Wilfried Endlicher et al. *Editor*

Perspectives in Urban Ecology

Studies of ecosystems and interactions between humans and nature in the metropolis of Berlin

Springer

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Editors

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Preface

Urban ecology in Berlin has been developing over the past 350 years, from garden floras and wild floras of castles and ruins to the Graduate Research Training Group 780 “Perspectives in Urban Ecology”. This program has brought together universities and scientific institutes from all over Berlin.

Since the beginning, urban ecology in Berlin has included approaches from biology and geography, leading to the current interdisciplinary work documented in this summarizing publication.

During the second half of the last century, urban ecology has evolved out of landscape ecology by intensively studying human settlements. As a separate discipline, urban ecology was established with systematic studies of climate, soil, water and organisms inhabiting cities. Urban habitats of many cities in Germany, Europe and other continents were described and mapped in detail in the context of science and nature conservation. Pioneering naturalists and scientists have always emphasized the importance of biological diversity in human-dominated systems. This emphasis has paved the way for cities to focus on nature conservation programs.

For the future, we hope for more studies in comparative urban ecology with investigations in different cities also stressing international cooperation. The knowledge about socio-economic factors interfering with the ecological dimension of the urban environment may foster the participation of all city dwellers in urban planning as shown at the “Langer Tag der Stadtnatur” (long day of urban nature) in Berlin with programs and excursions during the day and night. Furthermore, ongoing climate change already affects many cities which encourages international collaborations. Besides the unsolved challenges in the context of climate change, particular adaptation measures in cities could improve the quality of urban planning and urban design in the future.

A rapidly growing proportion of the global human population lives in cities. Studies of cities including the nature in cities should be supported by international programs.

Berlin, Germany Herbert Sukopp

Foreword

The Graduate Research Training Group (RTG; Graduiertenkolleg) 780 *Perspectives in Urban Ecology of a European metropolis – the example of Berlin* presents its most important results in this book. First discussions on the interdisciplinary concept of this programme, funded by the German Research Foundation (DFG), started in 1999, involving scientists of the three Berlin universities (HU, TU, and FU). RTG 780 was finally established in 2002 and the third and last cohort will conclude its work in 2012. The successful organisation of five international conferences, three transatlantic excursions (Seattle, San Francisco, Mexico City), and several interdisciplinary workshops as well as the edition of three books and the carrying out of an integrated study programme over 18 semesters are some of the performances of RTG 780, contributing to our knowledge of urban ecology as an interdisciplinary science.

I thank all participants of the three cohorts for stimulating discussions, interdisciplinary exchange, and reciprocal support. I am especially thankful for the deep understanding, mutual respect, and innovative cooperation between the principle investigators, my colleagues Patrick Hostert, Elmar Kulke, Ingo Kowarik, Julia Lossau, Gunnar Nützmann, Marlies Schulz, Gerd Wessolek, and Elke van der Meer.

The exchange with international institutions, mainly with our American partner project, the Integrative Graduate Education and Research Traineeship (IGERT) *Urban Ecology* of the University of Washington in Seattle, was a great asset for all of us. For that, I have to thank John Marzluff, Marina Alberti, Gordon Bradley, Eric Shulenberger, Craig ZumBrunnen, and Clare Ryan.

The scientific life and exchange of innovative ideas with the postdocs and doctoral students was a great privilege for me, which I deeply acknowledge. The postdocs of the 1st cohort, Norbert Lanfer and Ute Simon, of the 2nd cohort, Marcel Langner, Nikolaus Zahnen, and Kerstin Krellenberg, and of the 3rd cohort, Johannes Max, Sonja Kübler, Barbara Clucas, and Katja Adelhof played a key role in the programme. Furthermore, I hope that the numerous research students employed by RTG 780 made the highest profit from knowledge and enthusiasm of their mentors. Finally, I thank the German Research Foundation for funding and Sabine Mönkemöller (DFG), Johannes Karte (DFG), and Ursula Michel (DFG) for their unbureaucratic support. Nadine Weber (HU) and Katharina Gabriel (IGB) were the best economic managers I could imagine. Both solved countless financial problems, which is deeply acknowledged as well.

However, RTG 780 was only another milestone in the framework of the Berlin School of Urban Ecology, established by Herbert Sukopp and others during the last half century. Therefore, I look very much forward to the next findings and future progress in this exciting scientific discipline.

Berlin, Germany Wilfried Endlicher, Speaker RTG 780
May 2011

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Chapter 1
Introduction: From Urban Nature Studies to Ecosystem Services

Wilfried Endlicher

A main goal of ecological research is to recognize problems that are connected to anthropogenic uses of nature, and to figure out solutions for a better development and a higher quality of life for humans (Haber 1993). From Carl Troll's landscape ecology developed the branch of urban ecology, which Leser characterized as "a landscape ecological field par excellence" (Troll 1973; Leser 1997, 2008; Reichholf 2007). Urban ecology is the study of ecosystems that includes humans living in cities and urbanizing landscapes (Marzluff et al. 2008). Alberti et al. (2003) defined urban ecology as the "study of ecosystems that includes humans living in cities and urbanizing landscapes. It investigates ecosystem services which are closely linked to patterns of urban development". The interdisciplinary concept of urban ecology covers multiple branches of science which deal with the linkages and relationships between biotic communities and their abiotic environment as well as between urban nature, city dwellers and urban planners (Sukopp and Trepl 1995). Urban ecology has a long history of research, especially in Europe (Sukopp 2002). However, as an independent branch of science, urban ecology is a comparably young discipline. Only 40 years ago, researchers began to investigate urban agglomerations more in detail from an ecological point of view (Sukopp 1973). It has been shown that the specific environmental conditions in urban settings compared with rural areas give rise to very specific ecological systems and particular species combinations.

1.1 State of the Art

The ecology of urban areas can be characterized as follows (see as well Sukopp 1997):

– A high number of disturbances exist, whereupon the level of disturbance becomes more and more important from the rural outskirts to the city centre.

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However, this zonal development is changed by azonal elements like public parks and linear structures like streets and waterways. The result is a heterogeneous mosaic of highly fragmentated ecological structures in cities, Sukopp's "Harlekin Pattern".

- Urban soils are partly sealed, heavily enriched with nutrients and toxic substances, and partly transported artificially into the city and redistributed (Burghardt 1991; Wessolek and Facklam 1997; Blume 1998).
- The climate is modified. Temperature is especially increased during summer nights (Oke 1973; Wanner 1986; Kuttler 1998), and as a result of the warmer climate, many plant species originating from southern regions establish communities in northern cities. Ecologically important for flora and fauna is especially the micro-climate between buildings (Sukopp and Wurzel 1995).
- The air quality is reduced and the urban air is loaded with nitrogen oxides, ozone, and particulate matter which is a problem for human health (Baumbach 1996).
- Urban waterways and lakes are characterized by their missing connection to terrestrial habitats and contain a high concentration of nutrients and pollutants (Schuhmacher and Thiesmeier 1991; Wessolek and Renger 1998; Haase 2009).
- The variety of plant species – in general, flourishing plants and ferns – is higher per area higher in the city centre than in rural areas (Kunick 1974; Kowarik 1990). This is also true for animals, especially for many groups of arthropods (Klausnitzer 1987).
- The composition of the urban flora is highly modified. An outstanding attribute of the urban flora and fauna is an increased proportion of non-native and invasive species (Sukopp et al. 1990; Wittig 1991, 2002; Meurer 1997; Sukopp and Wittig 1998a; Kowarik 2003).
- Different phases of historical development of urban agglomerations have resulted in novel, city-specific biocoenoses. The mosaic of urban ecotopes offers hiding places for species which are endangered in intensively used agricultural landscapes (Sukopp and Weiler 1986).
- Natural habitats are almost nonexistent and mostly small in size. They usually exist only as small islands or patches. Some species (for example, rock breeding species of the avifauna) can find shelter and ideal breeding places in the concrete canyons of the urban "stone desert". Undisturbed resting places are less available or they are different from the rural ones (Strohbach et al. 2009).
- Many different animals, especially synanthropic species such as rodents and opportunistic birds, profit greatly from the increased food supply over the entire year.
- Urban ecosystems offer a multitude of social and cultural functions which are not relevant in rural areas. Therefore, economic and social aspects become more and more important (Breuste and Wächter 1999).

These characteristics legitimate the establishment of a special scientific discipline, whose research aims are:

(a) The scientific investigation of the history, structure, and function of urban ecosystems.

(b) The research on its characteristics in comparison with other ecosystems.
(c) The integration of humans into ecology.

1.2 Global Change and the Urban System

Under the process of global change is to be understood the radical change of demographic, economic, ecological, and social development. Global change has profound consequences for each metropolis. The current worldwide processes of global change, such as climate change, economic change, or demographic change, have already initiated a new way of thinking in science. For approximately 15 years, earth and climate are considered to be systems. Earth system science and the science of global climate change have become increasingly important in the last decades. The earth system is seen as a composition of smaller subdivisions or spheres which interact with each other. Research on the earth system needs a global approach, while research on urban ecology is mostly carried out at local levels. However, there are important global inputs to local urban ecosystems. The city can be seen as a small aperture of the earth system in which nearly all spheres or subdivisions, the abiotic ones as well as the biotic ones, are represented. Apart from the cryosphere, every relevant sphere of the earth system, the atmosphere, hydrosphere, pedosphere, and biosphere is clearly represented in the city. This systemic approach permits the modelling of present and future developments (scenarios) which is extremely important on all scales from global (earth) to local (cities).

However, the dominant presence of humans and their influence on all spheres at all scales are special topics of the urban ecosystem. The most striking characteristic of cities, in comparison to rural areas, is the visible predominance of the anthroposphere. Therefore, the anthroposphere is nowadays a central issue of urban ecological studies (Fig. 1.1).

This idea becomes even more evident by the perception that we entered at least 200 years ago into the era of the anthropocene, with its global transformations taking place more and more rapidly (Crutzen 2006; Ehlers 2008). Without any doubt, the anthropocene will be the era of cities as well.

There are many concerted efforts worldwide to bring city dwellers in touch with the ecology of their immediate living space. The remote distance to nature in urban life needs every endeavour, so that people do not lose contact with their natural environment. Research on urban ecological patterns must take this into account (Fig. 1.2).

1.3 The Berlin School of Urban Ecology

Research on urban ecology started in Berlin in the late 1960s under the leadership of Herbert Sukopp. Herbert Sukopp made the best of the political isolation of West Berlin and formed an interdisciplinary team with a research focus on the urban

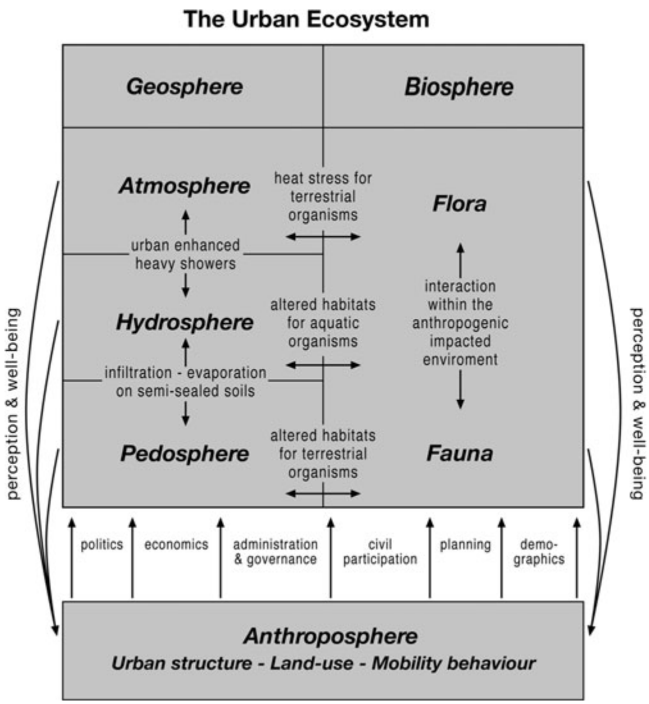

Fig. 1.1 Basic components of the urban ecosystem; this concept is focused on the spheres of the earth system important for cities (Endlicher et al. 2007, slightly modified)

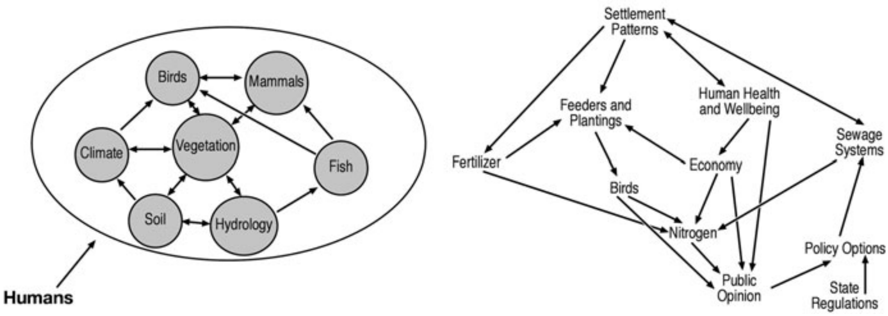

Fig. 1.2 Example of relationships in a typical study of ecology *in* the city (*left*) and ecology *of* the city (*right*) (Marzluff et al. 2008)

nature and environment of Berlin. This innovative and interdisciplinary group published the basic articles and books a large number of urban ecology in Germany (Sukopp 1973, 1990; Sukopp and Wittig 1998a). Herbert Sukopp and Rüdiger Wittig have been the first academic researchers to define the emerging science of urban ecology. They proposed even two definitions: following the first definition, within the natural sciences, urban ecology addresses biological patterns and environmental processes in urban areas as a sub-discipline of biology and ecology. The second definition, however, implies a human perspective, positioning urban ecology as a multidisciplinary approach in order to improve the conditions of life for city dwellers, referring to the ecological functions of urban habitats or ecosystems for people including aspects of social, cultural, and especially planning sciences (see Sukopp and Wittig 1998b).

The *Graduate Research Training Group (RTG) 780 "Perspectives in Urban Ecology of a European Metropolis – the example of Berlin*" (2002–2012), funded by the German Research Foundation, has continued and expanded the urban ecological research established by Sukopp and his colleagues, but has also introduced new topics. The transformation processes after the breakdown of the Berlin Wall and the unification of East and West Berlin have been extremely fast and influential for biotic and abiotic environments. These dynamics are a unique example of the changes occurring in urban ecological networks. A large number of innovative, interdisciplinary, and integrated studies on urban ecology have been carried out in the last decade. Because urban ecological problems are challenges in all cities, international collaboration has been especially important. Based on a close exchange with the North American partner program *Integrative Graduate Education and Research Traineeship (IGERT) "Urban Ecology"* of the University of Washington in Seattle, an international textbook has been published (Marzluff et al. 2008).

During its activities, the RTG 780 extended Sukopp's and Wittig's second definition of urban ecology. Because of its interdisciplinary nature and unique focus on natural systems and humans within urbanized areas, urban ecology is described as the study of nature within cities, humans within cities, and the coupled relationship of humans and nature within cities (Endlicher et al. 2007; Langner and Endlicher 2007) (Fig. 1.3).

1.4 Urban Ecology and Sustainable Development

The importance of urban ecology will increase in the future due to the increasing urbanization in the world. There are strong relationships between ecosystem functions and human well-being (MA 2005). In the 1950s, only 29% of the world population lived in cities, but already in the year 2020, scientists expect that more than 57% of the world population might be city dwellers, with a rapidly increasing tendency. By 1980, already more than 69% of Europe's population lived in urban areas. At the moment, about 75% of Europe's population lieves in cities and this percentage will increase until the year 2020 to 80% (World Commission Urban 21, 2000; UN 2008). Germany already reached this number in the 1990s (Charta 1994). The holistic approach to solving the growing disequilibrium between city and the countryside – including social, economic, and ecological aspects – is often combined under the term "sustainability". Sustainability is mentioned in the German

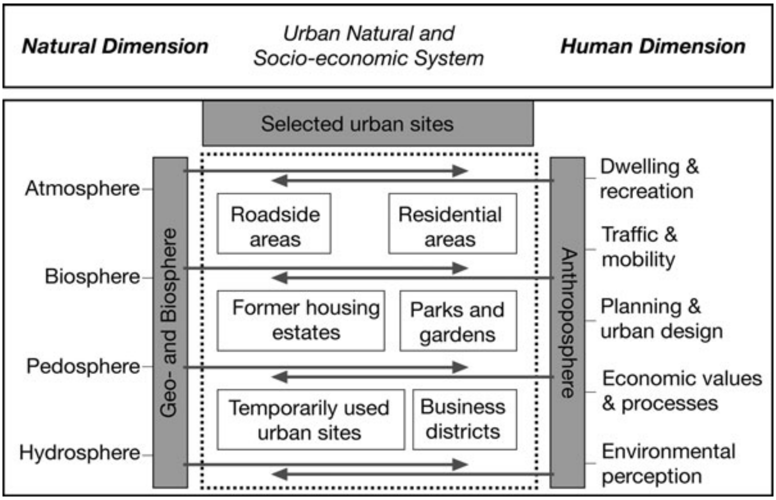

Fig. 1.3 Concept of integrated research in urban ecology. The main focus is on the human dimension and its interferences with the urban natural system. A robust integration of human activities into urban ecology seems necessary due to the distinct disconnection between nature and daily urban life. To accomplish this, research should be carried out simultaneously from environmental and social sciences at the same urban sites (Endlicher et al. 2007)

Constitution under article 20a as a national aim since 1994. Ecological systems with their long development and long history on earth are the best examples of sustainability. Urban ecosystem research can reveal the parameters and references for an ecologically, economically, and socially sustainable development in cities. Reaching international aims of such a sustainable development is simply not possible without the comprehension of the city (BUND and Misereor 1996; Schellnhuber et al. 2010). "Cities have emerged as the source of the biggest challenges the planet has faced since humans became social, yet cities are also the source of the solution since they are the reservoir of creativity and ideas" (West 2010).

1.5 Research Design

In Berlin, we can find a large number and variety of physiotopes and biotopes, which are sharply bordered and relatively homogenous. Next to the natural disparities, however, a city is known for its architectural and socio-economic differences, expressed in typical urban belts or functional areas like industrial zones or shopping areas. These are superimposed over the natural structures and there exist multiple interferences. In most European cities, we find a typical concentric structure. Therefore, urban ecological research often takes place along transects through these zones, starting in the inner city core, crossing over residential areas and finishing in the urban-rural mixed zone and the suburbs (Haase and Nuissl 2010).

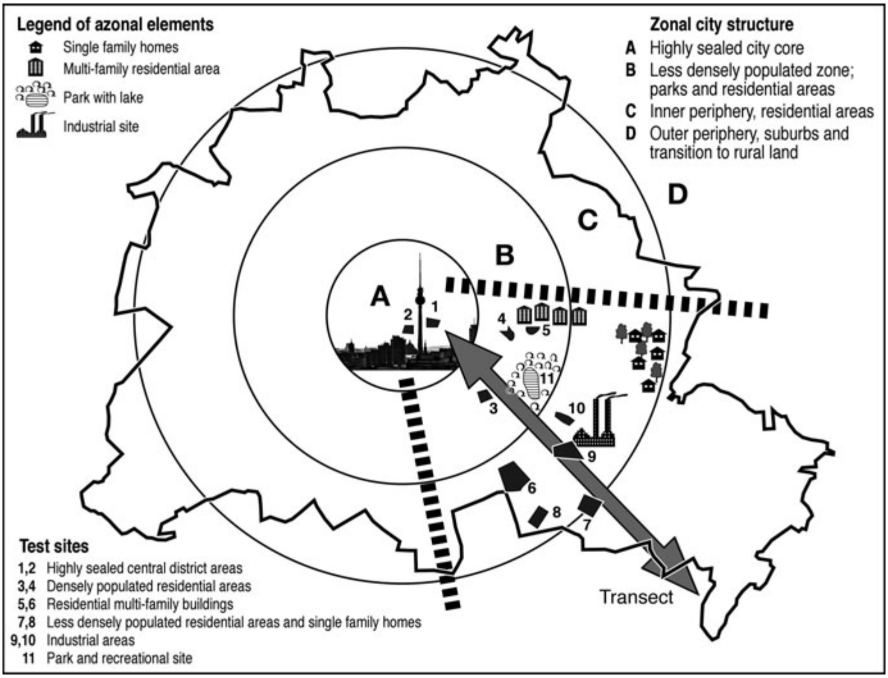

Fig. 1.4 Concentric urban model and ecological research on a transect through the urban rings of the city of Berlin (adapted from Wittig et al. 1998)

Research along this gradient, from the inner to outer zones, is a very popular method based on the theoretical work developed by Herbert Sukopp (Fig. 1.4).

This method of interdisciplinary research on transects can be combined, expanded, and completed with other research methods, for example, with research in different urban structural types with their specific ecological characteristics (Breuste 2009). Such a classification may distinguish the following categories:

– *Densely built-up areas* (e.g., densely built-up city cores, commercial and industrial areas, as well as traffic vectors and zones) with limited ecological functions and rarely used habitats. However, traffic zones are often the only public space for habitats. *Roadsides* and the middle of traffic lanes may sometimes offer possibilities to develop stable natural functions.
– Well-greened *residential areas and single-family homes surrounded by large gardens* offer more possibilities for nature development on private ground.
– *Residential multi-family buildings* are as well often planned in the middle of green zones of different structures and types.
– *Urban brownfields* have become especially interesting recently in their increasing availability in many European industrial cities due to structural and demographic changes. These spaces offer a large potential for urban nature development. Abandoned railroad yards have been transformed over a few decades to urban

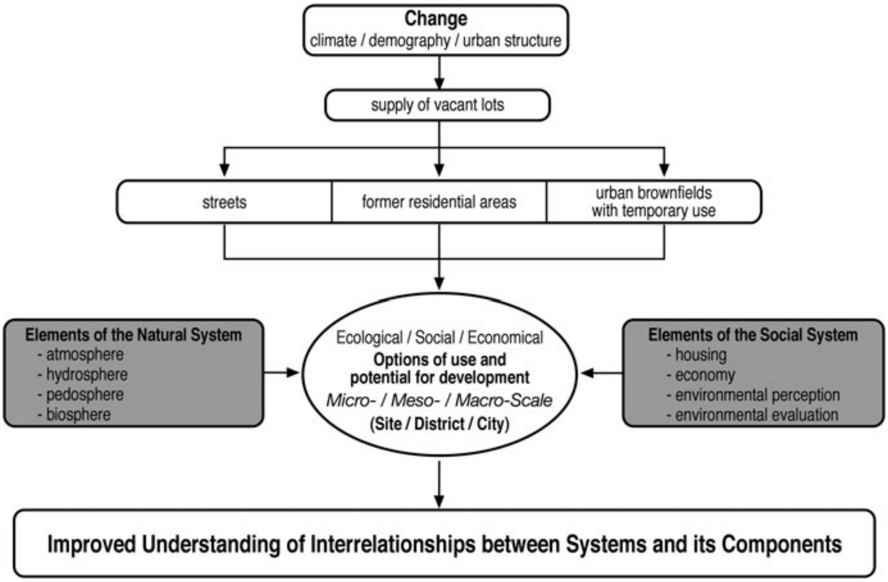

Fig. 1.5 Research design of RTG 780, second cohort (2005–2008), as an example of an approach in urban ecology that considers three scales with specific reference to processes of change (Endlicher et al. 2007)

forests or wilderness. Often, solutions for temporary use must be developed, in order to allow for the development of nature, at least during a fraction of time.

Urban ecological research in the city can be carried out on *different levels of benchmarks*, because urban problems are manifested at different scales, which can be observed along the transects. On the one hand, we have to take into account *microscales or local dimensions* for field experiments, necessary in empirical research. On the other hand, studies on the *mesoscale* are mandatory, as they are presented in the urban structural types such as city quarters, and the interrelationships between ecological and socio-economical aspects. Such areas are usually predetermined through the administrative level of an *urban district*. Finally, the urban ecological aspects on the *macroscale of the entire city* include the suburban zone and the surrounding countryside. The aim of any approach at the macroscale should be to reach a certain level of generalization or even a simulation of a virtual city. It is necessary to develop or to modify existing, generally valid, and ecologically relevant perspectives for actions (Fig. 1.5).

1.6 Research Topics

Research on urban ecology must contribute to all three dimensions of sustainability. Therefore, the research program of RTG 780 was not only focused on ecology, but also on economic and social aspects of greater Berlin. Three examples of important research topics at the beginning of the twenty-first century are briefly introduced below.

1.6.1 Global Change, Local Issues, and the Growth of Megacities

The worldwide spread of metropolises and megacities is an increasing problem with unique characteristics. The significant local effects of uncontrolled growth in the human-environment system, "the city", and the flows of material and energy are outstanding aspects of global change (Grimm et al. 2008). One example of global climate change is the increasing significance of global warming to local urban heat islands and the growing impact of extreme weather events like floods and heat waves. Global climate change and its consequences for biodiversity and quality of life in cities is a growing concern of the Intergovernmental Panel on Climate Change (IPCC 2007). More frequent and more intense heat waves, heavy rains, and decreasing periods of frost become more and more important for urban vegetation and wildlife, and for city dwellers alike. Of course, not only climate and demographic change are relevant for urban ecology. The globalization of the economy causes severe environmental problems, especially in megacities of developing nations. Associated changes in the social systems and in the culture of the concerned countries are relevant for environment and nature in their cities.

Furthermore, the Environmental Program of the United Nations has pointed out in its balance GEO-4 that the time for sustainable environmental planning is quickly running out (UNEP 2007). Impacts on natural resources such as water, air, and soil, as well as loss of biodiversity are urgent environmental problems that must be handled globally.

1.6.2 Shrinking Cities and Urban Brownfields

In the old industrialized countries of Europe and North America, not the growth of the population, but its shrinkage is a problem. Cities and metropolises are often affected by the loss of functions of former intensively used industrial areas, commercial areas, railroad tracks and marshalling yards, closed airports, etc. These areas are known as "*urban brownfields*". A lack of financial resources by public authorities, private persons, companies, or institutions prevents an active change of use or its further development. This phenomenon has become internationally recognized as the process of "*shrinking cities*". It is characteristic for old industrial cities, e.g. in the Ruhr region or in Eastern Germany, in Middle England or in the "Rust Belt" in the Midwest of the USA. The term of the shrinking city identifies not only the phenomenon of a decreasing population. A shrinking urban population implies a profound structural change. From an urban ecological point of view, shrinking cities and their associated brownfields offer new chances for urban forest and wildlife (Sukopp et al. 1979; Kowarik and Körner 2005). Their development may become even more sustainable. Urban ecological research must therefore identify and evaluate ecological, economical, and social chances which are connected to the shrinking processes (Haase 2008).

1.6.3 Ecosystem Services: Linking Human Wellbeing to the Functions of Urban Ecosystems

Cities provide important ecosystem services at local, regional, and even global levels (Costanza et al. 1997; Daily 1997; De Groot et al. 2002; Bastian et al. 2011; Breuste et al. 2011). The search for sustainable urban land use patterns that maintain ecosystem services under the pressures of global change is one of the most challenging research questions. How can the city structure be modified in order to reduce the urban footprint (consumption of land, energy, and materials), to reduce its vulnerability to climate change, and to enhance its resilience to upcoming problems of global change? Should we strengthen the idea of a "finite" or an "endless" city? Should we promote the "compact city" or the "perforated city?" Cities are drivers of global processes and are at the same time driven by global change. How can the ecological footprint of cities be reduced on the one hand, and how can innovative mitigation and adaptation strategies be developed on the other hand? How can the necessary ecosystem services be sustained in the rapidly growing (mega)cities of Africa, Asia, and Latin America? How we can resolve urban ecological problems, reach ecological aims, and find solutions for malnutrition, poverty, slums, unhealthy and unsafe working conditions, political instability, and crime? Is a high ecological quality only possible in cities of rich countries and not in megacities like Dhaka (Bangladesh), Cairo (Egypt), or Lima (Peru)?

Taking into account only these few topics, the importance of understanding the patterns of urban nature and optimizing the interactions between humans and the environment is evident. To date, there is no doubt that the young discipline of urban ecology will become even more important in the near future.

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Chapter 2
Particulate Matter in the Urban Atmosphere: Concentration, Distribution, Reduction – Results of Studies in the Berlin Metropolitan Area

Marcel Langner, Thomas Draheim, and Wilfried Endlicher

2.1 Introduction: Air Quality and Urban Ecology

Urban agglomerations are places of increased emissions of anthropogenic pollutants into the atmosphere. Since most of these pollutants are harmful to humans, reduction of their ambient concentrations is a major issue of environmental policy on international, national, and local levels. According to Wiederkehr and Yoon (1998), air pollutants can be grouped into major and trace or hazardous air pollutants. Major air pollutants comprise six classical pollutants: sulphur dioxide (SO_2), airborne particles, nitrogen dioxide (NO_2), carbon monoxide (CO), lead (Pb), and ozone (O_3). Hazardous air pollutants can be found in much smaller concentrations than major air pollutants and include different chemical, physical, and biological agents, like volatile organic compounds (VOCs), radio-nuclides, and micro-organisms.

Concentrations of air pollutants are not only governed by various physical, chemical, or biological processes within the atmosphere, but also by anthropogenic actions. Levels of most air pollutants in the urban atmosphere are linked to economic activity. They are typically increasing with income per capita until a turning point is reached. Beyond this point, concentration levels decrease with increasing income (Fenger 1999). Therefore, if urban ecology is defined as a multidisciplinary approach, including natural and social sciences, to improve conditions of life for humans in cities (Endlicher et al. 2007), air quality and related pollution problems are a major issue of urban ecology where natural and anthropogenic aspects are intimately interwoven.

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The dependency of air quality on economic development is also reflected in a typical temporal sequence of air pollutant levels (Fenger 1999). Concentrations tend to raise during the start of industrial development and initial emission controls. After peaking during a period of stabilization, an improvement in air quality is reached and the subsequent application of high technology leads to concentrations levels which meet WHO guidelines or national standards. In many industrialised countries, an improvement in air quality could be observed since the 1980s. Especially, sulphur dioxide concentrations could be lowered by the use of flue gas desulphurization technology and sulphur-free fuels. In Germany, the deindustrialization in many areas of its former socialistic part accelerated this process, since the burning of sulphur-containing lignite was reduced markedly. Together with sulphur dioxide, the major pollutants carbon monoxide and lead as well as the hazardous air pollutant benzene do not exceed effective limit values in Germany at present (UBA 2010). However, concentrations of airborne particles, nitrogen dioxide, and ozone at least occasionally exceed limit or target values. Therefore, air pollution control in Germany focuses on these pollutants. Whereas annual means of particles and nitrogen dioxide are typically higher in urban areas compared to rural background stations, ozone shows highest mean concentrations outside of urban agglomerations. The elevated ozone levels at rural stations result from complex reactions and transport processes in the atmosphere, which lead both to the formation as well as to the subsequent destruction of ozone in ambient air. From an urban perspective, particles and nitrogen dioxide are thus of special interest for air pollution control.

Within this chapter, the focus is laid on ambient particle concentrations. After an introduction including possible measures of particles, their sources and current limit values, results from two studies are shown, which were conducted in the Berlin metropolitan area. The first study used data from the air quality monitoring network to analyse particle concentrations and to investigate their dependency on weather types. During the second study, particle concentrations on an urban brownfield were measured and the influence of vegetation on particle distribution was determined.

2.2 Particles in the Urban Atmosphere

Unlike gases, which have a defined chemical structure and therefore show certain physical properties, particles in the urban atmosphere vary in size, shape, and chemical composition. Their concentrations in ambient air may therefore be quantified by different measures like number, surface, or mass concentrations, and these measures can also be given for different particle sizes.

