

Maintaining and exploiting osier-beds is a very old trade, not only in the Biesbosch, but also along the tidal sections of the Large Rivers, e.g. along the river Waal as far upstream as Zaltbommel (location Fig. 5.5). After 1421 the Biesbosch gradually became the centre of the cultivation of osier-beds, in particular the culture of ‘hakgrienden’. Maintaining osier-beds is a labour-intensive trade, which demands much labour mainly during winter. The labourers stayed during the week in the Biesbosch, slept in their barracks and went home during weekends. The willows were planted in rows and narrow trenches were dug in between the lines of willows, in order to enhance the draining of floodwater, separated *ca.* 2.5 m from each other. The workers in the coppice embanked areas of the flood forests, and built culverts in the low levees to manage the water level, mainly to decrease the flooding frequency. A well-maintained osier-bed was a plantation of willows, where the undergrowth of herbs was seen as redundant weeds. Once per 3–5 years the willows were coppiced, and the wood was transported by boat to the wharfs. Osiers, willow shoots and branches, had many applications (cf. Chapter 7). The handling of wood in its diversification was skilful labour, transmitted from father to son. Basket-making (Fig. 18.10) and hoop-making (e.g. for herring casks) were two of the most familiar applications, and numerous small family trades have existed in the neighbourhood. After World War II iron hoops have expelled the wooden hoops from the market. Willow wood was frequently used in hydraulic projects, e.g. for the construction of willow matting, the basement of levees and dykes (Chapter 9). Nowadays the exploitation of willow-holms has almost totally lost its profitability, and consequently the maintenance of the remaining osier-beds is abandoned. As ‘an echo of the past’ nature conservation agencies maintain some small lots, as demonstration projects to the public. The culture of poplar trees is more cost-effective than maintaining the labour-intensive osier-beds, and consequently some abandoned and ‘worn out’ reed and willow sites have been re-cultivated into poplar stands (Zonneveld, 1959, 1999; Smit and Coops, 1990; Strouken, 1993).

## 18.6 Conclusions

– A complex of lotic and lentic communities with snags, macrophytes, macrophyte debris and undisturbed sandy banks and river islands as habitats for benthic organisms, including aquatic macrophytes and numerous rheophilous insects,

**Fig. 18.10** Basket-maker (Etching from Luiken, 1694)

mainly scrapers and shredders, have vanished, due to regulation and normalisation works and shipping traffic.

- The biodiversity of hard substrate dwellers, snails, mussels, and especially, macro-crustaceans is at present higher than in the early 20th century, mainly resulting from the invasion of exotics from all over the world.
- The present-day situation strongly deviates from the situation in the past: species richness of phyto- and zooplankton, aquatic macrophytes and macro-invertebrates increase with a decreasing degree of connectivity with the main river channel.
- In past centuries a spatial ecological gradient existed in the river flood plains, from the remote, not fertilised grasslands with nutrient-poor water to the enriched fields close to the farms. The introduction of artificial fertiliser at the

end of the 19th century has abruptly changed this situation, and is considered as a major negative impact on the semi-natural vegetation.

- The characteristic species-rich flora of river basins, the semi-natural river-corridor grassland (rich in lime) and grassland-on-peat (poor in lime) that has developed in past centuries under the management regime of farmers, has lost much of its former qualities in the 20th century, owing to habitat loss, intensive draining, fertilisation, pollution and land use.
- Radical changes in land use were detrimental for pioneer and marsh vegetations, reed marshes, species-rich wet blue-grasslands and dry river foreland grasslands. The growth of hardwood flood-plain forests to maturity conflicts with river management.
- Artificial elevation of the water table in river flood plains during summer can be detrimental for the vegetation. Phosphate concentrations may increase several fold as a result of prolonged anoxic conditions. Aerobic conditions are needed in summer, to stimulate oxidative nitrification processes.
- Large-scale dyke reinforcement schemes after World War II annihilated the majority of the dry flower-rich grasslands on river dykes. The deterioration of the river-dyke flora, however, is a reversible process, e.g. by sparing a strip of the original vegetation during the reconstruction measures.
- Before 1970 freshwater tidal marshes in the SW Delta were characterised by zoning of vegetation, associated with tidal inundation and exposure to tidal currents. In the low intertidal areas rushes dominated, on higher elevations succeeded by reed marshes, and alluvial forests. After the closure of the estuary the vast fresh and brackish water tidal marshes were eliminated, and the intertidal sand flats gradually disappeared under water, and lost their vegetation.
- Three groups of plants from the (tidal) freshwater habitats in particular were economically highly valued, rushes, reed and willow trees. Nowadays the exploitation of willow-holms has lost its profitability, and consequently the maintenance of the remaining osier-beds is abandoned.

# Chapter 19
# Changes in Biodiversity: Birds and Mammals and their Use

## 19.1 Introduction

Birds and mammals far out are the best studied of all animals in the Delta, and in this chapter a variety of these creatures will pass in review. Until the early decades of the 20th century almost all bird species in the Delta were caught or hunted, either for their eggs or feathers or for human consumption. Much has changed since then in favour of the birds. At present *ca*. 40% of the avifauna species in the Delta have international significance in terms of the IUCN Red list and the EU Bird Directive. In this chapter attention will be given to recent (19th and 20th century) changes in avian species richness and their ecology, particularly waterfowl, connected to the use humans have made of birds. Birds are conspicuous by their direct and quick response to changing environmental conditions, availability of food and resting and breeding sites.

In this chapter a number of birds and mammals will be discussed that have an ecological connection with river habitats, mainly to demonstrate the subjective way of treating these animals as 'harmful' or 'useful' in the course of the history of the Delta. Notwithstanding the focus on wetland species, the choice remains arbitrary, mainly based on public interest and the 'cuddliness' of specific species. In the past mammals were exposed to the same fate as birds. 'Useful' species, either big game or small game, were hunted after and poached, and prepared for human consumption and many other applications. 'Harmful' species, like wolf and brown bear, were prematurely annihilated, because of their threat for humans, cattle and game. Some other species, like the harbour seal and the otter, were considered as a severe threat to fisheries, and fell victim to bounty hunters. Just like birds, since a few decades almost all mammal species have a legally protected status, and their population size is artificially controlled. Some species, on the contrary, are rigorously chased because of their assumed harmful habits. What birds and mammals have in common are the large quantitative changes in population size in a given space of time, the past two centuries. Extremes in weather conditions, habitat loss, changes in agricultural practice, environmental pollution and eutrophication, increased pressure of humans on remote and rural areas, and many other factors have been responsible for these fluctuations. Many of these relations will be discussed in this chapter.

P.H. Nienhuis, *Environmental History of the Rhine—Meuse Delta,*

## 19.2 The Avifauna of the Delta

### *19.2.1 Prehistoric and Historic Trends*

Van Eerden (1997) postulated that the total number of individuals of 36 species of waterfowl present during winter in the Delta gradually must have increased from the early Atlanticum (*ca.* 7,000 years BP) until the late Sub-Atlanticum, i.e. the late Middle Ages (*ca.*AD 1350), during which period several wetland types reached their greatest range (Fig. 19.1). This assumption is based on the estimated size of specific habitats, tentatively derived from available palaeo-geographical maps. Estimated data about bird density per habitat type necessarily come from recent investigations, and consequently the data in Fig. 19.1 are based on tentative extrapolations, that should be considered with caution. All categories of water birds, except herbivores, peaked in the Middle Ages, still little influenced by man. One of the most important effects of man's subsequent historic actions was habitat loss by the transformation of 'nature' into grassland and arable land. Other measures led to the disappearance of tidal forces, owing to the construction of large seawalls and enclosure dams, together with the strict regulation of river flows, which caused the large-scale disappearance of transitional wetland zones. The historic extension of grasslands and arable land became significant, mainly at the cost of peatland, heath and salt marshes. Compared to the Middle Ages, this led to an explosive, almost sevenfold increase in the number of wintering herbivorous water birds, despite the loss of salt marshes and river flood plains. Although the total number of wintering water birds is estimated to be higher today than at any time before (going back until 7,000 years BP), a considerable number of species of the non-herbivorous water birds have strongly decreased since the late Middle Ages due to the land-use activities of man. Calculated numbers of wintering benthos-eaters and fish-eaters have sharply declined, due to the flagrant decrease in brackish and marine shallow waters. Also planktivorous water birds like shoveler (*Anas clypeata*) are estimated to have severely declined since the late Middle Ages (Van Eerden, 1997).

Van Eerden (1997) tentatively concluded that with respect to species composition, the avian fauna of wetlands in the Rhine–Meuse Delta has not changed dramatically over the past 7,000 years. Birds are able to fly, and owing to that habit birds may avoid extinction, because they may reach and colonise isolated patches of wetland. Compared to mammals and some plant and insect groups, birds respond faster to changes in habitat availability. Due to this highly versatile behaviour, only a very small number of waterfowl have become (locally) extinct in the last 7,000 years, based on evidence from archaeological finds and historical data. Quantitatively, however, the changes in numbers of individuals per species in the course of time were significant, mainly caused by the changes in land use and the management of aquatic habitats (Fig. 19.1), and last but not least, by the changes in the habits of man: from hunting and severe suppression to overall protection in the last decades of the 20th century.

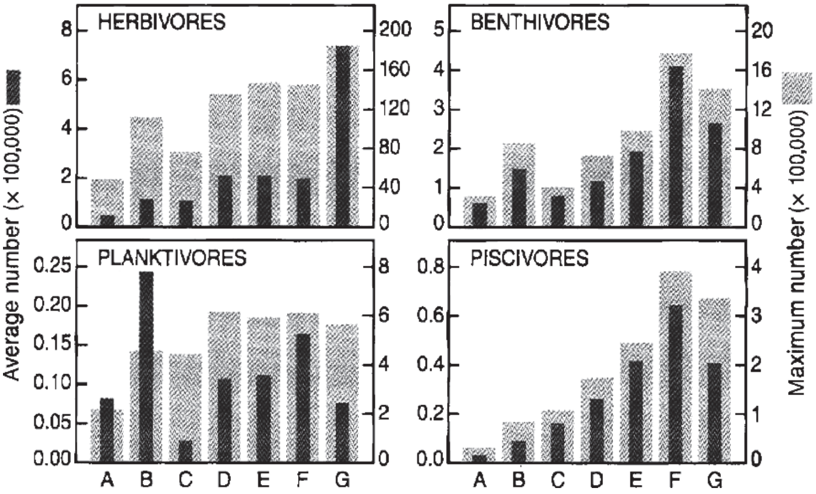

**Fig. 19.1** Assumed composition of the avian fauna (36 species) for seven geological periods (A: early Atlanticum, 7000 BP; B: late Atlanticum, 5500 BP; C: mid-Subboreal, 3500 BP; D: early Sub-Atlanticum, 2100 BP; early Middle Ages/mid Sub-Atlanticum, AD 850; F: late Middle Ages/late Sub-Atlanticum, AD 1350; G: present time, 1995) and four functional groups of water birds. Maximum numbers during migration, and average mid-winter numbers are indicated. The calculated numbers are considered indicative, assuming roughly the same migratory abilities as the birds show nowadays. The calculated numbers are mainly based on the assumed size of specific habitats, derived from a compilation of available palaeo-geographical maps of the Delta. During the late Sub-Atlanticum several habitat types reached their greatest range: freshwater marshes (arbitrarily calculated surface area 390,000 ha), salt marshes (560,000 ha), mudflats (262,000 ha) and brackish shallow water (111,000 ha), while still considerable areas of fen-peat (332, 000 ha) and raised bogs (357, 000 ha) existed; all categories of water birds, except the herbivores, peaked in this period, still little influenced by man. Characteristic for the present-day wetland are the shallow open freshwater lakes (<10 m deep, 294, 000 ha; e.g. IJsselmeer, Volkerak-Zoommeer) and hundreds of thousands of hectares of farmland (herbivores) (Van Eerden, 1997)

Until the early 20th century everything nature provided was used by humans (see, e.g. Chapters 7 and 8). The use of birds and eggs was no exception. Birds were caught for consumption, using a variety of devices, such as decoys, nets, lime-twigs, etc. Egg-picking was a widespread habit, and parts of birds, such as feathers, had broad applications, e.g. as writing-material and for ornamental functions. ‘Harmful’ birds were severely persecuted, and whether a bird was ‘harmful’ or ‘useful’ was subjectively defined by the landowner. Particularly fish-eating birds were hunted without mercy, because of the (supposed) competition with fishermen. Many breeding colonies of fish-eating birds have been completely annihilated, including their habitat. Exploitation and repression of colonially breeding water birds was a common habit until protective laws came in operation in the 20th century. Historical documents provide detailed information about the numbers caught and sold on the market. From sales accounts from the 14th century it is known that large numbers of colonial birds such as grey herons (*Ardea cinerea*), spoonbills

(*Platalea leucorodia*) and night herons (*Nycticorax nycticorax*) were caught and sold. From the 16th century onwards more historical data are known. Official documents ordered by the magistrates aimed at the regulation of hunting and catching of birds, and egg-culling of many waterfowl.

From 1906 onwards some bird species got a formally protected status (e.g. terns). The Bird Act of 1912 was a further step, but the edible and harmful species remained outlawed. Almost a century later, in 2002 the new Flora- and Fauna Act passed parliament, including the older bird protection and hunting regulations. In general almost all bird species are protected now, and hunting is only permitted on pheasant, mallard and wood pigeon. Hunters are also engaged to reduce damage to agricultural produce by, e.g. mute swans, coots and geese. These dispensation measures are not considered as regular hunting but as ‘management’ of the population (Bijlsma et al., 2001; Van der Windt and Knegtering, 2005).

### *19.2.2 Waterfowl and Agriculture in the 20th Century*

Changes in agricultural practice after World War II have had a tremendous impact on waterfowl populations in the Delta. Most herbivores are directly affected by changes in food supply, other groups are indirectly affected through changes in water quality. High nutrient loads in freshwater ecosystems have led to a switch from a clear water, macrophyte-dominated system to a turbid water, algae-dominated system which has caused a decline in the populations of macrophyte-depending, herbivorous waterfowl (Chapter 14). The degree of dependence on agricultural land and natural habitat for different species of herbivorous waterfowl from the western migratory routes is significant. Mute swan (*Cygnus olor*), bean goose (*Anser fabalis*) and greylag goose (*Anser anser*) spend on average 9 months per year on agricultural land. The use of agricultural habitats is related to body size; the large species spend more time on agricultural land than smaller species. In other words, only the small herbivores still rely on natural habitat for the greater part of the year.

The present winter distribution of herbivorous *Anatidae* in western Europe is closely linked to the presence of improved grasslands. Figure 19.2 shows an idealised reconstruction of the changes in grassland quality during the 20th century. It is based on the shift in date of first cut of the grass, the extended use of grass in late autumn and the effect of nitrogen fertiliser on the quality of grassland throughout the year. The larger *Anatidae* responded earlier in time to the continual improvement of the grass sward than the smaller avian herbivores. One of the consequences of the greater dependence of waterfowl on agricultural food is the apparent conflict with the interests of man. Damage by grazing geese, ducks and swans has been reported for decades, and different solutions put forward. The increased quality of the food has led to the situation that growing populations of several species no longer depend on natural food in winter. This seems particularly true for the larger species which can only be dispersed, rather than distracted from the agricultural scene. It is no solution to suggest that, in combination with scaring practices, the still available natural areas can support these birds. As grasses form the major food plants for grazing waterfowl in winter, grassland and young cereals will therefore remain important future food sources. As cereals compared to grass are much more sensitive to grazing with respect to a reduction of the yield, and the greater economic losses per hectare, much effort has been put in research aiming at quantifying and resolving the conflict between damage and conservation.

One of the obvious aims is the distraction of geese and ducks from cereals and the attempt to concentrate them on less vulnerable pastures. This approach can only be successful if the energetic return of grass for the grazing birds is equal or higher, and this is only the case at a high level of fertilisation of the grass sward. The reduction in nitrogen application to grasslands, which is a governmental goal, is likely to further increase the difference in quality, which means an increasing risk of damage to cereals. Also, the change in the management of nature areas by a ban on cattle grazing, partly set by the lower number of cattle available, leads to a deterioration of the composition of wet meadow and salt-marsh vegetation and will unavoidably result in a greater risk of damage to cereals in the coastal regions of the countries bordering the North Sea. Especially the smaller species such as wigeon, brent goose and barnacle goose will be forced in the future to concentrate both on winter cereals and on the remaining high quality pastures, as their demand for protein is higher than in the larger species such as greylag geese and Bewick's swans (Van Eerden, 1997).

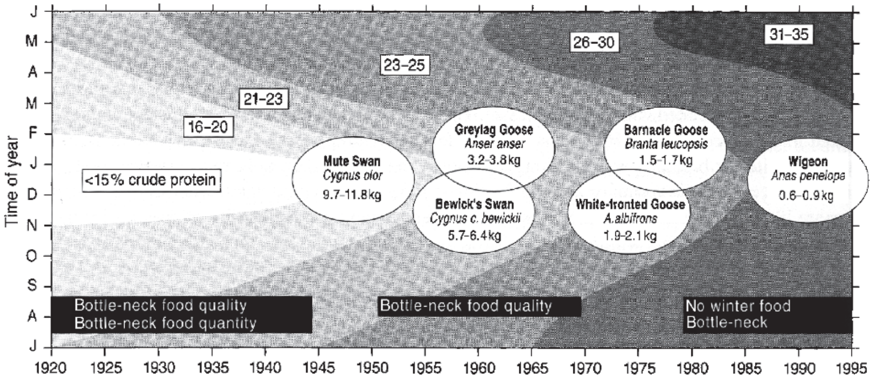

**Fig. 19.2** Approximated presentation of long-term changes in food quality of grasslands on dairy farms in the Delta in the course of the year. The picture shows crude protein content on dry matter base as a measure of quality. The somewhat idealised picture has been derived from data indicating the shift in date of first and last cut over the years as well as the seasonal pattern of crude protein content in fertilised and unfertilised swards. On the horizontal time axis indicated for different species of herbivorous *Anatidae* is the start of period of full dependence on improved grassland during the winter period. Species with less body mass shifted later than larger species (Van Eerden, 1997)

## *19.2.3 Avian Biodiversity*

### 19.2.3.1 Swans, Geese and Ducks

European mute swan (*C. olor*) populations have been divided in 'wild' and 'tame' ones, and since olden times escaped or released 'tame' mute swans have bred in the Delta, but the population remained fairly scarce until the first half of the 20th century, because of widespread persecution and systematic nest disturbance. After World War II variations in numbers and range outside the breeding season were related to water pollution and availability of food resources, especially stoneworts and *Potamogeton* in autumn and early winter, and grass in late winter. Bewick's swan (*Cygnus bewickii*) is a fairly common passage migrant and winter visitor. Numbers of Bewick's swans increased after submerged water plants, particularly *Potamogeton* species, proliferated following the enclosure of the Zuiderzee in 1932. The newly created freshwater IJsselmeer and its immediate surroundings have been important wintering sites ever since, although water pollution afflicted stoneworts and *Potamogeton* in the 1970s and 1980s, forcing Bewick's swans to start foraging on grasslands. Presently, the main wintering areas are situated in the NW Delta, and later in winter also the river district and SW Delta. Further expansion of staging areas took place in the 1980s, when flocks started to forage on arable land in the N Delta.

In the 20th century several migratory and breeding geese species in the Rhine–Meuse Delta were on the brink of extinction, presumably mainly by over-hunting. After a ban on hunting in several countries in the 1970s the numbers of wintering geese in the Delta showed a spectacular increase, both greylag goose (*Anser anser anser*), greater white-fronted goose (*Anser albifrons*) and barnacle goose (*Branta leucopsis*). Geese started to profit from their protected status, the increase in numbers of staging areas, and from the increasing crude protein content of grasslands, resulting from the sixfold increase in use of fertiliser in the period 1940–1985. The estuarine dark-bellied brent goose (*Branta bernicla*) suffered severely from the eelgrass decline in the 1930s (cf. Chapter 16) in combination with hunting pressure, and these facts have led to a marked population crash. Numbers started to recover in the 1960s and particularly in the 1970s, coinciding with a shift to foraging on enriched grassland and autumn-sown cereals (Bijlsma et al., 2001).

Ducks have always been very numerous in the water-rich Delta (Fig. 19.3), and the hunting and catching of ducks for human consumption has been normal practice until the present day (cf. Chapters 6 and 7), on the understanding that the regulations recently became very strict: all duck species are protected now, except the mallard (*Anas platyrhynchos*). The red-crested pochard (*Netta rufina*) showed a decrease in the 1960s owing to a decline of stoneworts, following the decreased turbidity of surface water. Water quality improvements in the early 1990s led to increase in red-crested pochard, and the recovery of stoneworts caused even an upsurge in numbers. Numbers of the common pochard (*Aythya farina*) increased also since the early 1990s caused by increased offer of food, i.e. stoneworts in autumn, and zebra mussels in winter (Veluwerandmeren). In 1970s and early 1980s numerous common pochards were observed at Haringvliet and Grevelingen.

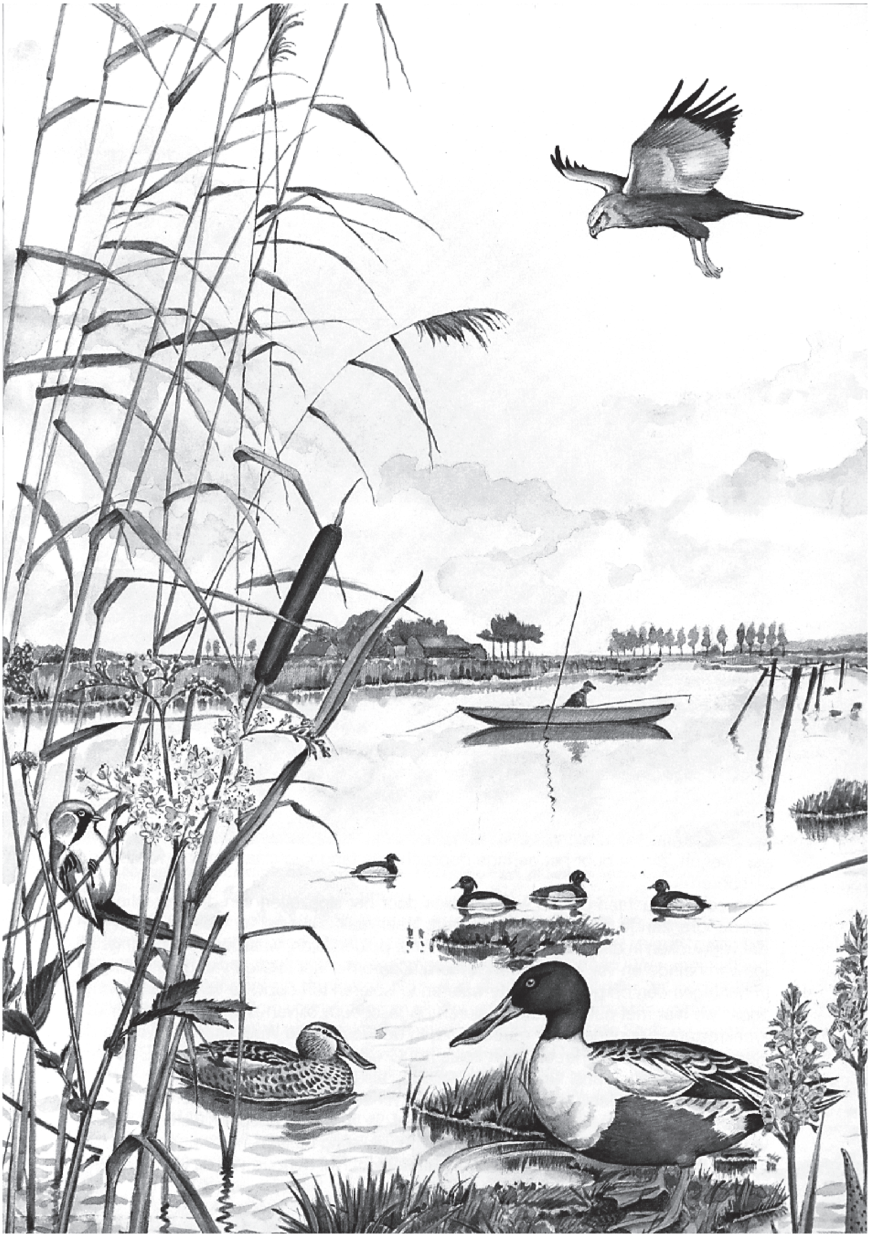

**Fig. 19.3** Contemporary wetland in the SW Delta with ducks, such as northern shoveler (*Anas clypeata*) and tufted duck (*Aythya fuligula*). In the reed marsh the bearded tit (*Panurus biarmicus*), and the marsh harrier (*Circus aeruginosus*) hovering overhead (From Nienhuis et al., 1986)

At night these birds foraged on the abundant eelgrass seeds in the Grevelingen and during the day they rested at the Haringvliet. Decline of eelgrass led to disappearance of this duck (cf. Chapter 16). The numbers of Eurasian wigeon (*Mareca penelope*) have also increased in recent decades. This duck showed a remarkable adaptability to dynamic agricultural habits: they increasingly started to forage on highly productive grasslands instead of salt marshes, and eelgrass beds, in many years favoured by mild winters.

The fear that the mallard would decrease owing to cultivation and drainage of wetlands and high hunting pressure, did not come through. This duck also showed great adaptability to changed habitats, agricultural fields. In contrast the garganey (*Anas querquedula*) decreased in numbers. The duck could not cope with the profound changes in grassland management and earlier mowing regime. The common teal (*Anas crecca*) shows fluctuating numbers, depending on the availability of food, e.g. seeds, and oligochaetes (Bijlsma et al., 2001).

The numbers of carnivorous ducks also showed erratic changes over time, mainly connected with habitat and food availability. The tufted duck (*Aythya fuligula*), feeding on invertebrates, e.g. zebra mussels in deeper water, left the polluted Veluwerandmeren in the 1970s, but strongly increased in numbers, now the lakes are clean again. The smew (*Mergellus albellus*) mainly occurs in the IJsselmeer feeding on smelt (*Osmerus eperlanus*). The common goldeneye (*Bucephala clangula*) is mainly a benthos feeder (e.g. *Dreissena polymorpha*). Its initial increase after the closure in 1969 in the clear Volkerakmeer, was followed by a sharp decrease due to progressive eutrophication and concomitant turbidity of the water (SOVON, 1987; Bijlsma et al., 2001).

#### 19.2.3.2 Grebes, Cormorants, Bitterns, Herons, Storks and Spoonbills

The grebes, cormorants, bitterns, herons, storks and spoonbills comprise a large group of mainly carnivorous waterfowl. The great crested grebe (*Podiceps cristatus*) is an opportunist, and thanks to the recently improved water quality, large numbers of wintering grebes are to be observed on the surface waters of the Delta. Over the past decades grebes showed a change in behaviour and habitat choice; they became less shy and colonised town canals and recreation sites. The great cormorant (*Phalacrocorax carbo*) is known as a breeding bird at least from the 17th century onwards, but intensive hunting of this ‘competitor’ by fishermen kept the stock low. The lowest numbers were counted during the1960s when surface waters in the Delta were severely polluted (cf. Chapter 14). The numbers of breeding cormorants have increased markedly since the late 1970s, however, in response to effective conservation and increased fish stocks. It is observed that the cormorants themselves locally showed an adaptation of their fishing behaviour, i.e. the performance of social foraging on eutrophic waters (Bijlsma et al., 2001).

The shy and inconspicuous great bittern (*Botaurus stellaris*) was a rather common bird from the 16th until the 19th century. The preferred breeding habitats were the large reed marshes in Central Delta, and the IJssel Delta. Great bitterns may show great changes in population size. The birds suffer greatly during severe winters (e.g. 1962–1963), particularly when common voles, as alternative food for fish and amphibians, are not available. The long-term and drastic decrease in numbers became apparent in the 1980s and 1990s, mainly to be attributed to the disappearance of extensive reed marshes, and to the expansion of towns and the intensification of water recreation. The dynamic changes in water levels needed to maintain reed marshes have mainly ceased in favour of artificially regulated water tables. The cutting of reed is no longer profitable, and consequently many reed marshes are growing solid, and wild shoots of willows and other trees are occurring all over. The little bittern (*Ixobrychus minutes*) was until the first half of the 20th century a rather rare, but locally more common, breeding bird. At present it is an extremely rare breeding bird in the peat marshes of the Central Delta, and along the Large Rivers. The causes of the decline are largely unknown, but the increased recreation pressure has certainly had a negative impact (Bijlsma et al., 2001).

The black-crowned night heron (*Nycticorax nycticorax*) was until halfway the 19th century a well-known breeding bird in colonies. Several large colonies have been described in historic documents from the 14th century onwards, but these concentrations disappeared owing to excessive egg-picking, ‘harvesting’ of the animals, clear felling of their breeding groves, and draining and cultivation of the peatlands. More recently increasing recreation pressure has led to the disturbance of the remaining colonies. From 1980s small numbers of the black-crowned night heron have been released, and small feral populations became anew established. The little egret (*Egretta garzetta*), in former centuries breeding in large colonies, was mentioned already in 14th century documents (‘the birds were harvested and sold’). It is now an extremely scarce breeding bird, which might be positively influenced by the construction of new wetlands and re-wetting measures (‘nature development’). In contrast to the little egret there are no indications of the occurrence in former centuries of breeding pairs of the great white egret (*Egretta alba*) in the Delta. From 1978 onwards the great egret is irregularly breeding in the Delta in large remote wetlands, such as the Oostvaarderplassen (Bijlsma et al., 2001).

The grey heron (*Ardea cinerea*) is known from the Middle Ages, breeding in large colonies. Hunting and deliberate disturbance of nests held the numbers at an artificially low level. Severe winters are killers of herons; e.g. the severest winter of the 20th century (1962–1963) decimated the population in the Delta. Notwithstanding the legal protection introduced in 1963, the population only showed a slow recovery. The grey heron is now a fairly common breeding bird in the Delta wetlands, and the species has remarkably well adapted to the drastically changed Delta landscape in the 20th century. The locally deteriorated feeding conditions, due to loss of habitat and water pollution, have been compensated by a spread in breeding colonies, e.g. breeding colonies in the gravel and sandpits along the river Meuse. The birds took advantage of the increase in numbers of several fish species in the eutrophicated surface waters. In the 1970s PCBs and mercury in fish were held responsible for the decline of the population. Improvement of water quality, creation of wetlands, ban on the spread of persistent pesticides and legal protection are thought to be responsible for the thriving population from the 1980s onwards.

The cease of their shyness after the proclamation of complete protection has greatly promoted breeding, foraging and survival of the grey heron. The birds are opportunists, they lucratively make friends with sport anglers and residents of retirement homes, but they also not shrink from penetrating kitchens and butcher's shops; this attitude presumably holds the key for further exploitation of the urbanised Delta in the 21st century. During centuries the purple heron (*Ardea purpurea*) has been a breeding bird for in the Delta. Large-scale egg-picking and 'harvesting' of chicks, and drainage of their breeding habitats, however, have decimated the populations. Presently the species is a scarce breeding bird, and habitat deterioration of breeding and feeding sites is playing an increasingly important role in population dynamics (SOVON, 1987; Bijlsma et al., 2001).

The black stork (*Ciconia nigra*) is coined as a keystone species in large-scale 'nature development' projects along the Large Rivers (De Bruin et al., 1987). Up to now it is an extremely scarce passage migrant, breeding in forested areas in eastern Europe. From olden times the white stork (*Ciconia ciconia*) was a well-known breeding bird in the Delta (Fig. 19.4), as may be derived from several medieval documents. For example, at Erp in the basin of the river Aa (Chapter 11) breeding storks in tree-nests have been known from 1320 onwards until 1910 without interruption. M. Schookius wrote his treatise on the occurrence of storks in the northern Delta in 1562: around 1550 large numbers of storks were breeding on chimneys in villages and towns (cf. Chapter 6). Notwithstanding the fact that storks were seen as heralds of happiness and the bringers of new life, they were drastically hunted, shot and traded (Caspers, 2007). The white stork is a culture follower, but not an opportunist as the grey heron. In former centuries the Delta was an optimum habitat for storks, owing to the combination of wet hay-fields and meadows, and higher situated grounds along rivers and brooks. Both in dry and in wet periods food was abundant and varied (mice, moles, frogs, fish, earthworms and larger insects). Owing to the intensification of agricultural practice, the use of pesticides, and the earlier mowing of grass the number of prey animals decreased drastically (SOVON, 1987).

The population of white storks in the Delta seriously declined in the 20th century, from *ca*. 500 pairs in 1913 to 312 pairs in 1939, to near extinction in the 1980s, not only due to habitat loss, but also to drought and locust control in the Sahelian wintering areas. A reintroduction programme was started in the 1970s. In 1971 the Society for Bird Protection founded 'stork station' Liesveld in the Alblasserwaard, in order to increase the number of storks in the Delta. Later on this successful initiative was followed by the erection of more satellite stations, and an increasing number of captive-bred birds were being released. The juveniles mostly depart southwest, to their wintering areas in tropical West Africa, but most adults are staying at the satellite stations, and survive on their winter feeding programmes. The present Delta population is a mixture of captive-bred and wild-bred birds from the Delta and Germany (Hayman et al., 1983). The village where I live, Rossum on the river Waal (cf. Fig. 5.5 for position), has also a satellite station. Clattering storks on their nests, hovering birds on the thermals high in the sky, 'eibers' stately following the farmer on his mowing machine, looking for moles and mice: these impressions bring old-fashioned memories back into reality.

**Fig. 19.4** The walled town of Helmond on the river Aa (Chapter 11) in the 17th century, with in the foreground a white stork on its nest. Text in Latin and in German (From Caspers, 2007)

The Eurasian spoonbill (*Platalea leucorodia*) has occurred in the Delta within living memory. The oldest findings date back to 580 BC (excavations near Alkmaar). The bird is mentioned in medieval documents, particularly from the Central Delta. It occupied large colonies which were intensively exploited by man, mainly for the collection of eggs and nestlings. Successive reclamation projects destroyed many colonies, but the spoonbill always remained a fairly scarce breeding bird, which had its lowest point in 1968–1969 probably due to water pollution with pesticides. In the 1990s some new sites became occupied, resulting from improvement of the water quality, the ban on the use of pesticides, the creation of new wetlands, improved protection, and the birds flexibility in feeding habits, and breeding behaviour (Bijlsma et al., 2001).

#### 19.2.3.3 Large Birds of Prey

The largest birds of prey that occur in the Delta are the osprey (*Pandion haliaetus*), and the white-tailed eagle (*Haliaeetus albicilla*). The osprey, a fish-eater is a very scarce passage migrant, observed in large freshwater wetlands in the Central and SW Delta. There are no indications that the osprey has ever had a breeding population in the Delta. The white-tailed eagle is in fact the largest bird of prey in western Europe, with its wingspan of 2.5 m. It is an extremely scarce winter visitor of the larger wetlands in the Delta, such as Oostvaarderplassen, Biesbosch-Hollands Diep and Lauwersmeer (N Delta), preying on fish, waterfowl and mammals. The birds visiting the Delta originate from northern and central European populations. It is not sure whether the white-tailed eagle has ever had a breeding population in the Delta. Although the bird has never been common, there are numerous observations documented from former centuries, e.g. in the NW Delta (Bijlsma et al., 2001). A breeding couple in the Oostvaardersplassen has successfully reared one young in 2006 and one in 2007, respectively. The young of 2006 returned after some rambles to the Oostvaardersplassen, implying that four individuals were present in July 2007: food for ornithologists (www.staatsbosbeheer.nl).

#### 19.2.3.4 Rails and Cranes

The corn crake (*Crex crex*) is a scarce breeding bird of hay-fields and arable fields in river basins and river forelands. The bird is on the decline owing to the loss of habitat and earlier mowing regime. In contrast, the common moorhen (*Gallinula chloropus*) is a common breeding bird, which takes advantage of urbanisation, and the construction of ponds and lawns, where additional feed is available for these herbivores, particularly during winter. Severe winters decimate the population, mainly when the snow cover is thick. The Eurasian coot (*Fulica atra*) is a common breeding bird, which showed a marked increase in newly created wetlands, farmland and built-up areas. Drastic regional changes in population size are induced by the availability of food. For example, in the period 1978–1986 large numbers fed on eelgrass in Grevelingen lagoon. In the period 1987–1990 the eelgrass population vanished (Chapter 16), and large numbers of coots were counted in Volkerak-Zoommeer feeding on the then abundant underwater vegetation. The common crane (*Grus grus*) disappeared centuries ago as breeding bird from the Delta; it is now fairly scarce passage migrant. The European population of cranes is expanding, showing a switch in feeding ecology: spilled maize is becoming more important than spilled grain, and hence the migrating birds are staying longer at German stopover sites (SOVON, 1987; Bijlsma et al., 2001).

#### 19.2.3.5 Plovers and Meadow-Birds

The little ringed plover (*Charadrius dubius*) is a pioneer. New ‘nature development’ areas are quickly occupied by this species, like new sandy islands in the enclosed estuaries in the SW Delta, and building sites raised with fluid sand. The population shows distinctive local ups and downs, related to the rapidly changing Delta landscape. The birds showed a quick reaction to the river floods in 1993–1994 along the Maas in Limburg: during the flood layers of gravel and sand were deposited on cultivated land in the river forelands, and these sediments were directly used as breeding sites.

The European golden plover (*Pluvialis apricaria*) is a numerous passage migrant and winter visitor, particularly in the NW Delta (Wadden Sea). Until the end of the 1930s the golden plover was a regular breeding bird in raised bog moors, until cultivation destroyed most of these habitats, and fragmented the remaining ones. The estimated numbers of annually killed golden plovers decreased from 40,000 to 80,000 in the 1940s and 1950s to 18,000 in 1969. Hunting is forbidden since 1978 (in Denmark since 1984). The 'wilsterflappers' the bird-catchers of the past, became the present-day bird-ringers (Jukema, 2001).

Ruffs (*Philomachus pugnax*) used to be common breeding birds in moist grassland areas until the early 1900s. The population crashed from the 1950s onwards, owing to the changed agricultural practice, such as the lowering of the groundwater level, the intensive fertilisation and heavy grazing pressure. Ruff did not make the change from the old-fashioned grasslands to the modern ones, and is now very scarce breeding bird. Ruffs are 'culture followers', which means that they spend the major part of their life in man-made habitats, such as rice fields in winter quarters or agricultural grasslands during breeding and migration. Being culture followers, they first took profit of the increasing intensification of agriculture. Due to better drainage and fertilisation larger and richer breeding habitats became available. Recently, however, the intensification of agriculture became very effective, implying that the area of wet, herb-rich grasslands, with a late mowing regime and extensive grazing regime, decreased significantly (cf. Chapter 7). As a consequence the preferred habitat of ruffs has disappeared at many sites in western Europe, including the Delta. Locally this has resulted in a strong decrease in the numbers of breeding pairs (Bijlsma et al., 2001).

The black-tailed godwit (*Limosa limosa*) was a common breeding bird in the Delta. In the early 20th century the breeding population in grassland habitats increased, owing to enhanced fertilisation and hence greater production of prey animals in grassland. During the same period breeding black-tailed godwits almost disappeared from raised bogs and wet heath fields, owing to the intense cultivation of these types of landscape. The continuing intensification of grassland management, however, is impacting offspring production to such an extent that normal adult mortality can no longer be compensated for. From the 1960s onwards numbers of breeding black-tailed godwits alarmingly declined: more and more grasslands were transformed into uniform dry 'billiard cloths'. The breeding numbers at many core sites dropped by more than 50% in 1960–1980 and more than 70% in less optimal breeding areas, and this decline is still continuing. A comparable decline is true for the common redshank (*Tringa totanus*). In the early decades of the 20th century the common redshank was still a common breeding bird in the Delta, but the decrease in population size between 1958 and 1987 is estimated at 50%. The northern lapwing (*Vanellus vanellus*) is a numerous breeding bird, and an abundant passage migrant. The lapwing is already known from the early 20th century as a common breeding bird. The loss of its favourite wet blue-grasslands did not lead to a decline of the population, because the birds successfully adapted to the changed agricultural circumstances, and switched to alternative habitats such as fertilised grasslands and arable fields (SOVON, 1987; Bijlsma et al., 2001).

In Fig. 19.5a semi-quantitative picture is given of the numbers of breeding meadow-birds in the large nature reserve Gelderse Poort, situated in the Rhine basin, around the bifurcation of the Waal and the Pannerdens Kanaal, east of Nijmegen (Fig. 4.8). Around 1900 the wet, not fertilised and extensively used grasslands harboured many breeding ruffs. Black-tailed godwits and lapwings increased in numbers only after World War II, favoured by the lowering of the groundwater table, the increased fertilisation and mowing regime of the fields, enhancing the biomass of soil invertebrates, mainly earthworms. From the 1980s onwards, the continuing intensification of agricultural practice, and the increased frequency of mowing have negatively influenced the population of breeding black-tailed godwits. Lapwings demonstrated indeed the greatest adaptability, increasingly breeding in dry arable fields, but even this meadow-bird is on the decline now (Bekhuis et al., 2002).

Not only in the Gelderse Poort lapwing and black-tailed godwit are decreasing in numbers. The breeding pairs of both meadow-birds are declining in the entire Delta, and this process seems to accelerate recently. In between 1990 and 2000

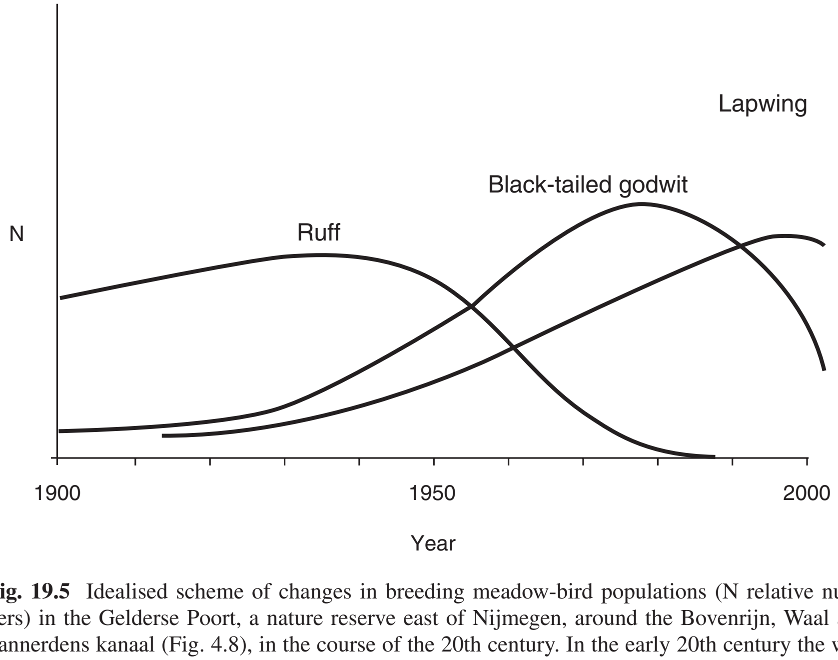

**Fig. 19.5** Idealised scheme of changes in breeding meadow-bird populations (N relative numbers) in the Gelderse Poort, a nature reserve east of Nijmegen, around the Bovenrijn, Waal and Pannerdens kanaal (Fig. 4.8), in the course of the 20th century. In the early 20th century the wet, soggy grasslands harboured mainly ruffs, common snipes and corn crakes. After 1950 draining, fertilisation, intensified management, and consequent increase of earthworms and other soil invertebrates stimulated the population of black-tailed godwit, common redshank and lapwing. In the 1980s grassland management has been maximised, which meant intensive draining, fertilisation and hay-making, resulting in drier grassland, where lapwing and oystercatcher are best adapted to (Bekhuis et al., 2002)

annually 1% of the population is disappearing, and since 2000 the annual decrease rose to almost 5%. The main causes are, it is said before, the continuing loss of suitable breeding habitats and the ongoing intensification of agricultural practice. The best breeding results are reached in grassland areas where a management contract is valid, aiming at the protection of the meadow-bird population, or in meadow-bird reserves. By localising the nests in spring and placing nest protection devices, the birds are artificially protected. The effectiveness of these measures is a matter of concern. In 2000 and 2004 numerous volunteers followed 90,000 respectively 69,000 egg clutches of meadow-birds subject to self-imposed protection measures, in agricultural grassland areas in the Delta, The results of this large-scale enterprise showed that more than 50% of the eggs hatch, and that *ca.* 10% of the hatchlings reach a stage in which they are able to fly. Roughly 25% of the eggs and a considerable number of hatchlings are lost by predation, mainly by birds of prey, blue heron and mammals. The increasing numbers of foxes in the Delta are often, intuitively and not based on facts, mentioned as fierce predators of meadow-birds, but in practice the fox is only responsible for a very small percentage of the lost birds (Teunissen et al., 2005).

#### 19.2.3.6 Gulls and Terns

The black-headed gull (*Larus ridibundus*) is a numerous breeding bird in the Delta; the small, persecuted breeding population in the early 20th century rapidly increased from 30,000 in the 1920s to 225,000 in 1980. The species breeds inland as well as in coastal areas. The original breeding success has to be attributed to an enlarged offer of food on refuse dumps, in built-up areas and owing to intensification of agriculture, possibly in combination with decreased persecution. After a period of inundation of the Large River forelands the black-headed gull can be abundantly observed foraging on deceased bottom fauna. The birds are omnivorous opportunists, feeding on fish, fish-offal and garbage in coastal localities, earthworms and other invertebrates on ploughed arable fields, mowed grassland, and refuse dumps. Large flocks can be seen during midsummer foraging high in the sky on flying insects, such as dragon flies (personal observation P.H. Nienhuis).

The European herring gull (*Larus argentatus*) is a common breeding bird of coastal areas, going far inland as passage migrant and winter visitor. The species was persecuted, during most of the 20th century, i.e. egg clutches were disturbed, and adult birds were killed. Conservation measures in the late 1960s and bans on organochlorine pesticides were followed by a rapid increase in breeding numbers. Numbers have declined, however, throughout the 1990s, probably caused by the covering or closure of local rubbish dumps. In the coastal zone the species mainly frequents fishing vessels, feeding on discards, and intertidally on benthic invertebrates. Inland the herring gull is an opportunistic omnivore feeding on worms and invertebrate larvae in pastures, road victims, rubbish dumps, flotsam and molluscs washed ashore along the Large Rivers. The herring gull is most abundant at rubbish tips, along the rivers and in the IJsselmeer (Van den Bergh et al., 1979).

Beekman (1980) described the intense fowling (mainly egg-picking) in the marshy areas ('inlagen') along the south coast of Schouwen-Duiveland, in the 19th and 20th century, until the flood disaster of 1953. In between 15 April and 15 June egg-picking from the nests of gulls and terns was a lucrative trade. The breeding sites of the sandwich tern (*Sterna sandvicensis*) and the common tern (*Sterna hirundo*) were let on lease, and management was done in a sustainable way, maintaining the colonies and preferably increasing the number of breeding pairs. The terns were offered nesting facilities, so called 'hillen', small islands in the brackish marshes, provided with cut up straw, to enhance the building of nests. In the years before the 1953 flood an annual harvest of 10,000 eggs was not uncommon. The breeding colonies of the sandwich tern collapsed in the 1960s due to the poisoning of their feed, mainly with non-degradable pesticides. Recovery took place in the 1970s, and nowadays the sandwich tern is a rather common bird, breeding in a few protected coastal colonies. The breeding populations of the common tern were severely suppressed until far in the 20th century, owing to egg-picking and hunting activities, e.g. for the collection of feathers for ladies hats. Just as with the sandwich tern, the decline in the 1960s is to be attributed to lethal poison in its feed. Nowadays the common tern is under pressure, because suitable breeding habitats are now taken or threatened by recreation activities.

In the first half of the 20th century black terns (*Chlidonias niger*) were common and widespread breeding birds of river oxbows along the Large Rivers and lowland marshes in the NE Delta. After World War II the floating vegetation in polluted, eutrophic waters, especially *Stratiotes aloides*, declined considerably, resulting in a substantial loss of breeding sites, aggravated by a decrease in food supply. Although the lack of proper breeding sites was locally counteracted by the supply of nesting-rafts, the changed management of the water tables, and increasing recreation pressure also added to the decline. The black tern is now a fairly scarce breeding bird (Bijlsma et al., 2001).

#### 19.2.3.7 Smaller Birds Such as Singing Birds, (Sky)Larks, Wagtails and Buntings

Although the smaller birds have been caught through the ages for consumption with diverse devices, such as nets and lime-twigs, none of the species was exterminated owing to these actions. In the course of the 20th century, however, many species of smaller breeding birds showed a decline, mainly caused by the dramatic changes in farming practice (e.g. Eurasian skylark (*Alauda arvensis*), whinchat (*Saxicola rubetra*), yellowhammer (*Emberiza citrinella*), corn bunting (*Miliaria calandra*) and ortolan bunting (*Emberiza hortulana*). Until the beginning of 20th century the ortolan bunting and the corn bunting were locally rather common breeding birds in their favourite habitats. The ortolan bunting preferred rye fields with verges rich in flowering weeds, and deciduous groves close by. Re-allotment schemes, the disappearance of small-scale agricultural practice and the massive use of herbicides, have brought the ortolan bunting on the brink of extinction in the Delta. The present distribution of the corn bunting has contracted to small pockets of 'natural' grassland along the Meuse and the river Waal. The negative trend for both species was caused by changes in farming practice, in which biomass production in grasslands, rather than hay-making, and reduction of cereal growing in favour of green maize, has been particularly detrimental. In the Meuse basin in Limburg alone, the area of maize fields increased from 130 ha in 1970 to *ca*. 15,000 ha in 1979 (Bijlsma et al., 2001).

The great reed warbler (*Acrocephalus arundinaceus*) is a special case. The species declined seriously in the second half of the 20th century, mainly caused by profound changes in water management and eutrophication. Natural fluctuations in water level, i.e. high in winter, low in summer, have been replaced by year-round stable water levels, thus impeding growth and regeneration of water reed. Moreover, the marshes were covered with a growth of tangled trees and shrubs, and the numbers of favoured prey species, such as larvae of dragonflies, decreased drastically, leaving only a very few suitable habitats for the great reed warbler. Local studies indicated that in 1995 only 13% of the marginal areas of peat marshes and lakes are bordered by dense reed vegetations, compared to 65% in 1926–1929 (Graveland and Coops, 1997).