Since particle sizes cover a range from a few nanometres up to more than 100 μm, according to their size, several classes of particles are distinguished in literature. The most important fractions are commonly referred to as ultrafine (particle diameter D_P smaller than 100 nm), fine (D_P smaller than 2.5 μm) and coarse particles (D_P between 2.5 and 10 μm). Sometimes, ultrafine particles are called nanoparticles, though occasionally, nanoparticles are defined as fractions including particles with diameters greater than 100 nm (e.g. Lin et al. 2005). At times, the term nanoparticles is only used in the context of artificially produced particles in the nanometer range. Particles greater than 10 μm are seldom investigated in air quality studies and therefore no common term exists for these particles. In the following, they are referred to as gigantic particles. This terminology is based on Junge (1963), who classified particles with D_P larger than 2 μm as giant particles.

2.2.1 Legal Definitions

According to the preamble of Directive 2008/50/EC on ambient air quality and cleaner air for Europe of the European Union, the main goal of air quality control is "to reduce pollution to levels which minimise harmful effects on human health, paying particular attention to sensitive populations, and the environment as a whole". Therefore, air quality research focuses on particles which can cause damage to human health. From that point of view it is of particular interest, how deep particles can penetrate into the human lung. Only particles smaller than 10 μm are able to pass the nose and penetrate into the pharynx or throat (Herbarth, 1998). Furthermore, particles in the range of 2–3 μm can reach the lower part of the respiratory airways, and finally, the remaining particles can penetrate into the terminal bronchioles and alveoli.

To measure and control inhalable particles in ambient air, air quality legislation uses mainly mass concentrations of particles belonging to different size fractions. These are abbreviated as PM_x, with PM meaning "particulate matter" and x referring to the respective aerodynamic diameter. For example, Directive 2008/50/EC defines PM_{10} in Article 2 as "particulate matter which passes through a size-selective inlet as defined in the reference method for the sampling and measurement of PM_{10}, EN 12341, with a 50% efficiency cut-off at 10 μm aerodynamic diameter". Simply speaking, PM_{10} may be considered as particles with diameter less than or equal to 10 μm. Since most particles are irregularly shaped, the determination of their diameter is based on the concept of the so-called aerodynamic diameter. The aerodynamic diameter means the diameter of a sphere of density 1 g cm^{-3} which shows the same terminal settling velocity in calm or laminar flowing air as the measured particle. Beside PM_{10}, which is also called the inhalable fraction, $PM_{2.5}$ or respirable PM and PM_1 are commonly used particle fractions.

Many industrialised countries have set up limit values for ambient concentrations of PM_{10} and $PM_{2.5}$. Within the European Union, limit values for PM_{10} became effective for the first time on 1 January 2005, based on Directive 1999/30/EC. There exist both a long-term and a short-term limit value. During a first stage, the long-term limit value refers to an annual mean of 40 μg m^{-3}, the short-term value demands a 24-h-average of 50 μg m^{-3} not to be exceeded more than 35 times a calendar year. It was intended to tighten up these values in a second stage in 2010 in the light of further information on health and environmental effects and technical feasibility. Since many member states had difficulties in keeping the limit values for PM_{10}, although they implemented reduction measures, and because studies showed that $PM_{2.5}$ may be more relevant to human health, the new Directive 2008/50/EC did not change numerical values of PM_{10} limits of the first stage. However, PM_{10} regulations have been qualitatively relaxed, since allowable subtraction of PM from natural sources has been increased (Brunekreef and Maynard 2008). Limit exceedances are determined after this subtraction. Simultaneously, a limit value for $PM_{2.5}$ of 25 μg m^{-3} as an annual mean was set up to become effective on 1 January 2015. In comparison, the US National Ambient Air Quality Standard sets a limit value of 15 μg m^{-3} for $PM_{2.5}$.

2.2.2 Health Effects of Particles

These limit values are intended for the protection of human health, since many adverse effects of ambient particles on human health have been reported, both related to short-term and long-term exposure (WHO 2004). Several epidemiological studies have shown that long-term exposure to PM for years is directly associated with mortality, mainly due to cardiovascular and respiratory diseases (Pelucchi et al. 2009). Morbidity is also affected by impacts on respiratory symptoms, lung growth, and function of the immune system (Kappos et al. 2004). Likewise, short-term elevations of PM levels on a daily basis show negative effects on the cardiovascular system as worsening heart failure or evoking cardiac arrhythmias (Franchini and Mannucci 2009) and on the respiratory system (Kappos et al. 2004). Although there are also numerous toxicological studies showing negative effects of particles on a cellular level, like cytotoxicity, mutagenicity, and DNA reactivity (de Kok et al. 2006), the mechanisms causing negative effects on human health are not fully understood. But, there is strong evidence that health effects depend on particle composition, particle surface area, and particle size with stronger effects for fine and ultrafine particles (Valavanidis et al. 2008). A threshold value for these adverse health effects could not be found (Kappos et al. 2004).

The association of more negative health effects with fine particles may be caused, on the one hand, by their capability to penetrate deeper into the human lung than coarse particles. On the other hand, fine particles in urban areas are often produced by human activities and therefore contain more metals and toxic organic compounds like PAHs. Fine particles constitute one of the two modes, which can be commonly found in the mass distribution of ambient particles (Seinfeld and Pandis 2006). These so-called accumulation-mode (ranging from ~0.1 to ~2 μm) particles are produced by various mechanisms, including primary emissions, condensation of gaseous precursors, and coagulation of smaller particles. Particles belonging to the coarse mode are mostly produced by mechanical processes like erosion of soil particles or abrasion. The coarse mode also contains sea-salt particles, particles from volcanic eruptions, pollen, and to a less extent, secondary sulphates and nitrates.

2.2.3 Emission of Particles

In urban agglomerations of industrialised countries, a variety of point and line sources of particles can be found. Whereas industrial activities, including power generation, and domestic heating with coal or oil are point sources, emission of particles from motorised traffic occurs mainly along roads and hence constitutes a line source. Emissions by motorised vehicles do not only include exhaust particles, but also abrasion products from tyres, brakes, clutches, and the road's surface. Furthermore, particles are emitted by re-suspension of previously deposited particles by vehicle-induced turbulence. Besides the local emissions, particle concentrations in cities are also influenced by advection due to particle transport from rural surroundings or long-range, often trans-boundary transport.

Due to this variety of different emission sources and particle formation processes within the atmosphere, particles in the urban atmosphere comprise a mixture of different sizes and diverse composition. Since most of the urban particles are of anthropogenic origin, the maximum of their number distribution is formed by particles smaller than 100 nm; the surface area distribution is dominated by particles in the 100–500 nm range. The mass distribution, on which measures for legal monitoring purposes are based, usually shows two distinct modes, one in the sub-micrometer regime and the other in the coarse particle regime (Seinfeld and Pandis 2006). The chemical composition shows clear differences between various cities. The main components of PM_{10} particles in European cities are non-sea-salt sulphates, sea salt, nitrate and ammonium, soil-derived compounds, elemental carbon, organic matter, and various trace elements (Table 2.1).

Table 2.1 Range of mean percentage contribution of main chemical compounds to $PM_{2.5}$ and $PM_{2.5-10}$ in six European cities (Sillanpaa et al. 2006)

	$PM_{2.5}$	$PM_{2.5-10}$		$PM_{2.5}$	$PM_{2.5-10}$
Non-sea-salt sulphates	14–31	0.8–6.8	Soil-derived compounds, water-soluble	1.3–3.3	9.1–22
Sea salt	1.1–10	3.5–34	Elemental carbon	5.4–9.0	1.0 –5.5
Ammonium	7.0–9.3	0.1–2.7	Particulate organic mater	21–54	9.4–27
Nitrate	1.1–18	3.7–14	Other elements	0.3–1.2	0.4–1.8
Soil-derived compounds, insoluble	1.1–4.2	13–43	Unidentified matter	−6.4 to 21	4.2–23

2.2.4 Dispersion and Distribution of Particles

The spatial distribution of particles in cities is mainly a product of the spatial configuration of emission sources and dispersion processes. On a micro-scale, an important dispersion process takes place in street canyons, where emissions are released into the atmosphere by traffic on the ground of the canyon. Dependent on atmospheric stability, wind velocity, and wind direction, vortexes may be formed within the canyon causing a complex horizontal and vertical distribution of particles (Xie et al. 2009). The dynamics of the shear layer above the canyon, which is caused by the forcing of the external flow, drives exchange processes between the street canyon and the overlying atmosphere (Salizzoni et al. 2009).

Once passed into the overlying atmosphere, particles are diluted within the so-called mixing layer. The height of the mixing layer confines the volume, which is available for particle dilution. Therefore, the height of the mixing layer is negatively correlated with particle concentrations in urban areas. In rural areas with no strong surface sources of particles and in the absence of particle advection, particle concentrations are mainly governed by formation and dissolution processes. Since particle formation itself tends to show a positive correlation with the height of the mixing layer, the correlation between mixing layer height and particle concentrations is weaker in rural areas (Schäfer et al. 2006).

The height of the mixing layer is governed by meteorology. Under anti-cylonic weather conditions, which are characterised by stable atmospheric air layers, the mixing layer height is depressed. Hence, particle concentrations tend to increase due to an accumulation of particles within the mixing layer. In contrast, lower pollution levels may be caused by increased vertical air movement and wet deposition processes during cyclonic weather conditions. Dilution processes within the mixing layer are also influenced by the topography of an urban area. On the one hand, cities located in basins or on valley bottoms, like the German cities Stuttgart or Dresden, have unfavourable air exchange conditions compared to cities on open plains, like Berlin or Hannover. On the other hand, local down-slope winds may carry fresh and cool air on clear, calm nights into the city.

The spatial distribution of emission sources and dispersion processes create a certain spatial pattern of particle concentrations. For legal monitoring purposes, it is common to distinguish between urban, suburban, and rural stations and with respect to dominant emission sources between traffic, industrial, and background stations. In urban agglomerations, three types of stations are of special interest. According to the Commission Decision 2001/752/EC, which amends the Annexes to Council Decision 97/101/EC and establishes reciprocal exchange of ambient air pollution information and data within the European Union, these three types are characterised as follows:

– Traffic stations
  Stations located such that their pollution level is influenced mainly by emissions from a nearby road or street

- Urban background stations
  Stations within continuously built-up areas with a pollution level which is not mainly influenced by any single source or street but rather by the integrated contribution by traffic, combustion sources, etc. upwind of the station
- Suburban stations
  Station located within a continuous settlement of detached buildings mixed with non-urbanised areas (small lakes, woods, agricultural)

2.2.5 Deposition of Particles

After emission into the atmosphere, dispersion, and chemical or physical transformations in the atmosphere, particles are removed by deposition from the atmosphere to the Earth's surface. Deposition caused by precipitation is called wet deposition; deposition processes which are not influenced by precipitation are summarized as dry deposition. A third kind of deposition, through which water droplets are deposited by interception of fog, mist, or clouds, is referred to as occult deposition. Since this process plays only a significant role in areas with frequent orographic cloud cover or advective fog (Dollard et al. 1983), it can be neglected in most urban areas, as in Berlin, too.

Wet deposition comprises processes in which particles are cooperated into droplets and subsequently transferred to the Earth's surface. Particles might either serve as condensation nuclei for atmospheric water and be incorporated into the formed droplet or collide with an existing droplet. If these processes occur within a cloud, they are called in-cloud scavenging or rainout. If they take place below the cloud, they are named below-cloud scavenging or washout (Seinfeld and Pandis 2006). Wet deposition is a very effective way to remove particles from the atmosphere. Due to numerical studies, weak precipitation with an intensity less than 0.1 mm h^{-1} is able to remove 50–80% of the below-cloud aerosol, both in terms of number and mass, during a 4-h period (Zhang et al. 2004). Urban areas are modifying precipitation patterns by a variety of processes (Kuttler 2008) and, therefore, they are thought to have an influence on wet deposition of particles. But, up to now, little is known about the order of magnitude by which cities alter wet deposition compared to rural surroundings.

The term dry deposition encompasses several mechanisms like turbulent diffusion, sedimentation, Brownian diffusion, interception, inertial forces, electrical migration, thermophoresis, and diffusiophoresis (Zufall and Davidson 1998). Resulting deposition rates are governed by many factors, including meteorological variables such as wind velocity or relative humidity; properties of the particles, such as particle size and shape; and variables of the surface, on which the particles are deposited (Sehmel 1980). If particles are deposited on technical surfaces, which show often sharp edges, friction velocity, micro-scale roughness, and surface temperature are important parameters with influence on the deposition process (Jonsson et al. 2008). When considering particle dry deposition in urban areas, a special focus is often laid on urban vegetation, since it provides a distinct larger surface area compared to the ground on which it stands. If particle capture by trees is calculated on a citywide scale, notable amounts of PM_{10} are removed from the atmosphere (e.g. Nowak 1994; McDonald et al. 2007). An optimised planting of vegetation along roads can also reduce re-suspension of particles by motorised traffic.

2.2.6 Abatement Strategies

Considering emission, dispersion, and deposition of particles, it becomes clear that strategies to lower ambient particle concentrations may either decrease emission or enhance deposition. On a micro-scale, improving dispersion may also be a suitable activity at traffic sites. Measures to accelerate deposition, like planting vegetation in urban areas, tend to show effects on the long run, and still, their quantitative effects regarding an improvement in particle pollution remain uncertain. On the other hand, the responsible authorities are mostly committed to lower concentrations of particles on the short run if limit values cannot be kept. In Article 23, Directive 2008/50/EC requests air quality plans in the case of exceedances of the limit values, "so that the exceedance period can be kept as short as possible". Therefore, the focus is laid on activities to lower emissions of particles. Such abatement measures include installation of new filter technology at industrial sites or optimized street cleaning and improvement in traffic flow in street canyons (Bruckmann et al. 2007). To reduce emissions by re-suspension of particles from the road's surface, application of calcium magnesium acetate (Norman and Johansson 2006) or magnesium chloride (Aldrin et al. 2008) showed significant reduction of ambient particle concentrations. Since these applications require an intensive use of resources, they may only be suitable to reduce peak levels. To lower particle concentrations extensively, at present in Germany, the most important measure is the exclusion of vehicles with high particle emissions from inner parts of the city. This is achieved by establishment of low-emission zones, which are called "*Umweltzonen*" in German, literally meaning "environmental zones". The aim of these low-emission zones is not only to lower particle concentrations, but also to reduce concentrations of nitrogen dioxide. To control the observance of driving restrictions, red, yellow, or green stickers on windscreens are used. The colour of the sticker depends on the emission level of the vehicle. For example, gasoline cars with a closed-looped catalytic converter and diesel cars which meet the Euro 4 emission standard are allowed to use a green sticker. Diesel cars, which meet only the Euro 2 emission standard, have to use a red sticker. Gasoline cars without a closed-looped catalytic converter and diesel cars meeting only the Euro 1 emission standard are not allowed to use any of the mentioned stickers. Diesel cars can be upgraded to a higher emission standard by retrofitting a particle filter. The low-emission zones themselves are implemented in several stages. During the first stage, vehicles with red, yellow, or green stickers are allowed to drive into the low-emission zone. In the last stage, only vehicles with green stickers have this permission. Hence, emission of diesel soot is particularly reduced by the implementation of the low-emission zones. As of 1 January 2008, Berlin, Hannover and Cologne were the first German cities implementing first stage low-emission zones. As of 1 January 2010, the last stage of the low-emission zone was introduced in Berlin and Hannover.

2.3 Analysis of Data from the Berlin Air Quality Monitoring Network

The study presented in this section used data from the Berlin Air Quality Monitoring Network to characterise particle pollution in Berlin and to analyse the influence of different weather types on pollution levels. Main aspects of this study have been previously published by Wolf-Benning et al. (2005). Before starting with the description of the study, a general overview of the temporal course of particle emission in Berlin is given in Table 2.2. The total amount of emitted PM_{10} particles decreased drastically from 17,580 tons in 1989 to 3,769 tons in 2005. Particles emitted by plants with need for a special permission to operate due to national air quality regulations and domestic heating showed a particular decline in the early 1990s. This was mainly caused by the closure of many heavy industry sites and the renewal of former coal-based heating systems in the eastern part of Berlin after the German reunification. Whereas the percentage of PM_{10} particles emitted by economic activities decreased from 56% in 1989 to 14% in 2005, the relative importance of traffic as a source for particle emission increased. While exhaust emissions decreased due to the modernisation of the vehicle fleet, emissions from abrasion and re-suspension remained more or less at the same level. As a consequence, the percentage of PM_{10} emitted by traffic increased from 18% in 1989 to 39% in 2005.

Table 2.2 Temporal course of PM_{10} emissions from different sources in Berlin in tons per year (online available at http://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/d312_01.htm#Tab1, 25.10.2010)

	1989	1994	2000	2002	2005	Trend 2015
Sum	17,580	8,804	4,729	4,199	3,769	3,494
Plants with need for a special permission to operate due to national air quality regulations	9,563	3,161	960	650	384	376
Domestic heating	2,693	1,148	131	132	96	77
Small business enterprises	250	220	160	153	149	134
Traffic (exhaust from cars)	1,736	1,135	667	394	355	166
Abrasion and re-suspension caused by cars	1,200	1,150	997	1,050	1,024	1,100
Other traffic	238	190	124	130	105	73
Other sources	1,900	1,800	1,690	1,690	1,656	1,568

2.3.1 PM and Weather Data

To investigate the spatial and temporal variations of ambient PM_{10} concentrations, data from the Berlin Air Quality Monitoring Network (BLUME) provided by the Senate Department for Health, Environment and Consumer Protection (SenGUV) were analysed.

Within the Berlin Air Quality Monitoring Network, particle concentrations are measured as 30-min averages using a β-absorption technique (FH62-I, Friesecke& Höpfner). Particles coarser than the PM_{10} fraction are separated by impaction in an inlet before they are captured by a glass-fibre band. This glass-fibre band is continuously penetrated by β-radiation. The band itself and the deposited particles attenuate the radiation, which is measured behind the band. The increasing attenuation is a measure of the mass of captured particles.

PM_{10} and total suspended particulate (TSP) data from eight monitoring stations of the Berlin Air Quality Monitoring Network were the basis for the analyses. The locations of the selected sites are displayed in Fig. 2.1. Three of these stations were

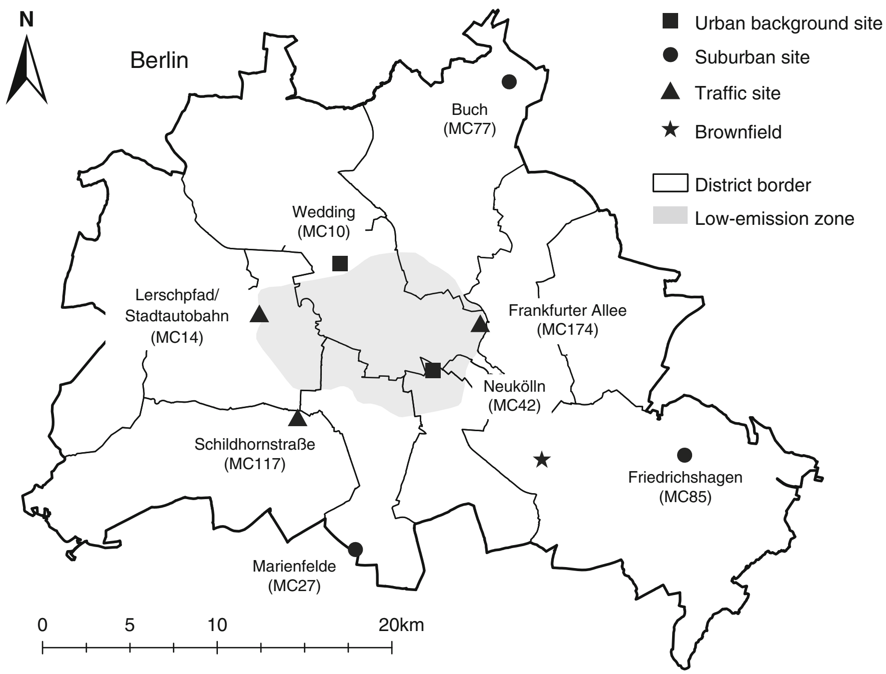

Fig. 2.1 Selected sites of the Berlin Air Quality Monitoring Network (BLUME), the measuring site on the urban brownfield and the low-emission zone in Berlin. The monitoring network is operated by the Senate Department for Health, Environment and Consumer Protection. The map shows also the borders of Berlin's administration districts. A complete PM_{10} dataset covering the years 2000–2004 is only available for five measuring sites (MC14, MC42, MC77, MC117, and MC174) (Data basis: ATKIS-Data © Geobasis-DE/SenStadt III, 2005)

traffic-related sites (MC14, MC117, and MC174), three were suburban stations (MC27, MC77, and MC85) and two stations monitored urban background concentrations (MC10 and MC42). Three further measuring stations were selected to represent the regional background PM_{10} concentrations. One measuring station is part of the air quality monitoring network of the Federal Environmental Agency and is located in the Schorfheide forest, approximately 40 km northeast of Berlin. The other two stations are part of the air quality monitoring network of the federal state of Mecklenburg-Western Pomerania. They are situated in Löcknitz (approximately 110 km northeast of Berlin) and in Göhlen (approximately 150 km northwest of Berlin).

The availability of PM_{10} data was limited due to the step-by-step progression from measuring TSP to measuring PM_{10} and the fact that PM_{10} measurements were not taken at all measuring sites. Hence, the number of monitoring stations used for the analyses varied over time. For example, a complete PM_{10} dataset covering the years 2000–2004 is only available for five of the mentioned Berlin measuring sites.

To study the impact of weather conditions on ambient particle pollution, data provided by Germany's National Meteorological Service (DWD) were analysed and correlated with PM_{10} data. To generalize weather patterns, weather types (Großwetterlagen) according to the classification of Heß and Brezowsky (Gerstengarbe and Werner 1999; Heß and Brezowsky 1977) were used. This classification is based on typical patterns of sea-level pressure and of the 500-hPa pressure surface. 29 weather types representing typical synoptic patterns for Central Europe were distinguished in this study. The number of 29 distinct synoptic patterns can be further reduced to eight general types (n – north, s – south, sw – southwest, w – west, nw – northwest, e – continental east, hm – high air pressure over Central Europe, tm – low air pressure over Central Europe). For the correlation with weather types, 24-h averages calculated from the 30-min PM_{10} data were used.

2.3.2 *Temporal and Spatial Aspects of PM_{10} Concentrations*

The long-term observation of PM_{10} annual averages in Fig. 2.2 exhibits a decreasing trend from 1991 to 2000. This reflects the decrease in PM_{10} emissions in Berlin (see Table 2.2).

From 2001 to 2009, PM_{10} concentrations at rural, suburban, and urban background sites stayed more or less at the same level with remarkable inter-annual variations. Only at the traffic stations, a slight decreasing trend can be observed during that period.

Highest PM_{10} concentrations were measured at sites at the kerbside of roads. At the three traffic-related sites, PM_{10} concentrations exceeded the annual mean value of 40 $\mu g\ m^{-3}$ in 2003 (the long-term limit in the European Union, which became effective in 2005). At the urban and suburban background stations, PM_{10} annual averages were significantly below the averages measured at traffic sites. At the rural monitoring stations, lowest PM_{10} annual averages were observed. Hence, it can be

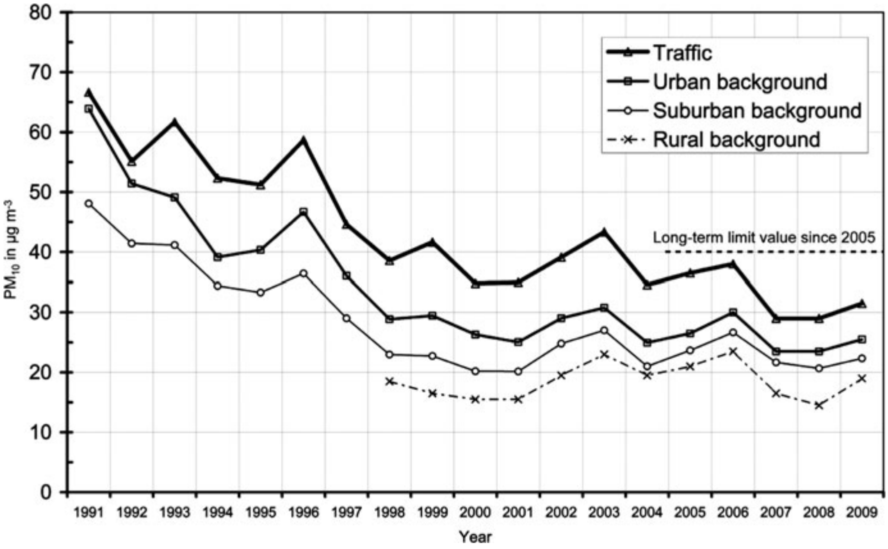

Fig. 2.2 Long-term change of ambient PM_{10} concentrations in Berlin from 1991 to 2009. Annual TSP values were converted to PM_{10} by a multiplication factor of 0.8. Selected measuring sites: MC14, MC117, MC174 (traffic); MC10, MC42 (urban background); MC27, MC77, MC85 (suburban background); concentration data were not available for all sites during the whole period. Rural background averages are based on two sites (Löcknitz and Göhlen) of the air quality monitoring network of Mecklenburg-Western Pomerania

assumed that the annual limit value of the EU will not be exceeded at background locations in the Berlin area in the future.

But, the annual limit value is only one side of the story. Keeping the short-term limit value is much more challenging for many German cities. An overview of the frequency of >50 µg m^{-3} PM_{10} daily averages (the EU short-term PM_{10} limit) between 2000 and 2009 for four measuring sites in Berlin is given in Fig. 2.3. At the two traffic-related sites, a daily average of PM_{10} exceeding 50 µg m^{-3} was observed more than 35 times per year in the 2000–2006 period. While the short-term limit could be kept at all sites in 2007 and 2008, there was an exceedance in 2009 at one of the analysed site. Exceedances at the background stations could only be observed in certain years. During these years, weather conditions may have played an important role in adhering to the short-term limit, because they influence both PM_{10} concentrations at traffic and background sites. Nevertheless, traffic-related sites are particularly vulnerable to violate the short-term limit.

Of special interest for air quality authorities is the effect of the implementation of the low-emission zone on exceedances of the limit values. As depicted in Fig. 2.2, mass concentrations at traffic sites stagnated after introduction of the low-emission zone and showed a slight increase in 2009. Due to the overall increase in ambient PM_{10} concentrations in 2009, traffic site MC174, which is located inside the low-emission zone and where the highest frequency of daily

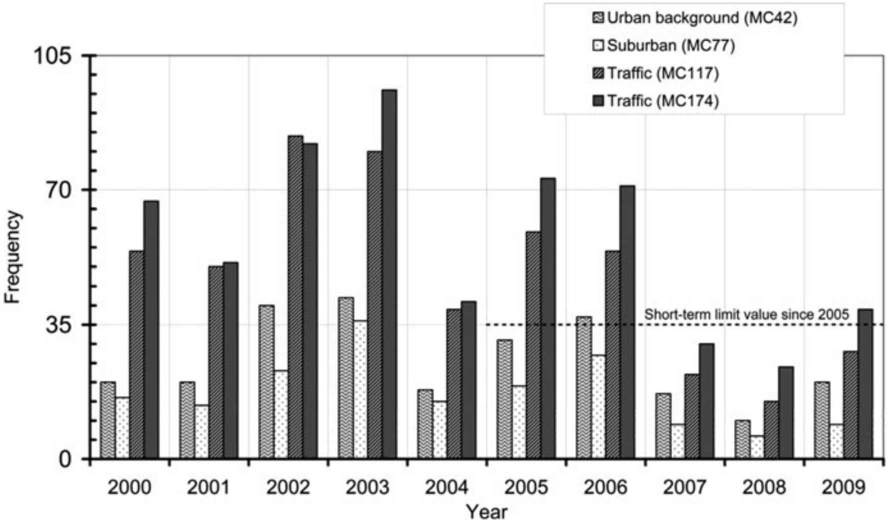

Fig. 2.3 Frequency of daily average PM_{10} concentration exceeding 50 μg m^{-3} at four selected monitoring sites in Berlin for the years 2000 to 2009. Calculation is based on data provided by the Berlin Air Quality Monitoring Network

exceedances of 50 μg m^{-3} occurred since 2006 (Fig. 2.3), showed an exceedance of the short-term limit value in the second year after implementation of the low-emission zone. Due to the dependence of PM_{10} concentrations on several factors, not only local emission but also local weather conditions and long-range particle transport, an assessment of the low-emission zone solely based on measured local PM_{10} concentrations is not appropriate. In fact, a detailed analysis revealed that PM_{10} concentrations would have been 3% higher at traffic sites without a low-emission zone in 2008 (Lutz and Rauterberg-Wulff 2009). This study also showed that the number of days with average PM_{10} values above 50 μg m^{-3} has been decreased by 4% and traffic-related ambient soot concentrations declined by 14–16%. This is of special interest, since it has been argued that mass concentrations may not be suitable to assess the effect of low-emission zones on human health. As especially emission of particles from diesel cars are lowered, which show disproportional adverse health effects compared to most other particles, positive health effects of low emission zones may be higher than expressed by variation of PM_{10} mass concentrations (Wichmann 2008).

The different PM_{10} concentrations for the four spatial categories of measuring sites (traffic, urban background, suburban, regional background) are shown in Fig. 2.4. If it is assumed that the concentration at a traffic hot spot within the agglomeration is the sum of the local traffic's share, urban background's share, suburban background's share, and regional background's share, then about 42% of the PM_{10} concentration observed at a traffic hot spot in Berlin represents the regional background (Fig. 2.4a). The relatively low settling velocity of PM_{10} particles promotes their long-distance transport, and hence, the differences between

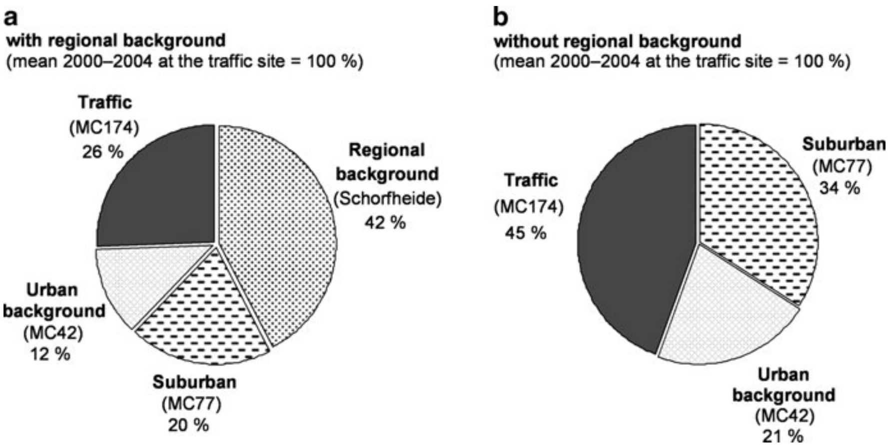

Fig. 2.4 Spatial distribution of PM_{10} in Berlin (**a**) with and (**b**) without regional background for the period 2000–2004. Average PM_{10} concentration at a traffic-related site is set to 100% [adopted from Wolf-Benning et al. (2005:109), slightly modified]

areas are not as high as observed for other pollutants, such as NO_2. Within the metropolis, nearly half of PM_{10} is attributed to the local traffic (Fig. 2.4b). Lenschow et al. (2001) mentioned that exhaust emissions and tyre abrasion contribute 55% and re-suspended soil material 45% to traffic-related PM_{10}. However, the emission data in Table 2.2 indicate that the portion of exhaust emission decreased during the last years and that mechanically generated particle emission will become more and more important.

Besides this characteristic spatial distribution within the Berlin metropolitan area, there are also pronounced intra-annual variations. An analysis of seasonal concentration patterns showed that PM_{10} concentrations during winter are typically higher than during summer (Wolf-Benning et al. 2009).

2.3.3 Influence of Weather Conditions on PM_{10} Concentrations

Weather conditions associated with high air stability and low wind velocities increase pollution levels, because of the reduced air exchange, and hence a decreased height of the mixing layer. They can also favour long-range atmospheric transport of airborne particles. Therefore, an above-average annual frequency of such weather conditions can lead to PM_{10} exceeding the EU limit more frequently.

Mean PM_{10} concentrations in Berlin associated with different weather conditions are given in Fig. 2.5 for the 2000–2009 period. Noticeably high PM_{10} concentrations in Berlin are related to three weather types in particular: "high pressure above Central Europe", "continental east", and "south", the latter two being predominantly characterised by anti-cyclonic conditions. Low PM_{10}

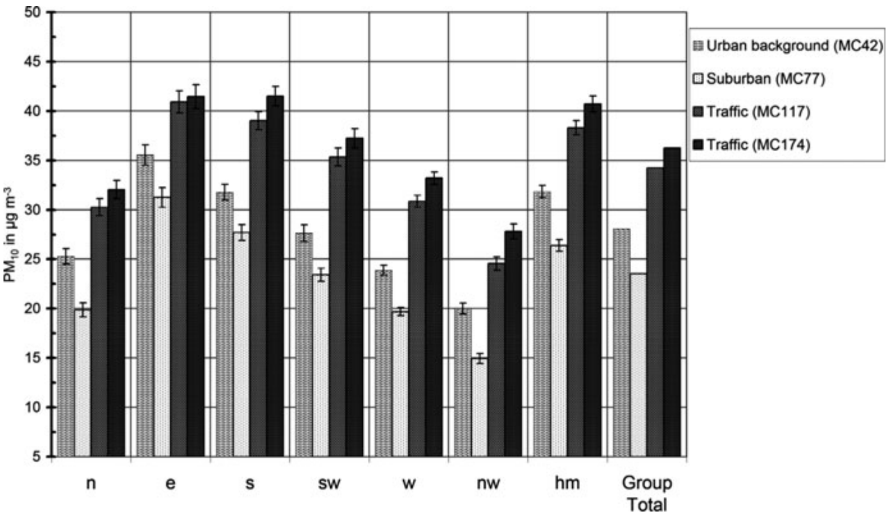

Fig. 2.5 PM_{10} concentrations in association with weather types (Großwettertypen according to Heß & Brezowsky) at four selected measuring sites in Berlin (period 2000–2009). Weather types: *n* north, *s* south, *sw* southwest, *w* west, *nw* northwest, *e* continental east, *hm* high pressure above central Europe. Data are means and standard errors. Data were provided by the Berlin Air Quality Monitoring Network and Germany's National Meteorological Service (DWD)

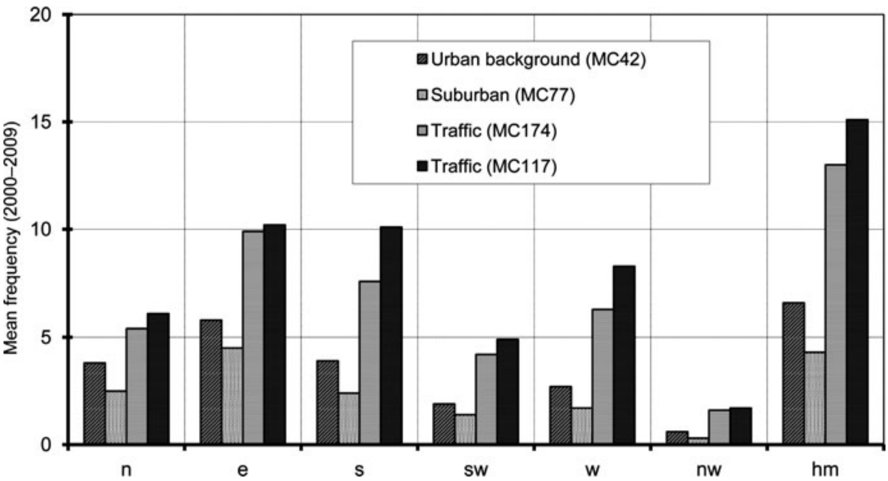

Fig. 2.6 Mean frequency (in days) of daily PM_{10} averages >50 µg m^{-3} associated with weather types at four sites in Berlin (period 2000–2009). Weather types: *n* north, *s* south, *sw* southwest, *w* west, *nw* northwest, *e* continental east, *hm* high pressure above central Europe. Calculations are based on data provided by the Berlin Air Quality Monitoring Network

concentrations are associated with both the "north" and the "northwest" type of weather characterised by cyclonic conditions. The mean frequency of daily PM_{10} averages exceeding 50 µg m^{-3}, correlated with different weather types, shows nearly the same picture (Fig. 2.6). Again, most exceedances were observed on traffic-related sites and especially during the autochthonous "high pressure above central Europe" type of weather. However, exceedances at the background station in the suburban area are more associated with the continental east type of weather.

This underlines the important role of weather conditions for PM_{10} levels. The weather types "continental east", "south", and "high pressure over central Europe" are linked to above-average PM_{10} concentrations. This association is probably caused by the high dust load of continental air masses, the long-range transport of PM_{10} released from industrial combustion or even by Saharan dust episodes (Henning et al. 2003), and the reduced exchange of air under anti-cyclonic conditions.

2.4 Particle Distribution on an Urban Brownfield

Urban brownfields are a collective term of various sites in cities. They include completely abandoned areas, sites with a decreased intensity of use, and locations that will be used in a new way (Fritsche et al. 2007). Especially in shrinking cities, they present interesting areas for various studies in urban ecology.

Within the study presented in this section, particle distribution on such an urban brownfield was investigated with special focus on effects of vegetation on ambient particle concentrations. Not only PM_{10} concentrations were measured, but also gigantic particles. Although PM_{10} is of special interest from a human health point of view, it seems worthwhile to look at particles greater than PM_{10} in the urban atmosphere. Certain pollen, which are mainly larger than PM_{10} particles and therefore are not able to reach the trachea and the lungs, yet cause discomfort to allergic persons. Therefore, particles greater than 10 μm in diameter, even if their particle number concentrations are very small, may have a negative impact on human health. Another point to consider is a scavenging effect to fine particles caused by larger ones (Friedlander et al. 1991). Therefore, gigantic particles may enhance deposition of PM_{10} particles.

2.4.1 Site Description and Methods

Particle concentrations were measured on an urban brownfield formerly used as a marshalling yard during 2006 and the beginning of 2007. The brownfield is located in the Southeast of Berlin (Fig. 2.1). It has an average width of 300 m and a length of roughly 3 km. It is bordered on its northeast side by a busy six-lane road with a traffic flow of about 50,000 vehicles per day. To the southwest, small industries and various types of unused brownfields are dominating. During the measurements, many construction sites with sand-heaps were located in this area. A large fraction was also covered by bare soil. Active railway lines – three on the northeast side and one on the southwest side – used by regional passenger trains run on both longitudinal sides of the site.

Particles were sampled both with active and passive systems. Sigma-2 samplers, as described in VDI-Guideline 2119/4, were used as passive samplers at a height of 2.5 m above ground. These sampling devices consist of a cylindrical tube with a height of about 27 cm made of antistatic plastic, which is topped by a cap. This cap has three rectangular windows at its side providing a passive entrance of particles at the top of the tube. Once entered the tube, particles settle down within the tube due to gravitation and are collected on transparent adhesive slides.

After exposition of the slides, particles were detected on the slides by the use of a light optical microscope using an 'automated optical image analysis' system. The geometric diameter of the deposited particles was determined and particles were grouped into size classes ranging from 3 to 6 μm, 6 to 12 μm, 12 to 24 μm, 24 to 48 μm, and 48 to 96 μm. The analysis system was also able to distinguish between transparent and opaque particles. The obtained deposition rates were converted to ambient concentrations using settling velocities calculated according to Stokes' law. Details of this procedure can be found in Dietze et al. (2006). The particle analyses were conducted at Germany's National Meteorological Service (DWD).

To gather information about different PM fractions, PM_{10}, $PM_{2.5}$, and PM_1 were measured with two optical particle counters (Grimm Environmental Dust Monitors #107). These particle monitors operate with an active airflow of 1.2 $l\ min^{-1}$. Particles are detected and counted by the scattering of a laser beam with a wavelength of 655 nm.

During a first sampling campaign, seven Sigma-2 samplers (G-R-1, G-R-2, G-R-3, G-R-4, G-R-5, G-R-6, and G-R-7, see Fig. 2.7) were placed along the road adjoining the brownfield to assess variation of concentrations along the road. This sampling campaign lasted from 4 January to 8 March 2006; the slides were exposed in 7-day intervals. The main sampling campaign was conducted from 8 March 2006 to 28 February 2007, also with a sampling interval of one week. While one Sigma-2 sampler (G-R-1) was left at its position at the road, six samplers were placed on the brownfield (G-B-1, G-B-2, G-B-3, G-B-4, G-B-5, and G-B-6). The samplers were arranged along two transects perpendicular to the road on the sampling site to determine the influence of different vegetation structures on spatial particle distribution. The first transect is dominated by annual herbaceous plants (G-B-1, G-B-2, and G-B-3, see Fig. 2.7) whereas trees and shrubs grow along the second transect (G-B-4, G-B-5, and G-B-6). The most frequent tree species are the Norway maple (*Acer platanoides*) and the black locust (*Robinia pseudoacacia*). Transect two is also characterised by some small buildings.

Measurements with optical particle counters were performed during several campaigns from 1 June 2006 to 18 April 2007. Concentration data were recorded as 10-min averages; the particle inlet was placed 2 m above ground. The four measurements sites (P-B-1, P-B-2, P-B-3, and P-B-4 in Fig. 2.7) were restricted to locations with access to permanent power supply. Occasionally, defects of the monitors resulted in gaps in the concentration data.

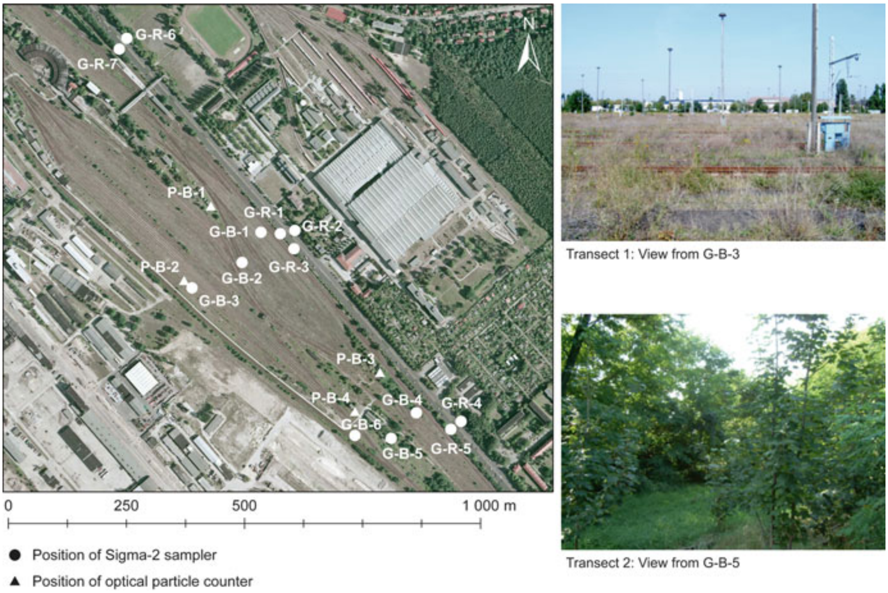

Fig. 2.7 Sampling site on an aerial photograph (original orthophoto scale 1:10,000, photo was taken in August 2004) and different types of vegetation in transect 1 and transect 2 (Data basis of the orthophoto © Geobasis-DE/SenStadt III, 2004)

The meteorological parameters wind velocity, wind direction, temperature, and relative humidity were determined at two sampling points (P-B-2 and P-B-3, Davis Weather Monitor II®). Measurements were made 3 m above ground and data were stored as 10-min averages.

2.4.2 Distribution of Gigantic Particles

During the first campaign in which particles were measured along the road, the Sigma-2 samplers were fixed to street lamps. Mean particle concentrations ranged from 24.1 to 28.0 μg m^{-3}. A cluster analysis showed two main clusters: one with positions G-R-1, G-R-3, G-R-5, and G-R-7; another with positions G-R-2, G-R-4, and G-R-6 (Fig. 2.8). The configuration of the positions depicted in Fig. 2.7 reveals that each cluster belongs to one side of the road. The formation of these clusters is mainly caused by different distances of the street lamps to the edge of the road. On the southwest side of the road this distance amounts to 0.85 m. On the northeast side, a bicycle lane separates the road from the lamps and thus they have a distance of about 3 m from the edge of the road. Within this short distance perpendicular to the road, mean particle concentrations decline from 27.8 to 25.0 μg m^{-3}, which is a reduction of about 11%. This concentrations gradient illustrates that the road is a strong line source for particles.

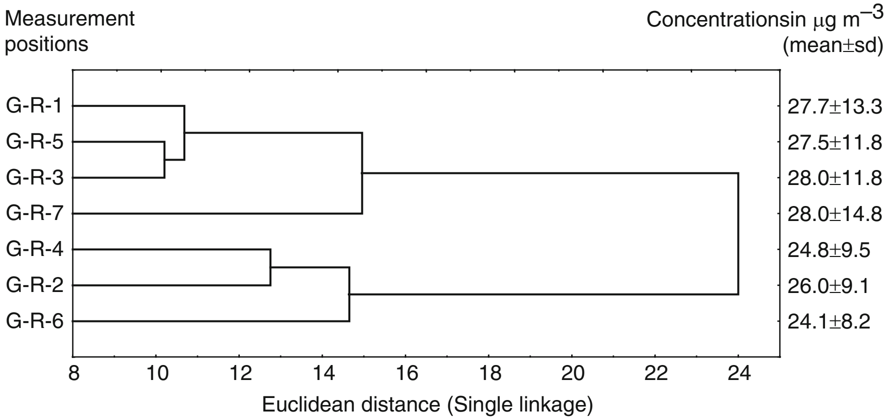

Fig. 2.8 Results of the cluster analysis of measurements during the first sampling campaign from 4 January to 8 March 2006 with a sampling interval of 7 days; concentrations of all gigantic particles from 3 to 96 µm were analysed

Since traffic is not disrupted by traffic lights at this section of the road, there is a steady traffic flow which results in uniform emissions of particles by traffic. Hence, particle concentrations show only minor differences at a fixed distance from the edge of the road. Therefore, it was concluded from the first measurement campaign, that concentrations at G-R-1 are representative for particle concentrations at the section of the road which borders the brownfield.

During the measurements with Sigma-2 samplers on the brownfield, the lowest concentration of particles from 3 to 96 µm on a one-week basis was 2.9 µg m^{-3} (measured at G-B-5 from 27 December 2006 to 3 January 2007), the highest concentration amounted to 48.7 µg m^{-3} (measured at G-R-6 from 10 May to 17 May 2006). Within the brownfield, mean concentrations ranged from 12.8 µg m^{-3} at G-B-5 to 15.5 at G-B-4. At the roadside position G-R-1, concentrations were usually higher compared to the positions on the brownfield and ranged from 4.1 to 73.4 µg m^{-3} with an average of 26.6 µg m^{-3}.

The steep gradient of particle concentrations nearby the road, detected during the first campaign, could be verified by measurements on the brownfield. At G-B-1 already, approximately 20 m from the edge of the road, concentrations are in the range of those measured at the other sites within the brownfield.

Particle concentrations showed a high variation with time with only minor spatial variation (see Fig. 2.9). High correlations could be found between the various sites. The strongest coefficient of determination was calculated between G-B-2 and G-B-3 ($R^2 = 0.96$), the weakest between G-R-1 and G-B-6 ($R^2 = 0.77$). Figure 2.9 also shows that concentrations tend to be higher during the vegetation period. This might be caused by re-suspension of soil material from adjoining brownfields often covered with bare soils and increased construction activity during dry summer periods.

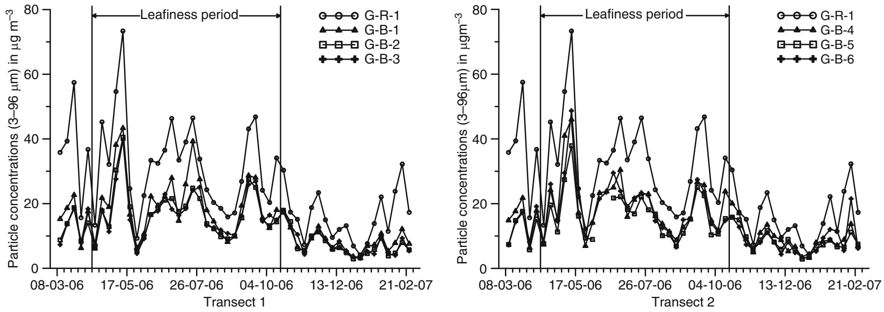

Fig. 2.9 Time course of ambient particle concentrations (3–96 μm) measured at indicated positions arranged in two transects on the urban brownfield and at position G-R-1 at the edge of the road; particles were measured with Sigma-2 samplers with a sampling interval of 7 days from 8 March 2006 to 28 February 2007

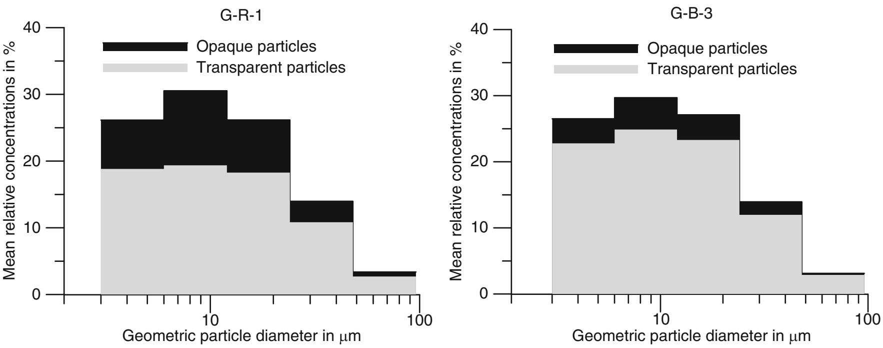

Fig. 2.10 Mean relative size distribution of opaque and transparent particles at the roadside position G-R-1 and at a measurement position within the brownfield (G-B-3). Distributions were calculated based on one-year sampling data from 8 March 2006 to 28 February 2007 obtained with a sampling interval of 7 days

There are not only quantitative differences between the roadside sampling site G-R-1 and the sampling sites on the brownfield; they differ also with respect to their qualitative composition. In Fig. 2.10, mean relative size distributions of opaque and transparent particles are shown. At G-R-1, 30% of sampled particles between 3 and 96 μm are opaque particles. On the brownfield, the fraction of these particles is much lower. At G-B-3, only 14% of all particles belong to the opaque fraction. This suggests that the road acts as a strong source of opaque particles. They consist of soot agglomerates and tyre wear, the latter being particularly enriched in the size range between 10 and 50 μm (Schultz, 1993). Although these differences between the brownfield and the roadside sampling site, the overall size distributions differ only slightly. Particles in the range between 6 and 12 μm dominate the size distribution and amount to about 30% of mass concentration. Between 48 and 96 μm, only 3% of particle mass could be found.

To have a closer look on the distribution of various particle classes, a principal component factor analysis using varimax rotation was conducted on the particle concentration data. These method is commonly used for source apportionment studies based on elemental concentrations (e.g. Yatkin and Bayram 2007). It extracts various factors from a multivariate particle dataset, which might be attributed to distinct emission sources. Since there were no concentration data available for single elements, concentrations of opaque and transparent particles in the measured size classes were used. The results of the factor analysis in Table 2.3 revealed that the first factor F1 is always dominated by opaque particles in the range between 3 and 24 μm, both at positions within the brownfield and at the road. Therefore, this particle fraction was regarded as an indicator for traffic-generated particles. The interpretation of the second factor F2 was less clear. Within the brownfield, it always contains transparent particles in the 24–96 μm range, whereas at the roadside position G-R-1, F2 is formed by transparent particles between 3 and 12 μm.

From a health point of view, behaviour and especially removal of traffic-related particles is of special interest. Thus, influence of vegetation on dispersion of opaque particle in the range between 3 and 24 μm was investigated. Because of high temporal fluctuations of these particles, they were normalised to the concentrations at G-R-1 prior to further analysis. Furthermore, concentration data were split into concentrations during the vegetation or leafiness period, which was defined by the foliation of taller vegetation on the brownfield, and concentrations during a leafless period. The leafiness period lasted from 12 April to 18 October 2006 on the brownfield. Regarding the opaque particles, only minor differences could be detected on the two transects by comparing leafless with leafiness period. According

Table 2.3 Results of factor analysis after varimax rotation for particle concentrations obtained with Sigma-2 samplers based on one-year sampling data from 8 March 2006 to 28 February 2007 obtained with a sampling interval of 7 days. Only factor loadings >0.7 for the two factors F1 and F2 are given

Position	G-R-1		G-B-1		G-B-2		G-B-3		G-B-4		G-B-5		G-B-6	
	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
Opaque particles														
48–96 μm														
24–48 μm	0.82													
12–24 μm	0.91		0.77		0.83		0.77		0.82		0.83		0.79	
6–12 μm	0.91		0.93		0.87		0.86		0.91		0.87		0.85	
3–6 μm	0.73		0.93		0.85		0.84		0.89		0.88		0.79	
Transparent particles														
48–96 μm				0.72		0.78		0.70		0.87		0.76		0.85
24–48 μm				0.85		0.88		0.89		0.90		0.88		0.92
12–24 μm						0.70		0.70	0.74					
6–12 μm		0.83	0.75			0.75			0.77					
3–6 μm		0.87	0.71						0.75				0.73	
Explained variance in %														
	39	31	46	24	35	34	35	28	46	27	36	27	38	29

to the U-test of Mann-Whitney, this particle fraction showed significantly decreased concentrations during the period of foliation at the positions G-B-3 and G-B-5 (Fig. 2.11).

A decrease of particle concentrations within a vegetation structure may be either the result of particle capture by leaf surfaces or caused by a modification of air flow. Vegetation acts as an obstacle to air flow and, therefore, it is able to redirect particle-laden air resulting in lower concentrations within the vegetation. Especially in street canyons, trees can have an important influence on particle dispersion by the modification of air flow, which has been proved by wind tunnel studies (Gromke and Ruck 2009) and numerical simulations (Ries and Eichhorn, 2001). To test the hypothesis, that reduction of opaque particles ranging from 3 to 24 µm may be caused by a modified air flow, distribution of transparent particles in the same size class was also analysed. Surprisingly, no reduction during the vegetation period could be found, rather a significant increase was detected at most of the measuring positions. This might be explained by the above mentioned increased re-suspension of soil-derived material. Therefore it is concluded that a modification of air flow had only a minor effect on particle dispersion and, thus, on spatial particle distribution on the brownfield. The reduction of opaque particle is caused mainly by particle capture which seems to depend strongly on particle properties.

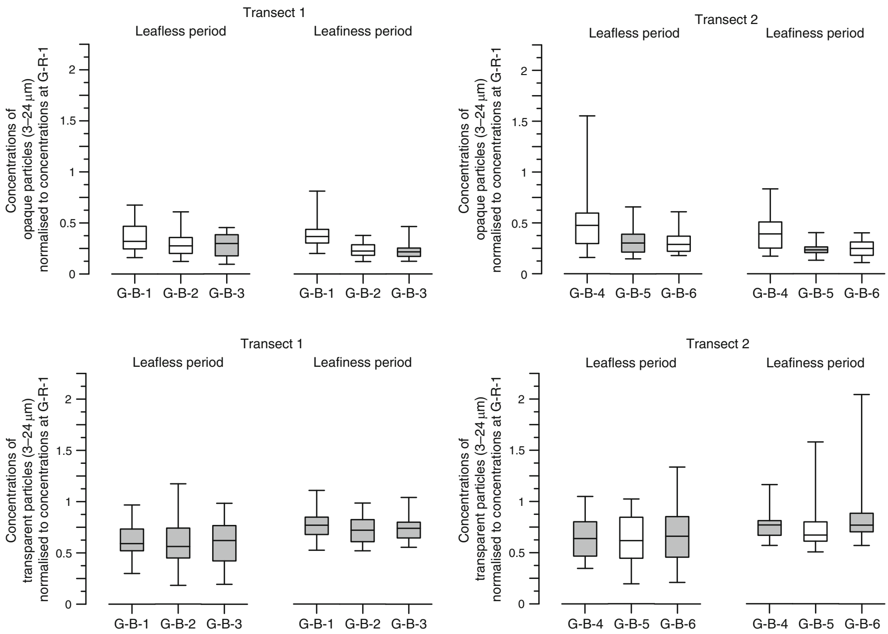

Fig. 2.11 Distribution of concentrations of transparent and opaque particles in the range from 3 to 24 µm within the two transects, divided into a leafless and leafiness period. All concentrations are normalised to concentrations at G-R-1. Concentrations with significant differences between leafless and leafiness period at one measurement position ($p = 0.05$, U-Test of Mann-Whitney) are shaded *grey*

2.4.3 Distribution of PM Particles and Examples of Short-Time Concentration Peaks

Particle measurements with Sigma-2 samplers proved to be a very robust method to get concentration data. Nevertheless, only 7-day averages could be obtained and no information about particles smaller than 3 μm is available from these measurements. To get short-time data of PM_x concentrations, additional measurements with optical particle counters were conducted.

Unfortunately, repeated parallel measurements during a period of 34 days with both counters at P-B-2 revealed remarkable differences between the two devices. Whereas mean PM_{10}, $PM_{2.5}$ and PM_1 concentrations obtain from one counter were 24.1 μg m^{-3}, 17.5 μg m^{-3} and 15.2 μg m^{-3}, respectively, the second counter gave mean concentrations of 18.1 μg m^{-3}, 15.0 μg m^{-3} and 13.5 μg m^{-3}. These problems may be caused by a faulty environmental sampling housing of one of the two samplers. Therefore, parallel measurements needed a correction prior to further analysis. This correction was performed using one counter (A) as a reference device. Concentrations of the second counter (B) were corrected using a multiple regression approach, according to

$$\frac{PM_{X,A}}{PM_{X,B}} = \beta_X + \beta_{X,10} \ln PM_{10,B} + \beta_{X,2.5} \ln PM_{2.5,B} + \beta_{X,1} \ln PM_{1,B}$$

with $X = 1, 2.5, 10$,

which proved to give the best fitting results.

The results obtained after this adjustment procedure are given in Table 2.4. For all PM_x fractions, only minor differences were found. Since the correction procedure itself has to be regarded as a source of error, the corrected data seemed not to meet the requirements for further sophisticated statistical analysis. Nevertheless, the data suggest that PM_x particles are homogeneously distributed on the brownfield.

Table 2.4 PM_x concentrations in μg m^{-3} (mean and standard deviation) at four positions within the brownfield obtained from paired measurements with two optical particle counters

Positions	Sampling period	PM_{10}, mean ± sd	$PM_{2.5}$, mean ± sd	PM_1, mean ± sd
P-B-2	34 days[a]	24.1 ± 18.5	17.5 ± 13.7	15.2 ± 13.1
P-B-2	34 days[a]	25.5 ± 20.2	18.1 ± 14.7	15.5 ± 13.7
P-B-1	40 days[b]	19.4 ± 15.5	11.8 ± 7.0	9.7 ± 6.5
P-B-2	40 days[b]	19.2 ± 12.6	11.9 ± 7.1	9.8 ± 6.5
P-B-3	37 days[c]	23.2 ± 12.2	12.2 ± 6.0	9.7 ± 5.6
P-B-4	37 days[c]	23.7 ± 18.3	11.6 ± 5.8	9.2 ± 5.4
P-B-2	128 days[d]	18.0 ± 13.9	15.4 ± 11.1	13.6 ± 10.6
P-B-3	128 days[d]	16.8 ± 16.6	13.9 ± 11.0	12.7 ± 10.4

[a] 1 Jun–7 Jun 2006; 6 Sep–7 Sep 2006; 13 Sep–20 Sep 2006; 2 Apr–18 Apr 2007
[b] 7 Jun–21 Jun 2006; 5 Jul–19 Jul 2006; 2 Aug–11 Aug 2006
[c] 21 Jun–5 Jul 2006; 19 Jul–2 Aug 2006; 24 Aug–30 Aug 2006
[d] 30 Aug–6 Sep 2006; 20 Sep–24 Sep 2006; 8 Nov 2006–22 Feb 2007; 18 Apr–25 Apr 2007

Such homogeneous distributions have been found also on another urban green (Langner and Meurer 2004) and indicate a rather low filtration of PM_x particles by vegetation. This is also supported by models of particle deposition on leaf surfaces predicting a minimum deposition velocity for particles in the size range between 0.1 and 1 μm (e.g. Slinn 1982).

Another interesting aspect of short-term measurements of particle concentrations is the detection of events with high particle loads in the ambient atmosphere. Examples of three events with short-term peaks are shown in Fig. 2.12, each of them caused by different circumstances. The first two events consist of a short and sharp increase of particle concentrations. The first short-term peak was caused by a local thunderstorm. The concentration peak was accompanied by heavy rain fall and an increase of wind speed with strong wind gusts. The latter were the reason for increased re-suspension, but the high particle concentrations may also be partly an artefact of bursting rain droplets, which are detected as particles by the optical counters. During the second event, the meteorological parameters showed no peculiarity during the concentration peak. This was clearly caused by fireworks on New Year's Eve. Although the measurements were made at P-B-2 and hence there have been no fireworks in direct vicinity to the particle counter, concentrations began to rise 10 min after midnight.

The third concentration peak differs from the other peaks in various respects. Increased concentrations lasted over several hours with a maximum PM_{10} concentration of 150 μg m^{-3} which resulted in a 24-h mean PM_{10} concentration of 56.8 μg m^{-3} on 24 March. There is also a clear difference regarding particle size distribution. Whereas the fraction of the coarse mode ($PM_{2.5}$–PM_{10}) amounted to 30% and 11% of PM_{10} during the first and second event, respectively, 54% of PM_{10}

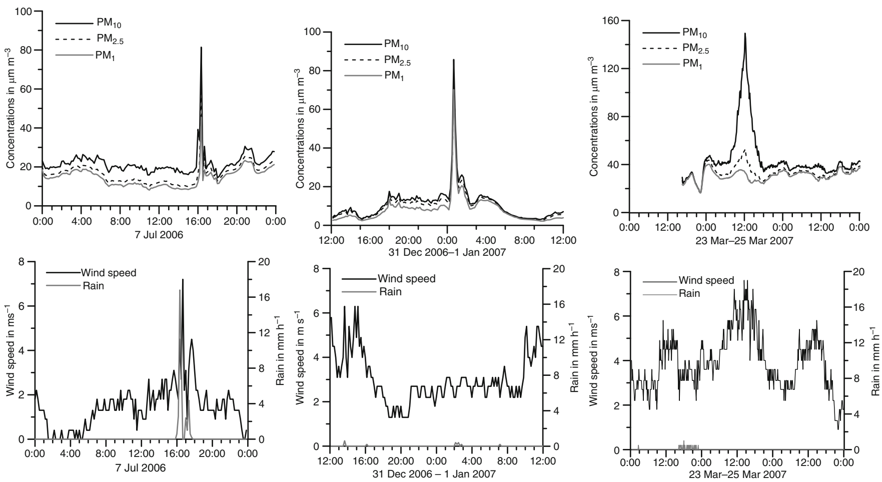

Fig. 2.12 Three examples of events with short-term peaks of PM_x concentrations and related meteorological conditions (wind speed and rain), measured with an optical particle counter on the urban brownfield. At the beginning of 23 March 2007, the particle counter was out of use

belonged to the coarse mode during the third event. Using a backward trajectory model, it could be confirmed that long-range transport of Saharan dust caused this relatively long lasting concentration peak in March 2007.