Not all smaller birds suffered from the continuous changes of the countryside, e.g. bluethroat (*Luscinia svecica*) and blackcap (*Sylvia atricapilla*) took advantage of the increasing number of man-made habitats and the present tendency of afforestation (SOVON, 1987).

### 19.2.3.8 Miscellaneous

In the first half of the 20th century the little owl (*Athene noctua*) was a common breeding bird, a typical bird of polder land with pollard willows, and high-tree orchards, but it nested also in the wooded Pleistocene areas. A marked decline was already apparent in the 1960s and 1970s probably in the wake of contamination with insecticides, mainly in fruit growing regions along the Large Rivers, and further owing to the degeneration of traditional farmland. The latter particularly affected nest-site availability and food resources. Declines in local populations could be partly reversed through provisioning of nest-boxes, thus providing circumstantial evidence of the deficit of suitable nest-sites. At present the little owl is a rather common breeding bird.

The population of the common kingfisher (*Alcedo atthis*) underwent a structural decrease in the second half of the 20th century owing to canalisation of brooks, water pollution and increased recreation pressure. The population size showed great fluctuations in relation to severe winters: under harsh winter conditions the species is almost exterminated in peripheral breeding areas. The common kingfisher is now a rare breeding bird, having a rather stable population in the Biesbosch where considerable river stretches are not completely frozen during severe winters (Bijlsma et al., 2001).

## 19.3 The Mammals of the Delta

### *19.3.1 Introduction*

From prehistoric and proto-historic archaeological findings scattered information can be distracted about the occurrence of mammals in the Delta. The oldest historic sources mentioning mammals, stemming from the Middle Ages, are charters, decrees and legal records with regard to hunting and the fight against harmful vermin. Only in the 17th century a general interest in natural history awoke, and thereafter the study of mammals developed in a more systematic and scientific manner (cf. Chapter 6). Some of the larger mammals, that still have viable populations in remote parts of Europe, were already extinct in the Delta before 1500, e.g. the brown bear, elk and lynx. Lynx has occurred until deep in the Middle Ages, but the species was persecuted because of its threat for cattle and game. From documents on hunting rights of the bishops of Utrecht it is known that the brown bear occurred in its natural state in the Delta at least until the 11th century (Broekhuizen et al., 1992; www.wikipedia.nl). The last wolf (*Canus lupus*) was observed in the Delta in 1869 (Flaton, 1989).

Nowadays *ca*. 60 mammals are indigenous in the Delta, among which 19 bat species and 8 shrew species (Broekhuizen et al., 1992). It is not my intention to give a full survey of all Delta mammals. I have made an arbitrary choice of a number of mammals that have a strong or weaker connection with river habitats, mainly to demonstrate the remarkable historic changes in human attitude considering these conspicuous animals. The distinction between ‘harmful’ and ‘useful’ has always been decisive for the way the animals were treated. Recently almost all mammals are protected, and their population size is controlled by stimulating measures (breeding stations, ecoducts, etc.) and ‘management hunting’, while others are still rigorously persecuted because of their supposed harmful habits.

### *19.3.2 The Wild Boar and Deer*

The wild boar (*Sus scrofa*) is known from prehistoric times onwards. It had a long range, wandering about between the Pleistocene forested habitats, and marshes and bogs along rivers and brooks. As much-wanted big game, and also because of its damage to agricultural fields, the wild boar was severely hunted. The species became almost extinct in the Netherlands in the 18th century. The animals were reintroduced in the Veluwe region in the early 20th century in favour of hunting parties. The wild boar is a protected species now; it lives in forested game reserves and in free range, completely isolated from their former habitat, the marshy river flood plains.

Fallow deer (*Cervus dama*) was an autochthonous species in the Delta, but it became extinct during the last Ice Age. It was reintroduced by the Romans, and it was introduced in the Delta in the beginning of the 16th century, possibly even earlier. Most of the introduced populations have disappeared again. It now lives in small numbers in enclosed areas the Veluwe region and in the coastal dunes.

In prehistoric and proto-historic times the red deer (*Cervus elaphus*) had a wide range of distribution in the Delta. It occurred in diverse habitats, the dunes, the Pleistocene cover sands and forests, the area of the Large Rivers, in raised bogs, in low-lying peat bogs and marshes, which originally covered two thirds of the Delta, and which are now almost completely gone. Valleys of rivers and brooks were the favourite habitat for the red deer. Intensive hunting and the annihilation and isolation of its living grounds led to the disappearance of the red deer in the Delta. At the beginning of the 19th century it only remained in the Veluwe region, in very low numbers. After the World War II their numbers have steadily increased, owing to changes in the hunting act. In former times the red deer was used to roam between the forests, providing shelter, and the fertile river grasslands, but nowadays it is driven back in a few enclosed forested stands. The red deer is not tolerated in agricultural areas, owing to its damage to the produce of the fields. Nowadays the river grasslands are completely isolated from the forest sections, intersected by motorways and bordered by high fences. Figure 3.4 illustrates this phenomenon for the transition area from the Pleistocene cover-sand area to the river flood plains of the Nederrijn.

In the beginning of the 19th century the roe deer (*Capreolus capreolus*), which used to be widespread, only survived in the Veluwe region. Since about 1855 the roe deer started to recover. Nowadays it is widespread in the Delta again, and can regularly be observed in the area of the Large Rivers (Broekhuizen et al., 1992; Thissen and Hollander, 1996).

### *19.3.3 The Harbour Seal*

The harbour seal (*Phoca vitulina*) is a contested mammal: from severely hunted until the mid-20th century, to a cuddled and strongly protected animal in recent years, and still hated by fishermen. Culls of harbour seals are regularly called for by those who believe that the seals are eating too much fish, despite evidence showing that the simplified view of ‘less seals equals more fish’ is misguided given the complexity of the marine food web. Those opposing such culls say that the seals are being made scapegoats, and that overfishing, habitat alteration and marine pollution are the causes of dramatic decreases in fish stocks. Many seal populations are only just now recovering from bounty schemes and organised hunting, most of which ended in the 1960s and 1970s. Local culls with the aim of protecting migrating fish still occur from time to time in some European countries. While there is currently no commercial hunting of the harbour seal, such hunting greatly reduced populations throughout the species’ range in the 19th and 20th centuries (www.pinnipeds.org).

The harbour seal used to have two considerable populations in the Delta. About 1900 there were approximately 7,000–16,000 common seals in the Dutch Wadden

Sea, and an estimated number between 6,000 and 11,000 in the SW Delta (Fig. 19.6; Thissen and Hollander, 1996; www.synbiosis.alterra.nl). The animals were frequently observed on sand flats exposed at low water in the Hollands Diep and the Biesbosch. Newspapers and reports from former centuries mentioned the occurrence of an occasional harbour seal as far upstream as Gorinchem and Woudrichem. Proper statistics did not exist before 1900. The data used for calculations are derived from hunting statistics, which are available from about 1900 onwards. Hunting was stimulated by payment of bounties on the grounds of fisheries protection. After 1949 the bounty system was abolished and the demand for train-oil had ended. The result was that the interest in adults diminished and only pups were killed for the fur industry. This led to an increased population decline. In 1954 seals were included in the provisions of the hunting law and could only be taken under license. The estimated numbers of seals killed in the SW Delta between 1900 and 1960 fluctuated between 300 and 1,000 annually, with a sharp decline towards 1960. The size of the over-exploited population in 1960 is estimated to amount to 350 animals. The harbour seal disappeared almost completely in 1968, and stayed close to zero until the 1990s. Significant loss of habitat has occurred due to closing off parts of the larger estuaries, and the enlargement of the entrance to the harbour of Rotterdam (Reijnders, 1994; Mees and Reijnders, 1994; Chapter 10). But the population is growing, and in 2004 *ca.* 155 harbour seals were counted (Fig. 19.6). Notwithstanding this positive development it is too early to decide whether the SW Delta contains a viable population (www.mnp.nl/natuurcompendium).

Also in the Wadden Sea prior to 1960 the common seal declined appreciably because it was severely hunted (Fig. 19.6). Between 1950 and 1960 the hunters concentrated on young animals, because their pelts are more valuable. The ban on the killing of seals that was implemented in the Delta area in 1961 and in the Dutch Wadden area in 1962 was followed by a recovery in the Wadden Sea, but thereafter a decline set in and a lowest point was reached in the 1970s, when the population counted about 500. The causes – the low reproduction rate and the high mortality of juveniles – were ascribed to pollution from PCBs, aggravated by increased disturbance from shipping and water tourism. In the Wadden Sea the harbour seal recovered to some extent in the 1970s, partly as a result of immigration from the German and Danish Wadden Sea and an improvement in water quality (Reijnders, 1981). But the recovery was nullified by an outbreak of a virus disease in 1988, leading to 60% mortality within the population. This incident was followed by rapid growth of the population to more than 4,000 individuals, in response to high reproduction, low mortality and immigration from the German and Danish Wadden Sea. But another epidemic of the virus disease phocine distemper, which broke out in June 2002, almost halved the population. The surviving animals are thought to be resistant now, and from 2004 onwards a strong increase in the population to *ca.* 3,200 individuals has been observed (Fig. 19.6; RIVM, 2003; www.mnp.nl/natuurcompendium).

Triggered by the sharp decline of the harbour seal population in the Wadden Sea after Word War II, a few seal rehabilitation stations have been erected in the Netherlands some 40–50 years ago. Considering the growth of the seal population, the original aims of these reception centres are now heavily debated. Some experts

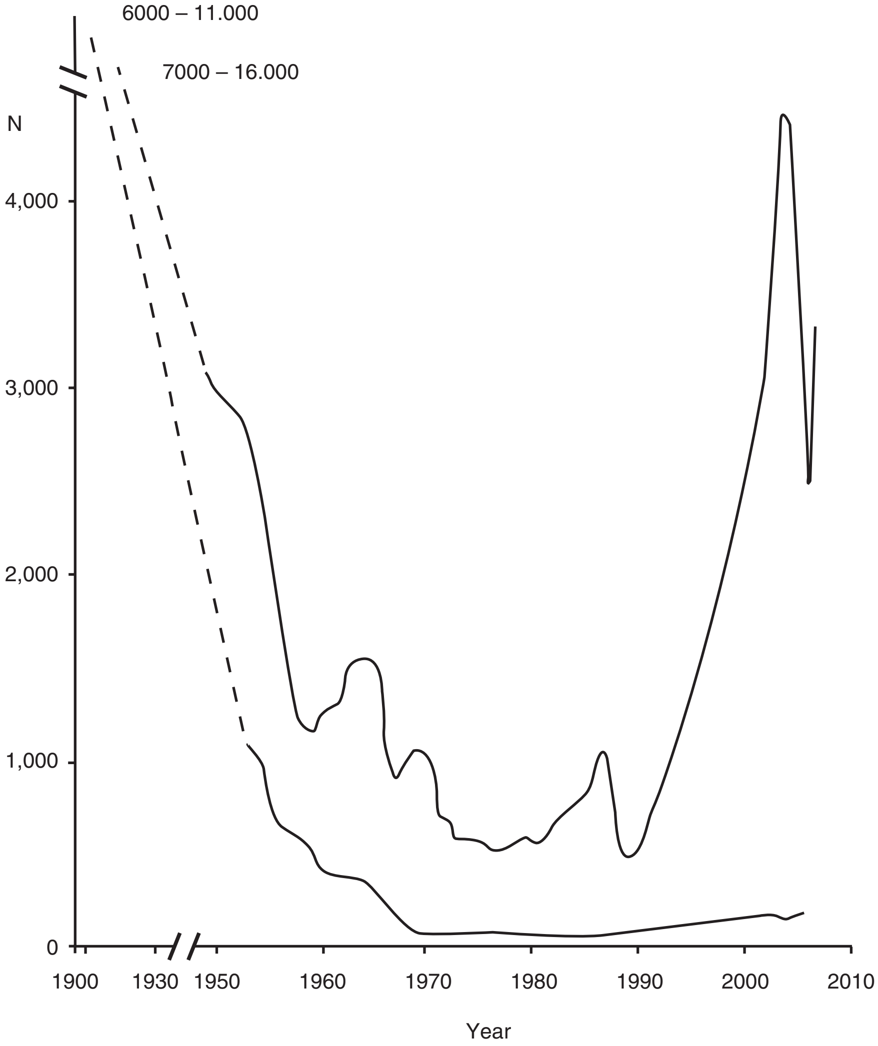

**Fig. 19.6** Wane and wax of the population of harbour seals in the Wadden Sea (upper graph) and in the SW Delta (lower graph) during the 20th century; the interrupted lines are historic estimates, the solid lines refer to regular counting (Reijnders, 1981, 1994; Thissen and Hollander, 1996)

argue that seal rehabilitation for the purpose of saving the population is unnecessary. The release of recovered animals into the natural population may eventually weaken the population. A seal rehabilitation facility in Esbjerg, Denmark, stopped accepting young seals in 1982, when it became clear that rehabilitation of those pups had no effect on the sustainability of the Danish seal population. The risk of introducing diseases into the environment when releasing rehabilitated pups could be greater than a potential benefit (Van der Toorn, 1996).

### *19.3.4 The Otter*

The otter (*Lutra lutra*) was a common and typical inhabitant of freshwater habitats in the entire Delta, feeding on fish, crayfish, frogs, molluscs and small birds. The otter was considered as a severe competitor of fishermen (cf. Chapter 6), and the animal was therefore systematically persecuted. The premium put on the head of a dead otter has seriously accelerated the extinction process. In the early 19th century the otter was still common everywhere in the Delta, but the numbers diminished. Counts in 1930–1940 revealed that the otter was seriously on the decline. Loss of habitat, owing to normalisation of brooks, cultivation of osiers and river flood plains, added to the killing, were the main causes of the decline. Owing to a change in the Hunting Act the population showed a small increase in the period 1942–1960. In 1960 the hunt on the otter was completely closed; the animal was no longer considered as 'harmful'. Water pollution, and particularly the non-degradable organic contaminants (PCBs) accumulating in invertebrates used as feed, gave the finishing stroke to the Delta population. In 1988 the last otter was found dead as a traffic victim in the NW Delta (Friesland).

The otter became extinct in the Netherlands in 1988 and after 14 years of absence, in the summer of 2002, the mammal has been reintroduced in the Delta freshwater ecosystem. Because of largely comparable habitat and climate, otter populations in Latvia and Belarus have been selected as potential donor populations from which wild otters were gathered. The aim is to restore a viable otter population in a large wetland and peat-bog area in the IJssel Delta and connected wetlands. Since it is not very likely that a reproducing and viable population will be established spontaneously within the next 50 years, it has been decided to reintroduce otters in order to achieve this goal. Much effort has been made to restore its habitat for this comeback in the NW Delta. Otters are claimed to be very vulnerable to PCB-contamination. Therefore a variety of measures have been taken to increase the water and sediment quality. Polluted sediments have been dredged from the wetlands, water courses have been adapted, and connected to less severely eutrophicated water bodies, and dangerous crossroads have been fenced off. All these measures indeed resulted in cleaner water, with an increased visibility, carrying less nutrients and polluting agents. A change in fish quantity has already been observed: recent fish studies estimate a biomass of 150–200 kg $ha^{-1}$, which should be sufficient for a viable otter population (www.vzz.nl).

The reintroduction of the otter has been more problematic than the reintroduction of the beaver. Some argue that the reintroduction did fully comply with IUCN guidelines (Van 't Hof and Van Langevelde, 2004), others claim that these were not sufficiently obeyed (Van Liere and Van Liere, 2005). The arguments against introduction concentrate on the PCB content in the sediment, which is a crucial factor as far as the survival of the otter population is concerned: PCBs negatively affect their reproduction. The PCB content of the sediment in the wetlands where the otter has been reintroduced will indeed not limit the growth of an otter population in that area. However, since otters have a large range of activity they may take up excessive PCBs when wandering, so a larger area should be taken into consideration.

In the remainder of the Delta influenced by the river Rhine, otter populations will not be sustainable. It would take another 10 years for the sediment quality in the surrounding wetlands to improve to a level that will sustain the development of otter populations. In other, more highly contaminated areas such as the Biesbosch, 60 years may be needed. Although 10 years of monitoring bioaccumulation have revealed a decline in the risk for fish-eating higher organisms in the catchment area of the Rhine, they do still remain at risk. Therefore, theoretically the otters should not leave the reintroduction area, since large parts of the Netherlands are not suitable for them because of poor sediment quality. This is difficult to reconcile with the aim of any reintroduction, which is the establishment of a free-ranging population (Van Liere and Van Liere, 2005).

A second argument against reintroduction concerns the mortality by motorised traffic. Special devices for otter safety have been constructed, but only in a relatively small area in respect to the actual activity range of otters. Of the 20 otters reintroduced since 2002, six had already been killed in traffic accidents by July 2005. In December 2005 two more newborn otters were found dead in traffic accidents. The number of vehicle kilometres continues to increase at a rapid rate. Thus, an important cause of decline and extinction is still present, and may augment (Van Liere and Van Liere, 2005).

### *19.3.5 The Beaver*

Some aspects of the beaver's profile have been given in Chapter 6, Martinet's (1777–1779) exclamations on the 'harmful' traits of this mammal, and in Chapter 14, the assumed toxicity of cadmium for the reintroduced beavers in the early 1990s. The beaver (*Castor fiber*) used to be a widely spread and common animal in the Delta, particularly along the Large Rivers and brooks (Fig. 19.7). The mammal, in demand because of its fur, meat and odour glands, was over-hunted throughout its range. The last beaver in the Delta is said to be killed in 1826. The nearest remaining beaver population lived in those days along the river Elbe in Germany, some 500 km removed from the Delta. Beavers are able to cut down mature trees, and they thus have a keystone function in riparian forests. The debate to reintroduce the beaver as a native species and as an 'ecosystem engineer' in river flood plains started already in the 1960s (Van Wijngaarden, 1966), but it lasted until the end of the 1980s until all the necessary formalities had been fulfilled.

After the successful reintroduction of some tens of beavers in the Brabantse Biesbosch between 1988 and 1991, the subsequent reproduction rate of these animals was unsatisfactorily low. Stress after moving the beavers from the German river Elbe to the unknown Biesbosch marsh in the Delta, was mentioned as one of the possible explanations for the failing reproduction. The most recent additional explanation is now a food deficiency, related to the difference in climate zones between the Elbe and the Delta of the Rhine–Meuse. Young willow leaves are rich in phosphor derivates, and pregnant beavers need these to produce healthy offspring,

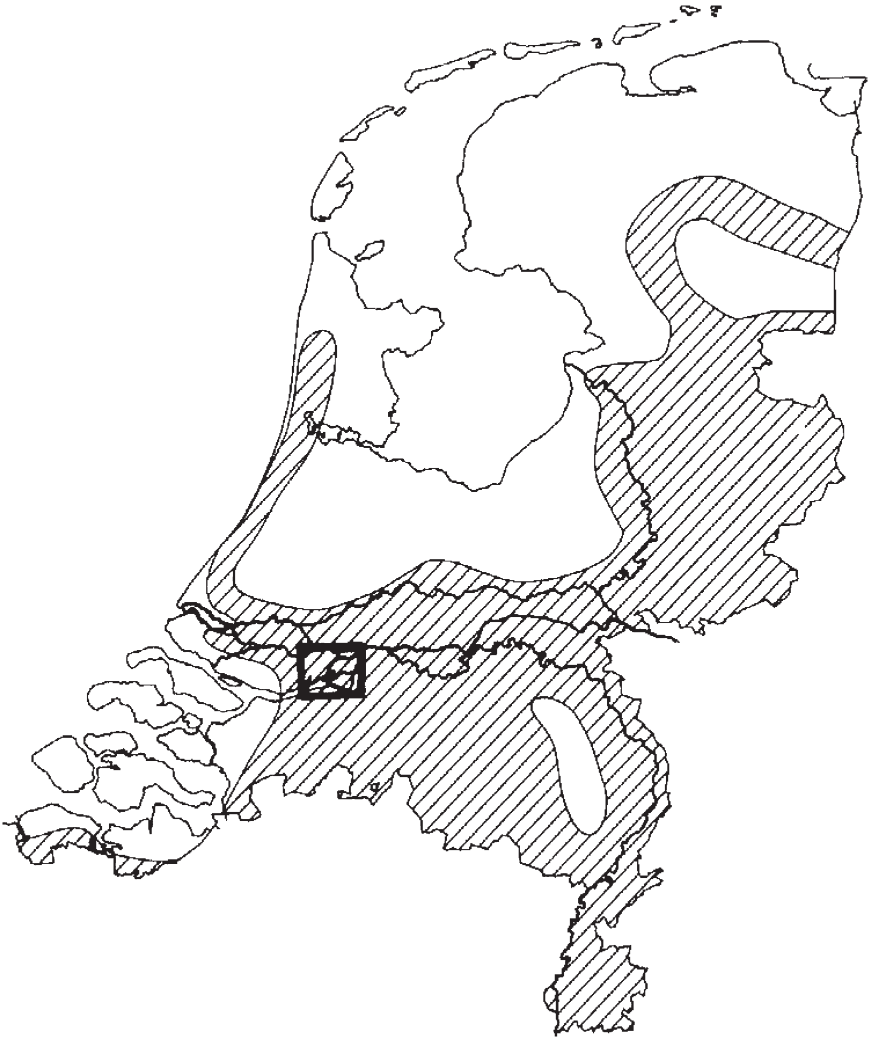

**Fig. 19.7** The former distribution of the beaver in the Delta based on historical records, (sub-)fossil finds and topomyms (Van Wijngaarden, 1966). The rectangle indicates the Biesbosch area. The current distribution of the beaver in the Delta is restricted to the Biesbosch and the Gelderse Poort (Fig. 5.5, east of Nijmegen). Recently (2003–2006) individuals have been spotted at localities in between; whether these are signs of the development of viable populations remains to be seen

but the older the leaves, the lower the food quality. The beavers were moved from an East German land climate to a more moderate Dutch sea climate, where willow leaves sprout up to a month earlier than what the beavers were used to. Because of this, the beaver mothers were suffering from phosphor deficiency in the last phase of their pregnancy. Originally, the pollution of their food, willow leaves, with heavy metals (e.g. Cd) was postulated as a possible explanation for the low birth rate, but this hypothesis could be dropped. In the Elbe region, where the beavers originate from, the species is showing normal reproduction despite of the same pollution (Nolet, 1994).

In the meantime, these long-living animals have adapted themselves to their new environment, and produce normal numbers of young comparable to their congeners in mid-Europe. The population is increasing nowadays. Apart from the Biesbosch, beavers have been introduced in the Gelderse Poort, and the idea is that the Biesbosch population and the Gelderse Poort population will spread along the Waal flood plains (Fig. 19.7), and finally will interbreed. In total, almost 300 individuals are living along the Waal River now (Nolet, 1994; Nolet and Heitkonig, 2006; www.vzz.nl).

### *19.3.6 The Muskrat*

The muskrat (*Ondatra zibethicus*) is a large (body 25–35 cm; tail 19–27 cm) North American–Canadian rat-like rodent mammal, the largest species of vole, found in lakes and slow-flowing rivers with dense plant cover on the banks. It has scent glands which secrete a substance, having a strong odour of musk. The long tail and webbing between the hind toes assist in swimming. In marshes in their natural habitat muskrats build conical lodges of twigs. The entrance to their living place is always under water. They feed on aquatic plants and invertebrates, such as molluscs. Their natural enemies are foxes and otters. They live preferably in deep swamps that do not freeze dry in winter.

Muskrats were kept for their fur in the fur-trade business in Europe. In autumn 1905 a few animals were evicted in a country seat near Prague, Czechoslovakia. The population migrated westwards and in May 1941 the first specimen was caught in the Delta near Valkenswaard in the Dommel basin. Since then the animals quickly spread over the country, and only along the North Sea coast the species is rather rare. Muskrats are feared for their destructive way of life, particularly in the man-made countryside of the Delta where everything is so nicely laid out, and asks for continuous management. The voles dig underground holes and tunnels, undermining banks and slopes of water courses, dykes and quays, resulting in a weakening or sagging of the soil, or in the most negative cases subsidence of part of the levee. The holes are invisible pitfalls for cattle, man and farm machinery. Consequently, of all animals in the Delta, the muskrat is most vigorously hunted. In 2003 roughly 400,000 muskrats were caught in traps and clamps by more than 500 professional rat-catchers in the Delta. In the area of the Large Rivers alone, approximately 50 rat-catchers are employed by the government. In 2001 they caught approximately 38,000 voles. There is a positive relation between the number of rat-catchers, together with the premiums offered, and the number of rats caught. In the Krimpenerwaard situated between the Hollandse IJssel and the Lek, veined with 5,100 km of ditches and watercourses, the number of rat-catchers increased in the period 1998–2003 from 5 to 15, and the numbers of rats caught increased from 2,500 to 44,000 (Goutbeek, 2004; Mensink, 2004).

But notwithstanding those rigorous measures, which are going on for decennia, the water managers do not succeed in getting the population of muskrats under control. Frequently occurring sequences of mild winters and an increasing number of accessible wetlands make that there is little hope that the population will ever be exterminated.