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Chapter 3
Contamination of Urban Surface and Ground Water Resources and Impact on Aquatic Species

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3.1 Introduction

Since people have been settling on flood plains, they influenced the freshwater resources more or less intensely. Historically, the process of population expansion and industrial development in urban areas has proved disastrous to the quantity and quality of both surface and ground waters (Ellis 1999). Thus, for an appropriate assessment and development of urban areas, the integrated surface and subsurface water systems, including their ecological functioning, are playing an important role (Zaadnoordijk et al. 2004). Stability criteria for both quantity and quality of urban water resources are on the one hand the "natural" discharges and recharges of rivers and groundwater, which are mainly controlled by anthropogenic and climate change effects. On the other hand, diffuse and direct pollutions with innumerable complex chemical compounds determine serious challenges for a sustainable urban water resources management (Lerner 2004). Whereas climate change is primarily influencing the water volumes of the hydrological cycle in all components and its effect has been quantified continuously, the surface and subsurface water pollution and the circulation of these substances represent qualitative parameters, which could have a large impact on the urban water resources again (Zhang et al. 2004). Last but not least, the interactions between all components of the urban water cycle and the connectivity of water quantity and quality in the urban hydrosphere are

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much stronger than in rural landscapes and environmental or ecological effects, respectively, are only partly known (Aphonen 2003).

The issue of urban water resources encapsulates many of our modern problems: sustainability, rapid urbanization and rising living standards, and complex management issues of optimal use of resources (Lerner 2004). Notwithstanding that the story of each city is different, there are some common themes like industrial pollution, sewage disposal, multiple use of water resources, and protection of surface and groundwater quality. In the case of Berlin, rivers, lakes, and aquifers are anthropogenic influenced during the last 100 years or more, and always, a considerable effort is necessary to protect these water resources against overstraining and pollution (Fritz et al. 2004, Wolter 2008). The city of Berlin has about 3.5 million inhabitants with a mean population density of 3,800 people per square kilometre. About 70% of Berlin's drinking water demand is gained by bank filtration and artificial groundwater recharge (Massmann et al. 2004a). In 2002, the water works of Berlin were abstracting 212 Mio. m^3 of drinking water via bank filtration and artificial groundwater recharge (this is 6.7 m^3 s^{-1}), and the five sewage water treatment plants are producing 241 Mio. m^3 treated wastewater per year (7.6 m^3 s^{-1}). For comparison, the mean discharges of the Havel River and the Spree River are 11.2 m^3 s^{-1} and 26.6 m^3 s^{-1}, respectively (1996–2005). Notwithstanding, the annual phosphorus load is considerable (in 2003, it was about 335 t P), which leads to a surface water quality between polytrophic and hypertrophic conditions (SenStadt 2004). Because of the bank filtration technique, there is an intensified impact of the surface waters of rivers and lakes on the main aquifer, and otherwise, brownfield sites inside and on the outskirts of the city are producing long-lasting groundwater pollution, which may influence the surface water resources.

The length of all streams is 240 km, where 195 km are navigable waterways (SenStadt 2004). The structure of the main river channels is strongly anthropogenic influenced and the water levels are regulated. Additionally, in Berlin, there are 1,116 major landing stages and marinas, including more than 27,371 boating slips; the tendency is increasing (Media Mare 2000). The high shipping frequency is given by about 26,000 sailing- or motorboats, 24,000 passenger ships, and 17,000 transport ships per year. The transportation of cargo increased on Berlin waterways, summing up to 3.7 Mio. t in 2007. In addition, the surface waters are used by 29 commercial fisheries and more than 38,000 registered anglers, which produced a total amount of 400 t of fish per year (Wolter et al. 2003). To sum up, these intensities of water use could be considered as typical for a stressed urban hydrosphere, which is important because the trend of urbanization in the world is still continuing.

Available urban water resources are usually both surface water and groundwater, although groundwater has a more constant and generally better quality and is therefore a more reliable source. Subject to the general urban land use and development in the last decades (e.g. industrialization, wastewater pollution, structural change of urban settlements), groundwater has become a vulnerable resource. In the past, only little attention was paid to the exchange processes between surface water and groundwater with ecological consequences for freshwater habitats. In this chapter, we discuss different aspects of ecotoxicology and hydrogeology that are important for the assessment of risks and the optimization of urban aquatic environmental development. In the first part (Sect. 3.2), we report about invasive and native bivalve aquatic species in highly anthropogenic influenced surface waters in Berlin to understand biochemical mechanisms behind adaptation processes. In the second part (Sect. 3.3), we investigate geochemical processes in the subsurface to quantify the degradation mechanisms of pollutants with the help of numerical models.

3.2 Invasive and Native Bivalve Species in Highly Anthropogenic Impacted Watercourses in Berlin

Stream ecosystems are increasingly impacted by multiple stressors causing a loss of sensitive species and an overall reduction in biodiversity (Palmer et al. 2010). Biodiversity decline or alteration towards a community consisting of migrating species is much more severe in freshwaters compared to terrestrial ecosystems (Sala et al. 2000). Those changes are mostly anthropogenic generated and include a degradation of habitat structure, frequency, and connectivity as well as a decrease in any other factor within the niche of the indigenous species, such as eutrophication or food availability as well as shelter from predation, non-excess parasitizing, moreover, all functions for reproduction and life cycle (Dudgeon et al. 2006). One of the less investigated contributions is the pollution scenario by anthropogenic activities. More tolerant migrating species may take advantage and colonize the respective area, either the available spots or by outcompeting indigenous species, as can be seen in many of the bigger waterways worldwide (Malmqvist and Rundle 2002). This pressure on freshwater ecosystems has been recognized by politicians, leading to regulations such as the Clean Water Act in the United States and the EU Water Framework Directive (WFD, European Commission 2000) in Europe, both protecting surface water resources.

A frequently applied restoration method in anthropogenic-impacted waterways is the increase in structural diversity, providing more habitat heterogeneity in order to increase biodiversity again. However, this is not always followed by success, as only a minor part of the 78 restorations reviewed by Palmer et al. (2010) could increase biodiversity back to reference sites. They concluded that restoring watercourses impacted by multiple stressors need to address the other stressors beside the habitat structure as well.

Urban watercourses in particular are highly modified habitats due to canalization, shoreline stabilization with sheet pile walls or ripraps, and regulation of water flow. They furthermore receive a reasonable high load of pollution from a constant discharge of treated domestic and industrial wastewater and traffic run-off after strong rains (Paul and Meyer 2001). Hence, organisms living in urban watercourses are constantly exposed to a mixture of organic and inorganic pollutants. Consequently, as for other waterways, urban watercourses are characterized by low biodiversity and often a lack of stable populations of sensitive native species (Papiri et al. 2003; Clements et al. 2006). In urban watercourses of the city of Berlin, habitat availability explained up to about 70% of species abundances, leaving more than 30% for the other mentioned factors (Leszinski, personal communication 2005).

In the context of establishment of neobiota, their capability to cope with environmental stress is assumed to be higher than that of indigenous species, thus contributing to their spreading. Mechanisms facilitating a better tolerance towards environmental pollutants include a higher ecological plasticity and intrinsic genetic variability. However, the biochemical mechanisms behind are not yet fully understood in comparison between species, especially in invertebrates.

The zebra mussel *Dreissena polymorpha* (Pallas 1771) is one of the introduced species taking advantage of the above-mentioned changes to limnic ecosystems and is simultaneously a further threat to the ecosystem (Fig. 3.1). It has proliferated from the Caspian Sea to European and North American rivers and lakes. It attaches to any kind of hard substrate, including pipes of water plants, thereby causing severe economic problems (Enserink 1999). Due to its moderate sensitivity to anthropogenic pollutants, combined with hard substrates as habitats and a planktonic larvae stadium, *D. polymorpha* established sustainable populations also in urban watercourses. *D. polymorpha* is a suspension feeder, filtering a wide size range of sestonic particles with a high clearance rate (Sylvester et al. 2005). Therefore, it is an established organism to conduct bioaccumulation studies for water quality investigations (Minier et al. 2006).

Assessing water quality of moderately polluted urban watercourses is possible by chemical and physical analysis. However, with that, an evaluation of the impact of the pollution mixtures on the aquatic organisms is not possible. Assessing water quality of those waters by biological reactions, on the other hand, requires an organism of a higher tolerance for pollution scenarios and simultaneously the application of sensitive physiological reactions as biomarkers. As *D. polymorpha* proves its tolerance by strong invasion of these watercourses, its physiological reactions towards the pollution scenarios have been investigated in this study and the species has been employed to assess and compare four differently impacted sites in the watercourses of Berlin.

One of the negative impacts of invading zebra mussels to the ecosystem affects the indigenous mussel species of the unionid family. All species of the Unionidae

Fig. 3.1 Zebra mussels (*D. polymorpha*) (**a**) overgrowing (**b**) swollen river mussel (*U. tumidus*), also shown on its own (**c**) (photos by Contardo-Jara and Burmester)

are under protection of the Federal Nature Conservation Act in Germany, as the population of Unionidae is endangered by water pollution, building activities (Jaedicke 1997), as well as the competition with *D. polymorpha* (Fig. 3.1). They are not competing for the same habitat, as the unionids need soft sediments (Ricciardi et al. 1996). As both species are filter feeders, they compete for food, especially as *D. polymorpha* is known to attach itself to the shells of the unionids, decreasing food availability for them (Burlakova et al. 2000). Furthermore, the burrowing of the carrying unionidae is impaired and the additional weight – up to more than the weight of the "host" – causes it to sink to deeper layers in the sediment (Burlakova et al. 2000). Thus, local food depletion and/or increased metabolic costs for the competing species may result in starvation of the native (Baker and Hornbach 1997).

Due to its limited abundance and protection in several countries, Unionidae bivalves are not used for biomonitoring purposes. Physiological responses of *Unio tumidus* to environmental pollutants are less investigated compared to *D. polymorpha*, focussing on oxidative-stress-related responses to environmental stress (e.g. Charissou et al. 2004).

Different adaptation capacities to environmental stress between both mussel species could add to the spreading of *D. polymorpha* in aquatic ecosystems. To understand biochemical mechanisms behind adaptation processes, the capacity of both mussel species to respond to environmental stress by their biotransformation and antioxidant system was compared, in relation to the physiological costs that are caused by environmental stressors. A cyanobacterial toxin was selected for this investigation, as this natural toxin contributes to the 'pollution scenario' in Berlin watercourses.

3.2.1 Cyanobacteria

In many limnic ecosystems, eutrophication on its own caused a biodiversity shift towards phytoplankton development, in particular cyanobacteria (Carmichael 1992). Cyanobacteria can be hazardous due to the production of toxic metabolites (cyanobacterial toxins), out of which the group of microcystins is the most relevant in limnic ecosystems (Wiegand and Pflugmacher 2005). Microcystins bind and inactivate the cellular steering enzyme protein phosphatase types 1 and 2A (MacKintosh et al. 1990). By this mechanism and furthermore causing oxidative stress, microcystins and other cyanobacterial compounds affect limnic organisms, including phytoplankton, zooplankton, invertebrates, and fish (Zurawell et al. 2005). Being filter feeders, bivalves are highly affected during toxic cyanobacterial blooms. In vertebrates, including humans, microcystins most severely affect the liver, including apoptotic reactions and intrahepatic bleeding, furthermore leading to tumour proliferation (Dittmann and Wiegand 2006).

All organisms evolved physiological reactions facilitating adaptation to natural stressful compounds such as cyanobacterial toxins. Enzymatic biotransformation and excretion processes as well as antioxidant response, amongst others, achieve this detoxification (detailed below). Biotransformation of microcystin-LR starts by conjugation to glutathione mediated by the glutathione S-transferase, increasing water solubility for better excretion (Pflugmacher et al. 1998). Microcystin-LR excretion is aided by the activity of P-glycoprotein, an ABC transporter protein belonging to the multi-xenobiotic resistance facilitating proteins (MXR, Contardo-Jara et al. 2008). Oxidative stress caused by cyanobacterial compounds can be quenched by antioxidant reactions (Cazenave et al. 2006). All those reactions enable organisms to survive toxic stress up to lethal concentrations.

3.2.2 *Physiological Biomarkers in a Moderate Sensitive Bivalve for Water Quality Assessment in Urban Watercourses*

The classical assessment of water quality implies in general physico-chemical characteristics such as temperature, pH, conductivity, dissolved oxygen, nutrients (e.g. nitrate-N, orthophosphates), biochemical and chemical oxygen demand, total suspended solids, and turbidity. Environmental pollutants such as pesticides, persistent organic pollutants (polyaromatic carbohydrates, PAH, or polyhalogenated organic compounds, e.g. polychlorinated biphenyls, PCBs, amongst others), or metals are rarely completely assessed. Furthermore, in particular, urban watercourses receive residues of pharmaceuticals and personal care products. All these so-called xenobiotics (gr: *xenos bios*, foreign to life) are present as a mixture and may act neutral, additive, synergistic, or antagonistic on organisms. Besides causing acute or chronic toxicity, pollutants might impair reproduction by endocrine-disrupting mechanisms (Gagne et al. 2006; Quinn et al. 2006).

Ecotoxicological research focused during the last decades on biomarkers, more precisely on biochemical, physiological, and histological reactions in organisms, which can be used to determine exposition or/and damage through environmental contamination (Huggett et al. 1992; Lam and Gray 2003). Compared to the chemical analysis, the clear advantage of the biomarker approach lies in the temporal integration of effects of the not permanently present chemical compounds. Also bioavailability (uptake and bioaccumulation potential) as well as the biological effects of chemical compounds are implemented in the organism response. Furthermore, the biological effect of metabolites and their potential to interact with each other or with natural substances (synergies and antagonisms) are included.

Biomonitoring can be conducted by sampling organisms living in the investigated areas (passive biomonitoring) or by exposure of organisms from a reference site or from laboratorial culture to the area of interest (active biomonitoring). Active biomonitoring has the advantage that the status of the organisms from an unpolluted reference site or under controlled conditions in the laboratory can be compared to changes caused by exposure at a polluted site. Active biomonitoring using transplanted mussels (e.g. *D. polymorpha*, *Mytilus edulis*) in particular has been applied in the marine as well as in the limnic system (Englund and Heino 1996; Cossu et al. 2000; Halldorsson et al. 2005; Pampanin et al. 2005).

3.2.2.1 Detoxification and Antioxidant Mechanism in Invertebrates

Most organic contaminants are lipophilic, making them easily absorbed across lipid membranes of the gills, skin, and digestive tract. Further fate and effect are largely dependent on susceptibility to biotransformation; while some compounds tend to accumulate in lipid-rich tissues, others are converted to more water-soluble compounds, which can hence be excreted more easily.

The xenobiotic metabolism (biotransformation) is a set of metabolic pathways that chemically modify the xenobiotics; it is present in all major groups of organisms. The biotransformation can be divided into three phases: activation, conjugation, and excretion (Fig. 3.2). The overall aim is to reduce toxicity of the compound (detoxication) and to excrete it.

In phase I, e.g. cytochrome P450 monooxygenase (CYP450), a membrane-associated enzyme adds one atom of molecular oxygen by oxidation as a functional group, rendering the lipophilic compound more water soluble, but also more reactive. If the parent xenobiotic already possesses an appropriate functional group, it can directly undergo a phase II reaction. Phase II links metabolites produced during phase I to various water-soluble endogenous compounds, which are present in the cell at high concentrations (Foureman et al. 1989). Conjugation to sugar derivates, amino acids, peptides, and sulphate produces metabolites with

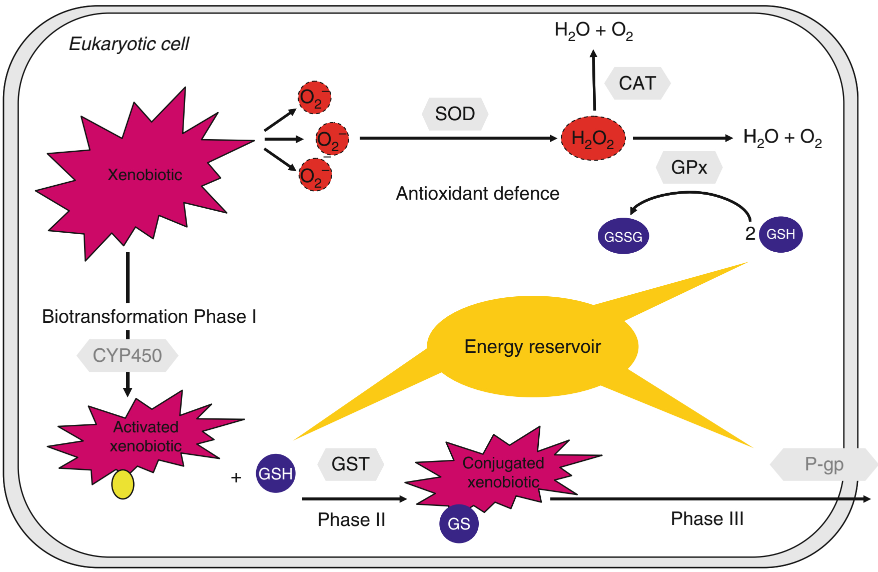

Fig. 3.2 Detoxification and antioxidant mechanism in eukaryotic cells

increased water solubility and generally reduced toxicity. These reactions are catalysed by a large group of broad-specificity transferases, which in combination can metabolise almost any hydrophobic compound containing nucleophilic or electrophilic groups. One of the most important phase II enzymes is the glutathione S-transferase (GST), conjugating a variety of electrophilic metabolites, as epoxides produced by CYP450, to glutathione (GSH), an endogenous tripeptide composed of the amino acids glutamate, cysteine, and glycine. GSTs can be present in the soluble form (sGST) or membrane bound (mGST).

Conjugates and their metabolites can be excreted by transporters of the multixenobiotic resistance protein family. These transporters are proteins [e.g. P-glycoprotein (P-gp)] of the family of ATP-binding cassette and can mediate the ATP-dependent transport of a huge variety of hydrophobic anions, and thus act to remove phase II products to the extra-cellular medium where they may be further metabolised or excreted (Smital et al. 2000). For many aquatic organisms, this mechanism has been identified furthermore as a general protection against cellular accumulation of environmental pollutants, as also excretion of non-metabolized substances via these transporters could be observed (Bard 2000).

Pollution exposure, other environmental stressors, and to a certain extent, the biotransformation process and metabolites themselves can enhance the production of reactive oxygen species (ROS) and lead to oxidative stress (Livingstone 2003) (Fig. 3.2). ROS include oxygen ions, free radicals, and peroxides. They are generally highly reactive due to the presence of unpaired valence shell electrons. ROS are present as a natural by-product of the normal oxygen metabolism and have important roles in cell signalling. However, during times of environmental stress, ROS levels can increase dramatically, which can result in significant damage to cell structures.

All forms of life maintain a reducing environment within their cells. Enzymes that maintain the reduced state through a constant input of metabolic energy preserve this reducing environment. Disturbances in this normal redox state can cause toxic effects through the production of peroxides and free radicals that damage all components of the cell, including proteins, lipids, and DNA. Hence, severe oxidative stress can cause cell death.

Water-soluble reductants such as glutathione, uric acid, and ascorbate, as well as the lipid-soluble radical scavengers α-tocopherol and β-carotene serve as antioxidants, besides the antioxidant enzymes superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx). The enzyme SOD catalyses the dismutation of superoxide into oxygen and hydrogen peroxide. Hydrogen peroxide itself is toxic and needs to be further reduced. CAT catalyses the decomposition of hydrogen peroxide to water and oxygen. The biochemical function of GPx is to reduce lipidhydroperoxides to their corresponding alcohols and to reduce free hydrogen peroxide to water. Hereby reduced monomeric glutathione is oxidised to glutathione disulphide.

All organisms need energy for physiological processes, growth, and reproduction. As heterotrophic organisms, animals gain energy from three classes of nutrition molecules in their food: carbohydrates, lipids, and proteins. Depending on the energy requirements of the organism, they are either instantly used to gain chemical energy or synthesized to larger molecules for storage purposes, such as polysaccharides, lipids, or proteins serving as energy reservoirs. In animal cells, the polysaccharide glycogen is the main carbohydrate reservoir. Glycogen consists of glucose units. As glucose is an important source of energy for ATP synthesis, glycogen is a vital energy reservoir for animals (Fig. 3.2). Glycogen serves as fast turnover energy storage as it can be synthesized as easily as it can be broken down, hence will supply energy rapidly, if required.

3.2.2.2 Biomarkers in Mussels

In mussels, different responses are used as biomarkers, starting from the whole organism level, e.g. the conch movement, to cellular or sub-cellular reactions such as apoptosis (programmed cell death), enzyme activities, or changes in gene expression.

To evaluate more a general kind of cellular stress, induction of heat shock proteins (HSPs) or the detection of apoptosis is used as a biomarker, e.g. for exposure to chlorinated effluent pollution, heavy metals, or highly persistent organic pollutants (Lawrence and Nicholson 1998; Clayton et al. 2000; Lesser and Kruse 2004). Useful biomarkers for heavy metal exposure showed to be, e.g. metallothioneins in combination with HSP induction (Piano et al. 2004) and also change in glutathione metabolism (Canesi et al. 1999). Lipidperoxidation in combination with changes in activity of antioxidant enzymes could be correlated to aquatic contamination and specifically to PAH exposure (Cossu et al. 1997; Frouin et al. 2007). In biomonitoring studies, alterations of biotransformation enzymes such as CYP450 or GST (Khessiba et al. 2001; Porte et al. 2001) were applied as biomarkers for pollution. The defence system against oxidative stress, which is highly promoted through chemical substances, can also serve as a physiological endpoint of exposure, e.g. the antioxidant enzymes SOD, CAT, GR, and GPx (Torres et al. 2002; Pampanin et al. 2005; Rocher et al. 2006).

3.2.2.3 Biomonitor

To apply the biomarker approach in urban watercourses, it is to consider that only species showing some tolerance against pollution can establish sustainable population and serve as biomonitors. Biomarker research has already focused to find sensitive organisms and specific physiological reactions to detect low pollution grades in the aquatic system (Hallare et al. 2005); thus, less knowledge exists about the applicability of less sensitive organisms in order to assess sites impacted by higher pollution. Since it is the aim to use physiological responses as biomarkers, biomonitoring with sensitive organisms in a highly charged area may cause mortalities; therefore, sensitivity of the biomonitor has to be adjusted to the pollution degree of the impacted site of interest.

This study investigates if an organism with less sensitivity, such as the bivalves *D. polymorpha*, can be employed to evaluate the extent of water and sediment pollution in urban areas. *D. polymorpha* is an established organism to conduct bioaccumulation studies in the aquatic environment or in the laboratory (Bouskill et al. 2006; Minier et al. 2006). It has also been shown to serve as a biomonitor using physiological reactions such as metallothioneine (MT) response, changes in lysosomal stability, and multixenobiotic resistance, as well as alterations of CYP450 enzymes and acetylcholine esterase (AChE) activity as biomarkers (Marie et al. 2006; Minier et al. 2006; Binelli et al. 2006). Passive biomonitoring with *D. polymorpha* in an urban watercourse devoted enzymes of the biotransformation and antioxidant system to be useful biomarkers for anthropogenic pollution as well (Rocher et al. 2006).

This study provides for the first time insight into the use of enzymatic changes of the biotransformation and antioxidant enzymes in active biomonitoring using the bivalve *D. polymorpha* as a biomonitor.

3.2.2.4 Biomonitoring Procedure

In the city of Berlin, four urban study sites with distinct contamination levels and mixture were selected to evaluate the response of the selected biomarkers: (1) the Teltow Canal, a focal point of high contamination load from ongoing industrial activities; (2) the Spree River section Oberschöneweide, a former industrial area directly bordering the river; (3) the New Wuhle known to be impacted by sewage output until 2003; and (4) Old Wuhle, a semi-natural small river, was chosen for comparison, besides the laboratory control. Water flow at all stations is comparably low, e.g. <5 cm s^{-1} in the Spree River in winter, whereas in summer, linitic conditions predominate.

Water samples were taken weekly, simultaneous to the biomonitoring sampling. Organochlorine compounds in the water samples were extracted and measured according to Kruger and Pudenz (2002). Determination of metal content was done according to DIN instructions.

D. polymorpha mussels with a size of 22–25 mm were collected during summertime 2 weeks prior to the experiments from Lake Liepnitzsee, located in a remote area north of Berlin. Mussels were allowed to acclimatise in the laboratory in artificial tank water (AFW, 100 mg L^{-1} Instant Ocean sea salt, 200 mg L^{-1} $CaCl_2$, 103 mg L^{-1} $NaHCO_3$) at the respective mean temperature measured in the field (20 ± 0.5°C), fed daily with a monoculture of *Monoraphidium minutum*. Light and dark phases were set to 14:10 h.

Field experiments were conducted at a mean water temperature of 20°C. Mussels were exposed at the four selected sites in two cages with ten individuals each at a depth of 30–50 cm below the water surface. Holes in the polyvinylchloride boxes (15 × 10 × 10 cm) guaranteed regular water flow.

Mussel samples were taken randomly from both cages. Whole animal tissue was sampled from three individuals ($n = 3$) at each site after 1 and 7 days and gills from four individuals ($n = 4$) at each site after 1, 4, and 7 days. Tissue samples were immediately shock-frozen in liquid nitrogen and then stored at $-80°C$ until enzyme extraction. Control samples (whole animals and gills, respectively) were taken at each time point, from the mussels kept in tanks in the laboratory.

3.2.2.5 Sample Treatment

Enzyme preparation was carried out according to Wiegand et al. (2000). Activities of sGST and mGST were determined according to Habig et al. (1974). SOD activity was measured using the colorimetric assay of xanthine/xanthine oxidase activity (SOD determination kit). CAT and GPx activities were determined according to Claiborne (1985) and Livingstone et al. (1992), respectively. Enzyme activities were related to the protein content in the sample, determined according to Bradford (1976).

Testing the significances of elevated and decreased enzyme activities between the different sampling sites and the laboratory control at each respective time point was performed using a two-way analysis of variance (ANOVA) with “cage” as the nested factor. The result for this factor was not significant ($p > 0.25$); hence, it was excluded from the model and a one-way ANOVA was conducted. Significance levels were evidenced by Duncan’s test ($*p \leq 0.05$, $**p \leq 0.005$, $***p \leq 0.001$) (StatSoft, Inc. 2000).

We conducted principle component analysis (PCA) with all enzyme activity alterations differing significantly from the laboratory control at the respective time point (PRIMER 6, PRIMER-E Ltd.). Enzyme activities of exposed mussels were treated as relative deviation from the respective activity of the laboratory control.

3.2.2.6 Evaluation of Biomarker Response in Urban Watercourses

For accurate interpretation of biomarker responses, it is recommendable to consider various sampling dates within the exposure time. Sampling after the first day of exposure can evidence stress due to the transplantation, whereas sampling after 1 week gives insight into, e.g. acclimatisation to the pollution scenario and it enables lipophilic environmental pollutants to reach a threshold concentration in the membranes, provoking, e.g. mGST response.

The capacity of *D. polymorpha* to cope with the environmental stress exposure at all sites was clearly evidenced. The selected enzymes of phase II of the biotransformation, GST, as well as of the antioxidant defence, SOD, CAT, and GPx, displayed significant changes in activities, at different times of exposure.

During stress reactions due to pollution, biotransformation enzymes are activated to metabolize harmful substances, reducing their toxicity and enhancing their excretion. Activation of those enzymes takes place after a threshold level at low pollutant concentrations. After increase in activities with pollutant concentration, higher pollution charges lead to deregulation/dysfunction at the cellular level, which may manifest in organism reactions, such as decreased growth or mortalities. As a side effect, inhibition of biotransformation or antioxidant enzymes frequently occurs. Graphically, physiological reactions of the investigated enzymes to increasing contaminants often lead to an inverted U-shaped curve. Having an inverted U-shaped response, exposure to a single concentration (or a mixture of contaminants as in our study) may result in increase as well as inhibition of enzyme activity compared to controls. Consequently, both of them have to be considered as stress responses of the organism.

Also, non-pollution-related variables such as sex, condition, and nutritional status might also have an additional effect on the enzyme system, interfering with biomarker responses. In our study, all the mussels were pre-cultured prior to exposure; hence, the same nutritional and conditional status can be assumed for the specimens, but as sex differentiation is not possible without harming the animal, this may count for some data variation.

3.2.2.7 Alterations of GST Activity

Unlike the sGST of total mussel tissue, sGST of gills was inhibited during the field exposure. Both, increase and decrease in enzyme activities have been observed in other studies: Rocher et al. (2006) conducted a passive biomonitoring with *D. polymorpha* and correlated increasing GST activity in gills to rising degrees of pollution, indicating the necessity of even longer exposure durations. On the other hand, Ploemen et al. (1996) emphasized the irreversible inhibition of sGST by covalent binding of activated carcinogens to the enzyme. Therefore, also activity decrease may be observed when those substances are part of the contamination mixture. This could be possible for exposure scenarios at the urban watercourses, taking into account the limited sGST concentrations in the gills in relation to sGST of the whole body tissue.

A biomarker gradient with strong sGST increase in whole mussel tissue and strongest sGST inhibition in gills was observed at Teltow Canal, where the highest charges of DDT, DDD, and PCB were detected. At this sampling site, also significant mGST elevation occurred after 7 days, in both gill tissue and whole mussel tissue. Also for marine mussels, it was possible to correlate DDT and PCB concentrations to biomarker gradients of GST, metallothioneins, and CAT (Lehtonen et al. 2006).

In this study, PCA identified the sGST activity alteration of whole mussel tissue after one and especially after 7 days as a strong variable when explaining the difference between sites. sGST of *D. polymorpha* proved to be a reliable biomarker of exposure to the pollution scenario in urban watercourses. Also, mGST can be recommended as a suitable biomarker for charges with PCBs, PAHs, and organopesticides in the limnic system due to possible bioaccumulation of those compounds in membranes.

3.2.2.8 Alterations of SOD, CAT, and GPx Activity

The clear elevation of SOD and GPx in whole mussel tissue at the three most polluted sampling sites indicates that animals suffered from oxidative stress, since elevation was still significant after 1 week, when stress due to the transplantation event can be excluded. At the sampling site where the highest SOD activity was detected (Old Wuhle), also significant CAT activity elevations occurred correlating to contamination with aluminium found at this site. Studies on the cytotoxicity of aluminium in vertebrates revealed that aluminium promotes oxidative stress by lipid peroxidation, but this can be prevented by activity of antioxidant stress enzymes SOD and CAT (Jena et al. 2002; Doyotte et al. 1997). The observed activation of enzymes of the cellular defence against oxidative stress is thought to avoid accumulation of ROS and free radicals and thus protects the cells from oxidative damage of DNA, proteins, and lipids (e.g. in membranes). Rocher et al. (2006) positively correlated especially SOD activities to metal body burden in *D. polymorpha* and *M. edulis*. In contrast, Doyotte et al. (1997) observed remaining or decreased activities of the antioxidant enzymes SOD and CAT in gill tissue of *U. tumidus*, similar to the results obtained in this study, with SOD and CAT revealing decreased activities and principally recuperation after longer exposure at the moderately polluted sampling sites.

Changes in SOD activity after 7 days occurring either in whole mussel tissue or in the gills was identified as the strongest enzymatic variable associated with the principle components (PCs) in explaining differences between sampling sites.

3.2.2.9 Evaluation of Investigated Sampling Sites

In general, Berlin surface waters are considered as being eutrophic and critically polluted, thus classified into the categories “up to twice target value” until “highly contaminated with significant negative impact on the ecosystem” (Bundesanzeiger, German Federal Ministry of Judiciary 2005). Furthermore, all detected metals, except for aluminium, and organochlorines are listed as hazardous to waters and their introduction to the limnic system is prohibited (German Drinking Water Ordinance 2001). Nevertheless, pesticide loads can be classified as low, as they are below the limit value for drinking water (sum of pesticides below 0.5 µg L^{-1}).

The enzymatic responses of the mussels were at almost all sites accordant with the degree of pollution, i.e. chemically quantified water contaminants (Table 3.1). PCB charges were highest at Teltow Canal, followed by the Spree River. Furthermore, still augmented levels of DDT and its metabolites were found in the Teltow Canal water, and to a lesser extent, at the Spree River. For contamination with DDT and its metabolites at all sites, it is uncertain whether the detected parent compound DDT originated from longstanding pollution. However, DDT is dominant opposed to the main metabolite DDE, suggesting that DDT has been newly and illegally introduced. HCH was present in the water column of all other sampling sites.

Table 3.1 Results of biological and chemical monitoring of selected urban sampling sites

Tissue	Biomarker	Biomonitoring Station											
		Teltow Canal			Spree River			Old Wuhle			New Wuhle		
		1 d	3 d	7 d	1 d	3 d	7 d	1 d	3 d	7 d	1 d	3 d	7 d
Whole mussel tissue	sGST	*		*			*	*		**			
	mGST			*									
	SOD			**			***	**		***	**		
	CAT									*			
	GPx	*		*	**		*			**	*		
Gill tissue	sGST			**			*			**			**
	mGST		**	**		*	**		**	**			
	SOD		**	**					***				
	CAT				*				**			**	
	GPx					***			*	**		*	*
Biological evaluation of the sampling sites		Slightly impacted			Slightly impacted			Moderate impacted			Good conditions		
Conductivity [μS cm^{-3}]		1,194 ± 79			640 ± 18			620 ± 72			466 ± 6		
Dissolved oxygen [%]		56.2 ± 8.0			70.6 ± 3.4			74.9 ± 15.6			62.5 ± 11.3		
Total PCB [ng L^{-1}]		30.6 ± 1.9			8.4 ± 1.8			4.8 ± 2.2			4.5 ± 3.1		
Total HCH [ng L^{-1}]		34.5 ± 6.3			4.2 ± 2.7			7.6 ± 5.8			6.2 ± 5.7		
Total DDT [ng L^{-1}]		67.9 ± 14.5			16.6 ± 2.3			18.9 ± 0.2			14.5 ± 3.3		
Al [μg L^{-1}]		165.0 ± 102.4			74.1 ± 27.9			613.2 ± 161.2			117.0 ± 122.5		
Cu [μg L^{-1}]		61.2 ± 35.8			20.5 ± 7.8			26.4 ± 5.1			33.6 ± 17.9		
Chemical evaluation of the sampling sites		Moderate impacted			Slightly impacted			Slightly impacted			Good conditions		
Appraisal of the biomarker response		"*Under-estimated*"			Adequate			"*Over-estimated*"			Adequate		

Significant differences (*$p \leq 0.05$, **$p \leq 0.005$, ***$p \leq 0.001$) of the single enzymes of exposed mussels at the sites and exposure durations investigated compared to control animals. White boxes indicate no significant changes compared to control, whereas grey boxes mark no sampling conducted

Regarding the biomarker response of field-exposed *D. polymorpha*, Teltow Canal and Spree River were depicted as more polluted compared to Old Wuhle and New Wuhle by activity increases of sGST of the whole mussel, mGST of the gills, and also decreases of sGST, SOD, CAT, and GPx activities in gill tissue. Nevertheless, for Teltow Canal, the biomarker response of the antioxidant defence was partly non-adequate as the biological evaluation seems to underestimate the chemical charges evidenced for this site.

The highest amounts of PCB, HCH, DDT, and metals, compared to the other sampling sites, did not provoke the strongest biomarker response in each case, especially in gill tissue. Keeping in mind dose-effect-relations occurring within organisms, possibly saturation of enzymatic activity was reached by the high contaminant concentrations compared to the other sampling sites. For Teltow Canal, reasonable pollution degrees are also reported for sediments (Schwarzbauer et al. 2003; Contardo-Jara and Wiegand 2008), supporting the assumption of long-term and continuous pollution in this watercourse.

For Spree River and New Wuhle, biomarker response showed a contamination gradient in accordance with the chemical analysis.

Old Wuhle can be classified as less polluted by pesticides (Heptachlor, DDT, and metabolites), but the biomarker response showed similar patterns as at Teltow Canal and Spree River and seems to overestimate the pollution degree. The clear enzymatic response of especially mGST at Old Wuhle indicates charges with organic lipophilic substances. Since mGST plays an important role in conjugation of reactive intermediates, mGST increase could therefore also evidence indirectly enhanced amounts of electrophilic metabolites, including lipid peroxides. Furthermore, the strikingly high amounts of aluminium (610 $\mu g\ L^{-1}$) observed at Old Wuhle may explain the increased antioxidant response of SOD and CAT of whole mussel tissue after 7 days.

Since New Wuhle receives no more sewage waters since 2003 and renaturation programmes were implemented, a recuperation of this stream was expected. At this site, no alteration in enzyme activity of whole mussel tissue occurred compared to the control group kept in the laboratory, confirming recuperation. However, sGST, CAT, and GPx in gill tissue displayed significant changes. Hence, from the data of this study, it can be confirmed that contamination residues (pesticides and metals) are still present at this sampling site, having a slight impact on *D. polymorpha*.

It was the aim, when selecting sampling sites, to include a semi-natural stream for comparison between sites. But, a laboratory control proved to be most adequate for overall relation, as the results show clearly that even at the semi-natural stream Old Wuhle, selected as a reference site, unexpected pollution loads were found and respective biomarker response compared to laboratory controls occurred. Finally, the biomarker response and the chemical analysis yield to the conclusion that New Wuhle, compared to either Old Wuhle or the laboratory control, can be declared as less polluted, due to renaturation efforts.

The PCA resulted in a separable distribution of the four sampling sites with SOD and sGST activity changes in whole mussel tissue after 7 days as the strongest associated variables. This clearly evidences that already two relatively unspecific biomarkers, SOD indicating oxidative stress and sGST indicating biotransformation processes. Both, determined after 7 days of active biomonitoring, are sufficient to separate differences between sites.

It can be concluded that biotransformation enzymes s- and mGST of *D. polymorpha* reacted sensitive to distinguish pollution grades of selected sites. The suitability of antioxidant defence enzyme SOD as a biomarker of oxidative stress was confirmed. SOD elevation in whole mussel tissue due to field exposure was identified by PCA as the strongest associated variable in explaining differences between sampling sites. Gills, displaying mainly inhibited enzyme activities due to exposure, proved to have a highly sensitive antioxidant defence mechanism able to detect environmental changes. The decreased enzyme activities have to be evaluated as a clear biomarker response.

With this study, we could prove that the combination of using a moderate sensitive species as *D. polymorpha* with adequate biomarkers, such as activity responses of GST and SOD, results in a reliable tool for assessing watercourses with moderate pollution, low biodiversity, and species abundances. Nevertheless, it goes without saying that the application is restricted to watercourses, where this species has already been introduced.

3.2.3 Differences in Susceptibility of Limnic Mussels to Cyanobacterial Toxins

Over the past years, species diversity and its decrease have moved into the focus of the media and scientific literature. The year 2010 has been declared by the United Nations as the international year of biodiversity. In Berlin's water bodies, it has become apparent that the abundance of endemic species such as Unionacea is decreasing. This could be a result of the decrease in habitats as a result of building structures in the rivers Havel and Spree and all the connecting channels. However, this cannot be the only reason, as even in suitable habitats, Unionacea often cannot be found anymore. Another possible reason for the decrease in endemic species is the increasing contamination of urban water bodies. A study on *Unio tumidus* in the river Spree shows a higher abundance in those parts of the river that have a lower abundance of xenobiotics than at the urban sampling sites where the abundance of xenobiotics is higher (Krofta 2004).

The swollen river mussel (*U. tumidus*) belongs to the endemic Unionacea. Unionidae live in the sediment, where they move along on their foot or completely bury themselves (Fig. 3.1). They prefer sandy ground in flowing water (Pusch et al. 2001). Depending on the ambient temperature, Unionacea can filter considerable amounts of water. The filtration rates of *U. tumidus* are 2.1–2.4 L h^{-1} (Krygar and Rissgård 1988). Because of their high filtration rates, the mussels contribute to the purification of water bodies. They filter particulate material from the water and add indigestible organic components to the sediment, where bacteria can further degrade it.

During summer months, slow current and a high nutrition load characterize the urban water bodies of Berlin, together favouring mass developments of cyanobacteria (Fig. 3.3). During cell lysis of cyanobacteria, cyanotoxins are released and pose a threat for aquatic organisms as well as for humans enjoying urban water bodies. Amongst these cyanotoxins, microcystin is the most common one. Freshwater mussels such as *D. polymorpha* and *U. tumidus* are non-selective filter feeders, obtaining high filtration activities, thus may accumulate the cyanotoxins during cyanobacterial blooms (Contardo-Jara et al. 2008).

In contrast to *U. tumidus*, the invasive *D. polymorpha* as a moderate sensitive species is able to develop sustainable population in contaminated water bodies (Contardo-Jara et al. 2009). *D. polymorpha* is tolerant to a wide range of environmental conditions (Claudi and Mackie 1993). For this reason, it was the aim to analyze whether *D. polymorpha* has better capacities for biotransformation (sGST) of cyanobacterial toxins and to cope with the oxidative stress (CAT) compared to *U. tumidus*. Furthermore, the energetic effort of both species to handle the toxin and repair possible damages was compared by their glycogen reservoirs as physiological costs.

3.2.3.1 Sampling and Acclimation of *D. polymorpha* and *U. tumidus*

D. polymorpha (22–25 mm shell length) and *U. tumidus* (50–61 mm shell length) were collected in July 2009 from Lake Küstrin, located in a remote area 150 km north of Berlin (Germany). The mussels were acclimated for 14 days to the same laboratory conditions as mentioned above (20 ± 0.5°C, l:d 14:10 h). During this period, *D. polymorpha* were placed in 10 L glass aquaria, each with approximately 100 individuals. *U. tumidus* were kept in 100 L glass aquaria, each with 30 individuals on a layer (10 cm) of sediment from Lake Küstrin. The AFW was

Fig. 3.3 Cyanobacterial bloom in summer at Lake Müggelsee (photo by Burmester)

changed every second day for *D. polymorpha* and weekly for *U. tumidus*. Mussels were fed twice daily with freeze-dried *Spirulina* sp. powder.

3.2.3.2 Experimental Setup

One day before the experiments were started, mussels were transferred into 3 L glass aquaria without sediment. Mussels were exposed for 24 h and 7 d to microcystin-LR at 10 μg L^{-1} and 50 μg L^{-1} (three tanks for each concentration and control). Each mussel was exposed in 100 mL medium (toxin in AFW or AFW for control). Control mussels were treated similarly except that no toxin was added. Water temperature, light, and nutrition conditions were equal to the acclimatization period. After exposure (24 h and 7 d), *D. polymorpha* were removed on ice from their shells. *U. tumidus* were dissected on ice and the digestive gland isolated from other organs. The samples were immediately frozen in liquid nitrogen and stored at −80°C until analyses.

Enzymes were extracted and measured as described above in the biomonitoring procedure. The glycogen content was determined colorimetric using the anthrone reagent (van Handel 1965) and calculated by means of a standard curve of glycogen. Enzyme activities and glycogen content of *D. polymorpha* were measured in whole mussel tissue and of *U. tumidus* in the digestive gland.

Statistical differences in enzyme activity and glycogen content between treatments were calculated by ANOVA. Significance levels were evidenced by Duncan's test, (*$p \leq 0.05$, **$p \leq 0.005$, ***$p \leq 0.001$).

3.2.3.3 Changes of Enzyme Activity and Glycogen Content Due to MC-LR Exposure

The sGST activities were elevated for the entire exposure period in whole tissues of *D. polymorpha*, compared to controls, increasing with exposure concentration

Table 3.2 Relative changes of enzyme activities (sGST and CAT) and glycogen content in *D. polymorpha* and *U. tumidus* after exposure to microcystin-LR (10 μg L^{-1} and 50 μg L^{-1}) for 24 h and 7 d compared to control animals

	10 μg L^{-1} MC-LR		50 μg L^{-1} MC-LR	
	24 h	7 d	24 h	7 d
Dreissena polymorpha (whole mussel)				
sGST	11.5% ± 1.7*	17.1% ± 1.4	25.1% ± 2.3	78.4% ± 10.6 ***
CAT	−16.8% ± 2.8	1.9% ± 0.5	16.3% ± 2.1	11.9% ± 2.6
Glycogen	−27.1% ± 3.6*	−2.9% ± 0.4	−50.8% ± 4.9	−21.3% ± 17.7
Unio tumidus (digestive gland)				
sGST	−2.4% ± 0.5	−19.6% ± 5.9	−2.8% ± 0.7	−46.7% ± 16.8
CAT	4.2% ± 1.3	0.4% ± 0.1	6.8% ± 1.7	3.6% ± 0.9
Glycogen	−18.1% ± 5.5	−31.7% ± 5.9	−56.7% ± 45.9	−5.4% ± 1.5

and duration (Table 3.2). Significant differences were seen at the beginning (24 h: $p \leq 0.05$) and after 7 days of exposure ($p \leq 0.001$). *D. polymorpha* seems to biotransform the microcystin-LR stronger with increase of MC-LR concentration or exposure duration. In a previous study, clearance of this toxin was evidenced for concentrations up to 100 μg L^{-1}, without harming the *D. polymorpha*, and the parent compound as well as biotransformation products were excreted into the medium (Contardo-Jara et al. 2008). High activities of the P-glycoprotein (MXR), found in that study, together with the activities of the sGST of this investigation evidence a strong biotransformation capacity of *D. polymorpha* for the cyanobacterial toxin.

Contrastingly, the sGST activity decreased in the digestive gland of *U. tumidus* with exposure duration, compared to control animals, and to an even lower value in the higher exposure scenario. Due to high variation between the individuals (samples were not pooled), these changes in enzymatic activities failed statistical significance. Nevertheless, it seems that with longer exposure duration, this species is impaired to perform biotransformation of the toxin via the GST system.

CAT activities were not significantly changed during the whole period in both species. It responded in *D. polymorpha* with decreased activities after short time exposure to 10 μg L^{-1} MC-LR and with slight increased activities at the higher concentration. CAT is the most efficient antioxidant enzyme; hence, the toxin concentrations were not sufficient to provoke an increase in activity. Similarly, the response of antioxidant enzymes of *U. tumidus* exposed to industrial impacted streams revealed minor changes for CAT and SOD but reduction in activities of GPx and glutathione reductase (Doyotte et al. 1997). Whether or not those enzymes would indicate oxidative stress in the mussels exposed to cyanobacterial toxins will be investigated further.

The glycogen content decreased in both species, indicating the requirement for energy due to the stress caused by the MC-LR exposure. The decrease of the glycogen content in *D. polymorpha* was statistically significant for the highest concentration after 24 h ($p \leq 0.05$). In all but one exposure scenario, the short time depletion of the glycogen storage was higher than the long-time usage from this energy reservoir, confirming its role as a fast energy supply.

We conclude that *D. polymorpha* is capable of detoxification of MC-LR but at the expense of energy. The results suggest that *U. tumidus* is less able to detoxify MC-LR via the biotransformation enzyme GST. Nevertheless, exposure to MC-LR enhanced the requirement for energy, as indicated by reduced glycogen content in both mussel species. Compared to *U. tumidus*, the invasive *D. polymorpha* seems to be better adapted to cyanotoxin exposure. This, in addition to the usage of habitats, the impact on Unionidae by attaching on them, indicates a contribution to an ecological benefit for *D. polymorpha* in comparison to *U. tumidus*. Further investigations will compare the above-mentioned antioxidant enzymes, furthermore, the glutathione content as an antioxidant, as well as the lipid storage as a long-term energy reservoir in both species in response to exposure to cyanobacterial toxins.

3.3 Contamination of Urban Water Resources: Long-Term Effects of Ammonium Transport in Groundwater and Degradation Processes of Blue Algae Toxins During Bank Filtration

The subsurface plays a key role in urban wastewater disposal, and is found to be impacted even in the presence of sewers. In the south-east of Berlin, sewage farm operation in the last century has resulted in a large-scale groundwater contamination, which influences pumping wells of waterworks. To assess the duration of the contamination and future trends of the hydrochemistry in the wells, numerical modelling was accomplished. The base of investigation was a large dataset of chemical and physical parameters of an opaque groundwater-monitoring network from a quarterly to half-yearly sampling program for 1998–2005 as well as extensive preliminary investigations of hydraulic and geochemical aquifer parameters. The ammonium plume migration is controlled by cation exchange. The distribution of the major elements is spatially and temporally high variable, caused by continuous reactions and heterogeneities in aquifer properties. After closing the sewage farm, the source strength is decreasing. Higher contents of sulphate than in the source suggest autotrophic denitrification by means of pyrite oxidation. In the subsurface area (0–10 m below surface), nitrate is dominating, which results from oxidation of organic nitrogen. In deeper areas, anaerobic conditions (iron to sulphate-reducing) occur exclusively with ammonium as an inorganic nitrogen species. The isotopic data of NH_4^+ indicate enrichment of $\delta^{15}N$ along the upper fringe of the plume. Hence, fate of ammonium by nitrification takes place. High contents of calcite in the aquifer matrix suggest a high buffer potential, likely for the next decades. However, this process yields an increase in groundwater hardness. Another consequence is an impact on cation exchange processes which govern the retardation of ammonia.

According to the varying pumping operation of the wells and the consequential unsteady flow field, a 3D transient flow model was developed (MODFLOW). Based on this, a multicomponent reactive transport model (PHT3D) was employed, which considers ion exchange, redox reactions, and mineral precipitation and solution. Flow and transport parameters were calibrated for the sewage farm operation period and beyond from 1906 to 2005. Subsequently, the future ammonium concentration was simulated. Based on the model results, elevated ammonium concentrations of about 10 mg L^{-1} at the wells can be expected for the next 150 years due to a long-term tailing phase.

If, as in the case of Berlin, urban drinking water production is based mostly on bank filtration, surface water and groundwater resources are strongly linked in terms of both quantity and quality. Over the past several years, there has been an increasing interest in microcystins and other cyanobacterial toxins in surface waters and oxic groundwater. Since these compounds are strong hepatotoxic agents, their presence in surface water is undesirable and can especially cause health problems if the contaminated surface water is used for drinking water abstraction by bank filtration. During the subsurface sediment passage, microcystins are biodegraded by adapted microorganisms in a co-metabolic way together with other compounds – a process which causes depletion of oxygen in the sediment and production of anoxic zones in the underground. Presence or absence of oxygen as an electron acceptor for microbial energetic metabolism is a crucial factor for degradation. Up to now, most studies focused on the fate of microcystin under oxic conditions. But, if during bank filtration anoxic zones occur, these approaches cannot be used for description and prediction of transport and degradation processes of microcystin at bank filtration sites.

For a better understanding of anoxic degradation of microcystins during subsurface sediment passage, laboratory column experiments were designed to simulate the transport and degradation conditions in the aquifer. In small columns of about 20-cm length, different cyanobacterial concentrations and potential electron acceptors were adjusted. The outflowing water was analyzed with respect to microcystin-LR and the main ion concentrations. Transport and sorption parameters were investigated by flow experiments, and quantification of the main parameters was done by inverse modelling using a MATLAB inverse transport model.

Flow and sorption experiments reconfirmed that microcystin-LR does not tend to sorb to the sandy material. Considering the anoxic degradation behaviour of the toxin, the redox state of the system was assumed to be the most important factor and was therefore varied during the experiments by adding supplemental nitrate. The experiments showed that when nitrate was present in unrealistic high concentrations, degradation of microcystin-LR occurred much faster than without nitrate. Addition of saccharose as an extra energy source did not result in a decrease in microcystin, indicating that anoxic biodegradation of microcystin-LR is a co-metabolic process in which compounds that are easier to metabolize – like saccharose – are preferred by the present microorganisms.

Parameters of the degradation kinetics were quantified by creating an inverse MATLAB model basing on Monod kinetics with oxygen and nitrate as electron acceptors. First estimates were performed by direct modelling using the geochemical model PhreeqC.

3.3.1 Long-Term Behaviour of Ammonium in an Urban Groundwater Contamination Caused by Sewage Infiltration

3.3.1.1 Introduction

Groundwater in urban areas is characterized by a large number of impacts qualitatively and quantitatively different from natural systems (e.g. Chilton et al. 1999; Ellis 1999; Lerner 2004). An important aspect often is the integrated use of the surface water and groundwater system for drinking water production and sewage water disposal. Depending on the technical conditions, more or less treated sewage water can contaminate groundwater aquifers. Sources are, e.g. urban sewage leakages (Paul et al. 2004), on-site sewage systems (e.g. MacQuarrie et al. 2001), urban areas without any septic system (e.g. Foppen 2002), and artificial groundwater enrichment with treated wastewater (Lee and Bennett 1998; Repert et al. 2006). In the case of untreated sewage water, such contaminations usually contain high amounts of ammonium. Ammonium is primary not harmful for the human health, but in surface water high concentrations can cause eutrophication. In Germany, the threshold value for ammonium in drinking water is regulated by the German Drinking Water Ordinance (TrinkwV 2001) with 0.5 mg L^{-1}. Under anaerobic conditions, ammonium is extremely persistent. One reason is the chemical stability of ammonium under anaerobic conditions. Furthermore, there is the high affinity of ammonium for sorption caused by cation exchange (Ceazan et al. 1989; Erskine 2000).

An important contaminant source could be sewage farms. They were present in many European cities from the end of the nineteenth until the end of the twentieth century. The principle of sewage farming is described in more detail by Richter et al. (2009).

In the suburbs of Berlin, untreated sewage water was percolated on sewage farm irrigation fields until the late 1980s. The amount of sewage water that, due to the high vertical flow gradient, infiltrated to the aquifer was estimated at 40% (Bjarsch 1997). One such contamination is located in the south-east of the city of Berlin (Fig. 3.4), where the former sewage farm of Münchehofe (SFM) operated for more than 80 years from 1906 to 1991. Due to the fact that the drinking water treatment plant Friedrichshagen (DWTP) is located directly downstream of the irrigation fields of the SFM, the drinking water production is endangered. The operation of

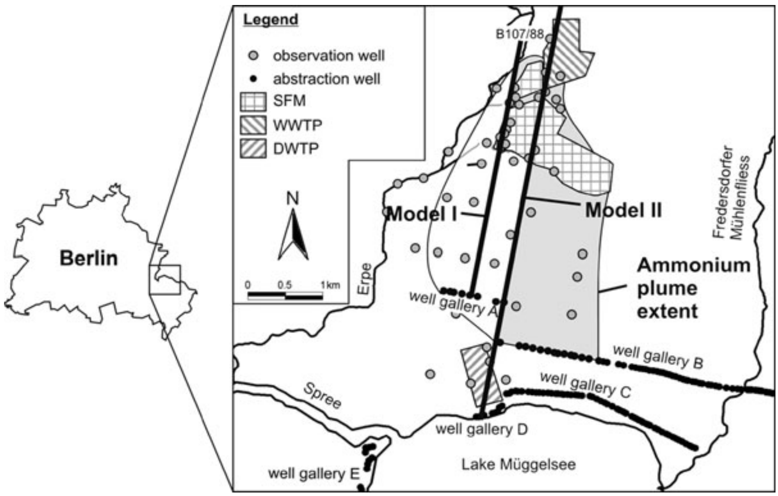

Fig. 3.4 Investigation area with the recent extent of the ammonium contamination (*grey area*) and the model transects I and II (*lines*)

the groundwater abstraction wells of the DWTP started at the same time as the irrigation at the SFM. Since then, an ammoniacal wastewater plume has been migrating from the SFM to the DWTP. The most hazardous compound is ammonium with up to 100 mg L^{-1}. Actually, the plume ranges from the SFM to a part of the abstraction wells of the DWTP (Fig. 3.4). The cause of such huge contamination, compared to the situation at the other sewage farm locations of Berlin, results from the particular geological setting of the site. In Berlin, the sewage farms were usually constructed on glacial plateaus, where the aquifer used for drinking water production is protected on the top by glacial till. The SFM, instead, is located at the southern boundary of a glacial plateau so that the glacial till wedges out directly below the SFM. Thereby, the contamination of the aquifer could develop.

In a previous model study for the prognosis of the ammonium decontamination time at the site, a linear sorption approach was applied for the description of ammonium retardation (BWB 2000). However, Bethke and Brady (2000) describe reasons for a limited applicability of this approach. Also, a reactive multicomponent transport model exists, where the ammonium retardation is implemented by cation exchange, for simulating an in-situ pre-treatment plant (Horner et al. 2009). However, it is spatially restricted to the closer DWTP well catchment area.

The aim of this study is to assess the long-term ammonium decontamination. For this purpose, a numerical reactive multicomponent transport model with a cation exchange approach was built. For model calibration flow, non-reactive and reactive transport were simulated from the beginning of the SFM operation until today (1906–2005). Based on this calibrated model, a prognosis of the ammonium decontamination in the aquifer between the SFM and the DWTP wells was performed.

3.3.1.2 Material and Methods

SFM Management

The irrigation of untreated sewage water occurred at the site from 1906 until the beginning of a wastewater treatment plant (WWTP) operation in 1976 (BWB 1992). The infiltrated amount increased exponentially, with 13,000 m^3 d^{-1} and 48,000 m^3 d^{-1} in the years 1935 and 1973, respectively (BWB 1992). In contrast, the maximum infiltration amount, which assured an unsaturated and therefore aerobic soil horizon, was approximately 17,000 m^3 d^{-1}. Since 1955, this infiltration capacity was exceeded, causing the saturation of the soil horizon, and so the cleaning capacity was seriously compromised. From 1976 to 1980, after the beginning of the WWTP operation, pre-treated wastewater was percolated (7,000–15,000 m^3 d^{-1}) in the south-eastern part of the SFM (BWB 1992). In the middle and north-western parts of the SFM, sewage sludge from the WWTP was stored and dehydrated from 1976 to 1991 (BWB 1992). The amount of infiltrated sludge water and therein contained contaminants are not documented. Basically, in the middle and north-western parts of the

SFM, the contaminant input was higher and more prolonged than in the south-eastern part.

Flow and Non-reactive Transport Model

Initially, two 2D vertical flow and non-reactive transport models were developed (Fig. 3.5). They are aligned parallel to the prevalent groundwater flow direction (Fig. 3.4). Two model transects were applied to demonstrate the reasons for the different ammonium concentrations at the well galleries A and B and their different temporal trends. The flow simulations were carried out with the USGS finite-difference flow simulator MODFLOW (McDonald and Harbaugh 1988). The non-reactive transport was approximated by simulating the chloride concentration in the DWTP wells using the transport simulator MT3DMS (Zheng and Wang 1999).

Model I extends over 3,700 m from the upstream area north of the SFM to the well gallery A. It captures the main input area of ammonium. Model II is aligned parallel to model I and extends over 6,800 m from the upstream area north of the SFM across the western well gallery B and well gallery D to the lake Müggelsee. It captures the central part of the contamination. In the models, only the first two aquifers are considered. The model base is defined by the top of the aquitard of the Holstein interglacial. So, the model thickness is approximately 50 m.

The horizontal cell size is 100 m north of the SFM and 50 m downstream. The models have ten layers, each of approximately 5 m. Model layers and the hydraulic conductivities for each cell were taken from a 3D model (FUGRO 2000). To be able to simulate the non-steady-state hydraulic conditions, controlled by the sewage water infiltration rate and the drinking water well abstraction, the models were temporal discretised to 53 stress periods. The length of the stress periods was

Fig. 3.5 Boundary conditions of model I (**a**) and model II (**b**). The vertical exaggeration is 20-fold. The isolines depict the hydraulic conductivity (m d^{-1})

adapted to the availability of input data for the flow boundary conditions. So, the first stress period was 30 years, the second and third were 10 years each, and the remaining 50 stress periods were 1 year each. The stress periods were further refined to monthly time steps.

A Dirichlet boundary condition was set to the upstream boundary in the north of both models. The same applies to the upper cell at the southern boundary of model II, which represents Lake Müggelsee. In both models, the wells, sewage input, and natural recharge are set as Neumann boundary conditions. The natural recharge is applied to the upper model cells and allocated uniformly to the year (150 mm a^{-1}). Despite a slight deep water rise across gaps in the Holstein aquitard during intense drinking water extraction at the DWTP wells, any exchange of water above the bottom of the model was neglected. Well extraction rates and the sewage discharge were calibration parameters but based on occasional measured data. The groundwater level at the northern boundary was specified to 39 m above sea level (a.s.l.) until 1975. For the following years, the groundwater level was lowered by 1 m due to a permanent decrease in natural precipitation since the end of the 1960s (Frey et al. 1992).

The chloride upstream and lake concentrations as well as the initial aquifer concentration was set to 16 mg L^{-1} according to the concentration at the background observation point B107/88. According to the measured maximum chloride concentration at the DWTP wells of 200 mg L^{-1} in the 1980s, the chloride concentration of the discharged sewage water was approximated to 200 mg L^{-1} for the operating period from 1906 to 1991, but also set as a calibration parameter.

The initial groundwater level in 1906 was calculated by a steady-state model run. At that time, the wells of the DWTP and the sewage discharge at the SFM were not yet in operation. Hence, only the ground water level at the northern boundary (39 m a.s.l.) and the lake water level at the southern boundary (32.4 m a.s.l.) were considered as boundary conditions.

Reaction Network

The reactive simulations were carried out with the multicomponent transport code PHT3D (Prommer et al. 2003), which couples MT3DMS with the geochemical model PHREEQC-2 (Parkhurst and Appelo 1999).

Due to the anaerobic conditions in the aquifer, ammonium retardation plays a key role in the ammonium transport and is controlled by cation exchange processes. Due to their site specificity, the selectivity constants for equilibrium ion exchange of Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Fe^{2+}, and NH_4^{+}, as provided in the PHREEQC-2 database, were modified (Table 3.3). The modification is based on the measured exchanger composition of one sediment sample from the shallow aquifer below the SFM (FUGRO 2000). The implementation and modifiability of ion exchange in PHREEQC-2 is described in Parkhurst and Appelo (1999).

Table 3.3 Comparison of the original and modified site-specific exchange selectivity coefficients (logK) in the PHREEQC database

Parameter	Reaction	Exchanger composition [mol(eq) l^{-1}]			logK [−]	
		Measured	Original database	Modified database	Original database	Modified database
Na-X	$Na^+ + X^- \leftrightarrow NaX$	9.71E-04	5.14E-05	9.96E-04	0.0[a]	0.0[a]
K-X	$K^+ + X^- \leftrightarrow KX$	2.08E-04	1.20E-04	2.31E-04	0.7	−0.2987
$Ca\text{-}X_2$	$Ca^{2+} + 2X^- \leftrightarrow CaX_2$	3.21E-03	3.43E-03	2.94E-03	0.8	−2.1255
Mg_X_2	$Mg^{2+} + 2X^- \leftrightarrow MgX_2$	3.31E-04	2.91E-04	3.02E-04	0.6	−2.2415
$Fe\text{-}X_2$	$Fe^{2+} + 2X^- \leftrightarrow FeX_2$	3.00E-04	3.58E-06	3.16E-04	0.44	−1.3492
$NH_4\text{-}X$	$NH_4^+ + X^- \leftrightarrow NH_4X$	2.60E-03	2.84E-04	2.82E-03	0.6	0.194

[a]Defined as a reference point (see Parkhurst and Appelo 1999)

Simulated Initial, Background, Sewage, and Recharge Water, and Aquifer Matrix Composition

PHT3D can only deal with equilibrated and charge-balanced water compositions. Therefore, and due to the competition of several cations for exchanger sites, all the measured major ions were taken into account. According to the measured calcite and iron oxyhydroxide contents in the aquifer sediment (FUGRO 2000), the initial and background water compositions were equilibrated with calcite and amorphous $Fe(OH)_3$. These minerals are implemented as equilibrium phases in the original PHREEQC database. Charge imbalances were balanced by adding chloride. The cation exchange was considered for the initial and background water implementing the site-specific exchanger selectivity coefficients and a cation exchange capacity (CEC) of 14 meq kg^{-1} dry weight (measured: 1.3–16.7 meq kg^{-1} dry weight in FUGRO 2000).