'Nature development' is the most important cause for the increase in numbers. The many reconstructed 'nature friendly' river banks hamper effective catches. There is an increasing number of arguments stating that catching muskrats is no solution to the problem. In many cases a quantification of the damage made by the muskrats is lacking, and it is unknown whether the costs of the combat outweigh the damage that will be prevented by catching the rats. The reproduction rate of the muskrat is high. Under normal circumstances the natural death rate by diseases, hypothermia, malnutrition, fights for territory and killings by predators, is balancing excessive birth rate. For a herbivore like the muskrat, the available habitat is mainly decisive for the size of the population. When the carrying capacity of a certain habitat is reached, which means that the numbers of muskrats are in harmony with the amount of feed and nesting-places, the reproduction rate is slowing down. By decreasing the population size artificially, the reproduction rate will maximise. Muskrat females are able to produce offspring 3–4 times a year, and litter 4–6 young at a birth. Even when in a specific area 90% of a population is caught, migrating rats are able to fill the open niches very quickly. Most likely, most animals that end their lives in cages now, would have perished of natural causes within some weeks or months. In Germany they have had positive experiences with a restrictive catching policy, and no premiums are offered for caught muskrats anymore (Broekhuizen et al., 1992; Goutbeek, 2004; Mensink, 2004).

By the way, muskrat meat seems to be tasty, which renders him the name 'water rabbit'. The water rabbit is served in Belgian restaurants, however, to my knowledge the animal is not consumed by humans in the Delta. You do not eat a 'rat'.

### *19.3.7 The Coypus*

The coypus (*Myocaster coypus*) is a South American species, introduced for its fur in Europe. The species is larger than the muskrat (40–45 cm, plus tail 35–40 cm). The coypus was introduced in the Delta in *ca.*1930; the species escaped and from 1935 onwards it was observed in river habitats, such as overgrown marshes, and river oxbows. Coypus has comparable habits as the muskrat, they feed on plant material, and because of their digging activities, they are a potential danger for earthen levees and dykes. During a severe winter the population may almost be exterminated: in the winter of 1962–1963 the entire Delta population was extinguished. Thereafter colonisation of habitats in the Delta took place from stocks in Germany. The species is rare along the Large Rivers, such as the Maas and tributaries, the Biesbosch, and the Waal (Broekhuizen et al., 1992).

## 19.4 Conclusions

- In former centuries everything nature provided was used by humans in one way or another. Only recently (20th century) a turning point was reached, from unbridled hunting and persecution to selective protection.
- Owing to their versatile behaviour only a very small number of waterfowl species became extinct in the Delta during the past two millennia.
- In contrast, large quantitative shifts in population size occurred, resulting from changes in land use, management of aquatic habitats and man's attitude towards waterfowl.
- The Delta avifauna adapted to traditional farmland practice showed large quantitative changes in the course of the 20th century. Meadow birds' populations declined under pressure of intensive land use. Herbivorous waterfowl have increased, mainly dependent on fertilised agricultural land, creating an apparent conflict with the interests of farmers. Opportunists took advantage of the increasing number of man-made habitats and the present tendency of afforestation.
- Until World War II fowling and egg-picking kept population size low. Fish-eating birds were merciless hunted because of the (supposed) competition with fishermen. Most bird species are protected now: *ca*. 40% of the present avifauna in the Delta has international significance in terms of the IUCN Red list and the EU Bird Directive.
- Some of the larger mammals that still have viable populations in remote parts of Europe became already extinct in the Delta before AD 1500.
- The distinction between 'harmful' and 'useful' has until recently been decisive for the way mammals were treated; 'harmful' mammals are still exterminated.
- Some extinct mammal species have been successfully reintroduced on a small scale; attempts to reintroduce the herbivorous beaver were more successful than with the carnivorous otter, still obstructed by water pollution.
- Compared with the situation of 200 years ago, the present ecological status of the Delta is considerably impoverished. But when the present status is compared with that of 30 years ago, positive effects of the rehabilitation measures are discernible.
- The present biodiversity of birds and mammals in the Delta is a reflection of the man-made landscapes and manipulated ecosystems. In international terms these man-made river and wetland landscapes, are valuable, rare and unique.

# Part V

# An Ecological Story on Evolving Human-Environmental Relations Coping with Climate Change and Sea-level Rise - A Synthesis

# Chapter 20
# The Making of the Delta

## 20.1 Introduction

In great strides through ten millennia of environmental history of the Delta reveal significant sea-level rise, and small, poorly documented oscillations in air temperature. The short-term, well-documented records of the past 150 years show a considerable number of anomalies in weather conditions, deviations from average conditions, such as extremely cold winters and very hot summers. (Temperatures inferred from borehole ice core data reveal that the magnitude of global warming from 1850 to 1990 is estimated to have been approximately 0.7°C ± 0.2°C [www.nap.edu], but no evidence for climate change focussed on the Delta can be derived from those data).

This chapter contains condensed stories. The story of the making of the Delta, originally instigated by the use of muscular strength and wind and water power, in the later Middle Ages progressed by technical achievements, the wind-watermill, and from 1800 to 2000 accelerated and scaled up by steam power and electricity. The story of the rising sea level, the constricted, silted-up riverbeds, the subsiding river polders and reclaimed land, and consequently the self-imposed risks of flooding. The story of dramatic quantitative loss of habitats, but also the loss of quality of the still existing habitats (e.g. the present squandering of plant nutrients versus the diversity of oligotrophic and mesotrophic habitats in the past), the annihilation of estuarine gradients, the complete separation between the inland flood plains and the river forelands and channels. Change is a keyword, slowly in the past, accelerated in the 20th century. A complete change from the wooded, freely braiding rivers in prehistoric times, the entire Delta as a flood plain, to the regulated and canalised rivers; less than 5% of the original 'room for the river' is left. The prehistoric natural Delta has been changed so completely by the actions of man that the new substitutive landscapes, the cultural landscapes themselves, attained new values. The inescapable struggle between economic incentives and ecological values is underlying these rigorous changes. In times of war and economic downfall, nature retakes its lost position, in prosperous times, the golden centuries, the use of technical innovations changed the existing landscapes fundamentally. Several of these new landscapes have now been included in the UNESCO World Heritage list (www.unesco.org).

P.H. Nienhuis, *Environmental History of the Rhine—Meuse Delta,*

Changes in landscape and environment of the Delta will be paid attention to in this chapter, including changes in biodiversity, and economic use of plants of animals. Up to the 20th century disappointingly little information is available on those changes per se, and most information is indirectly derived from the sediment archive opened up by physical geographers, and from the well-documented fields of water management, including floods and flood protection, agriculture and fisheries. Human activities in the built-up areas, dominated by the steadily, and in the 20th century exponentially growing human population, also provide useful information.

Until the 20th century everything nature provided was used, for one reason or another, but gradually hard-working men and women, directly dependent on the produce from nature, have disappeared from the stage. The 20th century is the century in which 'nature' obtained two meanings. The first meaning is 'nature' as appreciated by biologists, biodiversity, i.e. the diversity of plants and animals evoked by the diversity of habitats as templates, physical spots where organisms live and perform their life history strategies. The past century is the first time in history that biodiversity is recognised and preserved because of its intrinsic values. The second meaning is 'nature' as appreciated by the layman, an aesthetical piece of green or blue landscape, a forest, a meadow, a pond, etc. Layman's nature has become an amenity, a luxury produce. The 20th century is the century of exaggeration and acceleration. Exaggeration is manifest in the availability of an overwhelmingly lot of information about 'nature', and acceleration is to be seen in the deterioration of landscape values but recently, paradoxically, also in the willingness to invest in the rehabilitation of habitats and biodiversity.

## 20.2 Human Occupation and Management of a Fertile Delta

### *20.2.1 Prehistory and Early History of the Delta*

The first inhabitants of the delta of the large European rivers Rhine and Meuse (in short the Delta) left their traces approximately 250,000 years ago, during the Saalien ice age, on the edge of a marshy flood plain of the river Meuse. The country became inhabitable during a subsequent warm period of sea-level rise (to NAP + 2 m), followed by the Weichselien ice age (sea level NAP − 130 m), that ended roughly 12,000 years ago. At the end of the last ice age the air temperature in July gradually rose from 0–5°C to 15–20°C in *ca.* 7000 BP. The low Delta of the rivers Rhine and Meuse situated in between higher Pleistocene cover-sand deposits was then characterised by freely braiding and meandering rivers, debouching in vast peat-moor and elevated bog-peat areas, behind ridges of barrier dunes parallel to the sea coast, over a distance of hundreds of kilometres. At several places the rivers intersected the dunes, discharging into the North Sea. The land was covered with dense forests and – as some scientists assume – parkland kept open by large grazers.

Archaeological findings from the New Stone Age, 6300 BP, revealed a hunters and fishermen campsite in the Delta, with remains of the same species of waterfowl and fish as we know nowadays. From pollen diagrams (2700 BP) a vegetation of water-plants and flood-plain forests could be reconstructed resembling very much the present-day species composition. The first prehistoric 'water management' measures dated back to the Bronze Age (3,500 BP), a system of trenches to drain the arable fields, surrounding farm sites. Recent archaeological excavations show that the oldest man-made dyke dated back to 100–200 BC, and the 'oldest delta works' (levees and culverts with recoil-valves) dated back to AD 100. It was already in the 2nd century AD that the bog-peat area of the Central Delta was systematically cultivated.

The Roman occupation from 15 BC to roughly AD 400, meant the start of (scanty) historical records. The river Rhine was the northern border of the empire, and the Romans had a considerable impact on the natural water systems: they adapted waterways, and built and exploited harbours, storage yards, fortified towns, fortresses and large farms. Progressive deforestation is mentioned from the Iron Age onwards (2500 BP); to keep the iron foundries at the desired temperature took vast amounts of charcoal. Roman descriptions mentioned the 'waterworks of Corbulo and Drusus', comprising the canalisation of water courses and the building of dams diverting the course of the main rivers. There is some disagreement about the exact position of the waterworks, but the dam and canal of Drusus are probably the first large-scale hydraulic engineering works in the Delta.

The period 300–800 is characterised by accelerated sea-level rise, transgressions of the sea, making the larger part of the Delta inhabitable; the Delta became depopulated, there were outbreaks of plague, and the remaining farmers lived on man-made dwelling mounds in the flood plains. The 10th century is generally taken as the start of water management measures in the Delta of Rhine and Meuse. Recent archaeological findings, however, showed that 'river management' actions are much older, and comprise a continuous and gradual process of measures from pre-Roman times onwards until the present time. The Romans gave indeed an advanced impulse to water management, and with ups (regressions of the sea) and downs (transgressions) these measures were continued by the then inhabitants of the Delta. From *ca.*800 onwards a gradual but continuous conversion was imposed on the natural landscape, changing the environment into what we nowadays recognise as the semi-natural or cultural landscape of the Delta of Rhine and Meuse. The start of that process is most likely driven by climate change and retardation of sea-level rise. These changes are characterised by, a steady increase of the human population (from 0.1 million in 800 to 16 million in 2000), increasing cultivation of flood plains for agricultural purposes, continuing deforestation and an ongoing fixation of the river landscape by levees and dykes (Chapter 2).

### 20.2.2 The Delta in the Later Middle Ages

During the period 800–1500 the rough outline of the river landscape of the Delta was shaped: the ring-dykes around the 'waarden' (river polders entirely enclosed by rivers) were closed, and the exploitation of the raised bogs in the Central Delta was completed. However, very little has been documented from that period, and our knowledge is mainly based on archaeological findings, and late medieval historical reconstructions. Natural levees and sandy channel belts were relatively densely populated in the early Middle Ages. Numerous (still existing) towns and villages date back to (post-)Roman settlements. Impressive Romanic and Gothic brick buildings indicate civilised prosperity, in an intense process of urbanisation and exploitation of the river flood plains. All medieval trade markets were founded on a river. In the Middle Ages an increasing quantity of wood was used as building material, and for fuel, actions which decimated the forests in the basins of rivers and brooks.

Owing to sustained actions of reclamation, the riverbeds became gradually constricted between man-made earthen dykes. The Large Rivers (IJssel, Waal, Merwede, Nederrijn, Lek, Maas) lost large areas of their flood plains by the actions of man, enhancing the amplitude between high water and low water. This problem became immanent soon after the first dykes surrounding the polders were closed, at the end of the 13th century. At the end of the Middle Ages the harnessing of the riverbeds, particularly the closure of the ring-dykes surrounding the river polders, was so far advanced that the fixed river basins of Rhine and Meuse occupied roughly the same macro-geographic position in the Delta as they have nowadays, however. Around 1350 all main branches of Rhine and Meuse were embanked, and consequently the unhindered drainage of superfluous water from the river polders ceased. From then on the river polders were protected against unwanted river floods from the ‘outside’, but at the same time the ‘inside’ water problem aggravated, caused by seepage and groundwater.

Between the 10th and the 14th century the vast moorlands and raised bogs in the western part of the Delta (Central Delta) were colonised. Large parts of the peat areas were systematically exploited in a relatively short period of time, between 950 and 1150. The ‘cope’ cultivation changed the raised-bog wilderness into a meticulously laid-out wetland landscape. The drastic change in landscape structure around the 10th century is to be attributed to the increase of the human population. Between 800 and 1250 the population of the Delta, increased from 100,000 to 800,000 inhabitants. Later on, the Black Death took its toll; the outbreaks of plague around 1350 and later, should be ranked as the greatest biological-environmental event in the early history of the Delta. Owing to the massive draining and digging of peat in the Central Delta, large land areas compacted and subsided, became eroded by wave attack and disappeared under water, creating large, shallow lakes. The development of these peat lakes, created after centuries of too greedy peat extraction, is one of the best known examples of massive ecological damage induced by man. Because this was a gradual process, the phenomenon was not perceived as a disaster.

The coastal raised bogs underwent the same fate. Centuries-long cultivation and draining of the coastal peat moors caused large areas to compact and to subside; the surface level was gradually lowered some metres, and large areas fell a prey to tidal forces. Between 800 and 1,250 large areas of land in the NW and in the SW Delta were lost, owing to a combination of factors, of which human occupation in the most important one. It is a common belief that the larger part of the coastal areas in the Delta consists of land that was reclaimed from the sea, but the opposite is true. In fact, we unwittingly allowed the sea to take vast areas that were originally situated above the level of the sea. The loss of embanked polders, to be attributed to the over-exploitation of (salt-saturated) peat, was too great a problem for the late medieval people. Before 1500 man could simply not cope with the forces of nature in an intrinsic dynamic and continuously changing estuarine landscape, owing to lack of knowledge and the absence of technical know how. The invention of a new technology, the wind-watermill in the early 14th century opened up a new era of land reclamation (Chapter 3).

### *20.2.3 Technical Achievements, the Wind-Watermill in Water Management*

From military history and the history of religion it appears that from Roman times onwards these societal forces contributed substantially to the level of economic prosperity of a region, and hence to the measures taken in the framework of water management. The period 1500–1800 is characterised by technical achievements, much progress but also setbacks, and above all scaling up of water projects. During prosperous times great projects were undertaken, assuming next to technical innovations a great willingness to invest. From *ca.*1450 onwards the landowners in the Delta scaled up the management of the water regime by taking optimal advantage of the new wind-watermill technology. The drained lakes and the river polders surrounded by ring-dykes owe their existence as well as their development to the draining capacity of the windmills. The regulated water household changed the river basins into cultural – or at best semi-natural – landscapes and water landscapes. Until the introduction of steam power, in the early 19th century, muscular strength of humans and animals (horses), sustained by wind and water power were the only sources of power that modelled and transformed the natural landscapes in the Delta into cultural water landscapes (Fig. 20.1).

In the Central and NW Delta large areas of land were lost owing to the massive dredging of peat. Wind and wave attack on the foreshores accelerated the process of land loss, and hence the creation of peat lakes. In the prosperous Golden Age (17th century) it became technically feasible to reclaim large areas of peatland, and to turn peat lakes into fertile land. The continuous battle of gaining and loosing land in the coastal parts of the Delta is characterised by the counteracting forces of the rising sea level and the subsiding land, mainly owing to the extraction of (salty) peat. Around 1500 large parts of the coastal Delta were lowered down to sea level. Again and again two steps forward were taken (reclamation) and one step backwards (loss of land of embanked areas). Tens of thousands of hectares of land have been successfully reclaimed in the prosperous 17th century, either applying new embankment techniques, or by piecemeal reclamation of newly accreted areas.

**Fig. 20.1** The miller (Etching by Luiken, 1694)

The paradox of water management became emergent: draining and dredging of peat lands, and harnessing rivers between higher and stronger dykes, unbridled natural forces not foreseen and not experienced before: land subsidence, expansion of peat lakes by wind and water forces, and increasing risks of river floods. Some visionaries pointed to these problems already in the 17th and 18th century. The construction of river dykes canalised the rivers, and took the room for manoeuvre they had in earlier centuries. Levee building counteracted the manageability of rivers; river floods became more devastating and more frequent than before. Maintenance of waterways and dykes was not seen as a supra-regional public task.

The natural water regime – high in winter, low in summer – was accepted as a natural phenomenon, and public authorities were not able to interfere in the river basin-wide water table. But the capricious rivers silted-up and became unmanageable, owing to centuries-long river abuse and neglect, counteracting interests and the failure of regional solutions to flooding problems. Navigability became laborious and unpredictable; regular floods changed the configuration of sandbanks and meanders, and summer droughts revealed silted-up thresholds. Local dredging could not cure that problem, it only meant a displacement of the sedimentation process. The construction of the Pannerdens kanaal (1707) bifurcation was the first large-scale measure to manipulate and to divert the discharge of the river Rhine.

Waterways were the arteries for the transport of people and goods (comparable to the present-day thoroughfares and main roads), and most medieval towns originated at the confluence of a main river and a tributary, a strategic position, from where the hinterland could be provided with goods and services, and allowing the municipality to levy toll on passing merchandise. Fortification of towns had been in practice since antiquity, but in the 10th century feudal lords began to develop the private fortress-residence known as the castle. After gunpowder and cannons became available in the late Middle Ages, both castles and city walls became much more vulnerable, and there was less point to a castle as a fortification. Gradually the medieval castles were demolished or rebuilt and changed into country seats, often surrounded by gardens and encircled by a canal. Many new country seats were built in the period 1600–1800 along all tributaries of the main rivers, and particularly along the Kromme Rijn, Utrechtse Vecht and Amstel by the wealthy merchandisers from Amsterdam and Utrecht. The Delta became a system of increasingly regulated waterways. In the 18th century thousands of kilometres of waterways formed far out the most extensive and reliable network for transport of humans and goods (trade barges). The track-boat, the passenger boat towed by horses, had it heydays from 1630 to 1700, and was in use until the mid-19th century; hundreds of kilometres of track-boat canals were dug in the course of time, and connected to already existing waterways.

The physical differences between the lowland tributaries of the Rhine, compared to the tributaries of the IJssel and Meuse, were (and still are) significant. The branches of IJssel and Meuse have their source on higher grounds, some tens to hundreds of metres above the level of the main river. From the late Middle Ages until the 20th century, far beyond the introduction of the steam engine, the drop of these brooks has been used to power the paddle-wheels of numerous watermills (Chapters 4 and 11).

### *20.2.4 River Management After 1800: Complete Regulation and Canalisation*

The threats of flooding and the consequent safety precautions that had to be taken have shaped the life of the inhabitants of the Delta. Trial and error have characterised the attempts to conquer these problems during the prehistoric era, and the historic period until the late Middle Ages: defensive earthen embankment were thrown up, and after a flood these levees were reinforced and heightened. From *ca.*1550 onwards rather detailed maps of the main rivers became available; channel and flow characteristics could be derived from these maps, and additional data on local depth measurements and discharge estimates were added. From roughly 1700 onwards flow velocity and discharge measurements could be executed. From the 19th century an ever-increasing number of data on river management became available, collected with ever-advancing measuring methods. This progress allowed the water managers to calculate the chance of being flooded, combined with the potential effects of a flood with ever-increasing precision. Economically important developments of agriculture and fisheries were equally well documented and sustained by practical research during the past 200 years (cf. Chapters 7 and 8).

During many centuries the rivers dominated life in this region. The rivers functioned as transport arteries, on the one hand they have provided the flood plains with fertile clay, but on the other hand they caused great misery during repeated flooding, they were a means of living for many generations of fishermen, and they provided the inhabitants with drinking water and water for their beer. The forces of nature were experienced with a mixture of respect, love and fear. The past 150 years life in the river polders gradually turned away from the river, transport of people and goods over water lost its main function, the ferries were closed, the river fisheries became a trade of the past and the threat of being flooded faded away from the memory of the inhabitants.

In the traditional agricultural society of the Delta the Industrial Revolution got under way relatively late, around 1850. Hence, developments in river management in the early 19th century were a continuation of a millennia old strategy: the use, maintenance and improvement of waterways as economic arteries for transport of humans and goods. Safety and navigability were important motives for river improvement. Safety against flooding demanded regulated rivers, strong and high dykes, and straight river channels without obstacles, sandbanks, etc., especially to avoid damage through drift ice. Effective transport demanded also a continuous, navigable shipping channel, reliable at low water and at high discharges.

Rigorous measures were especially taken in the 19th and early 20th century, to ‘normalise’, i.e. completely regulate and canalise the riverbeds of Rhine and Meuse. The removal of numerous meanders and sandbanks, the building of hundreds of groynes to narrow and deepen the channels, the digging of lateral canals and bypasses, and the building of weirs and ship locks fully canalised the Meuse, and large sections of the Rhine (Nederrijn-Lek). The execution of the projects was favoured by the improved economical situation in the second half of the 19th century. The main rivers Rhine and Meuse were definitely separated in 1904, by the opening of the Bergse Maas, and the closure of the spillways at Heerewaarden. The Beerse Maas, a medieval spillway of the river Meuse was closed in 1943.

River regulation schemes are part of an endless spiral of civil engineering measures that should necessarily be executed in the future to alleviate the flooding problem and to enhance international shipping. The systematic normalisation changed the rivers into tamed and regulated streams. The amputation of the smaller landscape elements is significant: sandbanks and flood-plain forests were removed, river branches were cut off, secondary channels became dry land and natural harbours were silted-up. Awaking interests in recreation and nature conservation in the first half of the 20th century did not play any role in the decision-making processes underlying the river normalisations.

Not only the Large Rivers Rhine and Meuse were severely influenced by man. Many tributaries, brooks and small rivers, have been mutilated as well. Particularly in the 20th century the enforced drainage of agricultural land, resulting in the lowering of the groundwater table, has deprived many brooks from their original flow, and has led to desiccation in summer of the adjoining pastures and arable land. On the other hand, the increased dynamics in discharge, caused by the regulation works to fight the continuous threat of flooding, have enhanced the instable erosive characteristics of many brooks, resulting in erosion and incision of the brook bed during peak floods. On top of all these changes in the landscape, the discharge of organic loads, the effluent of sewage treatment plants, the unplanned load of untreated sewage water, and atmospheric deposition have further deteriorated the brook environment.

The 19th and early 20th centuries are the great age of canal digging, initially by hand with spade and wheelbarrow but increasingly facilitated by steam power. Hundreds of kilometres of shipping canals were dug, artificial alternatives for the unpredictable, in terms of transport almost useless natural rivers. Reclamation of peat lakes continued in the 19th century. Owing to the application of the new steam-pumping station technology the Haarlemmermeer fell dry in 1852 and 18,000 ha of new land was opened to settlement. The aim of the project was flood protection, not the gaining of land. In response to the devastating storm flood of 1916 the Zuiderzee was closed off in 1932; the resulting reclamation of the IJsselmeer polders between 1927 and 1968 surpassed all other projects before in acreage. This scheme had three objectives: the reclamation of 205,000 ha of new farmland, the reduction of the coastline by 300 km, and the provision of a large freshwater reservoir. In the 1980s a significant change in policy took place from the gaining of more agricultural land to the development of nature reserves (e.g. the Oostvaardersplassen in Zuidelijk Flevoland), built-up areas and infrastructure (Chapters 5 and 11).

### 20.2.5 1953 and 1995: The Delta Plan and the Delta Plan Large Rivers

The storm flood disaster of February 1, 1953 induced the Delta project. Under the motto ‘this never again’ (more than 1,850 human casualties; uncountable damage to human goods and chattels) the open mouths of the estuaries in the SW Delta had to be closed by massive seawalls, and the estuaries should be turned into freshwater lakes. The Delta Act was already implemented in 1957, and the estuaries were closed, one by one in the 1960s and 1970s. The internationally rare estuarine gradients, the majority of the original mudflats and salt marshes and ecological zoning patterns on hard substrates were annihilated, and changed into non-resilient marine and freshwater compartments sealed off by large seawalls and locks. From the very beginning of the Delta project numerous long-term environmental problems asked for mitigating solutions, e.g. the accumulation of polluted Meuse, and mainly Rhine sediments in the Hollands Diep, Nieuwe Merwede, Biesbosch area, and the nutrient accumulation by agricultural run-off, causing mass blooming of blue-green algae, in the Krammer-Volkerak. In 1986 the construction of the storm surge barrier in the mouth of Oosterschelde estuary was finished. The barrier was considered the crown on the Delta Plan, and the entire Delta schema is a solid candidate to be ranked under the 'world wonders of civil engineering'.

However, each medal has two sides. The side of ecology, the disappearance of a unique tidal delta, in favour of safety for the human population: it was in fact not done to bring that up after the horrendous disaster of 1953. Ecologists, of course, did worry about the consequences of the Delta Plan, and their arguments have played a decisive role in the political choice in favour of the saline Grevelingen, and the construction of the storm surge barrier, maintaining the semi-tidal Oosterschelde. Ecological motives did not play any role in the original decision-making process in the 1950s, but in the past 30 years the appreciation for ecology as a science, and for ecological values has increased considerably. In the meantime, the Delta waters developed into instable 'compartments', difficult to manage, and teased by environmental problems. Only 20 years have passed since the construction of the storm surge barrier in the Oosterschelde, the crown on the Delta project, was finished, and the positive state of mind about the chosen solution has tempered. The hydrographical characteristics of the estuary have changed negatively, resulting in erosion and permanent inundation of the highly valued intertidal sand and mudflats. The understanding has grown that estuaries, with their tidal rhythm and their gradients from saline to freshwater, are ecologically much more 'healthy' than the present separated and isolated waters. The return of tidal dynamics, and the reconstruction of the natural connections between the separated water bodies is a presently debated option, under the prerequisite of full maintenance of safety for the human population. The near-disasters of 1993 and 1995, the river floods, have amplified these ideas. Climate change is predicted to lead to increased river discharges, and the SW Delta of Rhine and Meuse is needed, just as before 1953, for the discharge of superfluous river water to the sea: the 'river continuum' concept in full practice (Chapter 10).

The incidents of 1993 and 1995, the extremely high water levels in the large rivers, induced the same shock-effect as in 1953: this never again. The Delta Plan Large Rivers passed parliament within a few months. Hundreds of kilometres of river dykes were reinforced, widened and heightened. In contrast to the situation in the 1950s, when ecology did not play any role, now the values of rare plants and animals and their distribution were explicitly taken into account. Safety, of course, remained the prime argument, but wherever possible landscape and cultural-historic values were preserved. In the meantime the statistical experts of our climate came with their alarming modelling results. The seasonal pattern of river discharges will change, and high water levels will increase in frequency in the future. One of the climate scenarios is that we deal with a structural change in the discharge regime of the large rivers. In the project ‘Room for the River as part of the ‘Water Policy in the 21st Century’ (www.ruimtevoorderivier.nl), a number of possible measures has been mentioned to cope with potential high water problems of the near future (see Chapter 21).

## 20.3 The Legacy of Human Intervention

### *20.3.1 Changes in the Relation Between Man and Nature*

Profound transformations in the way of thinking were set in motion in Europe by the Scientific Revolution (*ca.*1540–1700) and the Age of Enlightenment (1700–1789), starting with the revolutionary developments in physics and astronomy. Practicing of natural history got momentum in the late 16th and 17th centuries (Van Leeuwenhoeck, Swammerdam, Linnaeus and others); the ‘Book of Nature’ was often the source of inspiration for scientific explorations. From the 16th up to and including the 19th centuries the knowledge of biology in the Delta greatly improved, and important systematic works on higher plants, birds, fish and invertebrates were published. Influential naturalists in the 18th century were professional clergymen (Nozeman, Martinet) with a great interest in natural history. ‘Walking vicars’ in the 19th century made rather detailed descriptions of their wanders, before the age of photography.

The interest of ‘naturalists’ in the aquatic environment of the Delta goes back many centuries. The accurateness of many descriptions of single biota, made by the 17th to 19th century Dutch naturalists can be falsified by present-day research. Descriptions of ecosystems and landscapes, however, cannot be falsified, because most of the images sketched have completely vanished, or have substantially changed. Indirect reconstructions of landscapes and waterscapes can be made, based on reports on the use of land and water for husbandry and fishery purposes, and on the use of wood and timber in forestry and other trades. Descriptions of landscapes were subjective, and coloured from considerations of religion and utility (Martinet), of a naïve, positive sense of history (Craandijk), or of romantic opportunism (Thijsse). ‘Ecological’ (the word did not exist) evidence per se remained non-existent until the 20th century. The societal need for accessible knowledge about nature was small. Nature was wilderness, ‘wasteland’, i.e. not-cultivated, useless land and water. Only very recently, from the 1950 onwards, a growing stream of publications on the regional ecology saw the light, including not only (the almost vanished) natural landscapes in the Delta, but especially the semi-natural, man-made landscapes.

The economic use of everything nature provided was a dominant principle until the beginning of the 20th century. Literally everything, all parts of animals and plants, were used, not only as food but for a wide variety of applications. The organised protection of nature awoke in the late 19th century, with forerunners like Jac. P. Thijsse and E. Heimans. The first milestone in 1905 was the protection of a peat lake, the Naardermeer, in the flood plain of the river Vecht, meant to function as a garbage dump for the city of Amsterdam. The history of scientific hydrobiology, or as it is presently named ‘aquatic ecology’, dates back to the 19th century. Redeke’s (1873–1945) well-known handbook ‘Hydrobiology of the Netherlands’, was posthumously published in 1948. Aquatic ecology developed in the Delta in the second half of the 20th century, until the present day in which the principle of ‘sustainable development’ is supposed to equally weigh economic and ecological interests, at least theoretically. Victor Westhoff (1916–2001) was the most influential nature conservationist in the Netherlands after 1945. He was a researcher and conservationist, and one of his major merits is that he bridged the gap in the debate concerning the supposed ‘natural landscapes’ and ‘cultural landscapes’ occurring in the Delta. He introduced the term ‘semi-nature’, in contrast to ‘real nature’, i.e. gated nature preferably without human influence.

Dutch scientists are often considered as pioneers in the quest for solutions to environmental problems. That may be true for technical applications in water management, but certainly not for their abilities to anticipate the loss of nature and environment in the Delta, and to work out solutions to contest the laws of unbridled economic growth. During the period 1950–1975 environmental deterioration was perceived in academic circles as a matter of secondary importance, and until recently the appreciation for pure science deviated from the appraisal of applied science. The systematic and large-scale collection and reworking of ecological data gained momentum after World War II. Compared to the situation of 40 years ago, a tremendous input has taken place regarding research on the quality and quantity of water and biota parameters in the Delta. The history of aquatic and terrestrial ecology in the Delta, regarding both the scientific and the applied aspects, is only fragmentary documented, and the real meaning in an international context remains to be evaluated (Chapter 6).

### *20.3.2 Exploitation of Land and Water, and the Transition Land–Water*

One of the main characteristics of the Delta landscape in the past were the dynamic changes in water tables, the erratic and uncontrolled flooding and seepage and the vast, inaccessible stretches of low-lying land during winter inundations. Extensive wetlands and marshes were considered as ‘wasteland’, good for hunting and fishing and the harvest of wood. This image has completely changed. Nowadays land = land and water = water. The absence of a well-developed littoral zone and the highly managed water levels of most lakes are typical for the present situation in the Delta. Erratic changes in water tables are not allowed anymore. Water tables are fully controlled by pumping stations, sluices, large weirs and culverts, and ultimately mini-weirs placed in the narrow ditches separating the parcels of grassland. Hundreds of thousands of artificial constructions spread over the Delta, ranging from the mighty storm surge barrier to the modest weir in a ditch or brook, in many cases electrically controlled, keep the water tables at the desired level. 'Everything under control'; only excessive rainfall or long lasting drought may disturb this image now and then. The polder boards work hard to smoothen these wrinkles in their management regime by applying ever more sophisticated measures.

In the past flooding was a continuum. In the late Middle Ages the farmers of the Central Delta were forced to change their conduct of business from arable farming to dairy farming. The more the river polders subsided, the more the seepage of river water became a problem. The introduction of steam engines in the 19th century did only slightly alleviate this nuisance. The farmers were subjected to erratic weather conditions, and repetitive disasters stroke both cattle and crops: seepage and flooding, cattle plague, infectious diseases, crop failure, harmful weeds, etc.

Woodmen and farmers traditionally made use of the self-renewing power of trees. Coppicing and suckering were efficient and reliable ways of getting a new crop. For many centuries numerous small wooded landscape elements characterised the semi-aquatic and terrestrial ecosystems of the Delta: duck decoys, hedges, wooded banks, osiers, timber and wood groves, ridge-and-furrow with underwood. Timber and wood had numerous applications: building material, firewood, faggots in bakers ovens, multi-purpose wood for farmers, poles for fences and tool-shafts, beanpoles, etc. Coppiced willow shoots were used for basket-making, for the production of hoops for barrels and casks (e.g. for herring!), as multi-purpose wood for farmers, e.g. to make fences and cattle hides of wattle work, and sheds and barns of wattle-and-daub. Willow shoots are still needed for the production of willow-matting for hydraulic engineering projects, and for the construction of noise baffles along motor highways, but the present-day use of willow shoots is only a rudiment of the applications in the past.

Wetlands were characterised by osiers, reed marshes and bulrush marshes, which delivered indispensable resources for numerous tradesmen. Decline in area and use started in the course of the 20th century, owing to the cease of tidal movements, deterioration of the environment, and availability of artificial alternatives. The large-scale river normalisation in the 19th and early 20th centuries had significant consequences for habitat structure and concomitant agricultural practice in river forelands. Small landscape elements were annihilated, such as meanders, secondary channels, marshes, groves and osiers. Although the normalisation of the great rivers in the 19th century brought considerable deterioration to the river landscape, it is generally believed that around 1880–1900 the green, fine-meshed cultural landscape of the Delta, comprising numerous small landscape elements, reached its climax.

Hedges (particularly hawthorn) were the cattle (and game) fences of the past. Barbed wire, invented in 1880, replaced this green network. Hundreds of thousands of kilometres of linear landscape elements have been removed in the course of the 20th century.

Until the end of the 19th century, the farmers manured their fields with animal dung. Manure was scarce. The introduction of artificial fertiliser around 1900 meant a revolution in Dutch agriculture. Artificial fertiliser became the great homogeniser of the lowland landscapes of the Delta: the subtle gradients between nutrient poor groundwater or seepage-fed grasslands and the fertilised field close to the human settlements have been annihilated, in favour of uniform fields over-enriched with nutrients.

From approximately the 18th century onwards grassland dominated the landscape of the Large Rivers and the Central Delta (50–70%). In the 20th century the semi-natural meadows and hay fields poor in nutrients, however, made completely room for intensively fertilised and (over)grazed pastures. The continuous modernisation and scaling up of agricultural practice in the 20th century led to significant changes. Meandering brooks were straightened, and rigorous re-allotment measures annihilated numerous small wetland landscape elements. After World War II this process was continued, systematically and accelerated. In the 1980s the number of small wooded landscape elements in the Delta had declined with 70% compared to the situation in the early decades of the 20th century. In the agricultural modernisation process the original use became obsolete. The groves still present are often strongly neglected. In the 20th century the ground rule of agriculture, to enhance the productivity per hectare, has led to systematic manipulation of biological and chemical processes, and increasing discrepancy between the natural environment and agricultural practice became manifest (Chapters 7 and 11).

Fishermen executed their trade on the open water of the Large Rivers. Owing to the fact that the spectacular marine fisheries, particularly on the peak of the Dutch herring catches in the 17th century, drew full attention both from contemporaries as well as from historians, the freshwater fisheries remained strongly underexposed. There are indications, however, that until far in the 16th and early 17th century, the consumption of freshwater fish was even more important than salt herring and other sea fish. From the late Middle Ages till far into the 19th century thousands of fishermen from villages and towns along the rivers practised their trade. They followed the seasonal cycles of the migratory fish, and fished on the rhythm of the tides. Their catch consisted of salmon, sturgeon and allis shad, completed with eel, twaite shad, houting, river lamprey, flounder, and smelt, all popular fish species. The fishermen made their own gear, only their boats were constructed somewhere else. They tarred their boats, made their baskets and knitted, mended and tanned their nets, particularly during winter when the river was frozen or pack ice hindered their job. Until the 20th century the making of baskets, weaved from willow twigs, was an important trade where whole families were involved in. No doubt, river fishery was an important trade until the 20th century. Each town along the major rivers had its own fish market or auction. River fishery is history now. The once abundant migratory fish (salmon!) has gone, owing to loss of habitat, river regulation and many other causes (Chapter 8).

### *20.3.3 Floods and Flood Protection*

The history of storm floods and river floods is a distinctive illustration of the mentality of the people in the sinking Delta, who have decided to maintain their population in this cesspit of the Rhine and Meuse, notwithstanding the rising sea and the predicted increase in the incidence of river-borne flash floods. The story of floods and flood protection is a story of endless misery (Fig. 20.2). Literally hundreds of storm surges and river floods have ravaged the Delta in the course of the centuries, but the inhabitants did not give up, and eventually succeeded in greatly expanding their country, while 'keeping their feet dry'.

Floods before 1400 have inadequately been documented. The literature is still by no means reliable as far as floods in the 15th and 16th centuries are concerned. Only since an ordnance level has been introduced in 1648 (improved in 1885–1894: NAP), the height of storm surges could be measured more or less objectively. But high water levels are not conclusive in case a flood strikes; the strength of a dyke may fail for other reasons (e.g. piping), and it is not always springtide during a disastrous storm flood. It is obvious that flood disasters have had serious consequences for the regional and national economy. The total or partial disappearance of settlements, the losses of land through floods and coastal erosion, increasingly followed by the victory when land was gained elsewhere, has had great impact. Historically, there is a fundamental difference between the periods before and after the construction of the dykes. Palaeographic reconstructions of medieval oscillations in sea-level rise revealed that accelerated sea-level rise, transgression of the sea, or a slight lowering of the sea level, regression of the sea, are valuable concepts for the period for which there are no written sources, but they lose their significance when dykes were built, and written documentation had started. The assumed relationship in the

**Fig. 20.2** Disastrous river flood at Erichem (Betuwe; Nederrijn–Linge) in 1809 (From Driessen, 1994)

literature between storm surges and river floods, or the direct relationship between storm surges and milder, ice-free winters does most likely not exist.

The early water defences built around the beginning of our era were low, not very watertight embankments of tamped earth. In contrast to the settlers in the coastal region, initially the inhabitants of the riverine areas felt little need for water defences. But, as population grew and reclamation spread further into the bogs, settlements protected by small earthen dykes came into being. The relatively densely populated natural levees and channel belt deposits offered fertile soil, renewable resources (forest, wood, game, fish) and transport routes. The settlements were gradually embanked, the river polders mainly got their physical shape as early as 1350–1400, when the ring-dykes surrounding the polders were closed. The building of ring-dykes, supposed to create safety against flooding, unbridled natural forces not foreseen and not experienced before. The meandering rivers lost room, silted-up and became innavigable, and consequently demanded regulation measures. The riverbeds degraded, incised and lost their characteristic landscape elements. Numerous devastating river floods called for ever higher dykes: the amplitude between high and low water increased from 1–2 m in the early Middle Ages to 9–11 m in recent times, gradually aggravating the flooding risk. Landscape and land use of the river polders changed: drainage of the fields led to oxidation of peat, compacting of clay and progressive subsidence and flooding during winter; arable land was changed into grassland.

At the end of the 19th century the river polders were characterised by oligotrophic surface water and seepage, dynamic changes in water tables, a diverse landscape ranging from waterlogged clay to dry sand, and sustainable use of everything nature offered. Great changes occurred in the 20th century: forced mechanical drainage, large-scale re-allotment, use of artificial fertiliser, annihilation of landscape elements, fully controlled, unnatural water tables and internal eutrophication. In summary, the present river polders are bathtubs floating on the polluted groundwater table of the invisible Rhine.

In the SW Delta, the great storm surges generally hit the eastern parts of the estuaries more severely than the islands situated closer to the North Sea. This is explained by the great driving up of the water eastwards when gales were blowing from between southwest and northwest. The damage caused by the storm flood of 1682 was described in detail by contemporary authors. This is the first time in history that extensive and detailed data have been published, polder by polder. In the 1730s the exotic shipworm ruined in short time most wooden dyke revetments along the coast of the Delta, causing numerous dyke breaches and flooding. The vulnerable vertical sheet-pilings were replaced by gently inclining dykes, in order to break the force of the waves. Exposed sea dykes were covered with stone revetments, for sheltered river dykes a turf of grass sufficed.

The documentation about the storm floods of 1570 and 1682, allows a prudent comparison between these historic floods and the recent disaster of 1953. The once-in-a-hundred-years-flood of 1953 was not an exception, and the dykes in the SW Delta, with their 1/50 years safety standard, and neglect in maintenance after World War II, were obviously not designed for the forces unchained in 1953. The storm flood of 1953 prompted extensive discussions on the risk of flooding in the Rhine and Meuse basins. Instead of the trial and error approach until then, the level of safety demanded by society became the starting point. From models fed with data on past river discharges and concurring water levels, the design discharge for the river Rhine at Lobith was calculated, and derived from that data the design water levels were decided for all stretches of dyke.

In historic perspective, the impression of safety bestowed by the massive dykes, invited people to invest money behind the embankments, towns and villages prospered and tended to grow. Although the frequency of a potential disaster has diminished after heightening and strengthening of the dykes, the potential damage to lives and goods has increased: the impression of complete safety is therefore false. It is, in fact, the strong belief in technological solutions that made the Dutch population blind to the real risks. Particularly during periods of poor maintenance of the dykes (war, recession) that became only too obvious. The answer to a devastating flood has always been: build higher and stronger dykes. The effects have always been: more investments behind the dykes, but the repetitive consequences were: larger damage during a subsequent catastrophe.

The majority of great river floods in the Delta were a result of the formation of ice dams in the rivers, were meltwater could accumulate and damage to the dykes was done by ice floes. After 1880 no dyke breaches have occurred caused by ice dams. After 1850 the large rivers in the Delta have been ‘normalised’, guaranteeing an improved discharge of ice and water. Moreover, in the 20th century the water temperature increased, declining the incidence of freezing over of the river. The most recent reinforcement of the river dykes, following the near-floods of 1993 and 1995, enhanced the safety level of 1/50–1/500 per year to a safety level of 1/1,250 per year. The non-embanked Meuse was provided with levees, guaranteeing a safety standard of 1/50–1/250 per year. Next to the primary objective, safety for human beings, secondary, ecological objectives were obeyed (Chapter 9).

## 20.4 History of Industrial Pollution and its Control

### *20.4.1 Changing Rhine and Meuse Ecosystems: Pollution and Rehabilitation*

The Rhine basin (1,320 km, 185,000 km$^2$) is shared by nine countries with a population of about 50 million people and provides drinking water to 30 million of them. The snow- and rainwater-fed Rhine is navigable from the North Sea up to Basel in Switzerland and is one of the most important international waterways in the world. The Meuse (900 km) catchments are six times smaller than the catchments of the Rhine (33,000 km$^2$), and shared by five countries with a population of about 8 million people, providing drinking water to 6 million people. The Meuse is an erratic rain-fed river; it is an important waterway in western Europe, navigable from the

North Sea up to Sedan and Verdun in France. Stretches of the French upper Meuse maintained a relatively good ecological quality. Along both Rhine and Meuse flood plains were reclaimed and forests were felled as early as the Middle Ages, and virtually all of the lowland forests, meadows and marshes have disappeared over the past 200 years. In the 18th to 20th century the channels of Rhine and Meuse had been subjected to drastic changes to improve navigation as well as the discharge of water, ice and sediment, e.g. a considerable reduction in length, the removal of islands and the construction of numerous hydro-dams and weirs, including shipping locks.

Coal was the main accelerator of industrial activities along the Rhine in the 19th century. By the 20th century new forms of energy came to the fore. Hydroelectric power, petroleum-based fuels and nuclear fission allowed the chemical industry to invade river spaces that had largely been spared the ecological damage of industrialisation. From 1945 until the early 1970s water pollution due to domestic and industrial wastewater increased dramatically. Hundreds of different chemicals found their way into rivers every day, among which heavy metals, chlorinated hydrocarbons, pesticides and organic micro-pollutants caused the greatest concern. Habitat loss and water and soil pollution water annihilated many plant and animal species. By 1975, the year generally considered to be the peak year of Rhine pollution, the entire navigable Rhine was so polluted that all natural biological conditions had been compromised, with the level of degradation increasing as the water moved downstream.

Just as for the Rhine, for many centuries natural resources of coal and heavy metals were exploited in the catchments of the Meuse. Coal from the Meuse minefields was the chief accelerator of industrial activities in the 19th century, and the Walloon coalfields can be considered as the cradle of the industrial revolution on the European continent. Severe pollution with heavy metals and organic micro-pollutants reached its climax earlier than in the Rhine basin. Ore mining was at a maximum at the end of the 19th century, and water pollution due to domestic and industrial wastewater turned the Meuse into an open sewer.

Concerted effort by the riparian states since the 1960s has reversed the downward spiral (the International Rhine Commission was founded in 1950), and the Rhine is now on its way to ecological recovery in three critical areas: water quality, biodiversity and flood-plain restoration. The greatest achievements so far have come in water quality. In contrast with the river Rhine, concerted action by the riparian states to improve the quality of the environment has only started in 1994 (foundation of the International Meuse Commission), and important stretches of the upper and lower Meuse are now on their way to ecological rehabilitation. The quality of the Belgian Meuse is seriously lagging behind. Indirect evidence suggests that the quality if the Meuse water around 1970 was relatively better that that of the Rhine. Around 2000 the situation has reversed: salinity is one of the few parameters where the Meuse scores better than the Rhine. Occupation of the catchments, encroachment on the narrow channel bed, habitat loss and water and soil pollution annihilated many plant and animal species. Serious contamination of flood-plain sediments in the lower Meuse basin with heavy metals and organic pollutants is a threat to public health and the quality of the environment.

With the improvement of water quality in the Rhine the dissolved oxygen concentrations are satisfactory for fish throughout the year. This is in contrast with the water quality in the Meuse, which is still not satisfactory for fish. In both rivers, however, fish as well as macro-invertebrate communities contain very few species with narrow ecological requirements. Efforts should be invested in the rehabilitation of the rivers and their tributaries, and measures for the further reintroduction of the salmon such as stocking, habitat enhancement and construction of fish passages should be taken.

Possibilities for the restoration of the rivers Rhine and Meuse are limited by the multi-purpose use of the rivers for shipping, hydropower, drinking water and agriculture. The poor habitat diversity, the lack of lateral connectivity between main channel and flood plains and the cumulative unknown effects of thousands of synthesised components in water seriously hamper further rehabilitation. The full impact of the restoration work will not be visible for a long time to come. Floodplain forests reach their full maturity only after hundreds of years. Toxic build-up of heavy metals and micro-pollutants in sediment deposits will also continue to affect riparian life long after the factories that produced them have been closed. A significant positive recent development is the EU Water Framework Directive: EU member states are required to compile river basin management plans and rivers should have a good ecological status by the year 2015. And this counts both for the Rhine as well as for the Meuse (Chapters 12 and 13).

### *20.4.2 Pollution and Rehabilitation of the Aquatic Environment in the Delta*

Industrial pollution is an old problem, going back to Roman times. Local but persistent, and sometimes toxic water pollution caused by urban trades dates back to the Middle Ages. Urban pollution was aggravated by the dumping of human faeces, animal garbage, etc., into public canals and on the streets. It was at that time widely believed that many acute infectious diseases were caused by ‘bad vapours’ as a result of poor urban drainage. Popular explanations included the ‘miasma’ theory that fevers were caused by foul damps arising from decaying organic material. The invention of sewers rinsed by water is coined as the most important medical breakthrough since 1840 in Britain and later on also introduced on the continent (www.bmj.com). The industrialisation in the Rhine and Meuse catchments in the 19th century magnified the problem, and entire stretches of rivers and connected groundwater, became severely polluted. Concerning its ecological impact, the disposal of non-biodegradable organic substances after World War II aggravated the pollution problem. Rhine and Meuse have been used as open sewerage systems for a considerable part of western Europe up to the middle of the 20th century. The Large Rivers were most severely polluted in the 1970s; the clean-up of the rivers started in the late 1970s and 1980s, and the obligatory building of sewage treatment plants after 1970 accelerated the cleaning process. Diffuse pollution from numerous sources, particularly from the river Meuse, is still a considerable problem, resulting, for example, in severe pollution of the underwater sediments of the Biesbosch-Hollands Diep-Haringvliet owing to the accumulation of contaminated sediments after the closure of the Haringvliet in 1970. The application of biogeochemical knowledge of the regulatory processes in ecosystem rehabilitation is insufficient. Advanced eco-toxicological investigations in the 1980s and 1990s, applying sophisticated detection methods, were executed too late to take the effects of pollution in the very act.

Water quality in the Rhine and Meuse Basins have improved substantially in the last 30 years, but sediment quality lags seriously behind. Border-crossing loads of pollutants, mainly in the Meuse catchments, still impose their impact on aquatic and terrestrial biota and river-bound food webs, but irreversible negative effects on ecosystem functioning could not be attained. The pollution problems that remain to be solved (except the eutrophication problem) can be typified as persistent, relatively inconspicuous and difficult to master (mainly diffuse sources). Prolonged neglect of these problems, however, may severely endanger the successful implementation of rehabilitation measures.

The oligotrophic to mesotrophic status of the surface water in the Delta changed drastically in the 20th century. At present excess rainwater and groundwater is drained into the sea, and most of the surface water in the Delta is mixed up and replenished with eutrophicated Rhine water (the invisible Rhine).Chronic eutrophication of the Delta surface waters is one of the main remaining environmental problems, viz. external eutrophication by inputs of nutrient-rich polluted water (N and P), and the sulphate-driven internal eutrophication in systems loaded with organic material (flood-plain lakes, peat lakes). Biomanipulation complements nutrient reduction in lake restoration, particularly in shallow lakes: if applied in conjunction with other measures, it speeds up the processes of lake rehabilitation (Chapter 14).