The initial and background groundwater compositions were calculated based on a sample at the upstream observation well B107/88 from 1998. The recharge composition is based on a chemical analysis of natural precipitation from Lake Stechlinsee from 2002. In PHREEQC, the ion concentration increase by evaporation was simulated, assuming a precipitation of 667 mm and a recharge of 150 mm. Subsequently, the water was equilibrated with carbon dioxide and oxygen partial pressures of 0.033 and 20.95%, respectively. The composition of the percolated sewage water as a basis for the concentration boundary condition at the SFM is only poorly documented for the dissolved components NH_4^+, Cl^-, SO_4^{2-}, and pH (BWB 1992). Therefore, a model composition was created. The dissolved non-redox dependent components, except for the measured, were taken from the mean composition of the treated wastewater of the WWTP from 1995 to 2006. Redox-dependent compounds were taken from Henze et al. (1995) for untreated wastewater. The content of particular organic matter (POM) in the sewage water was not considered.

Sewage water recharge was applied to the model for the operating period 1906–1991. The detailed model groundwater compositions for background, initial, and boundary water are listed in Hamann (2009).

Model Calibration

The calibration of the numerical model was carried out in two steps. In the first step, only the flow model was calibrated. For this purpose, the groundwater level was adapted by adjusting the DWTP well extraction rate and the SFM sewage water infiltration rate. The hydraulic conductivity was not modified due to its calibration in the basal 3D model (Hamann 2009). In Fig. 3.6, the calibration results for model I are illustrated. The fitting of the groundwater level is sufficiently well until the end of the 1970s. Indeed the temporal dynamic of the measured groundwater level is higher due to the seasonal different natural recharge rates, which are not considered as detailed in the model. But, due to an agreement of the long-term levels, the model is appropriate to simulate solute transport. The higher modelled levels near the SFM after the severe decrease in sewage water infiltration in 1976 are probably caused by overestimating the groundwater level at the northern boundary. However, there are no detailed records from the groundwater level in this area.

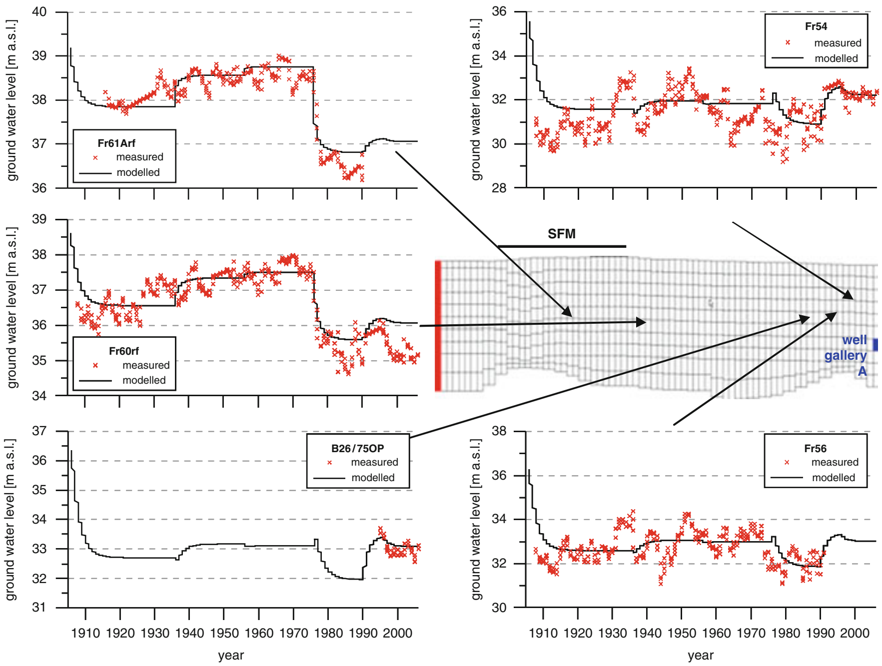

Fig. 3.6 Comparison of the measured and modelled groundwater levels at representative observation wells of the calibrated flow model I

In the second step, the nonreactive transport model was calibrated. By adjusting the effective porosity n_{eff} and the hydrodynamic dispersivity within plausible ranges, the chloride breakthrough curve at the DWTP well gallery A, originated from the sewage water, was adapted (Fig. 3.7). Also, the sewage water chloride concentration was adjusted, since there was only one measured value in the entire SFM operating period. Due to the fact that model II is located further to the east of well gallery A, the chloride breakthrough in the cell at the same latitude and depth of well gallery A was calibrated. For the longitudinal, horizontal transversal, and vertical transversal dispersivity (D_L, D_{TH}, D_{TV}) a reasonable ratio was specified with 100:10:1 (Gelhar et al. 1992).

During the model calibration, it was found that the simulation results were most sensitive to the effective porosity and only slightly sensitive to the hydrodynamic dispersivity. So, merely a range can be given for the best fit, which is $n_{eff} = 0.2$, $D_L = 10–100$ m, and $C_{chloride} = 200–220$ mg L^{-1}. The steeper decrease of the modelled compared to the measured concentration in the decontamination phase at the well gallery A is assumed to be caused by an overestimated groundwater gradient. As described above, the modelled groundwater level below the SFM is slightly higher than measured, and therefore the gradient. So, the resulting modelled flow velocity is slightly too high, in fact about 25%, according to calculations in Hamann (2009).

During the reactive simulations, the transport parameters could further be adjusted. The best fit was obtained with $n_{eff} = 0.2$ for model I (not shown) and 0.22 for model II (Fig. 3.8a) and $D_L = 10$ m (Fig. 3.8b) for both models (only shown for model II), confirming the non-reactive calibration results. Compared with the empirical correlations of D_L and the transport distance (Gelhar et al. 1992), the calibrated D_L is rather low. However, it is assumable that the small-scale heterogeneity of the hydraulic conductivity (see Fig. 3.5) causes an additional artificial hydrodynamic dispersion. It is remarkable that the choice of the applied cation exchange selective coefficients has such a high impact on the simulated ammonium breakthrough (Fig. 3.8c). Using the selectivity coefficients of the standard PHREEQC database, an appropriate CEC of 0.15 mol(eq) L^{-1} would

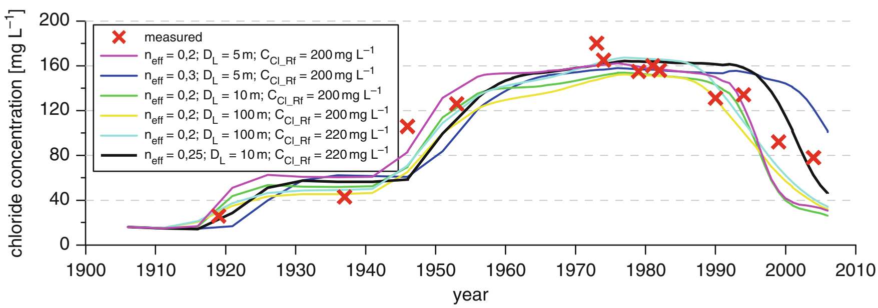

Fig. 3.7 Measured and simulated chloride breakthroughs at DWTP well gallery A for model II for different physical transport parameters as well as sewage input concentrations

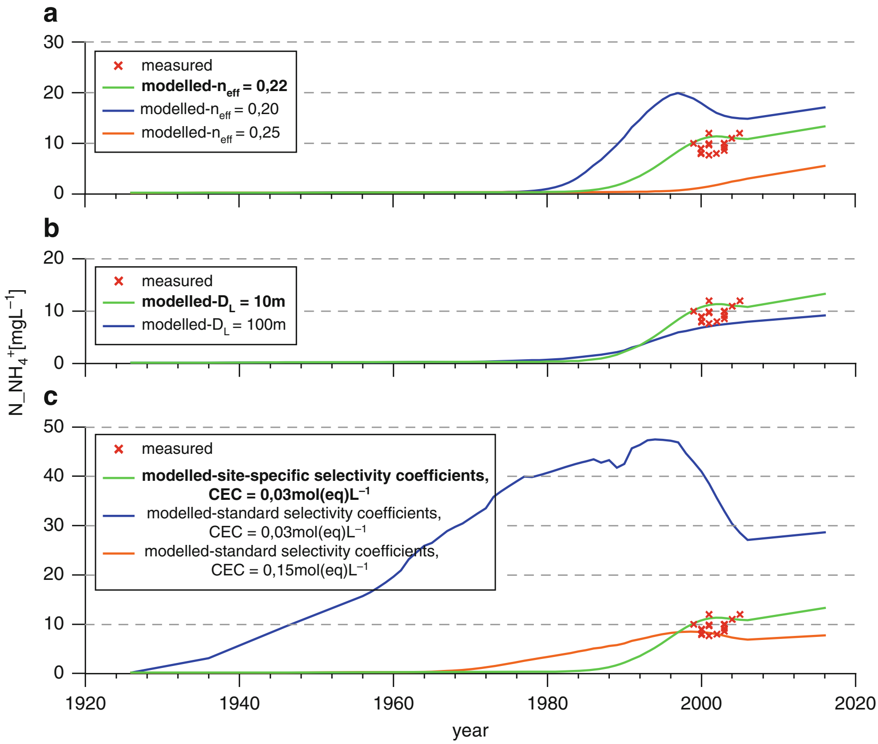

Fig. 3.8 Sensitivity of the ammonium concentration at the eastern DWTP well gallery B, simulated by adjusting the effective porosity (**a**), the longitudinal dispersivity (**b**), and the cation exchange selectivity coefficients (**c**) in model II. The *green plot* in (**a**), (**b**) and (**c**) is the best fit (corresponding parameters in the legend printed in *bold*)

have to be applied to fit the ammonium values, which is five times higher than the measured CEC.

3.3.1.3 Results and Discussion

The simulated long-term ammonium concentration profiles are very similar in both models (Fig. 3.9). The profiles are dividable into 3 phases. In the first phase, a continuous concentration increase is recognizable, caused by a continuous increase in the input flux at the SFM. After attaining the maximum concentration, due to the closure of the SFM, a steep concentration decrease up to 10–20 mgN L^{-1} is recognisable. It is followed by the third phase, the so-called tailing phase, with a lesser steep long-term concentration decrease. The different slopes in the second and third phases can be explained as follows. During the continuous contamination of the aquifer, the available sorption places become saturated by an excess of sorbable ammonium. This excess ammonium is transported unretarded through the aquifer to

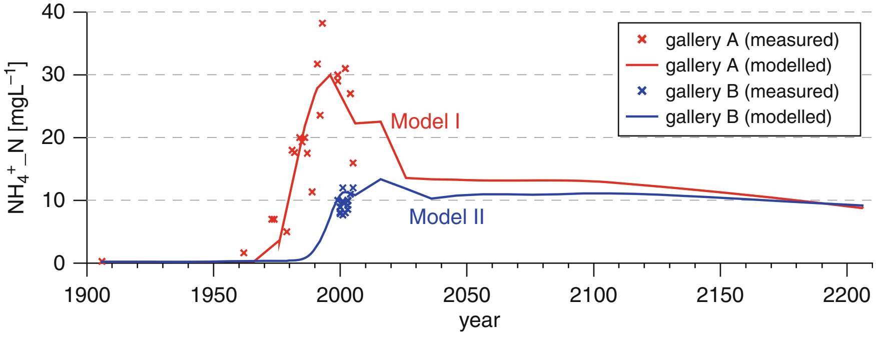

Fig. 3.9 Ammonium breakthrough curves at the DWTP well galleries A and B for the best-fit simulations of models I and II. The measured values are annual mean values

the front of the ammonium contamination, where sorption places are still available. The ongoing adsorption of ammonium at the contaminant front also explains the decrease in the maximum concentration depending on the distance to the source. The second phase with a steep concentration decrease reflects exactly the removal of this excess ammonium. Afterwards, in the third phase, the sorbed ammonium is removing. The duration of the tailing phase depends on the amount of competing cations in the upstream pristine groundwater displacing the contaminated groundwater, the CEC, respectively, the amount of sorbed ammonium and the size of the contamination. In the models, concentrations above 10 mg L^{-1} are to be expected for the next 150 years. For comparison, the modelling study in FUGRO (2000) with a linear retardation approach revealed a decontamination time of 80 years.

However, it has to be pointed out that there are two assumptions in the model concept: (1) the sorption of ammonium is fully reversible and (2) an ammonium input to the aquifer is restricted to the SFM operation until 1991. Former sediment analyses revealed a share of fixed ammonium of 20% (FUGRO 2000).

Accordingly, the concentration of dissolved ammonium during the tailing phase is overestimated at 20%. But, in contrast, by the second assumption, the duration of tailing is underestimated. Still, 18 years after closure of the SFM, the ammonium concentration in the aquifer adjacent to the SFM is up to 90 mg L^{-1} (data not shown). One can assume that the infiltration of untreated sewage water caused a concomitant accumulation of POM adjacent to the SFM. Thus, on the one hand, organic nitrogen was accumulated. On the other hand, the CEC was increased, which in turn was accompanied by an elevated concentration of sorbed ammonium. In the model, this accumulation process was not considered; instead, the ammonium release in the entire aquifer was coupled to the pristine CEC before the POM accumulation. Consequently, the model underestimates the release of sorbed ammonium and thus the duration of the tailing phase, respectively, the aquifer decontamination time.

A further uncertainty due to the assumption of the ammonium decontamination is the progression of aerobic conditions adjacent to the SFM, caused by an input of oxygen to the aquifer. Thereby, ammonium degrades by nitrification and is therefore removed from the aquifer. However, currently, the nitrification cannot compensate for the additional release of ammonium from the accumulated POM.

3.3.1.4 Conclusions

The flow and non-reactive transport models could be calibrated sufficiently to simulate the ammonium transport in the aquifer controlled by cation exchange processes. The simulation results show that the ammonium concentrations at the DWTP well galleries A and B are expected to be in the order of 10 mg L^{-1} at least for the next 150 years, due to a long-term tailing phase. Indeed, there is nitrification adjacent to the SFM, but on the contrary, this degradation process never compensates for the long-term release of accumulated ammonium adjacent to the SFM. With the two model transects, one can show that the maximum concentration of ammonium at the DWTP wells depends on the distance from the former source.

For high stressed urban areas, where drinking water production and sewage water disposal often are in a localized manner, this issue is important. Once the groundwater is contaminated by ammonium, natural attenuation is very time consuming, due to the persistence of ammonium. Therefore, the identification and quantification of urban water flow and solute transport is necessary for a sustainable water resource management. Numerical models can support this.

3.3.2 Fate of the Cyanobacterial Toxin Microcystin-LR During Sediment Passage

3.3.2.1 Introduction

In many urban areas, drinking water is won by bank filtration, a technique that uses sorption and degradation processes in the subsurface to remove contaminants from groundwater. Purification potential with respect to a certain toxic compound depends on manifold factors. Understanding the relevant elimination processes is therefore a challenging issue. The objective of this project is to describe the fate of the potent natural toxin microcystin-LR during subsurface passage. This project especially focuses on degradation of microcystin-LR in anaerobic zones as they occur in many bank filtration sites.

Microcystins are a group of potent natural toxins which are frequently released by cyanobacteria in eutrophic surface waters. Especially during summer months, algal blooms are observed worldwide, consisting, among others, of cyanobacteria. Two of the most common cyanobacterial species producing toxic microcystins are *Anabaena* and *Microcystis*. Microcystins are highly soluble in water and due to their cyclic structure chemically very stable (Carmichael 1994; Jones and Orr 1994).

More than 60 structural variants are known, which differ in their toxicity (Sivonen and Jones 1999). Microcystin-LR is the structural variant which is supposed to be the most hazardous one due to its high acute toxicity. A concentration limit of 1 μg microcystin-LR L^{-1} was therefore defined by the World Health Organisation. In this project, we consider exclusively microcystin-LR. Along with other microcystins, microcystin-LR is released into the water bodies when the cyanobacterial cells die. Once released into the water, microcystin-LR is transported into the groundwater with the infiltrating surface water.

The infiltrating water undergoes quality changes caused by physical, chemical, and biological processes (Jacobs et al. 1988; von Gunten et al. 1991; von Gunten and Zobrist 1993). Sorption to sandy sediment as it is typical for bank filtration sites is not a main process of microcystin elimination during sediment passage (Gruetzmacher et al. 2010). Tendency of microcystin-LR to sorb to sediment was shown to depend on the type of sediment. Conducting batch experiments, Miller et al. (2001) and Miller and Fallowfield (2001) obtained k_d values from 0.80 mL g^{-1} in sandy material to 4.4 mL g^{-1} in material with high content of clay.

Biological reactions include microbially mediated redox reactions. They are driven by oxidative decomposition of organic substrates and go along with reduction of so-called terminal electron acceptors. Following thermodynamic principles, consumption of electron acceptors proceeds from the highest to the lowest energy yield downwards and causes development of redox zones in the subsurface (Hunter et al. 1998; Massmann et al. 2004a, b). In this project, we focus on consumption of NO_3^- following oxygen depletion, since degradation processes of microcystins under anaerobic, denitrifying conditions are still not very well investigated. This is especially important with respect to anaerobic zones which are present at many bank filtration sites. Various studies about aerobic biodegradation of microcystin-LR showed that if oxygen is available, microcystin-LR usually is completely degraded within a few days (e.g. Bourne et al. 1996; Chen et al. 2010; Christoffersen et al. 2002; Jones and Orr 1994; Lahti et al. 1997). During aerobic degradation, oxygen becomes depleted and since consumption of NO_3^- as the next electron acceptor means a lower energy yield for the microorganisms, metabolizing microcystin-LR degradation rates decrease. Holst et al. (2003), Chen et al. (2010), and Gruetzmacher et al. (2010) showed that microcystin-LR is indeed degradable under anaerobic conditions. Coupling of denitrification processes and microcystin degradation was investigated by Holst et al. (2003) and Chen et al. (2010) using laboratory batch experiments. Results of both studies were contradictory. Adding $C_6H_{12}O_6$, Holst et al. (2003) and Chen et al. (2010) investigated in a series of batch-experiments whether biodegradation of microcystin-LR is a co-metabolic process in which the toxin is biodegraded along with other organic compounds. Results of these experiments were contradictory as well. Besides the rare and substantially varying results, an application of these findings to field bank filtration sites is not reasonable. This study is the first attempt to investigate coupling of denitrification and biodegradation of microcystin-LR using laboratory column experiments. They ensure a more realistic sediment/water ratio and most realistic flow settings. Furthermore, in all experiments presented here, microcystin-LR was used in naturally occurring low concentrations contrary to most other studies in which toxin concentrations exceeded reported groundwater levels by far.

The aim of this project is to examine sorption and degradation behaviours of microcystin-LR during sediment passage. The focus is set on anaerobic biodegradation with respect to the influence of NO_3^- as an attractive electron acceptor and $C_{12}H_{22}O_{11}$ as an extra source of energy on biodegradation of microcystin-LR.

3.3.2.2 Materials and Methods

To simulate conditions in an aquifer, four small columns were filled with filter sand and flown through by water spiked with a commercial microcystin-LR standard in naturally occurring low concentrations of 2–4 μg L^{-1}. Sorption and degradation behaviours of microcystin-LR were investigated, whereas the focus was laid on anaerobic degradation behaviour. The four columns used in the experiments were quartz glass cylinders which were closed with glass frits at both ends (Fig. 3.11a). Filling and operation of the columns followed advices given in the Supporting Information of Gruetzmacher et al. 2010.

For transport experiments, the columns were operated in a flow-through mode (Fig. 3.10a). Microcystin-LR (2 μg L^{-1}) and a tracer (NaCl) were added to the water flowing through the column. At the outlet of the column, electric conductivity and concentration of microcystin-LR were measured continuously. Flow rates were adjusted to filtration velocities of 0.20 ± 0.01 mL min^{-1}.

Quantification of the relevant transport parameters (hydrodynamic dispersion coefficient D and retardation coefficient R) was done by inverse modelling using a MATLAB inverse transport model. The model is based on the 1D advection-dispersion equation and describes the transport of microcystin-LR through saturated porous media. Modelling results were compared with results obtained by another inverse transport model, VisualCXTFIT (Nuetzmann et al. 2006).

For biodegradation experiments, the columns were operated in closed-loop arrangement (Fig. 3.10b). Water in a reservoir was once spiked with microcystin-LR

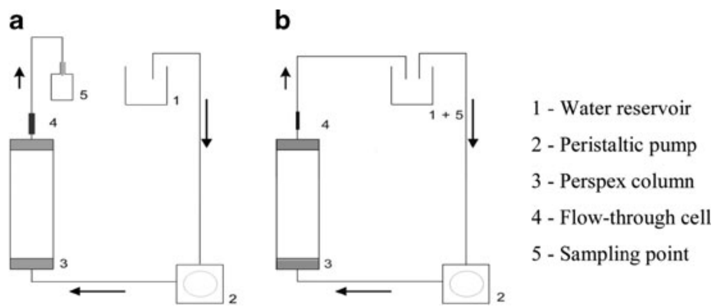

Fig. 3.10 (**a**) Scheme of flow-through column experimental setup (transport experiments), (**b**) Scheme of closed-loop column arrangement (degradation experiments)

in concentrations of 2 μg L^{-1} and pumped through the column continuously. The water reservoir was sampled every day with respect to microcystin-LR, pH, redox potential, and dissolved O_2. Aerobic as well as anaerobic biodegradation experiments were conducted. The aim of the aerobic experiments was simply to test whether the relevant microcystin degrading microorganisms were present in the sediment used and showed degradation behaviour comparable to other studies.

For anaerobic biodegradation experiments, the experimental setup was transferred into a nitrogen-flushed glove box to exclude O_2 supply (Fig. 3.11b). We followed two main strategies. First, the influence of NO_3^- as an attractive terminal electron acceptor was investigated by addition of varying amounts of NO_3^- to concentrations of 0, 50, and 500 mg L^{-1}. Second, $C_{12}H_{22}O_{11}$ as a labile carbon source that should stimulate the overall microbial activity was added in surplus (60 mM). After adding microcystin-LR and NO_3^- or $C_{12}H_{22}O_{11}$ to the water reservoir, it was analysed regularly with respect to microcystin-LR, pH, redox potential, and dissolved O_2 in aerobic experiments and additionally NO_3^-, NO_2^- and Fe^{2+}/Fe_{total} in anaerobic experiments.

Sediment used in all experiments was taken from a slow sand filter of a facility for technical-scale slow sand and filtration experiments of the Federal Environment Agency. The average grain size d_{50} was 0.5 mm and loss of ignition was 0.29%. Sediment was homogenized and sieved to a maximum particle size of 2 mm before it was filled into the column. Water used in the experiments originated from the same pond as the sediment. To avoid clogging of tubes and jointers, the water was filtered using a membrane filter of 0.45-μm pore size. In the experiments, a commercial microcystin-LR standard was used (*Alexis Biochemicals*). Analysis of microcystin-LR was conducted with an enzyme linked immuno-sorbent assay (ELISA) after storage of the samples at −20 °C. Redox potential, pH, and dissolved oxygen concentrations in the water reservoirs were measured using a WTW hand meter with a SenTix ORP redox electrode, SenTix 41 pH electrode, and CellOx 325 O_2 sensor. NO_3^-, NO_2^-, and Fe^{2+} were measured photometrically by means of

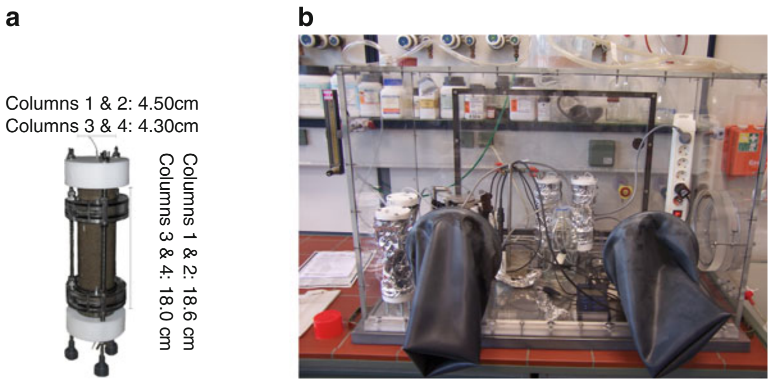

Fig. 3.11 (**a**) Quartz glass column used in flow-through and closed-loop column experiments, (**b**) Nitrogen-flushed glove box used for anaerobic biodegradation experiments

Table 3.4 Overview of experiments

Type of experiment	Testwater + ...	Column	Time	Parameters obtained
Transport experiment	2 μg L^{-1} MC-LR + Tracer (NaCl)	1, 2	24 h	Flow velocity v_a Retardation coefficient R Hydrodynamic dispersion D
Aerobic degradation	2 μg L^{-1} MC-LR	1, 2	10 d	Degradation rate λ
Anaerobic degradation Series I	4 μg L^{-1} MC-LR	1, 2, 3, 4	28 d	Degradation rate λ
Anaerobic degradation Series II	4 μg L^{-1} MC-LR +500 mg L^{-1} NO_3^-	1	36 d	Degradation rate λ
	4 μg L^{-1} MC-LR + 50 mg L^{-1} NO_3^-	2	36 d	Degradation rate λ
	4 μg L^{-1} MC-LR	3	36 d	Degradation rate λ
	4 μg L^{-1} MC-LR + 20 g L^{-1} $C_{12}H_{22}O_{11}$	4	36 d	Degradation rate λ

HACH Lange vessel tests (Fe^{2+}: LCK 320; NO_3^-: LCK 339 and 340; NO_2^-: LCK 341 and 342). An overview of all experiments conducted and specific treatment of each column is given in Table 3.4.

Parameters of aerobic and anaerobic biodegradation kinetics were quantified by creating an inverse MATLAB model based on simple Monod kinetics and stoichiometric calculations. Provided that enough data was available, an enhanced model including NO_3^- as an electron acceptor was set up using the geochemical speciation program PhreeqC for first estimates (Parkhurst and Appelo 1999).

3.3.2.3 Results and Discussion

Transport Experiments

Transport experiments reconfirmed that microcystin-LR does not sorb to the sandy material. Analysis of break-through curves and inverse transport modelling resulted in a pore velocity v_a of 0.48 m d^{-2}, retardation coefficient R of 1.23, dispersion coefficient D of 0.0011 m^2 d^{-2}, and effective porosity n_{eff} of 0.39. Retardation and dispersion coefficients calculated with the MATLAB model are in accordance with literature values. The retardation coefficient R of 1.23 obtained using the MATLAB model is in the range of retardation factors reported in literature (Gruetzmacher et al. 2010). Transport experiments affirmed that sorption is not the dominant elimination process of microcystin-LR during sediment passage.

Aerobic Biodegradation Experiments

After finishing transport experiments with the result that sorption is a negligible process of microcystin-LR, elimination biodegradation experiments were started.

Elimination of microcystin-LR is known to be a microbially driven reaction (e.g. Jones and Orr 1994; Bourne et al. 1996; Takenaka and Watanabe 1997; Lahti et al. 1998; Christoffersen et al. 2002; Holst et al. 2003; Chen et al. 2010; Gruetzmacher et al. 2010). Due to its cyclic structure, microcystin-LR is chemically very stable (Carmichael 1994; Chorus and Bartram 1999; Sivonen and Jones 1999). Therefore, abiotic degradation of the toxin was supposed to be a negligible elimination process as well.

The aim of the aerobic degradation experiments was to ensure that relevant microorganisms are present in the sediment. Under aerobic conditions, microcystin-LR concentrations declined within 10 days below the detection limit. A lag phase of 3 days occurred in one of the columns. The first-order degradation rate of microcystin-LR was 0.36 d^{-1} for column 2 (data not shown). This rate corresponds to degradation rates reported in literature (Gruetzmacher et al. 2010; Holst et al. 2003) for comparable conditions. Due to the lag phase in column 1, a simple Monod kinetics was applied to the measured values instead of a first-order rate constant. Using Monod kinetics was appropriate to describe the lag phase and subsequent toxin degradation. Monod kinetics was also applied to the toxin curve of column 2. Biomass was represented in the model as $C_5H_7O_2N$. Table 3.5 shows parameters obtained by the inverse MATLAB model for all experiments conducted. Although taken from the same pond, microorganisms in the sediment of columns 1 and 2 showed different toxin degradation behaviours, which were probably caused by inhomogenities in the microbial population.

Anaerobic Degradation Experiments

Two series of anaerobic experiments were conducted. The aim of the first series was to investigate degradation of microcystin-LR under anaerobic conditions without addition of potential accelerators. Therefore, the water in the water reservoir of each column was spiked solely with microcystin-LR in a concentration of 4 μg L^{-1}.

Table 3.5 Monod kinetic parameters of aerobic and all anaerobic degradation experiments except column 1 (see Table 3.6); Y in [mol biomass mol^{-1} microcystin-LR]; q, b in [d^{-1}]; k_s in [mol L^{-1}]; lag phase in [d]

		Microbial yield coefficient, Y	Max. growth rate, q	Microbial death rate, b	Half saturation constant, k_S	Lag phase
Aerobic degradation	Column 1	1.355	0.5	6.313e-15	1.178e-11	3
	Column 2	0.0097	0.047	6.313e-15	6.024e-10	–
Anaerobic degradation Series I	Column 1	1.355	0.250	6.313e-15	1.178e-11	14
	Column 3	0.0104	0.035	6.313e-15	8.500e-10	–
Anaerobic degradation Series II	Column 2 *+ 50 mg NO_3^- L^{-1}*	0.0045	0.004	6.313e-15	5.010e-10	–
	Column 3 *no NO_3^- added*	1.111	0.251	6.313e-15	3.091e-09	11

Analysis of microcystin-LR concentrations in the water reservoir showed that in columns 1 and 2, lag phases of 14 days occurred. In the following two weeks, toxin concentrations declined to values of about 0.5 μg L^{-1}, which then remained constant until the experiment was stopped after 30 days. Columns 3 and 4 showed different behaviours. Biodegradation of microcystin-LR in these two columns was characterized by complete absence of a lag phase. Within the first two weeks, toxin concentrations slowly decreased until they reached concentrations of 0.2–0.5 μg L^{-1}. In the remaining 2 weeks of the experiment, no further decline in toxin concentrations could be observed. Degradation of microcystin-LR in all four columns was described using simple Monod kinetics. Kinetic parameters fitted to the measured toxin concentrations with the inverse MATLAB model are shown in Table 3.5.

For comparison of the results, first-order degradation rates were calculated in columns 3 and 4, where no lag phase was observed. Degradation rates were similar to literature values (Gruetzmacher et al. 2010). Afterwards, the second series was started. Its results showed that addition of small amounts of NO_3^- as a potential attractive electron acceptor, represented by a concentration of 50 mg L^{-1}, did not clearly accelerate degradation of microcystin-LR (Fig. 3.12). In contrast, addition of high amounts of NO_3^- (500 mg L^{-1}) accelerated the degradation of microcystin-LR by 35.8%. After NO_3^- was depleted on the 5th day of the experiment, no further acceleration could be observed. Microcystin concentrations slowly declined to a value of 0.35 μg L^{-1} at day 36 when the experiment was stopped.