## 20.5 Ecology of Biota in a Man-Made Landscape: Deterioration and Rehabilitation

### *20.5.1 Changes in Biodiversity: Lower Organisms, Vegetation and Flora*

River habitats together with their plants and animals have changed significantly over time. A complex of lotic and lentic communities with snags, macrophytes, macrophyte debris and undisturbed sandy banks and river islands as habitats for benthic organisms, including aquatic macrophytes and numerous rheophilous insects, mainly scrapers and shredders, have vanished, due to regulation and normalisation works and shipping traffic. The biodiversity of hard substrate dwellers, snails, mussels, and especially, macro-crustaceans is at present higher than in the early 20th century, mainly resulting from the invasion of exotics from all over the world. Increasingly, water bodies have been disconnected from the river proper and the river forelands. Isolated flood-plain lakes have nowadays a richer biodiversity than the main river channel: species richness of phytoplankton and zooplankton, aquatic macrophytes and macro-invertebrates increase with a decreasing degree of connectivity with the main river channel.

In past centuries a spatial ecological gradient existed in the river flood plains, from the remote, not-fertilised grasslands with nutrient-poor water to the enriched fields close to the farms. The introduction of artificial fertiliser at the end of the 19th century has abruptly changed this situation, and is considered as a major negative impact on the semi-natural vegetation. In the course of the 20th century the groundwater table in all river polders has been lowered artificially in favour of farming. ‘Nature development’ measures are aiming at the recovery of a higher, more natural groundwater level. Artificial elevation of the water table in river flood plains during summer, however, can be detrimental for the vegetation. Phosphate concentrations may increase several fold as a result of prolonged anoxic conditions. Aerobic conditions are needed in summer to stimulate oxidative nitrification processes.

Three groups of plants from the (tidal) freshwater habitats in particular were economically highly valued, rushes, reed and willow trees. Nowadays the exploitation of willow-holms has lost its profitability, and consequently the maintenance of the remaining osier-beds is abandoned. The characteristic species-rich flora of river basins and grassland-on-peat that has developed in past centuries under the management regime of farmers has lost much of its former qualities in the 20th century, owing to habitat loss, intensive draining, fertilisation, pollution and land use. Radical changes in land use were detrimental for pioneer and marsh vegetations, reed marshes, species-rich wet blue-grasslands and dry river foreland grasslands. The growth of hardwood flood-plain forests to maturity conflicts with river management. Large-scale dyke reinforcement schemes after World War II annihilated the majority of the dry flower-rich grasslands on river dykes. The deterioration of the river-dyke flora, however, is a reversible process, e.g. by sparing a strip of the original vegetation during the reconstruction measures (Chapter 18).

Before 1970 freshwater tidal marshes in the SW Delta were characterised by zoning of vegetation, associated with tidal inundation and exposure to tidal currents. In the low intertidal areas rushes dominated, on higher elevations succeeded by reed marshes, and alluvial forests. After the closure of the estuary the vast fresh and brackish water tidal marshes were eliminated, and the intertidal sand flats gradually disappeared under water, and lost their vegetation. The estuarine gradient between the Wadden Sea and the Zuiderzee was lost in 1932, and the gradient between the North Sea and the estuaries in the SW Delta was largely annihilated between 1964 and 1986. The disappearance of the vast sublittoral *Z. marina* beds in the western Wadden Sea and in Grevelingen lagoon is an interesting example of large-scale effects on estuarine ecosystems by human interference. Eelgrass played a dominant role in estuarine habitats of the Delta: a complete ecosystem including algae, invertebrates, fish and bird species has vanished owing to the regulation and closing off of main estuaries (Chapter 16).

Ecological history is for a considerable part the history of biological invasions, the story of constant changes in biodiversity. The perception of an invasion differs between the USA and Europe, because Europeans are familiar with invasions for thousands of years. In the semi-natural landscapes of river basins the inherent susceptibility of disturbed areas to invasions, has become an accepted cultural-historic phenomenon. The problem of invasive plants is taken far more serious in the Delta than the introduction of invasive animals, mainly because the mass development of these plants forms a severe threat to the polder drainage systems. The profile of an exotic comprises the following characteristics: euryhaline, thermophilous, trophic generalist, invading open niches in disturbed or simple habitats; their fast distribution is strongly facilitated by the interconnection of river basins. Migration routes and range extensions of numerous species of invertebrates and higher plants have been described; conspicuous is the Ponto-Caspian connection, along which a considerable number of SE European and Asian invertebrates invaded the interconnected western European lowland rivers (Chapter 17).

### 20.5.2 Changes in Biodiversity: Fish, Birds and Mammals and their Use

Ecological fish guilds appear to be good indicators of ecological integrity and functioning of river–flood-plain systems. A transversal succession gradient in fish communities, perpendicular to the main axis of the river, resembles the longitudinal gradient that is present in large rivers from the headwaters to the mouth (River Continuum Concept). Overall, richness and diversity of species and ecological fish guilds decrease with decreasing hydrological connectivity of flood-plain water bodies with the main channels of the Large Rivers. Anthropogenic disturbances have affected fish species unevenly: guilds of specialised species that are highly adapted to specifically riverine conditions have declined far more than generalist species. Fish habitats in the main and secondary channels have suffered most from regulation and contain the highest percentage of threatened species. Rheophilic fishes have become rare in the Large River basins because their lotic reproductive habitats are severely degraded, fragmented, absent or unreachable. Limnophilic fishes have become rare too, mainly as a result of eutrophication, and eurytopic fishes have become dominant everywhere.

For the rehabilitation of sustainable populations of characteristic and threatened riverine fish species (rheophilic cyprinids, salmonids, etc.) river managers should switch their attention from pursuing further water quality improvements, towards restoration or redevelopment of lost habitats, including connectivity between main channel and headwater streams. At present, flood-plain managers are creating secondary channels along the Large Rivers in the framework of flood protection and ‘nature development’ measures. There is a stock of rheophilic fish present in the lower Rhine which has the ability to reproduce and grow and has the potential to profit from the new secondary channels and reconnected oxbow lakes. In the regulated

Large Rivers with reduced availability of spawning and nursery habitats, potential recruitment from lowland tributaries may be particularly important for a wide variety of fish species, provided that obstacles that prevent fish migration will be removed (Chapter 15).

Owing to their versatile behaviour only a very small number of waterfowl species became extinct in the Delta during the past two millennia. In contrast, large quantitative shifts in population size occurred, resulting from changes in land use, management of aquatic habitats and man's attitude towards waterfowl. The Delta avifauna adapted to traditional farmland practice showed large quantitative ups and downs in the course of the 20th century. Meadow birds' populations declined under pressure of intensive land use. Herbivorous waterfowl have increased, mainly dependent on fertilised agricultural land, creating an apparent conflict with the interests of farmers. Opportunists took advantage of the increasing number of man-made habitats and the present tendency of afforestation. Until World War II fowling and egg-picking kept population size low. Fish-eating birds were merciless hunted because of the (supposed) competition with fishermen. Most bird species are protected now: *ca*. 40% of the present avifauna in the Delta has international significance in terms of the IUCN Red list and the EU Bird Directive.

Some of the larger mammals that still have viable populations in remote parts of Europe became already extinct in the Delta before AD 1500. In former centuries everything nature provided was used by humans in one way or another. The distinction between 'harmful' and 'useful' has until recently been decisive for the way mammals were treated; 'harmful' mammals are still exterminated. Only recently (20th century) a turning point was reached, from unbridled hunting and persecution to selective protection. Some extinct mammal species have been successfully reintroduced on a small scale; attempts to reintroduce the herbivorous beaver were more successful than with the carnivorous otter, still obstructed by water pollution (Chapter 19).

Compared with the situation of 200 years ago, the present ecological status of the Delta is considerably impoverished. But when the present status is compared with that of 30 years ago, positive effects of the rehabilitation measures are discernible. The present biodiversity of higher plants, birds and mammals in the Delta is a reflection of the man-made landscapes and manipulated ecosystems. In international terms these man-made river and wetland landscapes, are valuable, rare and unique. The current policy of the Dutch government is that the total area of 'natural' landscape in the flood plains of the Rhine branches and along the Meuse will be 'developed' to increase to approximately 18,000 ha in 2015 (www.nmp.nl) owing to active management in which agricultural land (mainly cultivated pastures) will be transformed into natural grassland, wetlands, dynamic braided or secondary river branches, and restricted areas of softwood and hardwood flood-plain forests (Chapters 18 and 19).

# Chapter 21

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# The Future of the Delta

## 21.1 Introduction

This synthesis will present a blueprint for future water management and restoration of the Delta: from progressive reclamation of land in the past, to adaptation of human needs to the inevitable forces of nature. Our main focus is on evolving human–environmental relations coping with climate change and sea-level rise. Prehistoric and historic ecological effects that should be assigned to a change in climate will be elucidated. The gradual but continuous conversion of the natural landscape that started in the early Middle Ages is most likely driven by climate change and retardation of sea-level rise. Concerning the past 150 years, it is impossible to separate the signal of significant climate change from the background noise, the short and long-term oscillations in climate and weather patterns. A fact is that the Delta is inescapably sinking under water, a process set in motion 2,000 years ago, exacerbated by the rising sea, and the subsiding land metres below the level of the sea. The risky river polders are continuously threatened by river floods, subsiding bathtubs between silted-up and elevated river basins floating on the polluted groundwater table of the invisible Rhine.

The 'Room for the River' project will be discussed, a several billion Euros plan of action set in motion to guarantee long-term safety to the inhabitants of the flood-prone Delta. The main action is to give a fraction of the lost flood plains back to the regulated and narrowed rivers. But eventually 'Room for the River' will appear to be unsatisfactory to guarantee sustainable solutions for the flood problem, and therefore some additional unorthodox plans and visions will be discussed. Sustainable management of river basins means that user functions of the catchments, such as navigation, agriculture, urbanisation and recreation, should be accommodated to the dynamics of the 'natural' river system, and not the other way around: if you cannot beat the river, you'd better join it. Visionaries have said the same in the far past, but their voice was not heard.

One innovative option is 'back to the past', living on dwelling mounds thrown up in the river flood plains, just as our forefathers did in prehistoric and protohistoric times. A second not customary option is the continuation of a Dutch tradition. The water-oriented tradition of the inhabitants of the Delta is completely lost, since from the mid-19th century onwards trains, and half a century later automobiles in particular have commenced their unstoppable advance. The skeleton of waterways, canals and lakes is still present, and also here user functions could be accommodated to the omnipresence of water in the Delta. Safety demanded rigorous civil engineering solutions in the SW and NW Delta, but the drawback was that estuarine gradients with their unique flora and fauna were lost. Restoration of tidal gradients is presently a debated option.

The Dutch consolation for lost nature is ‘nature development’, the creation of ‘new’ attainable nature in the human-manipulated Delta with its deteriorated landscapes and annihilated habitats. ‘Nature development’, of course, involves subjective debates about which type of nature should be strived after. The man-made landscapes at the end of the 19th century, with their highly valued cultural additions, are the most appreciated types of landscape in the Delta.

Finally, the international dimension of environmental history of lowland rivers will be discussed. No uniform recipes for flood protection and ecological restoration of lost river habitat can be given. Short-term, tailor-made solutions are most frequently occurring. The entire scheme of climate robust measures depends on the specific characteristics of a country, whether economic or ecological choices prevail and the political willingness to invest in long-term sustainable solutions.

## 21.2 Climate Change and Sea-Level Rise

Evidence about human impact on climate change is increasing. According to the IPCC report of February 2007 (IPCC, 2007) warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level. Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations. Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores, spanning many thousands of years. The global increases in carbon dioxide concentration are due primarily to fossil fuel use and land-use change, while those of methane and nitrous oxide are primarily due to agriculture.

According to Van Dorland and Jansen (2007) the IPCC report provides too little detail to work out in-depth scenarios on the consequences of climate change for the Rhine–Meuse Delta. One of the predictions of climate change (among many other scenarios) is increased rainfall in winter, resulting in higher water levels in Delta rivers. More dynamic changes in water levels might favour the origin of rare habitats, such as flood-plain forests, natural levees and river dunes. A scenario with considerably decreasing rainfall in summer results in lower discharge of the Large Rivers, causing problems for navigation. Low discharges combined with higher temperatures have a negative effect on water quality and the availability of cooling water for power plants. In combination with sea-level rise, lower discharges cause increase of salt intrusion in the SW and Central Delta, the former tidal area. IPCC scenarios predict an absolute sea-level rise worldwide of 18–59 cm in the 21st century, compared to 1990. Subsidence of the Delta (*ca.* 10 cm in the past century) may lead to a larger relative sea-level rise.

As a result of the sudden increase in temperature at the end of the Weichselien ice age (*ca.* 15,000 years ago) the sea level rose quickly, 1–2 m per century (cf. Fig. 2.2). Those prehistoric climate changes are now believed to be responsible for the extinction of a number of large mammals, and not, as older hypotheses postulated, extermination by hunting humans (Guthrie, 2006). In historic times sea-level rise slowed down to some decimetres per century. Recent reconstructions of sea-level rise in the Wadden Sea revealed that the sea level was 30 centimetre higher during the warm medieval period (*ca.* AD 1000–1450) than during the little ice age (*ca.*1450–1850), at a difference in temperature of *ca.* 1°C. And the little ice age itself showed several minima each separated by slightly warmer intervals. Consequently, it is premature to ascribe the recently documented changes in biodiversity in the Delta river systems to climate change, because there are so many simultaneous developments going on: changes in water management, changes in water quality, invasions of exotics replacing autochthonous species (Geilen et al., 2004). It is a serious drawback for the interpretation of assumed recent climate change events that real time measurements only started at the end of the little ice age, around 1830. No wonder that many data series show an upward trend, such as air temperature followed by $CO_2$ concentrations. We simply do not have enough data to look back on even a small-scale climate cycle. All data sampled in the past were proxy data, indirect measurements based on pollen grain profiles, tree rings, market prices of resources, historic data and old maps, with all implicit difficulties of interpretation (Kroonenberg, 2006).

The recently aroused interest for climate change is all too eagerly coined as explanation for various invasion patterns of allochthonous plants and animals. It is nevertheless striking that southern species thrive in Delta waters, but these data are too scanty for firm conclusions related to the changing climate. Changes in distribution patterns of specific biota can better be attributed to anomalies in weather conditions, instead as to long-term changes in climate. One severe winter (cf. winter 1962–1963) or one major volcanic eruption (cf. Tambora, Soembawa, eruption in 1815 causing significant cooling around the entire northern hemisphere in 1816, ‘the year without a summer’) may alter the interpretation of the observed phenomena. Human perception reveals a paradox: on the one hand our society is progressive, open and susceptible to technical advancements and changes, on the other hand the same society is conservative to changes in biodiversity. Flora and fauna should be ‘preserved’, i.e. should not change. Changes in biodiversity are often seen as a threat suggested to be connected with climate change. Ecological history shows, however, continuous quantitative and qualitative changes in flora and fauna. Immigrants should not be stigmatised by defending purely autochthonous biota. A plea for an unchangeable flora and fauna is an untenable viewpoint in an open society.

In popular publications everything is lumped together: the buzzword 'climate change' is coupled to sea-level rise, and to increasing incidence of storm floods and river floods. However, the changes in climate over the past thousands of years are erratic, and not unequivocally connected with a continuous rise in temperature. The sea level is undoubtedly rising, as it did for the past 15,000 years. There is a persistent hypothesis in the literature (e.g. Bakker, 1958; De Vries and Van der Woude, 2005) stating that a correlation exists between periods with mild winters and a high storm surge frequency, on the one hand, and periods with hard winters and a low storm surge frequency, on the other hand. It is, however, very difficult to decide whether the number of serious storm surges increased or decreased in the course of time. A storm flood is subjectively defined as a situation with strong winds and extremely high water, and above all severe damage to human lives and properties. It may be assumed that the medieval inhabitants of the Delta had developed a high tolerance for the nuisance caused by water in general, and particularly for the devastation caused by floods. They were certainly fully depending on the height and the strength of their dykes and seawalls, and these structures had to be strengthened again and again. Only since an ordnance level (NAP) has been introduced at the end of the 19th century, one is able to measure the height of storm surges more or less objectively. But even now we have the NAP datum, it is not possible to judge the negative impact of a river flood or storm flood properly: the strength of a dyke may fail for other reasons, and it is not always springtide when a storm flood strikes (e.g. neap tide in 1421, St. Elisabeth flood). And above that, the size of the damage done by a flood is also depending on wind direction, and concurring river floods.

Detailed historical analyses of the frequency and strength of storm floods in relation to sea-level oscillations revealed that storm surges occurred at very irregular intervals during the course of the centuries. The relation between climate change and the frequency of storm floods is non-existent, neither is a direct relation between storm surges and milder, ice-free winters substantiated. The relationship between storm surges and river floods is also purely hypothetical. The majority of great river floods in the Delta were a result of the formation of ice dams in the rivers, the accumulation of the meltwater and damage to the dykes by ice floes (Gottschalk, 1975, 1977; Augustyn, 1992; Kroonenberg, 2006). It is the interaction between climate and society that matters. It is obvious that flood disasters have had serious consequences for the regional and national economy. An assumed increase in river floods and storm surges is not so much related to changes in climate but to the readiness to strengthen and maintain seawalls and river embankments.

## 21.3 The Inescapable Fate of the Delta

The environmental history of the Rhine–Meuse Delta covers the legacy of human intervention, the inescapable fate of reclaimed, nevertheless subsiding and sinking polders, 'bathtubs' attacked by numerous floods, reclaimed in the Middle Ages and unwittingly exposed to the rising sea level and the increased amplitude between high and low water in the rivers (cf. Fig. 3.2). The river channels, constricted and regulated between embankments, lost their flood plains, silted-up, degraded and incised. Cultivation of raised bog deposits led to oxidation and compacting of peat and clay, resulting in progressive subsidence and flooding; arable land had to be changed into grassland and wetland. For millennia muscular strength and wind and water powers moulded the country into its basic form. From 1800 onwards, acceleration and scaling up by steam power and electricity, and exponential population growth, resulted in the erection of human structures 'fixed forever', and severe pressure on the environment. At the end of the 20th century a process of more than 1,000 years of embankment and reclamation of wetlands was arrested, which meant the end of a long-lasting tradition (cf. Wolff, 1992). The present-day Delta is a large wetland several metres below sea level, where humans 'keep their feet dry' only by the application of advanced technical means. An additional threat comes from below, the groundwater level irresistibly pushed upwards by the rising sea, but artificially lowered by technical means. A horror scenario of a major country-wide electricity supply breakdown will result within 24 h in the complete inundation of numerous polders, starting with the flooding of the lower parts of the Dutch cities and towns, tunnels, basements, followed by deep polders, and eventually flooding shallow polders.

Times of war and connected decline alternated with times of economic prosperity. Progress in technological water management and economic and social welfare go hand in hand. Major plans to decrease the risks of flooding have been conceived through the ages, but the projects of the past were executed without public participation in the decision making process. Roughly 170 years ago the historian Bilderdijk (1832) lamented that the Dutch should better never have started to embank their rivers and to drain and excavate their land. If hydraulic engineers in the past would have had a truly long-term vision, they would have let the rivers keep moving, resulting in natural growth and elevation of the land, and safe dwelling places above the level of the rivers. Theoretically Bilderdijk was right, of course, but that is hindsight, ignoring the fact that the Delta owes the greater part of its prosperity to the economic exploitation of land and water. Already from the early embankments in the Middle Ages, continuous river management became inescapable. The capricious, unpredictable river dynamics are diametrically opposed to physical planning and land use and derived prosperity. The river flood of 1861 evoked discussions on the governmental level how to lower the risk of future floods. Instead of strengthening and reinforcement of the existing dykes, plans for widening of the winter-bed of the river, straightening of meanders and replacement of dykes were proposed (Moorman van Kappen et al., 1977). The discussions that are pursued nowadays in the Room for the River project are almost a replicate of considerations from the past.

Compared to the past, there are two important differences in the recent decision-making processes, viz. the upgraded significance of ecology and public participation in democratic decision-making procedures. The relation between 'ecology' and 'safety' has always been strained in the densely populated Delta, and in many cases loss of biodiversity and habitats has not been compensated for. The man-made landscapes, dictated by stringent water management, have put ‘ecology’ in a straightjacket, an irreversible process of changes in ‘cultural’ biodiversity. Public participation and support in all phases of the design of the plans to improve safety, set back by the NIMBY-syndrome, may paralyse the execution of the civil engineering schemes, and may consequently jeopardise safety. The public memory for flood disasters is short, and after 10–20 years the sense of urgency is fading away. But the physical process is irreversible, the sea level will continue to rise, and future flooding events should be anticipated. In the well-known definition of sustainable development, the practical value of the principle is reversibility, and keeping options open for future generations (De Groot and Lenders, 2006). The Delta tragedy is that water management per definition is not sustainable, because the steps to be taken are inescapable and for the greater part not reversible. Notwithstanding the great schemes and long-term visions to diminish the risk of flooding, short-term, defensive measures are the only solutions conceivable in a process of an unavoidably subsiding Delta threatened by sea-level rise and climate change, and consequently gradually disappearing under water.

## 21.4 ‘Room for the River’

The Delta Act of 1957, following the severe storm flood of 1953, was meant to protect the human population and their goods in the Delta against flooding from the sea. Not only marine storm floods caused problems, but also irregular river floods called for ever higher dykes. Two river floods that reached a comparable level (*ca.* 12,000 $m^3\ s^{-1}$) to the one in 1926 occurred on the Rhine basin in the years 1993 and 1995. In January–February 1995 prohibitive evacuation took place of 250,000 people, living in the Rhine basin at places where the risk of being flooded was still 1/50 $year^{-1}$. Stimulated by a sense of urgency, already in April 1995 the Delta Act Large Rivers passed parliament. The objective was to guarantee safety for the Large River’s population in 2000 at a risk of being flooded of 1/1,250 $year^{-1}$, without jeopardising the ecological values. In the period 1996–2000 roughly 450 km of river dykes have been reinforced and heightened from a safety level of 1/50–1/500 $year^{-1}$ to a safety level of 1/1,250 $year^{-1}$. The towns and villages on the non-embanked parts of the Maas were provided with levees, mainly small walls of brickwork, guaranteeing a safety standard of 1/50 to 1/250 $year^{-1}$. In 2000 the project was finished: the larger part of the river polders obey the 1/1,250 $year^{-1}$ safety standard now, some smaller parts have a standard of 1/500 $year^{-1}$ or lower.

There is more. The near-floods of 1993 and 1995 have biased the existing models on which the Delta Act Large Rivers was based: the ‘design discharge’ calculated for the year 2000, had to be raised from 15,000 $m^3\ s^{-1}$ to 16,000 $m^3\ s^{-1}$, heralding another round of flood alleviating measures. But the process of heightening and strengthening of the dykes cannot be continued forever. The risk of being flooded behind the massive river embankments, separating the low-lying, ever-subsiding and compacting inhabited river polders from the higher situated silted-up river forelands, although small, is nevertheless a reality. And this counts even more for the polders in the SW Delta. Risk calculations for 1953 compared to those for 2006 indicate that the probability of a disaster has declined indeed, but that the potential effects have increased dramatically: more people and infrastructure than in the past will now be damaged by a major river flood or storm flood (Smits et al., 2006).

In the course of millennia the Large Rivers have been deprived from hundreds of thousands of hectares of flood plains. In the past 150 years alone an additional area of *ca.* 35,000 ha of flood plains were lost for reclamation purposes, alternative land use, built-up areas and infrastructure. During the period 2000–2006 a massive project was prepared by the Dutch government aiming to further improve the safety of the inhabitants of the river polders, considering the risk of being flooded. The idea behind this project is a change in the current trends: not to heighten and strengthen the dykes any further, but to return the lost flood plains to the river. After a long and complicated procedure the Physical Planning Core Decision 'Room for the River' was ratified by parliament in June 2006 (www.ruimtevoorderivier.nl). A total of 37 projects have been proposed, designed to protect 4 million people in 2015 against river floods with a maximum discharge of 16,000 $m^3$ $s^{-1}$ at Lobith, and anticipating floods with a maximum discharge of 18,000 $m^3$ $s^{-1}$ in the further future. 'Room for the River' comprise a suit of rigorous measures (Fig. 21.1), such as the repositioning of river dykes, and the excavation of flood plains along the river IJssel, together with the removal of fluvial deposits in the most stream-downward section of the IJssel. Along the Nederrijn large-scale flood-plain excavations are foreseen, together with improvements of the river dykes. For the river Waal lowering of the groynes is the intended measure. Groynes were built at the end of the 19th century and in the 20th century; they are meant to stabilise and deepen the navigation channel. But in the course of time the constricted channel of the Rhine suffered from severe bed degradation: the river incised its bed, and the groynes are situated at a too-elevated level now, and hinder the proper dispatch of floodwater. It is the intention to lower the groynes on both sides of the river *ca.* 1 m.

Along the river Merwede flood plains will be excavated and the dykes around the polders of a large part of the Biesbosch, the Noordwaard, will be removed or lowered, in order to give the river free access to the area (Fig. 21.1). The topographic structure of the small Biesbosch polders in 1905, separated by tidal gullies, will function as the leading principle for the entire reconstruction scheme (Bureau Noordwaard, 2006). The removal of the old polder dykes around the arable fields and grasslands, recalls reminiscences to olden times when the river (and the tidal movements up to 1970) had free access to the area.