Experiments showed that when NO_3^- was present in unrealistic high concentrations (>100 mg L^{-1}), degradation of microcystin-LR occurred much faster than without NO_3^-. This finding affirms results of an anaerobic, denitrifying batch study

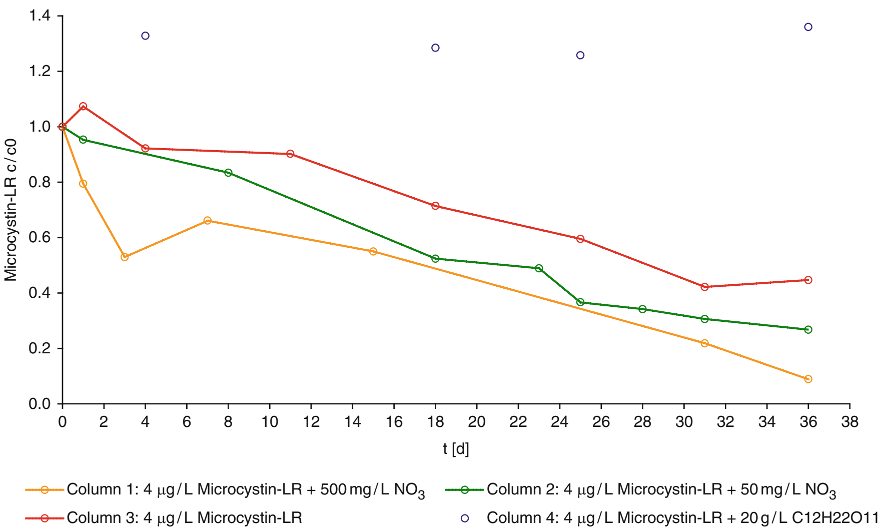

Fig. 3.12 Results of anaerobic degradation experiments, series II

by Holst et al. (2003), in which addition of 500 mg L^{-1} KNO_3^- improved microcystin degradation by 54% within the first 3 days. Afterwards, no further decline could be observed. Obviously, degradation rates of Holst et al. (2003) and our study vary widely. Differences may be caused by varying initial concentrations which may initiate another degradation pathway. Contrary to Holst et al. (2003) and the results presented here, Chen et al. (2010) observed a significant negative effect of NO_3^- on the degradation of microcystin-LR using batch experiments. Adding 20, 100, and 1,000 mg L^{-1} $NaNO_3^-$ to the bottles resulted in decreasing first-order degradation rates of 0.1, 0.08, and 0.07 d^{-1} compared to a degradation rate of 0.26 d^{-1} without additional NO_3^-. In our study, anaerobic first-order degradation rates were substantially lower: adding 50 or 500 mg L^{-1} NO_3^- led to degradation rates of 0.04 and 0.05 d^{-1}, respectively. Varying results may be caused by different experimental setups and initial conditions. Holst et al. (2003) and Chen et al. (2010) used batch experiments. Initial concentrations of microcystin-LR were in both studies unnaturally high (100 μg L^{-1} and 5 mg L^{-1}, respectively). On the contrary, in our study, we investigated degradation processes in anaerobic environment under most nature-like flow conditions using flow-through column experiments. Microcystin-LR was added to the columns in naturally occurring low concentrations of 2–4 μg L^{-1}. Also, different sediment/water ratios and varying nutrient supply caused by different flow conditions in batch and column experiments could have influenced the degradation behaviour of microcystin degradation microorganisms in the sediment (Gruetzmacher et al. 2010). Application of Monod kinetics was found to be appropriate for description of the anaerobic degradation process as well. All kinetic parameters of the simple Monod kinetics applied to measured data are listed in Table 3.5. Elimination of microcystin in column 1, which had additionally been spiked with 500 mg L^{-1} NO_3^-, was described using double Monod kinetics with NO_3^- embedded as an electron acceptor. Parameters fitted to the measured toxin contents are shown in Table 3.6.

Table 3.6 Double Monod kinetic parameters including NO_3^- as electron acceptor (column 1)

		Anaerobic degradation Series II	
		Column 1 + *500 mg* NO_3^- L^{-1}	
		NO_3^- >2.8e-3 mol L^{-1}	NO_3^- <2.8e-3 mol L^{-1}
Microbial yield coefficient Y	[mol biomass mol^{-1} microcystin-LR]	0.00004	0.00485
Max. specific rate of microcystin-LR utilization $q_{microcystin\text{-}LR}$	[d^{-1}]	0.00039	0.0048
First-order microbial decay coefficient b	[d^{-1}]	6.313e-15	6.313e-15
Half saturation constant microcystin-LR k_S	[mol L^{-1}]	1.290e-10	
Half saturation constant NO_3^- k_S	[mol L^{-1}]	5.06e-04	
NO_3^- turnover rate	[mol NO_3^- mol^{-1} microcystin-LR]	5.978	
Max. specific rate of NO_3^- utilization q_{NO3-}	[d^{-1}]	0.00032	
Lag phase	[d]	–	

Addition of $C_{12}H_{22}O_{11}$ to column 4 as an extra source of energy did not result in a decrease in microcystin-LR at all. Concentration of $C_{12}H_{22}O_{11}$ was not analysed during experiments. The fact that addition of $C_{12}H_{22}O_{11}$ completely inhibited microcystin degradation suggests that the labile carbon source $C_{12}H_{22}O_{11}$ was metabolized prior to microcystin-LR. Holst et al. (2003) found that addition of $C_6H_{12}O_6$ in low concentrations improved the degradation of the toxin. In contrast, Chen et al. (2010) showed that addition of $C_6H_{12}O_6$ had no statistical significant effect on microcystin metabolization. Comparing the results of our study to Holst et al. (2003) and Chen et al. (2010), one can conclude that addition of labile carbon sources such as $C_6H_{12}O_6$ or $C_{12}H_{22}O_{11}$ in very high amounts can have a negative effect on viability of microcystin degrading microorganisms. This is probably due to the fact that metabolization of $C_6H_{12}O_6$ or $C_{12}H_{22}O_{11}$ goes along with production of lactic acid and thus resulting in a lowering of pH, which may have a negative effect on viability of bacterial cells, as indicated by Surono et al. (2008).

3.3.2.4 Conclusions

Presence of microcystin-LR in surface waters may impose a risk to human health when these surface waters are used for drinking water abstraction by bank filtration. Since many bank filtration sites possess anaerobic zones, elimination of the toxin is not always guaranteed. Flow-through column experiments were conducted to ensure that sorption and transport behaviours were comparable to conditions in field sites. Considering biodegradation experiments, the results of this study imply that anaerobic biodegradation of microcystin-LR can be significantly stimulated if an attractive electron acceptor (NO_3^-) is available for the microcystin degrading microorganisms. The limiting factor of this acceleration was found to be the concentration of the electron acceptor NO_3^-. Below a threshold concentration of 100 mg L^{-1} NO_3^-, no further acceleration could be observed. The coupling of denitrification and biodegradation of microcystin-LR was shown using column experiments contrary to batch experiments showing the same behaviour reported in literature. Addition of $C_{12}H_{22}O_{11}$ as a labile carbon source completely inhibited microcystin metabolization. Production of lactic acid followed by $C_{12}H_{22}O_{11}$ metabolization was assumed to have had a negative effect on the viability of the microcystin degrading bacteria. Since microcystin-LR was not degraded at all, one can conclude that the anaerobic biodegradation process of the toxin is not co-metabolic. Previous studies on influences of NO_3^- and other carbon sources such as $C_6H_{12}O_6$ used batch experiments. The results obtained in this study and results of these batch experiments vary substantially. Differences may be attributed to varying initial conditions or different sediment/water ratios and therefore varying nutrient and electron acceptor supply. These differences may induce other degradation pathways which lead to different degradation rates.

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Chapter 4
Urban Soils in the Vadose Zone

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4.1 Introduction

Between the soggy ceiling of the ground water aquifer and the uppermost interface of earth and air is the unsaturated space of soil particles and pores invisible to most surface dwellers – the *vadose zone*. In cities, this space can be frozen in time under buildings and sidewalks, and contaminated with various kinds and concentrations of polluting substances. With more than 50% of the world's population living in cities as of 2007, research on the composition, function and dynamics of urban soils is of utmost importance for urban ecological questions as well as the for the well-being of city dwellers world wide. Even before the 50% demographic benchmark, interest in anthropogenic soils began stirring in Germany in the 1970s in Berlin and Essen (Burghardt 1995; Blume 1975). At that time, research concerns revolved around the proper classification of soils in urban areas and the dilemma of restoring and re-using former industrial sites. From the 1980s until the beginning of the 1990s, pollution of urban soils with organic and inorganic contaminants became the focus of many studies (Thornton 1991; Lux 1993; Radtke et al. 1997). Since then, research on urban soils has substantially broadened. The *BMBF* (Federal Ministry of Education and Research) project "Evaluation of Urban Soils" from 1993 to 1996, for example, included groundbreaking work on the chemical, physical and biological properties of anthropogenic soils, involving major soil science institutions from the universities of Kiel, Essen, Hohenheim, Halle, Rostock and Berlin. Results are presented in Blume and Schleuss (1997).

Despite growing interest in urban soils, not much is known about the interrelated processes within the vadose zone. The following contribution seeks to address this knowledge gap by highlighting the results of studies conducted from 2001 to 2010 by two research groups on urban soils. The material introduced here has been specifically chosen to give a broad and relevant overview of urban soils, their

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associated uses and potential risks. Key issues include the dynamics of water and soil materials at urban locations under consideration of spatial heterogeneity, organic soil substance, and soil-biological transformation processes (*DFG research group Interurban, Water and Organic Matter in Anthropogenic Soils: Dynamics and Processes*) as well as the hydraulic and sorption properties of urban soils under consideration of land use and soil management *(DFG-GRAKO graduate research group, Perspectives on Urban Ecology*).

We start out by presenting some general ideas on urban soils and several guiding principals in their evaluation. We then examine the properties and utilization of several urban soils, their influence on the vadose zone and finally their cultural significance for urban societies. The first section addresses soil material prevalent in nearly every city of the world – rubble, and in the case of Berlin, massive deposits of building rubble from WWII. What is the physical, chemical and biological nature of rubble as a soil substrate? Aspects of soil development on rubble, hydrological behavior and the associated release of sulphur are closely examined in two locations – a former urban brownfield at Lützowplatz and a gradient downslope of Teufelsberg, the highest slag heap (114.7 m) in the greater area of Berlin.

The second section addresses areas that have been partly sealed because of building development. What is the impact on the local water balance and to what extent can partly sealed soils fulfill their filter function? Furthermore the question is taken up as to whether it is justifiable to treat these areas with herbicides (Roundup) to get rid of the vegetation in the cracks of the sidewalk. The third section discusses roadside soils. As before, changes in soil properties due to road construction and long-term traffic are a focus of attention. We examine the water balance of roadside soils and the long-term relocation of heavy metals at the AVUS Highway in Berlin, the oldest motorway in the world.

Finally, we consider the task of communicating the function and fragility of the vadose zone. While fundamental research on the properties and dynamics of urban soils is the main focus of our efforts, we are also concerned with the greater understanding and appreciation of soil physical and hydrological concepts. In the final section, several public outreach projects are introduced as examples of innovative communication. They specifically address issues featured in the other parts of this chapter, demonstrating how representatives from the arts and humanities are confronting challenges such as soil sealing, storm water run-off and contamination.

4.2 Characteristics and Evaluation of Urban Soils

Urban soils are distinguished from agricultural and natural soils by a range of anthropogenic factors such as the presence of human artifacts and contaminants, alkaline pH, high black carbon content, high bulk density, low soil moisture, warmer soil temperatures, and a relatively young stage of pedogenetic development. The heterogeneity of urban substrates and their constituents is much greater than in natural soils. The same is true for disturbances, such as compaction or mixing of horizons. Even more importantly, the pollutants in the substrates and the immissions themselves often have very heterogeneous compositions.

Given this heterogeneity, quantitative information on hydraulic properties and their impact on the groundwater is required for the evaluation of urban soils in the vadose zone. This is especially the case when future management targets come into play. The evaluation of soil water balance, sorption behavior, and associated physical aspects, for example, plays an important role in urban and environmental planning decisions. As we learn more about the physical properties of urban soils, we also uncover remnants of past planning schemes and can use this integrated knowledge for future land use management.

Pollutants in older, densely populated neighborhoods, for example, are often a consequence of unregulated waste management from times past. Specific contaminants might include combustion residues of heating processes, feces and refuse that were disposed of, in, and on the surrounding soils. Waste materials associated with certain manufacturing and production processes also accumulate on industrial and commercial sites due to leakages and accidents (Blume and Schleuss 1997). While many of these sites are no longer in use, a number of papers and projects have examined the contamination of urban soils by organic and inorganic pollutants. Atmospheric emissions represent another source of excess nutrient inputs in the soil. And research on the impact of animal excrements (dog urine) on the vitality of urban trees has also been made available (Balder 1994).

While the transport processes of such contaminating substances are influenced by the same factors as those found in natural soils, their characteristics are quite different. Important distinctions are sealed and partly sealed areas, typically characterized by concentrated infiltration, soil compaction, and the occurrence of technogenic (as opposed to geogenic) materials. Excessive exposure to nutrients and pollutants causes surface contamination of sealed and partly sealed areas. After a period of time, these contaminants are then conveyed through the soil substrate via the rainwater through seams and open pore spaces into the subsoil and vadose zone, or directly into the canalization.

The degree of pollutant fluctuation can vary greatly within a specific location and unit of soil. Fluctuation depends foremost on the type of substrate (e.g., debris, building rubble, ashes, slag and domestic refuse) and the source of the pollution, such as effluents, sewage sludge or depositions from traffic (Renger and Mekiffer 1998; Hiller and Meuser 1998; Kocher et al. 2005; Mekiffer 2008). Mekiffer for example, has shown both (1) that total contents of heavy metals in general have a wide span in urban soils, and (2) that regular ranges of content or depth gradient specific to certain substrates are not recognizable.

This means that the mobility of heavy metals from technogenic soil substrates can differ greatly for the same total contents. Non-point pollution inputs with a diffuse distribution can come from industrial, traffic and domestic fuel immissions. Point contaminations, on the other hand, are often a local, i.e. a discrete result of industrial use, waste disposal or sewage farms. Despite this variability, a preliminary risk evaluation into the existence and type of pollutants in urban soils can be partly achieved with the help of observable on-site findings. Meuser (1996) developed a substrate key that allows a first identification and diagnosis of soil-extrinsic admixtures as well as guidelines for risk assessment. The following site factors are taken into account when evaluating the mobility of heavy metals and their potential risk to the groundwater:

- Substrate materials
- Depth of groundwater level
- Mobility determining soil characteristics (e.g., pH-value, clay and humus content, DOC, redox potential)
- Source and type of pollutants (e.g., lead, cadmium)
- Interaction with other cations or electrolytes
- Kind and duration of site use (time period and length of use, time since use discontinued).

Another important question in the urban context concerns the consequences for the local water balance due to increased sealing through buildings and roads. In the highly industrialized countries of Europe, America and Asia, sealed and developed areas take up a vast percentage of land surfaces. For example in Germany over 12% of the total land area is already sealed, with a continuing upward trend. In addition to aspects concerning the drainage of sealed surfaces, we know that sealing can contribute to the generation and aggravation of heat stress. Because of this, green spaces in urban environments fulfill an important climatologic balancing function. The question arises as to whether we can estimate the actual evaporation for different degrees of sealing and furthermore whether and how we can strategically use this knowledge in urban planning and development.

4.3 Soils on WWII Rubble

4.3.1 Introduction

A common soil substrate in cities across Europe and the globe, rubble often makes up a large component of the soil hidden beneath parks and private gardens, sidewalks, and other public places. When the last smoke cleared on May 8th, 1945, much of Europe lay buried in rubble. Approximately 400 million m^3 of debris was left in the wake of World War II in Germany alone, due to the bombing of residential and industrial buildings (Blaum-Jordan 1947). In Berlin, about 30% of the residential buildings were destroyed completely, and another 45% partly razed (Arndt 1947). In the past 65 years, neighborhoods have been rebuilt and parks reforested, obscuring traces of approximately 75 million m^3 of debris deposited throughout the city.

The soils we discuss in this section contain large amounts of fired brick and mortar. They developed on WWII rubble or on century-long accumulations of debris due to the cyclic demolition and reconstruction of houses. The soil type

Fig. 4.1 Urban soil with a rubble layer from WWII in 30–60 cm depth

developing on rubble material from buildings is usually a Pararendzina because of the calcareous parent material. Figure 4.1 shows a typical soil with rubble material in the subsoil. The nature of rubble influences the physical, chemical and biological properties of the soil. It also affects the quality of water percolation. For example, the water budget may be altered due to the gradual release of sulphur from the mortar or other technogenic substrates (ashes, coal) that can be found in various buried materials.

In this section we start out with a discussion on the characteristics of rubble material. We evaluated >50 sites in Berlin with rubble deposits in order to get information on typical site properties. Specifically, we included a soil genesis study by Blume and Runge that analysed a rubble soil development on a former urban brownfield at the Lützowplatz, Berlin in 1978. Finally, we address concerns about sulphate leaching associated with desorption from rubble and other technogenic components we studied along a down-slope gradient on Berlin's largest slag heap, Teufelsberg (Devil's Mountain in English).

4.3.2 Soil Material Properties

Parent material for the pedogenesis of rubble soils comes from different types of building materials, which were constructed and demolished in different ways and at different times. The sorting and disposal of materials also differs from place to place and generation to generation. For our purposes here, we may distinguish between three groups of materials:

1. Metals, ceramics, glass, bitumen
2. Leather, slate, marble, limestone fragments
3. Carbon, organic carbon of the fine earth fraction, inorganic carbon of the coarse fraction

Some basic information on debris soils and their components are listed in Table 4.1.

In most cases soils developed on rubble from WWII have a high coarse fraction (>2 mm). Dominating skeletal components are brick, mortar (including plaster and stucco), slag, ashes and sometimes unburnt coal. The analyzed components are characterised by alkaline pH-values. Seventy-five percent of the samples demonstrate an electrical conductivity of up to 141 µS/cm. This is a first indicator of the slightly saline conditions of the heterogeneous material. Bricks mainly consist of oxygenates from Si, followed by oxygenates from Al, Ca, Fe, Mg, and K. X-ray analysis of bricks showed that the most common minerals are clay minerals (kaolinite, illite, montmorillonite, chlorite), quartz, and carbonates (calcite, dolomite an siderite). At a lower percentage, the bricks contain Fe-oxides (hematite, goethite), sulphates, and sulphides (gypsum, pyrite, markasite). Five to twenty percent of the minerals are X-ray amorphous. Mortar, on the other hand, is characterised by a high amount of silicates (up to 80%). The samples that were investigated showed a lower percentage of Al- and Ca-compounds than bricks.

For ashes and slag, there is a wide range of chemical compositions, depending on the nature of their origin. In soils developed on debris from WWII, for example, ashes from domestic fuel are prevalent. Ashes originating from anthracite coal contain oxides of Si (40–55%), Al (23–35%), Fe (4–17%), Ca (1–8%), Mg (0.8–4.8%), K (1.5–4.5%), Na (0.1–3.5%), S (0.1–2%) and Ti (0.5–1.3%). The most important minerals are quartz, mullite, illite, hematite and magnetite, and sometimes carbonates and sulphates. Slag is of an inhomogeneous composition. It often contains inclusions of other materials such as ashes, molten products and stones.

The release of cations and anions from skeletal components was investigated using the soil water extracted from two different grain sizes of every sample (2–6.3 mm and <2 mm). The release is influenced by the size of the grains, but the dominating factor is their chemical composition.

Table 4.1 Properties of urban soils containing rubble [according to Blume and Runge (1978) and own measurements]

Component	Fraction	C	$CaCO_3$	B	Cu	Mn	Zn	Porosity	Wilting Point	Field Capacity
	Weight%			ppm				Vol.%		
Fine earth <2 mm	60	0.7	10.3	30	100	160	800	40	5	18
Constituents										
Brick	22.4	0	3.0	20	30	500	200	45	17	38
Mortar	12.4	0.1	15.5	10	30	14o	300	34	3	26
Coal		62.0	2.3	3	40	120	9,000	–	–	–
Slag	0.6	6.2	1.7	60	80	1,500	300	–	–	–
Artificial products	2.7	5.3	11.0	70	2,200	900	24,000	–	–	–
Natural products	1.9		n.b.	n.b.	n.b.	n.b.	n.b.	–	–	–

Rubble contains up to 15% $CaCO_3$ and high total contents of trace elements such as Cu, Mn and Zn. However, due to high pH-values, the availability of these elements in the soil solution for plants as well as for the transport into the groundwater is mostly low. Toxic reactions to Zn may be expected after a sharp decrease of pH-value. As long as the pH-value remains high trace elements such as Pb and Cd are not harmful, despite high levels. Because of the high amount of fine pores, the porosity and the field capacity of brick is relatively high.

The available water holding capacity (AWmax) of sites with rubble depends on the size and amount of bricks. As Blume and Runge (1978) have already shown, mostly ranges of 50–120 mm were found. However the origin and manufacturing process of the bricks also plays an important role in the water holding capacity in the pores, as Fig. 4.2 demonstrates. While the traditional loam brick has a relatively high water capacity of >25 Vol%, industrial clay or loam bricks have <20 Vol%. One reason might be the higher burning temperature of the industrial brick material during the manufacturing process. Many bricks, especially those with black color contures, have been burned twice – the first time during their production and a second time during the war because of extremely high temperatures of the fire blast after bombing.

The quantity of plant available water on sites with rubble not only depends on the size and kind of bricks but also on the surrounding soil material. Table 4.2 shows the typical composition of rubble soils with their technosol constituents. From Fig. 4.3 one can see that urban soils consisting of building rubble have an

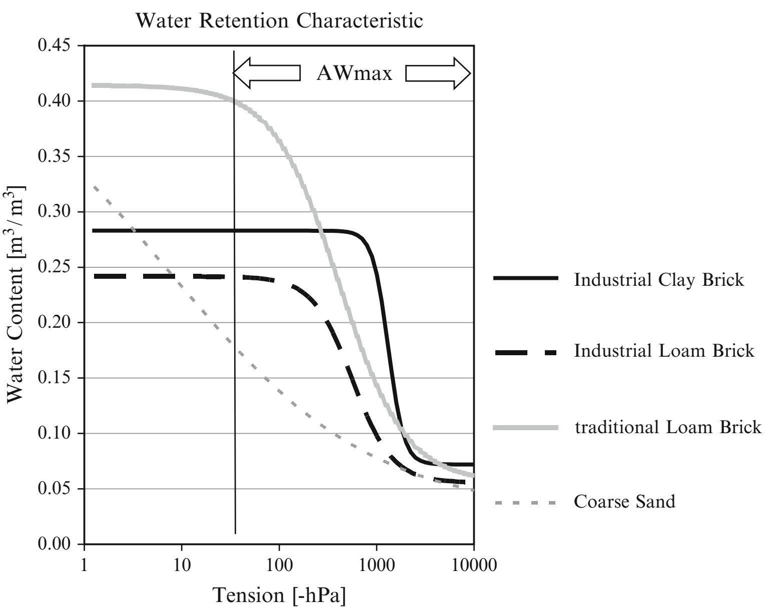

Fig. 4.2 Available water capacity (AWmax) for various bricks

Table 4.2 Debris material and its main technogenic components

Component	Percentage (vol.%)
Brick	2 – 60
Mortar	2 – 50
Slag	2 – 30
Ashes	2 – 50
Glas	2 – 10
Tar	5 – 10
Charcoal	up to 5
Concrete	5 – 10
Soot	up to 2

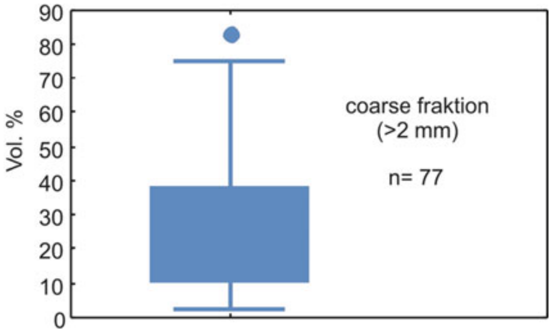

Fig. 4.3 Coarse fraction (>2 mm) of urban soils consisting of rubble

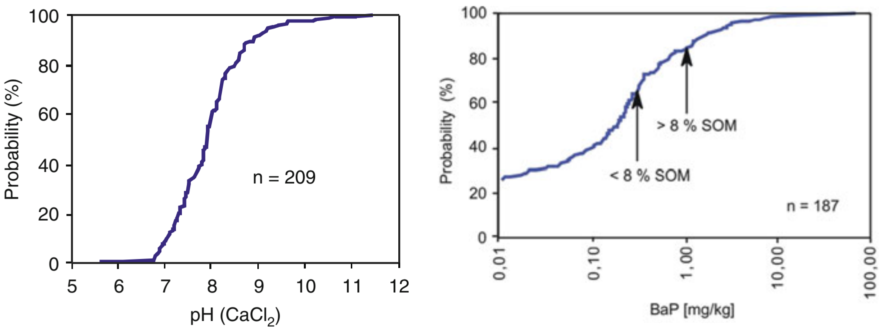

Fig. 4.4 Probability distribution of pH value (*left*) and benzo-a-pyrene (BaP) concentrations (*right*) in urban soils consisting of rubble

average skeletal fraction of 25%, with a wide degree of variance. In some urban soil horizons >80% rubble exists.

The average pH-value of the technogenic rubble substrates lies in the weakly alkaline region, as indicated by Fig. 4.4 on the left. 35% of the samples have a benzo-a-pyrene content that lies above the precautionary limit for soils with humus content of <8%, according to the Federal Soil Protection Act. This is actually less than expected from the manifold effects of combustion on rubble material. The low percentage is suggestive of an inaccurate classification of substrates.

Table 4.3 Characteristic parameters of trace element distributions in rubble soils

[mg/kg]	pH-value	Pb	Cd	Cu	Zn	BaP
Median	7.9	108	0.115	28.05	180	0.183
Mean value	7.96	366	0.66	260.99	478.72	1.096
25 Percentile	7.42	44.3	<NWG	10.8	65.2	0.0048
75 Percentile	8.3	330	0.63	68	590	0.483
90 Percentile	8.9	1,000	1.3	138	1,297	1.5
Maximum value	11.4	7,170	17.2	2,500	4,100	69
Trigger values of the SPA, sand with SOM <8%	–	70	38	72	76	35

SPA Soil protection act of Germany, *SOM* soil organic matter content

Heavy metals such as lead, cadmium, copper and zinc are partly found in high concentrations in rubble soils. The content of Pb, Cu and Zn spans several orders of magnitude in this substrate. In a considerable percentage of samples, these three heavy metals exceed the precautionary limits for the soil type sand according to the Federal Soil Protection Act (Table 4.3). Moreover, the distribution of lead and zinc is characterized by a high proportion of outlying and extreme values.

4.3.3 Soil Genesis

Rubble soils were analysed for the first time by Runge (1974) and Blume and Runge (1978). They analyzed soil samples taken from 1972 to 1974 at the Lützowplatz in Berlin-Tiergarten. The buildings of this site were destroyed during WWII and removed at the end of the war. This resulted in the development of a typical urban wasteland with its characteristic ruderal vegetation. In 1985 the same authors conducted a second soil analysis in order to examine soil forming tendencies. By the end of the 1980s, a hotel and gardens were built on the site of the original study location and today Lützowplatz no longer exists in its open, post-war appearance. After the German unification in 1989, subsequent construction of new buildings and pavements gradually redeveloped the area over time.

One of the first and most important soil forming processes is humus accumulation, or the incremental deposition of organic matter from decaying plant litter, excrement and animal residues. In the 1970s Runge (1974) found 3–6 kg/m^2 of organic matter accumulated in a depth of 10 cm. A comparable soil profile contained 5.2 kg/m^2 more organic matter than its parent material. Recent data have shown an accumulation of 7.6 kg/m^2, which was found at depths of up to 30 cm. The average increase of organic matter amounts to 0.4 kg/m^2 per annum for the first 12 years and 0.2 kg/m^2 per annum for the second 12 years.

The increase in organic nitrogen was even more substantial than the increases in organic matter. In 1972 the profile at Lützow Platz shows an N-increase of 150 g/m^2 in comparison to the parent material, and in 1985 an increase of 210 g/m^2 could be found. For the two time periods this implies a rise of 12 g/m^2 per annum in the first 12 years and 6 g/m^2 per annum for the second 12 years (or 120 and 60 kg/ha per annum). This increase was a result of the N-uptake of soil bacteria in symbiosis with wild-growing black locust (Robinia pseudoacacia) trees. It is also worthwhile to mention that the C- and N-amounts in the upper soil horizon (0–2 cm) were in steady equilibrium after only 12 years. After this period their amounts did not increase anymore (Blume and Runge 1978).

Many urban soils have a low skeletal fraction of rubble in the top 10–20 cm. This may be due to crushing under heavy leveling machines, weathering of mortar and the activity of animals, especially arthropods. The loss of carbonates in the upper soil horizon is partly redistributed in the subsoil. Blume and Runge calculated carbonate losses of 4–5 kg/m^2, an extremely high amount, which was probably caused by the inhomogeneous parent material. The additional loss during the last decade would add up to 40–50 g/m^2 per annum, which is 400–500 kg/ha per annum. According to the authors, soil acidification has not led to any significant consequences because there is still enough free calcium carbonate in all the horizons. Although clay formation cannot yet be proven, it is obvious that through the disintegration and decalcification of particles, more clay and silt is present in the upper 6 cm of the profile.

Urban soils with rubble components usually have a deep, sometimes very deep root system, depending on the size and compaction of stones in the subsoil. The root zone often ends with a compacted rubble layer, which forms a mechanical barrier. For the most part, roots are unable to enter the cracks of bricks and other stones, but nonetheless one can observe a high density of root hairs on the surface of bricks and other rubble components. Due to a high total pore space and especially a high coarse pore volume, the soils are extremely well aerated and drain rapidly. The total water capacity is comparatively high with 300–500 l/m^2 down to a depth of 2 m, even though only 80–120 1/m^2 are available for plants because of dead water in the fine pores of the brick materials. This means that deep-rooted plants and trees, such as the black locust have a sufficient water supply, whereas plants with shallow roots suffer from water shortages. The low humidity and the higher temperature in the inner city increase evaporation and interception. As a consequence water stress may occur occasionally, even for plants with deeper root zones.

The nutrient conditions of the soils studied are generally good. The total and especially available potassium and phosphorus are higher than levels in pure sandy soils in the city. This is still the case even after the high stone fraction is taken into account. The main root zone already shows comparable amounts of available nitrogen to agricultural soils in Berlin (Blume and Runge 1978). The favourable nitrification conditions are indicated by nitrate domination. An additional input of 20–30 kg N/ha per annum through pollution also has to be taken into account. An even higher eutrophication is caused by animal excrements and urine.

Finally, the heavy metals Pb and Cd are also accumulated in the topsoil (Pb 400–450, Cd 0.5–0.6 ppm) due to the deposition of dust in the upper 4 cm and also in a depth of 10 cm (Pb 200–250, Cd 0.3–0.35 ppm). In contrast, B, Cu and Zn-contents are stable or depleted through seepage or plant uptake.

4.3.4 Sulphate Leaching from Rubble Deposits

Sulphate concentrations in the upper aquifers of many German cities have been increasing continuously over the last 40 years (Pekdeger et al. 1997). Particularly in the inner city of Berlin, sulphate concentrations exceed precautionary limits set out in the Federal Drinking Water Act. High sulfate concentrations in the groundwater negatively affect the taste of drinking water and enhance oxidation processes, which lead to corrosion of water works infrastructures because of aggressive acids.