The 'Room for the River' programme is exclusively meant for the main branches of the river Rhine. The project 'Maaswerken' ('Work on the Meuse') is in progress for the river Meuse (cf. Chapter 5), also triggered by the river floods of 1993 and 1995 (Fig. 21.1). This large programme has roughly the same motives as 'Room for the River', viz. flood protection, 'nature development', and improvement of the navigation route. Along the undyked sections of the Meuse the flood incidence will decrease to 1:250 per year, owing to a series of measures, viz. the building of quays or embankments along the waterfront of the larger towns, the deepening and widening

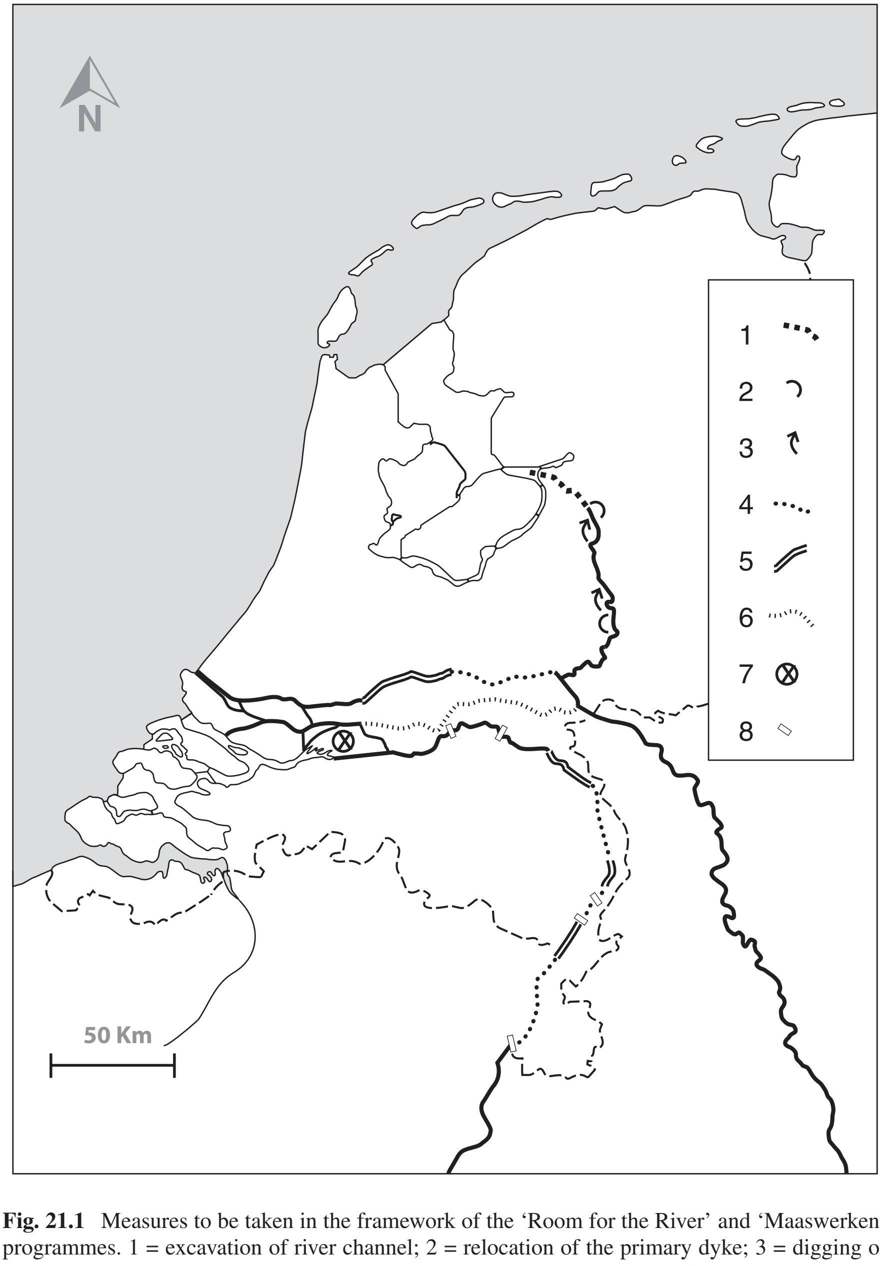

**Fig. 21.1** Measures to be taken in the framework of the 'Room for the River' and 'Maaswerken' programmes. 1 = excavation of river channel; 2 = relocation of the primary dyke; 3 = digging of river bypasses; 4 = heightening and strengthening of existing river dykes; 5 = excavation of river forelands; 6 = lowering of groynes; 7 = 'ontpolderen', i.e. giving land (polder) back to the river; 8 = adaptation of weirs and locks (Derived from Planologische Kernbeslissing Ruimte voor de Rivier Deel III, December 2005, Kaart 2 basispakket [www.ruimtevoorderivier.nl] and Maaswerken [www.maaswerken.nl])

of river channels and the excavation of water-retention basins and secondary channels. It is intended that the rigorous adaptations of the Meuse basin in the Delta will be finished in 2015–2018. Flood protection and ‘nature development’ go hand in hand along the Meuse, and the gaining of gravel, sand and clay makes the works affordable. The Meuse basin is over large stretches bordered by Pleistocene cover sands, and the potentials of the use of clean seepage water for ‘nature development’ in the flood plains can far better be exploited here than in the basin of the Rhine (www.maaswerken.nl).

## 21.5 Back to the Past: Dwelling Mounds

The platitude is that the Delta is composed of alluvial deposits, marine and freshwater sediments accreted during millennia. To give the rivers room unconceivable large volumes of sediment have to be removed from the riverbeds: 85 million $m^3$ $year^{-1}$ of spoil from dredging operations is available for the decades to come. The innovative idea is, instead of dealing with this spoil as a waste product of the affluent society, to use it as building material to construct dwelling mounds, small mounds for farm sites, or country houses, or as refuges during floods, and large mounds for building villages and gardens. Living on raised grounds (mounds), has been common practice in the N and SW Delta from 2400 BP till mediaeval times (Fig. 2.9). Large mounds thrown up from clay and garbage in prehistoric times were extended over the centuries, and after christianisation often a central brick church was erected on top, surrounded by farms and houses. Small dwelling mounds for single farms were built until far in the 19th century. This way of living was lost from the collective memory of the inhabitants of the Delta, because two millennia ago throwing up protective embankments, surrounding human dwellings and surrounding fields, was chosen as a solution to fight flooding. However, the resulting land subsidence has rendered the country vulnerable to some of the predicted effects of climate change, such as rising sea and groundwater levels. The unconventional idea to combine the surplus of enormous quantities of spoil with the fight against the dangers of flooding may enhance the support for rigorous measures indicated in the ‘Room for the River’ programme. The ideas for the ‘Dwelling Mound from River Spoil’ were created by an innovation platform directed by the national water management authority, Rijkswaterstaat. The concept was well received by societal and industrial parties, the potentials are undeniable. In 2006 the preparations for the building of a dwelling mound in the SW Delta were in full swing (www.waterinnovatiebron.nl).

The ‘Room for the River’ policy has inspired several inventive landscape architects to design new ‘water cities’ in the flood plains of the Large Rivers. Lynn and West 8 (2005), for example, designed a large dwelling mound in the flood plain of the river IJssel near Deventer (Fig. 21.2). Here, the river forelands are very wide and several secondary channels connected to the main channel could be excavated to enhance the river discharge during floods. Between the newly excavated secondary channels of the IJssel, a dwelling mound, beyond the 1:1,250 year flooding standard, but intimately connected with the river, could serve as a central location

**Fig. 21.2** Design of a dwelling mound in the widened flood plains of the river IJssel (Lynn and West 8, 2005)

for hundreds of houses, and amenities. A bridge is linking this built-up mound with the main river dyke and the mainland.

To accommodate excess water or to avoid further subsidence of peatlands temporal or continual flooding of specific polders has to be accepted. Common practice is still to build infrastructure in deep polders metres below sea level. Built-up areas will need additional water protection measures, supposed they are to be maintained.

Van der Meulen et al. (2007) came up with the idea to introduce a strategic land-raising programme. Marine sand is the most appropriate resource for this purpose, and the supply infrastructure for this enterprise is in fact available, such as pipelines and suction dredgers. To use three to four times as much sand as is used nowadays may elevate a potential building site, a mega-mound, above sea level. This idea of supplying excessive amounts of sand is not new. The nourishment of beaches and coastal strips of the Delta as a compensation for sediment loss along the coastal system has been common practice since 1990; it involves the addition of *ca.* 12 million cubic metres of sand per year (Van Koningsveld and Mulder, 2004).

Obviously, adaptation to climate change by compensation of sediment deficiency involves more than bringing in bulk amounts of sand. Most polders in the Delta lowlands have an agricultural function, while nature reserves are concentrated on the higher Pleistocene sandy grounds; this long-established general zoning has been consolidated in the most recent national spatial planning procedure (www.vrom.nl). In view of the above, however, partial transfer of these functions may be called for: wetland may be turned into nature instead of farmland between raised built-up areas in the polders, and in contrast more agricultural use may be allowed on the higher sandy grounds instead of nature reserves. An interesting aspect of wetlands is the potential to reinstate peat formation, which could offer some additional compensation for sediment deficiency, and may act as carbonate sink (Van der Meulen, 2007).

## 21.6 ‘Nature Development’

‘And then: what’s left of nature in this land? Woodlands, as a postage stamp as grand’ (poem by J.C. Bloem, 1947). Indeed, the question what is ‘nature’ in the man-made Delta, is a rhetoric one. Literally every square centimetre of soil has been repeatedly turned upside down by man in the course of history. It is the policy of the government of the Netherlands to realise the Ecological Main Structure, an interconnected system of nature reserves and ‘nature development’ areas, in the greater part of the Rhine–Meuse Delta. The total area of ‘natural’ landscape in the flood plains of the Rhine branches and along the Meuse will be ‘developed’ to increase to approximately 18,000 ha in 2015. Agricultural use is still the main land use in the fertile Delta, but the area of non-profitable farmers’ land (mainly cultivated pastures) is quickly increasing. Therefore the concept of ‘nature development’ was implemented, to be considered as active management in which agricultural land will be transformed into natural grassland, wetlands, dynamic braided or secondary river branches, and restricted areas of softwood and hardwood flood-plain forests (www.mnp.nl). (I put the words ‘nature development’ consequently between inverted commas throughout the book, questioning the idea whether ‘nature’ can be ‘developed’ by humans). ‘Nature development’, a concept that quickly gained momentum after 1980, is in fact the creation of another cultural landscape, according to the standards set by present-day nature managers.

The historic reference situation necessary as a blueprint for ecological restoration of river ecosystems is a matter of much debate. To re-establish the protohistoric 'near-natural wilderness' means allowing the natural process of vegetation succession in river flood plains for hundreds of years without human intervention. This is virtually impossible because it is in contrast with the forced evolution of the river basin and conflicts with several other functions of the rivers, viz. flood protection and shipping. Going back to the Middle Ages when the rivers freely meandered and were still lined with extensive hardwood flood-plain forests, under moderate human impact, is also an illusion. In practice any reference situation to strive after is jeopardised by a number of stringent boundary conditions, of which the most rigid one is safety for the population and their goods. Nowadays Dutch river stretches are harnessed by high dykes, avoiding flooding of the hinterland in case of flash floods. One of the policy-driven boundary conditions of river management is that ecological rehabilitation may not result in higher Standard High-Water Levels in the river. In other words: fully fledged river lowland forests, following their natural succession for about 30 years, will not be allowed at spots of vital importance for river hydraulics. This vegetation is hindering the quick dispatch of floodwater, and will consequently conflict with the safety standards applied. 'Nature development' means in this context a contradiction in terms: the spontaneous developments of nature leading to softwood and hardwood forests in the flood plains should continuously be managed and removed by grazing and cutting (Nienhuis and Leuven, 1998).

But practical Dutch river managers disassociated themselves from the high-stepping theoretical reference images. 'Nature development' became in fact the managed return of lost or threatened species, and communities, by unpretentious measures, comprising a lot of trial and error (Londo, 1997). To accommodate the conflict 'nature versus safety' the concept of 'cyclic rejuvenation' was introduced, i.e. the management of river bound communities, conflicting with flood defence, by bringing them back to an earlier stage in their development, mainly by cutting trees and removing undergrowth (Peters et al., 2006).

In the period 1985–2000 the water quality of the Delta rivers has considerably improved, and in the years to come the surface area of 'natural' communities will further increase, but old sources of pollution are still forming a great threat to river ecosystems. The hydro-morphological status of the 'normalised' rivers is in general terms negative, as compared to a 'natural' river. 'Natural' types of landscape cover only 19% of the river basin (Reeze et al., 2005). Deep water, demanded for navigation purposes, agricultural land and built-up areas dominate the river landscape. Hence, a 'good ecological status in 2015' as required by the Water Framework Directive of the EU is not feasible.

In general, flood plains are rather rich in plant species and breeding birds. These species have locally profited of the changes in management from agricultural use to a more dynamic natural regime. The status of the water plants has improved, particularly in channels and ponds in the flood plains. The surface area of undergrowth vegetations is increasing, exemplified in the numbers of breeding birds depending on these habitats. Most bird species in areas covered by the EU Bird

Directive maintain or reinforce 'a favourable status of preservation'. The numbers of over-wintering geese and ducks are strongly increasing. These birds are well protected in Bird Directive areas.

Notwithstanding these positive trends it is clear that the characteristic river flora has lost much of its former qualities, such as pioneer and marsh vegetations rich in species, and the characteristic flood-plain forests, and vegetations of dry habitats, e.g. species-rich hay fields; dry flood-plain vegetation of stream corridors and hardwood flood-plain forests. Many vulnerable plant species characteristic for the river area are on the Red List, but these species are not adequately protected. The connection between European river catchments, especially between Rhine and Danube, gave rise to invasions of exotics species. This has led and will lead to dramatic shifts in dominance of plant and animal communities, particularly in macrofauna communities (Chapter 17). The present-day fish stocks are unbalanced, and dominated by a few generalists. Some species, such as Atlantic salmon (*Salmo salar*), and houting (*Coregonus oxyrhynchus*), are fully dependent on restocking programmes (Chapter 15). Concerning the birds, the great bittern (*Botaurus stellaris*), and great reed warbler (*Acrocephalus arundinaceus*), demand specific attention. These bird species, covered by the EU Bird Directive, are decreasing in number, owing to a decrease in size and quality of their habitats, mainly extensive reed marshes.

In general, the effectiveness of 'nature development' measures is positive, and this strategy has locally led to an increase of natural river communities and characteristic species (e.g. the Gelderse Poort; Bekhuis et al., 2002). The digging of a number of secondary river channels has been successful, in terms of rehabilitation of biodiversity, e.g. of the flood-plain vegetation, the benthic macrofauna and the fish fauna. Owing to the fact that a number of fish passages have been built in the weir systems of Rhine and Meuse branches, migratory fish is increasing along a major part of the Large Rivers. The measures in favour of 'nature development' have locally a positive effect indeed, but the measures are insignificant on the level of an entire river basin. Erosion and sedimentation processes continuously conflict with the demands of a 'regulated' river, in terms of navigation and safety restrictions, and the development of natural flood-plain forests and rough overgrowth seriously hinders the discharge capacity of the river during flash floods. The ongoing building of civil engineering works, such as basins to catch sediments, and systems to regulate the discharge of water over the various river branches remains necessary to alleviate these problems.

The Rhine of today is a fundamentally different riparian habitat from the river of the early 1800s. The old riverbank vegetation is all but gone, as are most of the old-growth forests and all of the salmon runs. They live today only in paintings and maps on museum walls and in the collective memory of poetry and song (Cioc, 2002). According to Kinzelbach (1995) more faunal changes have occurred in the Rhine basin in the past 150 years, than in the previous 10,000 years. The present ecological status of the Large Rivers is indeed rather deplorable, at least when it is compared with the situation of 200 years ago. But when the present status is compared with that of 30 years ago, there are certainly reasons to be optimistic, because of the positive effects of the rehabilitation measures.

## 21.7 The Fifth Dimension

The Delta was built by man, and from olden times disastrous floods have inspired water managers, landscape architects, building contractors and the like to come up with their innovative ideas to transform and to reshape the river landscape. Since the shock effects of 1995 (the near river floods) the boundary condition for all measures in river basins is to guarantee safety at all costs, and this forces the government to take inevitable, draconic measures. Safety and ecology, however, are two sides of the same medal. It is our concern, however, that after 40 years from now, the realisation of the uniform measures foreseen in the 'Room for the River' programme, will in ecological terms be negatively appreciated. Recently it became clear that the feared discharge of 18,000 $m^3 s^{-1}$ at the Rhine near Lobith is extremely unlikely. When this doom-scenario occurs, large parts of Nordrhein-Westfalen will be flooded, and this leads to strongly decreased discharges to the Netherlands. It is true, maintenance of the riverbed is in arrears, the downstream sections of Rhine and Meuse are net collectors of sand and silt, and dredging must continue forever. But 'nature development' should not be used as a mere eyewash. Nature development suggests that 'nature' is absent, or vaguely noticeable, in the present situation, and that by dredging gullies and lowering the surface level of the flood plains, 'new nature' will arise. This thought is diametrically opposed to the current appreciation for the river landscape, moulded by man in the course of centuries. 'Nature development' is a hardly defendable option at places where present cultural-historic and landscape values dominate. It is not sensible to take too great steps in a process of which the long-term ecological consequences cannot be estimated. It should be avoided that everywhere the same solution is chosen, under the motto 'secondary gullies improve biodiversity, so we shall dredge a secondary gully everywhere, even though there has never been one in the past'.

Notwithstanding the semi-natural status of our large rivers, the landscape is appreciated as 'typical Dutch', comprising values that belong to the national heritage. River basins fit fully into the Ecological Main Structure, the prestigious international concept of interconnected nature reserves. A string of National and Regional Nature Reserves along the rivers exemplifies those values. Large areas are covered by the Habitat Directive and the Birds Directive of the European Commission, guaranteeing international protection. It must be possible to adapt a number of stakeholder interests to sustainable, ecological river management, and not the other way around. Our plea: do not choose the same solution everywhere. Do not decide overhasty about the future development of ancient flood plains. Leave some flood plains, demonstrating specific natural and cultural values, untouched. As Victor Westhoff (1999) repeatedly stated: 'To manage our semi-natural landscapes, the best action is to perform everywhere a different measure, but to maintain these measures over time. The common management practice nowadays is a continual change in measures, and everywhere the same measures'. Illustrative for this type of management is the dredging of secondary gullies, the grazing with large cattle, compacting and manuring the soil, and the uniform mowing regime on the dykes. The ecological plea, optimisation of habitat and ecosystem diversity, implies management in favour of communities at localities poor in plant nutrients and at sandy spots, to take advantage of seepage habitats, to manage the wetlands without the threat of hidden toxicants, and to allow natural succession the time it takes.

For the time being, a pragmatic, 'learning-by-doing' approach appears to be the best guarantee for successful ecological restoration projects in the Delta. The spontaneous colonization by plants and animals, following habitat reconstruction, is preferred. But sometimes the reintroduction of keystone species, e.g. eelgrass (Chapter 16), salmon (Chapter 15), beaver and otter (Chapter 19), is necessary in case the potential habitats are isolated or fragmented (Cals et al., 1998; Nienhuis et al., 2002a). A closer look to this pragmatic approach, however, shows that behind the screens the theoretical discussion on the goals of 'nature development', as a step towards a healthy river, is ongoing. The disciples of the 'large grazers' school promote the idea that introduced races of cows and horses enhance the natural processes in nature reserves, and increase the biodiversity of grassland. Their opponents of the 'mowers' school argue that selective grazing will eventually exhaust the seed bank, so that vulnerable species (e.g. orchids) will disappear. The members of the 'mowers' school plea for old-fashioned mowing and sod-cutting of grassland.

In the course of time the Dutch river landscape has gained values that should be counted for. These values may be called 'the fifth dimension of the landscape' (Lenders, 2003). Besides the three physical dimensions of a landscape, there is 'time' as the fourth dimension, the history of its origin and development. Then there is the fifth dimension, comprising the cultural and historical assets, shaping the landscape to what it really is. Natural succession needs time, sometimes hundreds of years, to show the full development of biodiversity. Our concern is that the concept of 'cyclic flood-plain rejuvenation' (take care, by management, that flood-plain ecosystems remain young; prevent the full growth of flood-plain forests; Peters et al., 2006) is too much going down on one's knees for the river managers, having as a consequence that the yellow dragline will be visible and audible in the flood plains more frequently than the black stork. The fifth dimension of the Dutch semi-natural river landscape is anchored in the collective memory of the inhabitants of the river basins. Part of this collective memory is formed by the flood-plain pastures studded with cows, the flowering hawthorn hedges bordering the meadow lots, the unfertilised, luxuriously flowering hay lands, the endangered wetland birds, and the tens of thousands of migratory geese in winter. The cultural side of the fifth dimension comprises the archaeological remnants dating back to the Roman 'limes', when the river Rhine was the northern border of their world empire, and also fortifications smothered in weeds as reminder of the paramount strategic function of rivers in the more recent military history (Nienhuis, 2006).

## 21.8 If You Cannot Beat the River, You'd Better Join It

### *21.8.1 Continuation of a Dutch Tradition*

Present-day water management in the Delta is suffering from several chronic problems: the counteracting forces of sea-level rise and subsidence of the drained land is most obvious here. The groundwater level is very close to the actual surface level, artificially maintained by pumping stations. The NW Delta is a 'bathtub', surrounded by water masses, situated *ca.* 3 m below the level of the sea, and bordered by dunes at the west side and dykes at the east. The Central Delta comprises the lowest polders in the Delta, situated 4–6 m below NAP. Most polders of the SW Delta are also situated below NAP, and, moreover, the area is still vulnerable to storm surges originating on the North Sea. An aspect of the implementation of the new national water policy was the search for areas where water could be stored in case of heavy rainfall or river floods. In desk studies hundreds of potential areas were located, viz. polders to be inundated, and basins to retain superfluous floodwater. One of the variants is the green river, a bypass to be used infrequently as overflow for river floods, connected to the main channel at both sides with a threshold or culvert (Bomas et al., 2002a).

In the awakening of the national water consciousness, landscape architects and physical planners came up with the design of a water throughway, connecting the SW Delta with the NW Delta via existing or upgraded water courses (Fig. 21.3). This sketch is aiming at the continuation of a typical Delta tradition, the revival of an historic-cultural phenomenon, now when we have turned our back upon the waterfront and transport over land became dominant. Until *ca.* 1.5 century ago transport in the Delta was completely focused on water (cf. Chapters 3–5), but many links in the chain have disappeared, owing to the pumping dry of polders, the building of dry infrastructure and built-up areas. Traces of the Delta water network are still recognisable as a system of old river courses, neglected track-boat canals, abandoned shipping canals, peat lakes and historic water defence lines. The Delta water throughway facilitates the growing demands of water tourism, and enhances the water storage and discharge functions of the waterways. The network runs through the large cities that are concentrated in the western part of the Delta (e.g. Dordrecht, Rotterdam, Gouda, Haarlem, Amsterdam, Alkmaar). The rehabilitation of the old system of water courses allows an intimate contact between the metropolitan ambience and the rural environment of the Delta polders. The increase of the capacity to retain and to discharge superfluous rainwater and river water is another significant aspect of this design; the connected lakes and water courses indicate a considerable increase of the water storage capacity in the Delta (Bomas et al., 2002b).

### *21.8.2 Restoration of Tidal Dynamics*

Triggered by the postulated consequences of the changing climate and the rise of the sea level, ambitious plans have been proposed to restore the tidal dynamics in

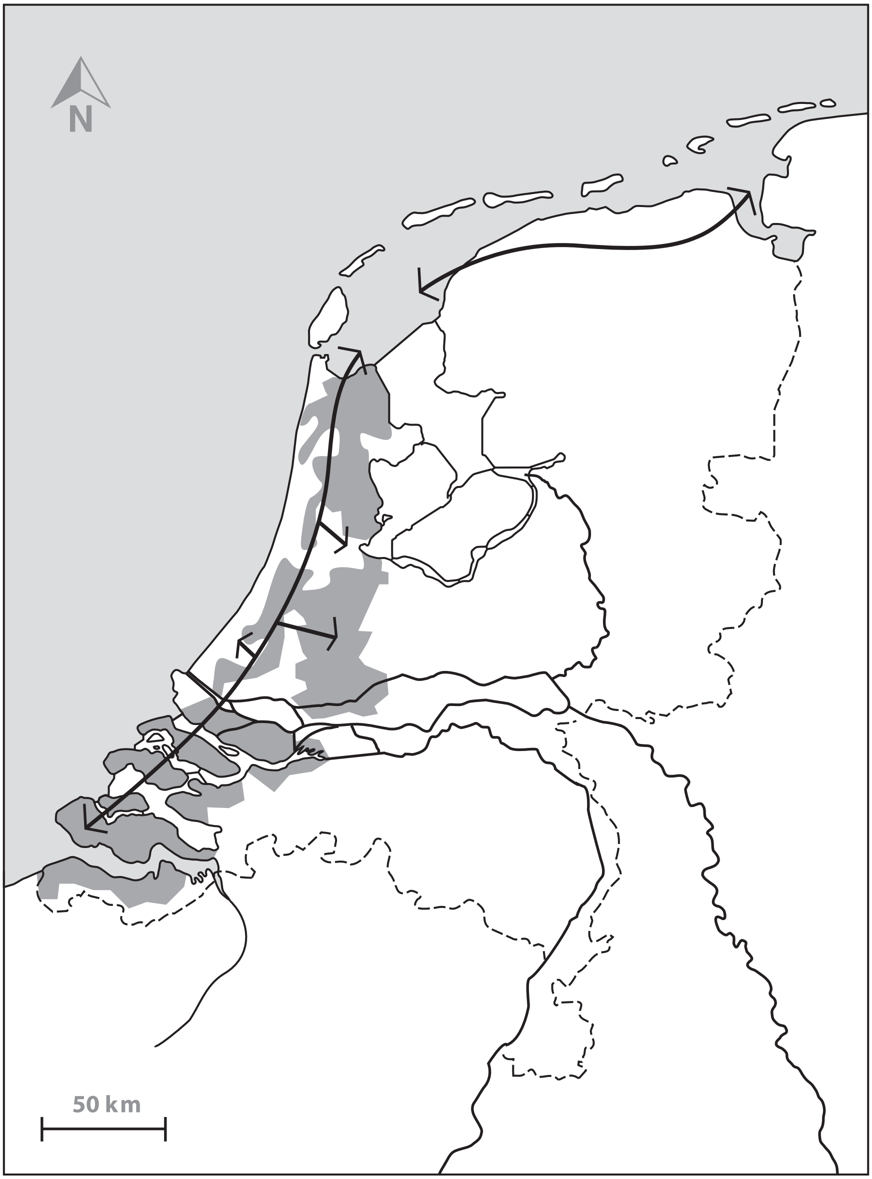

**Fig. 21.3** Design of a re-established water network connecting the SW Delta and the NW Delta based on ancient river courses, peat lakes, neglected shipping canals, old track-boat canals and town canals (arrows). Potential areas for water storage in the future are also indicated (dark grey) (Derived from Bomas et al., 2002a, b; drawing Arjan Nienhuis)

SW Delta, and to abandon parts of the islands to the sea (e.g. www.biennalerotterdam.nl). The feasibility of these comprehensive plans, however, is very small, and a gradual step by step approach might best ascertain political support. Spatial planning in areas that are at a risk of flooding demand reversible and flexible solutions. When ongoing modifications of the ‘natural’ system seem to be inevitable, the execution of reversible measures is to be propagated. As knowledge develops, other solutions might be found which could then be applied. The hydro-morphological and ecological changes that will occur when an estuary is modified are still poorly understood, and predictions have to deal with a great amount of uncertainty. Changes in the importance of agricultural land in the European context, offer an opportunity to give arable fields back to the sea in order to absorb tidal energy and to allow the land to rise simultaneously with the sea. To reach this goal suitable economic drivers are needed. Each (semi-natural) landscape has its own characteristics and, considering the fact that the values of the existing ecosystems are recognised and integrated into economic development strategies, extreme disturbance of the environment should be avoided. Economic drivers should be developed that are compatible with the conditions of the natural environment, in the SW Delta, e.g. fishery, aquaculture, saltwater crops, and marine-wetland oriented recreation and trades. Reversible and resilient economic measures within the limits of the natural processes are preferable.

A future (idealised, we agree) perspective for the SW Delta is a newly developed landscape, where people and investments are located in safe places, surrounded by a landscape that is ruled by the forces of nature. In the recent past large industrial investors took refuge on artificial mounds, the most ancient and the most modern way to survive storm floods (Section 21.5). Floating or sea-encircled artificial dwelling mounds deserve full attention as a long-term strategy for safe building in the lowest parts of the Delta. New approaches such as developed in the Westerschelde (controlled inundation areas via large culverts penetrating the seawalls) offer flexible solutions to flooding problems, and are worth a broader evaluation (Smits et al., 2006).

To illustrate the above views, one example has been worked out by Nienhuis and Van Schuppen (2006), as a contribution to a contest for landscape architectural designs. The Hulster Ambacht on the Westerschelde in the SW Delta (Fig. 21.4) was chosen as a model. The Westerschelde has been regulated and narrowed in the course of the centuries (see Chapter 10), just as the estuaries of Rhine and Meuse. Reclamation of the flood plains led to higher flood levels, resulting in the driving up of floodwater to the harbours of Antwerpen. Flood protection is a major problem, and the Westerschelde needs more room for the storage of floodwater. A second motive to choose this area is the structural depopulation of the area, and immigration of civilians to Belgium.

The Hulster Ambacht harbours all the potentials for a future varied water landscape, viz. low-lying polders under NAP, higher situated silted-up areas and gradients to the Pleistocene cover sands in the south. The area has an eventful history, characterised by raised bogs in the early Middle Ages, peat delving in the late Middle Ages, transgressions of the sea and consequent loss of land. After the year 1,000 vast areas of land were gained on the sea. The oldest polders were surrounded by dykes before 1200, and the most recent ones in the 20th century. The ancient town of Hulst gained municipal rights in 1180; it was originally a harbour on the Westerschelde (see coastline *ca.* 1,550; Fig. 21.4) but in the course of centuries the

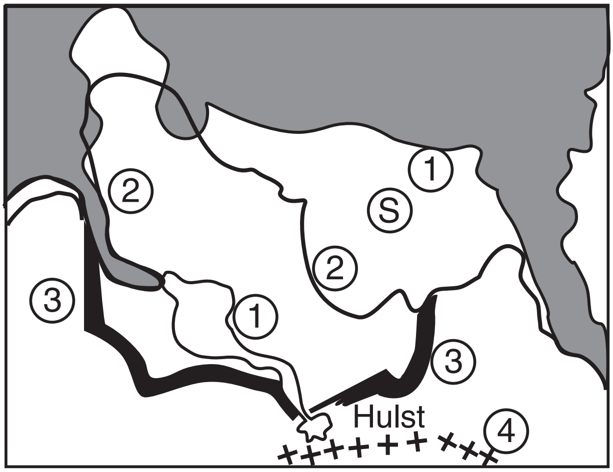

**Fig. 21.4** Design of the transformation of a system of marine clay polders situated between NAP + 1.5 m and NAP – 1 m into a semi-intertidal area of the Westerschelde, comprising controlled inundation basins. The sea dykes of the water-board Hulster Ambacht in *ca.*1550 (1), 1800 (2) and a tentative design of the primary flood defence in 2100 (3) are indicated. In the Middle Ages the harbour of Hulst connected the fortress of Hulst with the Westerschelde. S = Verdronken Land van Saeftinghe, a large salt-marsh area, originally a number of medieval polders, taken by the sea in the 16th century (1530, 1570), partially reclaimed thereafter, but eventually abandoned to the sea in the 18th century. 4 = northernmost border of the elevated Pleistocene cover sands. Grey = Westerschelde – see Fig. 10.9 for position; the depicted area covers *ca.* 15 × 20 km$^2$ (Derived from Sponselee and Buise [1979] and from Nienhuis and Van Schuppen [2006])

harbour silted-up. The polders in the present Verdronken Land van Saefthinge were lost during the storm flood of 1570 (cf. Chapters 9 and 10). The flood was followed by attempts to reclaim the lost land, but eventually the entire area was given up in the 18th century (Fig. 21.4, coastline in *ca.*1800). Saefthinge is now one of the largest brackish tidal marshes of western Europe.

Nienhuis and Van Schuppen (2006) suggested to gradually transform this area into a tidal landscape, not within one generation, but in the course of *ca.* 100 years. An initial but decisive measure should be taken in *ca.*2020: the building of a primary flood defence with a higher status of protection than 1:4,000 years will replace the function of the present seawall (Fig. 21.4). The marine clay polders in between the new primary flood defence and the present sea dyke will step by step be allowed a lower status of protection than 1:4,000 years. Gradually the need to maintain the present low groundwater levels becomes obsolete, and marshy areas come into existence. Agricultural activities on the higher grounds will be continued, but on the lower situated fields, where salt seepage is becoming dominant, salt-tolerant crops will be cultivated. Habitation is sustained in the original embanked settlements, on newly constructed dwelling mounds, or in floating houses. The present sea dyke remains in position, as a secondary sea defence.

By the construction of large culverts the controlled inundation areas may be regularly flooded, and silt will be deposited. By lowering parts of the present dyke, storm floods may enter the area and may consequently dissipate part of their tidal energy. Human occupation is allowed, but should be strictly directed to the dynamic circumstances of the tidal landscape. The remainders of the old polder dykes are functioning as dry transport routes. Around *ca.*2100 the area in between the primary seawall and the secondary one, may become permanent intertidal area (Nienhuis and Van Schuppen, 2006).

The storm floods of 1916 and 1953 have left deep traces in the environmental history of the Delta of the 20th century. And these disasters were literally preceded by numerous devastating storm surges in past centuries. In the meantime the sea is rising and the single line flood defence strategy, comprising dunes, and massive seawalls, appears to be a vulnerable and inadequate concept for the future. New innovative ideas are emerging. ComCoast – COMbined functions in COASTal defence zones – is a European project which develops and demonstrates innovative solutions for flood protection in coastal areas. Rijkswaterstaat, a part of the Dutch Ministry of Public Works and Water Management, leads the project. Besides the Netherlands, four other North Sea countries are involved (UK, Germany, Belgium and Denmark). The ComCoast concept aims to create multifunctional flood management schemes as alternatives to the traditional single line flood defence strategy, with a more gradual transition from sea to land. Depending on the regional demands, ComCoast develops tailor-made solutions: (1) to cope with the future increase of wave overtopping of the embankments; (2) to improve the wave breaking effect of the fore shore, e.g. by using recharge schemes; (3) to create salty wetland conditions with tidal exchange in the primary sea defence using culvert constructions or by realigning the coastal defence system. Between 2005 and 2007, ComCoast will deliver a number of pilot projects in England, Germany and The Netherlands (www.comcoast.org).

## 21.9 Double Shrinkage: Decline of Human Population and Decrease of Dry Land

The spectacular exponential growth of the human population during the 20th century is one of the main drivers for the economic growth in the Delta, and hence for the deterioration of the landscape. The population grew in the period 1900–1950 from *ca.* 5 million to 10 million, on average 100,000 individuals per year, in the period 1950–2000 from *ca.* 10 million to 16 million, on average 120,000 per year. In 2001 the Dutch population increased with 118,125 people, and in 2005 with ‘only’ 29,983. Structural causes underlying these phenomena are the decreasing birth rate, and the emigration surplus. A scenario is that the population in the Netherlands will increase to 17 million in 2035, 700,000 individuals more than in 2005, followed by the actual shrinkage of the population in 2050 to 16.9 million inhabitants (Fig. 1.4). Demographic shrinkage is already manifest in peripheral parts of the Delta, but also in the densely populated and prosperous region of Rotterdam and suburbia (decrease of 6,000 people in 2005) (Latten and De Jong, 2005). The causes of this conspicuous phenomenon are beyond the framework of this book.

Not only the population of the Delta will decline in the long term, but also the area of available dry land. To keep the Delta dry and to continue the supply of freshwater becomes more and more problematic. The question becomes relevant: at what societal costs will we keep the Delta dry? Land will be given up to water claims, and water regimes with differentiated risks of flooding will be created, a new concept in the Delta with its up to now uniform calculated risks of flooding (cf. Chapter 9). Water landscapes with greater dynamics in water regime, and with variable flood risk profiles will be constructed. A decrease in the human population will lower the pressure on scarce goods. This will facilitate abandoning or allowed to lie fallow areas troubled by flooding, or to change the physical planning. The agricultural practice in the Delta will gradually decline. The number of farms in 1980 amounted to 150,000, in 2000 to 97,500, and the expected number in 2015 is only 50,000. Agricultural land use did not decrease significantly between 1980 and 2000, which means that the size of the farms is increasing. But the tendency to abandon grassland is increasing, and the peat landscape in the Central Delta will most radically change. Now, roughly 50% of the land is grassland, and that is used by dairy farmers. The function of the grasslands will change into 'nature', more natural management and rewetting. On marine clay in the SW and NW Delta agriculture will remain to dominate (Pols et al., 2005).

The double shrinkage of both the human population and the area of dry land widens the possibilities to search for locations for 'Room for the River' measures. Not only agricultural land will be considered for water retention, but redeveloped districts in towns can be used as well. Living with floods demands a change in attitude. Clear choices have to be made directed towards water-oriented physical planning, choices based on the contour map of a particular area and consequent calculated risks of being flooded. Along these lines of future physical planning more dynamic water landscapes will be created in the Delta, characterised by variable risk profiles with regard to flooding (Nienhuis and Van Schuppen, 2005). On the one hand building projects and investments on dry land meant 'for eternity' should be intensified, and on the other hand temporal and flexible land use and building projects should be realised in flood-prone areas. Demographic shrinkage may jeopardise large building projects, e.g. large-scale house-building in one of the wettest and lowest (6 m below NAP) polders in the Delta, the Zuidplaspolder near Gouda. To accommodate future water problems, it should be better to intensify land use in urban centres, and execute building projects only where they can be protected and managed 'forever' (Nienhuis and Van Schuppen, 2005; Fig. 21.5a, b)

In low-lying areas where claims for water storage or rehabilitation of the natural water dynamics are inescapable, projects for house-building should be made more extensive. Real estate should gradually be changed into floating real estate, immovable property should become floating property (Fig. 21.6). The future areas rich in water will be put under variable water regimes, and consequently under a variable risk of

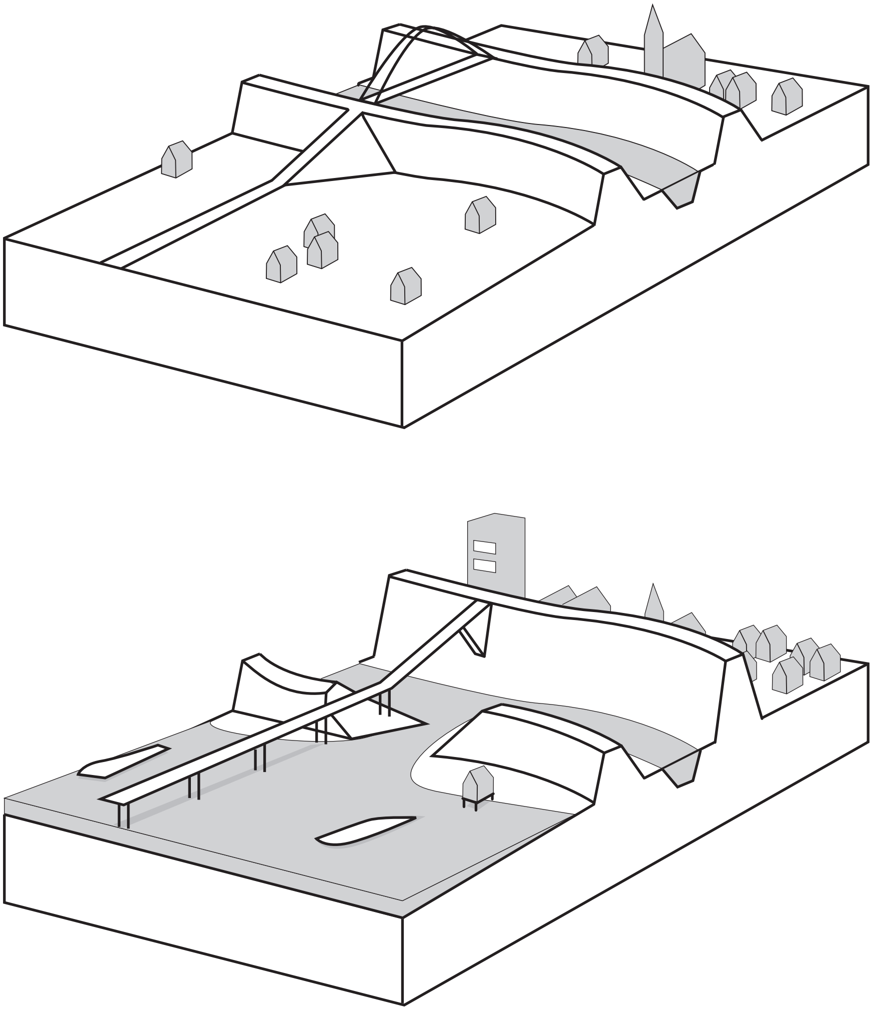

**Fig. 21.5** Potential future choices towards water-oriented physical planning. Transition from the present situation (a) to a possible future situation (b). Building projects on dry land meant 'for eternity' should be protected against floods and built-up areas should be intensified. In flood-prone areas water storage should be accommodated, temporal and flexible land use should be stimulated and building should be made more extensive (Drawing Arjan Nienhuis)

flooding. Owners of newly built houses should take into account these standards, and inhabitants should be aware of the variable safety risks. It is a balance between living in the countryside, experiencing the dynamics of water movements, and connected ecological phenomena, and the increased insurable risks of flooding conditions. Floating houses may even be transported to other localities. The water household should not be seen as a burden, but as a pleasure (Figs. 21.4 and 21.5a, b).

**Fig. 21.6** Housing in the future: solid real estate will become floating real estate. Floating houses in Maasbommel on the river Maas, November 2005 (Photograph P.H. Nienhuis)

How to manage or, better, how to keep company with water is strongly anchored in the culture and history of the Delta, including the risks of being flooded. But all too often a cultural historic approach comes to a dead stop in care for isolated historic monuments or new buildings erected in an old fashioned, historical style. Future physical planning should better make use of the intrinsic dynamic nature of the Delta. A good example is the ‘inlaag’ (Chapter 10). Along the vulnerable coastline of Schouwen-Duiveland, ravaged by coastal erosion, land inwards of the primary sea dyke secondary sea dykes were constructed, in case the primary levee would collapse during a storm surge. The area in between the two dykes was used for the winning of clay for the building of the secondary dyke, and became inadequate for regular farming. Nowadays the brackish marshes of the ‘inlagen’ are seen as prime examples of avant la lettre ‘nature development’, but the attitude underlying the development and existence of the ‘inlaag’ has faded away. It was an attitude in which retreat for the ‘water wolf’ was an essential element, an attitude in which the farmers indulged themselves in the forces of nature, and submitted their will to the tricks of their fate. We have lost that mentality; the sense of vulnerability for the consequences of floods has mainly vanished from the inhabitants of the Delta. The present-day civilians demand ‘absolute’ safety, provided by the government, but this aim is unachievable. The new approaches towards water management should recall part of this ‘old-fashioned’ attitude, including a growing appreciation for ecological values (Nienhuis and Van Schuppen, 2005).

## 21.10 The International Dimension

The integrated approach to environmental history has not yet come to full maturity in western Europe, likely owing to the complexity of the subject and the way the education system at our universities is organised, strictly according to academic disciplines. Although there exists a long and valuable tradition of scholarship by historians and geographers that examine western Europe's past from an environmental perspective, such works have generally employed a restricted focus (agricultural history, urban history, etc.). Still most authors on environmental history items have a mono-disciplinary background, but recently environmental history is emerging more and more as a meta-discipline (e.g. Hughes, 2006), although the mono-disciplinary bias is often undeniable. Several recent works of environmental historians demonstrate the growth towards maturity of the special field, e.g. Simmons (2001) in his wide-ranging environmental history of Great Britain from 10,000 years ago to the present, and Petts et al. (2002) in their popular scientific issue on the environmental history of (urban) rivers in Britain. The work of Cioc (2002) on the river Rhine (1815–2000) is coined as the first comprehensive environmental history of a major European river in English.

My bias stems from aquatic ecology. In ecology scholarship has become monopolised by studies that are extremely narrow in focus and academics have abandoned the task of synthesis to others. Ecology is a young and expanding discipline, always looking for new frontiers, and most practitioners have little interest in retrospection and synthesis. After my retirement I considered it as a challenge to take up the gauntlet, melting together a few pieces of the legacy of human intervention in the Rhine–Meuse Delta, presently one of the most densely populated places on earth.

Agricultural history would seem to occupy a place close to the centre of gravity of environmental history from near the beginning, since humanity has been practicing agriculture for more than 10,000 years, and for at least the latter half of that period agriculture has provided the vast preponderance of food that humans have drawn from nature (Hughes, 2006). Worldwide the alternative, i.e. the use of wild animals and plants, is relatively minor, but hunting and fishing have always supplied a considerable proportion of protein needs for many inhabitants of Delta water-land.

The second focus of environmental history of lowland rivers is water management, closely connected with the expansion of agriculture. The development of agricultural practice in the rivers' flood plains in the Middle Ages asked for the throwing up of dykes, generally built on natural levees, as close to the river's channels as possible. In the area of the Large Rivers and in the Central Delta embanking was completed around 1350. Since that time, the area inundated during the floods was confined to a narrow strip of land, several hundreds of metres to a few kilometres wide along either side of the river. As a result, sedimentation of river silt, which formerly occurred all over the flood plain, concentrated on the river's forelands which were thus raised in height relative to the land behind the dykes. Despite all efforts to keep the dykes in a good condition, frequent flooding of the land behind the dykes took place, in many cases owing to the formation of ice dams in the river. The rivers Rhine and Meuse were eventually completely regulated in the 19th century to early 20th century. This involved channel rectification and fixation, followed by channel constriction and bed degradation. Interest in the ecological consequences of river engineering and in the need to minimise damage to the natural environment did not arise until the1970s, when ecological restoration of the Large Rivers became an important issue.

Over the past 50 years, firm concepts, sophisticated laboratory and field experiments and simulation models have produced a much better understanding of the processes in large riverine ecosystems. The state of affairs as regards the development of river science is rapidly expanding (Giller, 2005; Petts, 2000), but international thinking in river and estuary research and management remains a distant prospect in many cases, in spite of the availability of more and more concepts and a rapidly growing body of literature and European directives (e.g. the ratified Water Framework Directive, and the proposed High-Water Directive). When it comes to ecological restoration it appears that each group in each region has its own school, e.g. the North American approach, with relatively undisturbed river stretches available (Palmer et al., 2005); the continental Anglo-European school, dealing with fully regulated and disturbed rivers (Petts, 2000; Petts et al., 2006; Nienhuis et al., 2002b; Van de Velde et al., 2006a), and the Australian school, confronted with salt lakes and dry land rivers (Ryder and Boulton, 2005). Most environmental problems have a local origin, and we are still far from a general framework for river management, and a synthesis in which the whole is more than the sum of the parts is still lacking. Palmer et al. (2005) proposed a number of criteria for measuring success, with emphasis on an ecological perspective. The design of an ecological river restoration project should be based on a specified guiding image of a more dynamic, healthy river that could exist at the site. Then, the river's ecological condition must be measurably improved, and the river system must be more self-sustaining and resilient to external perturbations so that only minimal follow-up maintenance is needed.

The application of Palmer's et al. (2005) criteria is a theoretical exercise for the Delta; river health is often subsidiary to other priorities, such as safety and reduction of the risk of flooding, navigation between Rotterdam main-port and the German and French industrial areas, recreation in a densely populated country, and the exploitation of over-fertilized maize fields instead of 'natural' wetlands. In practice the 'double-Dutch' agenda is operating, where the profits gained from the excavation of sand and gravel, and the dumping of class IV polluted sludge in deep gravel pits are supposed to pay off the costs involved in 'nature development'. Furthermore, our thinking about river management is driven by local and regional disasters. After the 1995 flood all building activities in flood plains were ceased, and obstacles hindering the unrestrained run off of river water were removed. In 2006 the ban on building in river forelands was lifted; in this case the 'memory for disasters' only lasted 10 years, and more urgent problems attracted greater attention.

Petts et al. (2006) agree with Palmer's et al. (2005) criteria, but they stress that the varying traditions and conventions used by the different disciplines that study rivers, exacerbate the difficulties of developing a common science framework to forecast the response of rivers to management actions. The contrast in approach is reflected by advances in aquatic ecology during the last thee decades, that can be broadly separated into two approaches, synthetic versus engineering, each with its own distinct origin and history of development. In the synthetic approach, scientists have attempted to understand the ecology of rivers at a holistic level and to describe how important river processes vary over time and space. The synthetic approach is useful from a theoretical standpoint, but insufficiently quantitative at the scale at which management decisions must be made. In the engineering approach, researchers have tried to develop suits of practical tools that could be used to predict river stages during the process of ecological restoration. Various physical and chemical processes can be adequately simulated, but the inherent problem is that the ecological responses to the changed abiotic conditions are generally not predictable. Neither the synthetic nor the engineering approaches, by themselves, are adequate to develop science-based management strategies for rivers. As long as the techniques and approaches used by synthesists and engineers remain separate, it is unlikely that river managers will have the tools or approaches available, necessary to manage for sustainability or to develop restoration plans for impacted rivers. Therefore, the logical next step is to promote the development of approaches that will allow the tools of both schools to be coupled together.

The basis of a recent trend and challenge emerging in western European countries is that ecological insights have to be presented in such a way as to be accessible to the public, and have to be transformed into appropriate measures. National governmental agencies are becoming aware that they have the overall responsibility to protect their river basins against floods and environmental disasters. At the same time, however, they also realize that top-down policies and legislation will only have the intended effects in a few specific cases. For example, the policies formulated by the International Commission for the Protection of the Rhine (ICPR) in the 1970s proved to be rather effective in controlling unbridled emissions of pollutants in the river Rhine and its tributaries. However, when it comes to putting the concept of alternative land use into practice, so that society may learn once again to live with natural dynamics instead of fighting them, things appear to be much more difficult. If the people involved fail to see the necessity and the economic benefits of this new approach, it is very difficult to support these policies and land owners will do their utmost to find ways around them, e.g. the resistance against the strategy of returning gained land to the sea in the SW Delta (Nienhuis and Leuven, 2001; Van der Velde et al., 2006a).

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