Sulphate leached from WWII rubble is among others one important source of sulphate concentrations in the groundwater. Assuming ideal solution conditions in Berlin, only 25% of the sulphur reserve of nearly 75 million tons of WWII rubble, has been solubilized and transported to the groundwater over the last 60 years. With sulphate levels already exceeding threshold levels in the inner city, an incalculable risk of groundwater contamination is developing for several catchment areas in Berlin in the medium term. Figure 4.5 shows sulphate concentrations of the main aquifer of Berlin. High sulphate concentrations furthermore correlate with sites that have high amounts of rubble deposits. Compared to other regions in Germany, the sulphate concentrations in the groundwater of Berlin are exceedingly high (Fig. 4.6) and pose a challenge to future environmental planning and mitigation schemes.

The S-pools of different technogenic materials from urban soils can vary significantly. Slag has the highest S-content, with up to 0.7%. Coal-ashes are also often SO_4-rich. The total S of brick varies between 0.01 and 0.3% and mortar shows

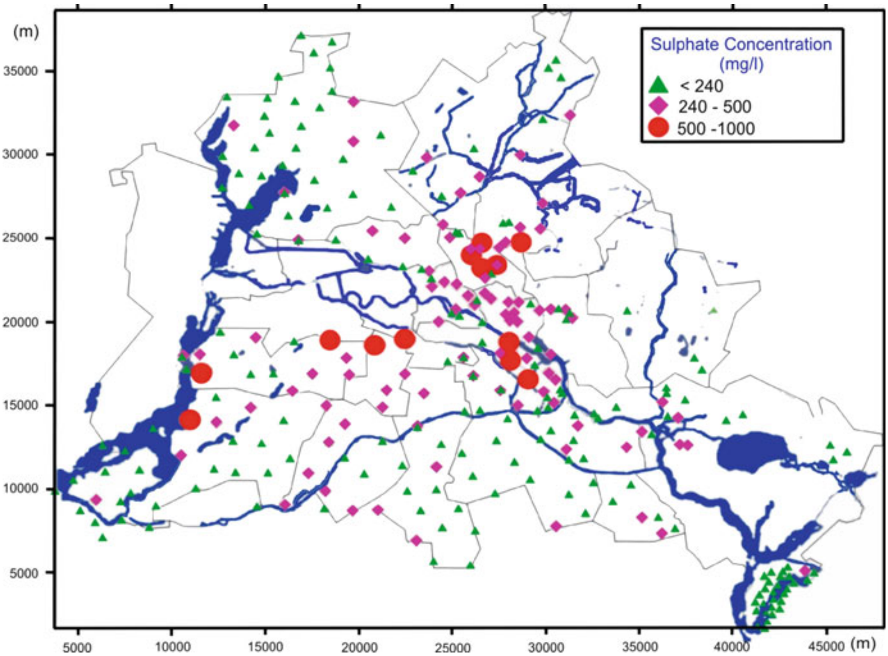

Fig. 4.5 Areas of high sulphate concentration in the main aquifer of Berlin (Pekdeger et al. 1997)

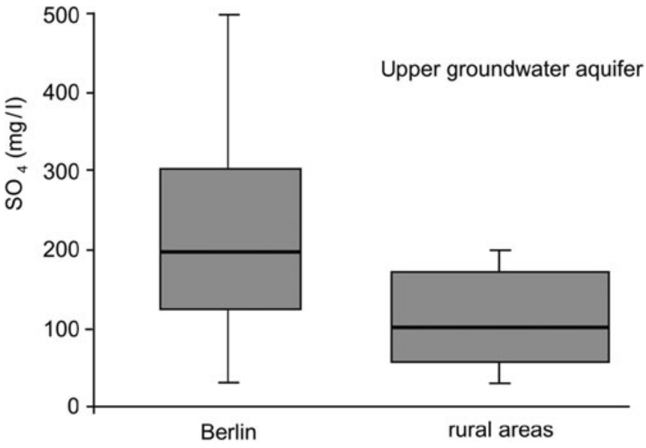

Fig. 4.6 Sulphate load of the surface-near aquifers of Berlin compared to those of rural areas, according to Hannappel et al. (2003)

S-Values between 0.08 and 0.12%. However, 75% of the 54 rubble samples taken from various sites in Berlin had a total S-content of under 0.14%. There was also no significant correlation between total S-amount and water-soluble SO_4. The reason for this behavior can be attributed to the different chemical S bonds in the samples taken. Technogenic components with a grain size of <2 mm have a higher bulk density, but a lower percolation velocity. Furthermore the concentration of ions in the leachate is higher than in the leachate of the coarse skeletal fraction (2–20 mm). Gypsum-rich material (10%) released a constant concentration of SO_4 during the whole experiment, unlike slag-rich material, which initially produced a high concentration of SO_4 in the leachate that decreased rapidly as a function of time. One can surmise that the type and grain size of the technogenic components have a strong influence on the release of SO_4.

In order to get a first impression of the leaching behavior of various rubble materials, soil column experiments were carried out in the laboratory. The advantages of column experiments are (1) controlled boundary conditions and (2) the use of defined soil material in the column. Moreover, one can easily study the effects of particle size of rubble material, various flow rates as well as pH and electrolyte concentration. Figure 4.7 shows an example of such a desorption experiment from a typical sample consisting of high amounts of rubble from WWII. At the beginning of the experiment, very high solute concentrations with >700 mg SO_4/l occur. However, after the sample passed through twice, the sulphate concentration decreased to values of <100 mg/L. These values are unproblematic according to the Federal Water Protection Act.

It appears that only the initial flush of percolation water has a high sulphate concentration. Although water repellent behavior is often observable in sandy urban soils, a long-term prognosis for sulphate concentrations is difficult to make, because only parts of the soil components are wettable and active in the transport of water and solutes.

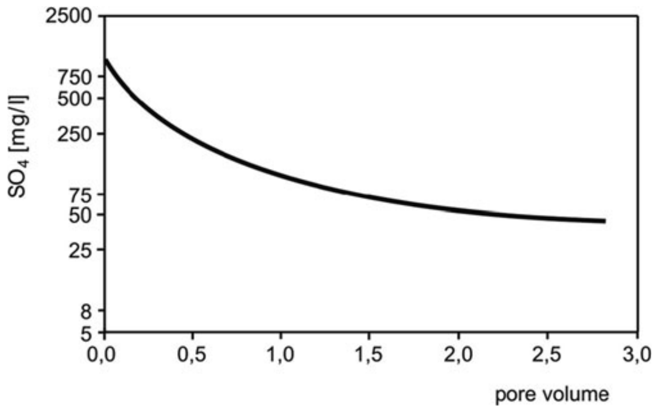

Fig. 4.7 Sulphate concentrations during a leaching experiment, pore volume of 1 means that the solute of the soil volume was percolated (break through) one time completely

4.3.5 Conclusions

Urban soils with rubble material from buildings can be found hidden beneath backyards and sidewalks worldwide. Depending on the amount, depth, compaction, particle size, and type of parent material, rubble can have positive effects on the water holding capacity and nutrient supply for plants. However, we have seen that technogenic composition as well as grain size also has a strong influence on sulphate leaching rates. In the future, research on long-term sulphate desorption may help to predict sulphate transport in the vadose zone. In combination with site-specific information on the active soil water flow parts of the soil, better prognoses can be given (1) to which extent the sulphate concentration will increase in future (Fig. 4.8) and (2) for how many years high sulphate concentrations in the first groundwater aquifer have to be expected.

4.4 Sealed Soils

4.4.1 Introduction

In 1997 Wessolek and Facklam started studying the physical and chemical site characteristics such as texture, heavy metal content, and infiltration rates of partly sealed urban soils. In collaboration with the Berliner Wasserbetriebe (Berlin Public Water Works), they began to investigate the annual and the long-term mean water components of partly sealed urban areas with the help of lysimeters with different surface coverings. In the first phase of the GRAKO research program Nehls et al. (2006, 2008) analysed the physico-chemical behaviour of seam materials. The focus

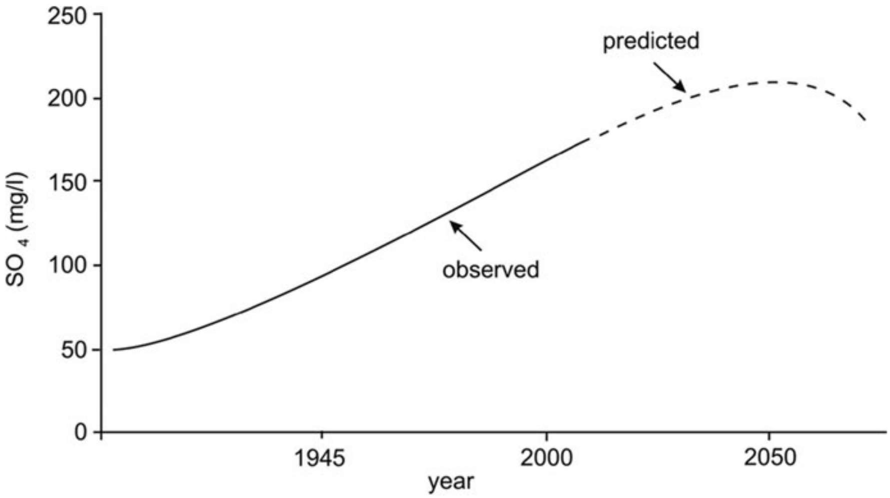

Fig. 4.8 Numerical scenarios help to predict sulphate concentration in the upper aquifer of Berlin (schematically)

lay on the sorption characteristics for trace elements deposited by dust, traffic and other emissions. In the second GRAKO research phase Klingelmann (2009) investigated the sorption behaviour and leaching of the herbicide Glyphosate, which is commonly used for weed control on pavements as a cost-effective chemical method. In the third GRAKO phase Rim analysed the runoff and infiltration behaviour of two different pavements using specially designed weighable lysimeters with a high temporal resolution. In this section interesting results of these investigations will be presented.

4.4.2 Hydraulic Characteristics and Water Components of Sealed Soils

Figure 4.9 shows the long-term mean soil water components of an agricultural site in Brandenburg compared to a partly sealed urban area in Berlin. When plants are growing, evapotranspiration consists of interception (an inactive process in which fallen rainwater evaporates directly from the plant surface into the atmosphere), active transpiration by root water uptake of the plants, and evaporation from the bare soil.

If the depth to groundwater is shallow, capillary rise from the groundwater into the root zone can take place and enhance evapotranspiration. The whole soil-vegetation-atmosphere system is driven by two boundary conditions: energy from atmospheric conditions and water supply by rain, soil water, and groundwater to enable evapotranspiration. In the city, evapotranspiration is drastically reduced

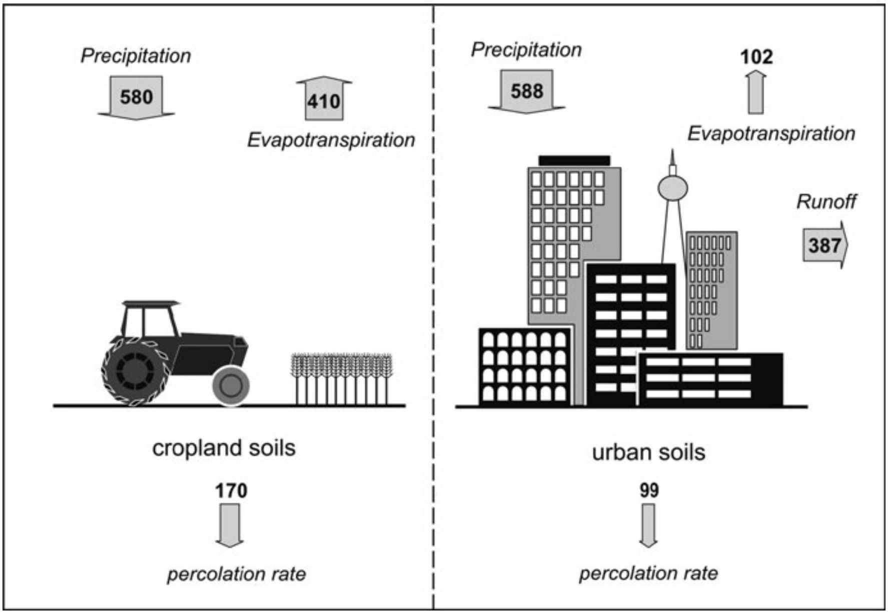

Fig. 4.9 Mean soil water components for arable land in Brandenburg (*left*) and partly sealed areas in Berlin (*right*)

because surfaces are covered by streets, pavements, and buildings. Only small patches of the soil surface are unsealed and participate in the infiltration process. As a consequence of increased surface sealing, runoff also increases and the mean percolation rate is reduced. If the soil surface is sealed, part of the rainfall runs off or evaporates while the rest infiltrates through the soil-filled gaps between the sealing materials. Seam material is often the only infiltration pathway on partly sealed pavement systems. It plays an important role concerning sorption processes of pollutants and for the transport to the upper groundwater aquifer. Partly sealed pavement systems are constructed with retention-weak materials to assure a high hydraulic conductivity (a rapid penetration of water) of the pavement bed and therewith prevent damages of the pavement system, e.g., by frost or flooding.

Different paved surfaces exhibit high infiltration rates (36 up to 180 mm h^{-1}) with a great variability between the different surface coverings as well as between different locations on the same paved area (Illgen et al. 2007). Illgen has shown that the infiltration rates decrease due to compaction and, with increasing age of the seam material, due to clogging effects caused by the accumulation of fine material in the upper layer of the seam material. A decrease in infiltration rates by a factor of 10 or even 100, as compared to newly constructed pavements, was observed for individual sites. Flöter (2006) has found that the infiltration rate on an 8-year-old pavement is still comparatively high. He observed that paving with a seam width of 3 mm and 5% seam material (95% paving stones) infiltrates up to 80% of the rainfall, if the rainfall intensity is low to moderate (<0.5 to 4 mm/h). Only heavy rainfall events cause high runoff rates. In order to derive runoff coefficients with a high resolution Rim et al. (2009) has analysed individual rainfall and runoff events using a weighable lysimeter with different pavement surfaces (Fig. 4.10).

About 160 rainfall events were identified and analyzed from April to September 2009. Rainfall events with intensities of >0.04 mm/min produced runoff from the cobble stone surface, whereas rainfall events with intensities of >0.02 mm/min caused runoff from the concrete slab pavement. After a rainfall event with an intensity of >0.2 mm/min up to 0.5 mm/min, the RCs for the concrete paving surfaces increased at a significantly slower rate compared to their increase at lower intensities. RCs for the cobble stone surface differed in so far, as that they continued to increase even after intensities of >0.4 mm/min were surpassed. These results lead to the conclusion that RCs are subject to a non-linear increase with rainfall intensity until a threshold of about 0.7 mm/min is reached. After that, one can expect the runoff coefficient to remain at a constant value. However, compared to natural soils, surface runoff increases as the infiltration rate decreases. The consequences can be fast and severe for sewage systems or watercourses, a relevant for predicting floods. Furthermore, it can cause an overflow of combined sewage systems, which increases the pollution risk of urban rivers with untreated wastewater (Heinzmann 1998). Another result of the decreased infiltration is a smaller amount of available soil water for evapotranspiration. The processes described above lead to a gain in sensible heat and a loss of latent heat: the city becomes warmer compared to the environment (Wessolek 2008). Soil sealing contributes to the urban heat island effect.

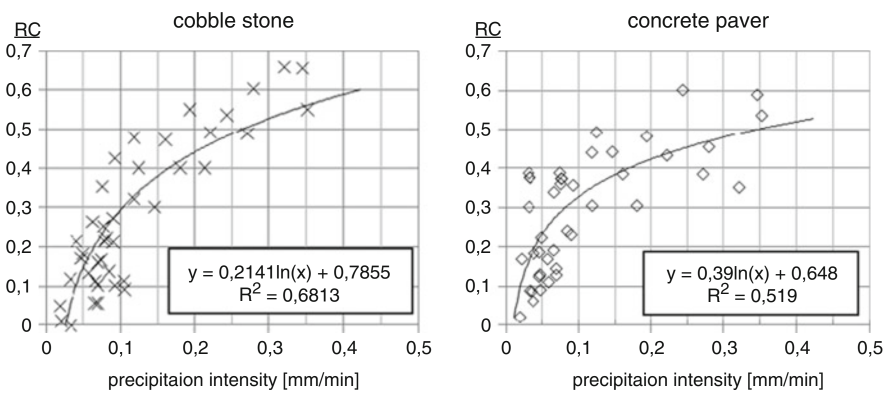

Fig. 4.10 Runoff coefficient (RC) for mosaic cobble stone pavement (*left*) and concrete pavement (*right*) as a function of the precipitation intensity

4.4.3 Seam Material

The term "seam material" describes the soil material developed from technogenic sand used between the pavestones of sidewalks. It has a black or brownish black colour and is mostly only 1 cm thick and contains all kinds of deposited urban dirt and dust, such as leaf litter, hair, oil, dog faeces, food residues, cigarette stubs, plastic packaging, glas shards – in short, any kind of urban waste that is small enough to lodge into the cracks in the pavement after being ground down by pedestrians or vehicles. As a consequence of this unintentional pavement-milling, pedestrians and cars also wear down the soles of their shoes and tyres, sending the resulting abrasions into the seams as well. Figure 4.11 shows a picture of typical seam material in detail.

Over the years, urban dirt and dust accumulates in the upper layer of the coarse sand between the paving stones. This results in a different composition and thus different properties of the upper layer of the seam material (Nehls et al. 2006). Compared to the original sandy seam material, the altered seam material shows significantly higher C_{org} contents and higher amounts of micro- and mesopores, leading to an increase in available water capacity of 0.05–0.11 $m^3\ m^{-3}$. Compared to natural sandy soils with similar contents of soil organic matter, the seam material possesses similar macropore volumes, but, due to the particulate character of its organic matter, the volume of mesopores and micropores is smaller. These characteristics are of particular interest as seam material takes on important soil functions, such as filtering, buffering and groundwater recharge in urban areas with a high degree of sealing, up to >35% (Wessolek 2008).

Among other factors, semi-permeable pavements are also responsible for the infiltration of rainwater in urban locations. The seams allow infiltration and reduce

Fig. 4.11 Photo of dark seam material (0–1 cm) and light original sandy seam filling (1–5 cm) of the sidewalk at Pfluegerstrasse, Berlin

evaporation. As a consequence, groundwater recharge rates are 99–208 mm per annum in sealed areas, compared to only 80 mm per annum for a pine-oak forest around Berlin (Wessolek and Renger 1998). If rainwater accumulates in puddles on the pavement, the groundwater recharge can be greater than 300 mm per annum. Puddles with up to 60 mm depth are no rarity in older neighbourhoods. We gauged a puddle on the pavement in front of our department with a volume of 56 L at a horizontal projection of only 2 m^2.

Rainwater runoff in urban areas is often contaminated, e.g., by heavy metals. Dannecker et al. (1990) and Boller (1997) found Pb concentrations of up to 0.3 mg/L in street runoff, while Cd concentrations were as high as 0.0076 mg/L (Dierkes and Geiger 1999). The high infiltration rates might result in high contaminant fluxes even if dissolved contaminant concentrations are low (Dannecker et al. 1990). An assessment of the risk of soil and groundwater contamination requires sorption parameters for the paving and construction material, which is mainly sand. However, one cannot extrapolate the filtering properties of other soils, because the organic carbon (C_{org}) of this material differs in origin, quality and function from non-urban, natural soils (Nehls et al. 2006). The percentage of black carbon for instance, a "combustion-produced black particulate carbon, having a graphitic microstructure" (Novakov 1984) in C_{org} is higher compared to natural soils. However, the increase of the cation exchange capacity (as an indicator for the sorption capacity) in seam material with increasing soil organic matter content is less distinct compared to agricultural and forest soils as described by Renger (1965) and Wilczynski et al. (1993) respectively (Fig. 4.12). One can conclude that the urban carbon quality (urban dirt or whatever else it may be) is less effective

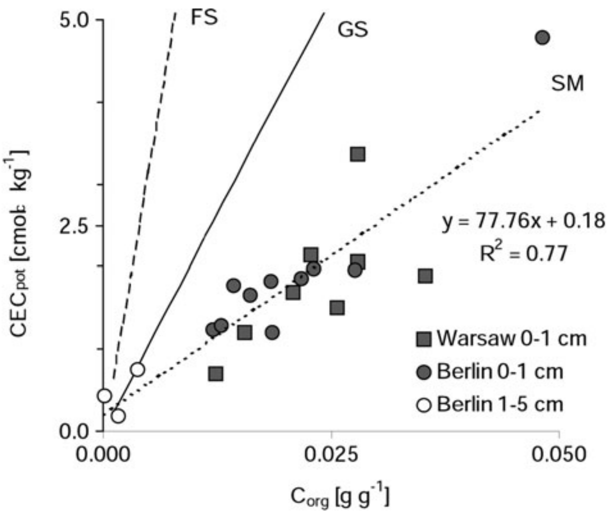

Fig. 4.12 Relationship between organic carbon content and potential cation exchange capacity (CECpot) in seam material (SM), sandy German soils (GS), according to Renger (1965), and sandy forest soils [FS, according to Wilczynski et al. (1993)]

compared to humic substances developed by humification processes in nature. In other words, to reach a sorption capacity of 2.5 cmolc/kg soil only a humus content of 0.6% Corg in a forest soil and 1% Corg in an agricultural soil is needed, but 3% Corg would be necessary to reach this value for an urban soil.

Though the sorption capacity of seam material is less pronounced compared to natural humic substances, seam material is a valuable filter and influences transport processes through the pavement. Nehls et al. (2008) has shown that even after 50 years of heavy metal input by dust and rain, most of the trace elements are still bound in the first few centimetres of the topsoil and not transported into deeper soil layers, despite high water fluxes in the seams.

4.4.4 Weed Control on Pavements

In addition to the important role for the infiltration of water on partly sealed areas, the seam material is also a habitat for plants. Pavements with a high percentage of seam material like mosaic pavements, which are common in Berlin, are especially prone to be partly covered by moss and weeds. However, as the main function of pavements is to provide a stable, secure, dry and level ground for pedestrians, weeds on pavements are often unwanted by municipal departments who maintain city streets and sidewalks. In addition to safety reasons, weed covered sidewalks can also be an aesthetically unwelcome sight in the perception of local residents. The presence of weeds on pavements tends to indicate a city in decline and is thus controlled by the public authorities.

For these reasons different chemical and non-chemical (thermal and mechanical) methods are available and frequently used (Hansen et al. 2004; Kempenaar and Spijker 2004; Rask and Kristoffersen 2007). While non-chemical methods are more time-consuming and therefore more expensive, most public authorities, such as the Berlin public sanitation service (Berliner Stadtreinigungsbetriebe), prefer to use the herbicide glyphosate (mainly in the commercial form of Roundup Ultra) for weed control on pavements as a cost-effective chemical method. In Germany the use of glyphosate on hard surfaces such as pavements and paved driveways, courtyards and squares, is forbidden. An exception for the use of glyphosate on hard surfaces can be granted by the competent authority of the federal states (Bundesländer) in accordance with § 6, 3 of the German Plant Protection Law (PflSchG 1998). Furthermore the authorities can regulate the application technique that should be used. In Berlin the only permitted technique is the application of Roundup Ultra via the risk-reducing roller wiper Rotofix. In contrast to spray applications, this machine coats the weeds with the herbicide via a roller. In this way a direct soil contamination should be avoided. Additionally, the principles of "good professional practice" (BMELV 2005), e.g., no application if rain is likely, are to be observed for every glyphosate application.

While no specific regulations for the use of glyphosate on pavements and road-sides exist in some countries (e.g., Finland, Latvia), other countries, e.g., The

Netherlands and Denmark, have started programs for weed control on hard surfaces aiming to reduce and phase-out herbicide use within urban areas (Kempenaar and Spijker 2004; Kristoffersen et al. 2004). This is ecologically important, as the use of herbicides in urban areas causes different environmental problems compared to their use in agriculture. This is especially due to the minimal opportunity for sorption of herbicides and the small areas of infiltration mentioned above. Water quality monitoring studies have demonstrated that a disproportionate contamination of waters by non-agricultural herbicide use exists (Kristoffersen et al. 2008). Several studies showed that the urban use of the herbicide glyphosate and its degradation products contribute to surface water contaminations (Skark et al. 2004; Kolpin et al. 2006; Byer et al. 2008).

4.4.5 Glyphosate

The herbicide glyphosate is frequently used for chemical weed control in urban areas due to its non-selectivity and its comparatively good environmental properties. Because of its pronounced tendency to adsorb to soil constituents, its fast microbial degradation and its low toxicity, the risk of surface or ground water contamination is generally assumed to be low (Vereecken 2005). Nevertheless, a wide contamination of surface water as well as some groundwater resources with glyphosate and its main degradation product amino-methylphosphonic acid (AMPA) has been reported (Feng and Thompson 1990; Newton et al. 1994). Furthermore, ecotoxicological studies showed negative effects of glyphosate and its formulation Roundup Ultra on non-target organisms in sublethal concentrations (Glusczak et al. 2006; Costa et al. 2008). As glyphosate is the most widely used herbicide in agriculture worldwide numerous studies investigating its fate in agricultural systems exist, especially since genetically modified glyphosate-resistant crops have been introduced in the USA and South America in the last ten years (Scribner et al. 2007). By contrast, investigations regarding the fate of glyphosate and its degradation products in urban areas, e.g., on pavements, are rare (Strange-Hansen et al. 2004; Spanoghe et al. 2005). As above mentioned studies concerning the transport and fate of glyphosate in agricultural systems have shown that the use of this herbicide can be problematic under certain circumstances, it is of great importance to gain more information about its fate in urban systems. Whereas agricultural soils have comparatively high retention capacities for glyphosate, urban systems, such as partly sealed pavements, exhibit low retention capacities and increased runoff and infiltration rates, rendering them more susceptible to negative effects.

4.4.6 Leaching of Glyphosate

Klingelmann (2009) has found unexpectedly high levels of glyphosate and AMPA in the leachate of a lysimeter experiment. She compared a sealed and unsealed

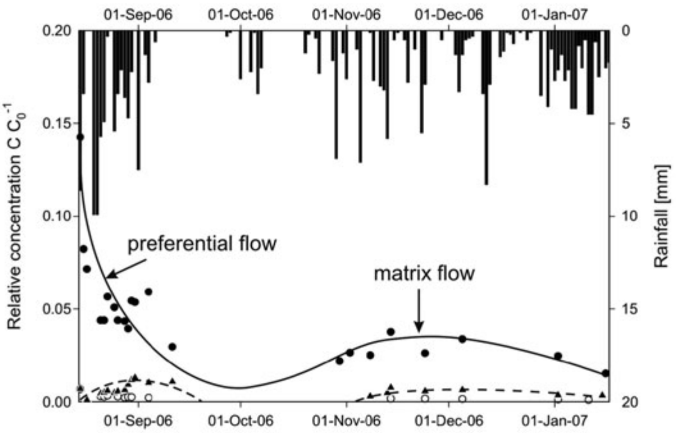

Fig. 4.13 Relative concentrations of glyphosate leaching of an unsealed and partly sealed lysimeter

lysimeter, both of which had been treated with Roundup Ultra from a Rotofix apparatus, just as they are applied in Berlin under site-similar conditions (Fig. 4.13).

The maximum glyphosate concentration in the leachate of the unsealed lysimeter was found to be 81.8 μg L^{-1}, compared to a maximum concentration of 1,184.3 μg L^{-1} of the lysimeter covered with a partly sealed pavement. At the beginning of the experiment a first flush of glyphosate leached through the lysimeter by preferential flow because of high rainfall intensities. Afterwards the herbicide was transported over a longer period by matrix flow. On the paved lysimeter 15.3% of the amount applied was leached in the form of glyphosate and 57.7% was leached as active ingredient equivalent (AMPA). The significantly different amounts of glyphosate and active ingredient equivalent leached from the lysimeters were definitely caused by their different surface covers. The unsealed lysimeter was covered with a 7 cm layer of loamy sand on sandy soil. Its sorption capacity was 14-fold higher than that of the coarse sand of the sealed lysimeter. Due to the higher sorption capacity, the amounts leached via matrix flux from the unsealed lysimeter were much smaller than those from the sealed lysimeter. Nevertheless, the amount of glyphosate transported via preferential flow by the unsealed lysimeter amounted to 0.3% of the total glyphosate applied, and was thus very similar to the amount transported by the sealed lysimeter. This can be explained by similar active pore volumes and the lack of sorption due to the very short contact times with the soil matrix. Even though only 30% flowed through the unsealed lysimeter, the higher pore volume of the unsealed lysimeter yielded the same active pore volume as for the sealed lysimeter. The amount of active ingredient equivalent that was leached from the sealed lysimeter was six times higher than the amount leached from a similar partly sealed lysimeter.

4.4.7 Conclusions

In urban areas sealing of soil surfaces often leads to ecological problems caused by the increased and accelerated runoff and reduced evapotranspiration in comparison to non-sealed soils. Therefore, cities are normally drier and hotter than the surrounding areas. During heavy rainfalls the excess water causes mixed sewage systems to overflow. This is one of the main threats to water quality of urban water bodies. Therefore, runoff reduction by increasing infiltration is one of the main ideas of ecological urban planning. This goal can be reached by an increased use of pervious pavements with a high degree of seam material. In many European cities, especially older ones, pervious pavements are common and used to infiltrate the rainwater directly in order to prevent runoff. We should encourage the practice of such traditional city planning ideas by avoiding a complete surface sealing and by keeping the soil water in the local system as long as possible. The natural infiltration processes of urban soils and seam material also cleans the percolation water and plays an important role in protecting groundwater. Moreover we can come to appreciate that even urban dirt has a filtering and buffering function. In a certain way one can say that dirt cleans dirt.

Finally a few comments should be made about the use of chemicals in weed control on urban pavements. Even though the experimental conditions enhanced natural percolation rates by preventing the occurrence of runoff and restricting the leaching depth, the glyphosate results suggest that the use of glyphosate in urban areas should be fundamentally challenged and further experiments concerning the leaching and runoff of glyphosate in urban areas should be conducted. If the use of glyphosate is deemed necessary, it should be limited to exceptional cases, in consideration of the following points. Due to the measured background concentrations of AMPA, the application of glyphosate should be limited to once a year.

The coarse sand and gravel normally used for pavement construction are likely to have low sorption capacities for glyphosate. Therefore, the application of glyphosate on partly sealed urban areas should be differentiated according to the construction age of the partly sealed areas, the geological parent material and the percentage of seam material, as leaching volumes from areas with a low percentage of seam material, like the lysimeter with 5% seam material, seem to be higher.

Klingelmann's study (2009) was limited to the leaching of glyphosate through soil on partly sealed areas. However, the transport of glyphosate with runoff is a hydrological bypass due to the missing retention in soils. In this case, contaminated water is routed directly into sewage systems or surface waters. This might be the more crucial issue regarding the contamination of surface waters with glyphosate. As methods for non-chemical weed control (mechanical and thermal methods) and combinations of chemical and non-chemical methods have been well tested (Hansen et al. 2004; Kempenaar and Spijker 2004; Kempenaar et al. 2004; Rask and Kristoffersen 2007), chemical application methods in urban areas should be substituted and reduced as much as possible.

4.5 Roadside Soils

The construction, traffic and maintenance of major roads and motorways significantly change the original physical, biological and chemical properties of the soil directly on-site and in the surrounding area. Figure 4.14 shows a schematic cross section of a road and the influenced road environment.

Under the asphalt and/or concrete layers of the road surface there is generally a gravel layer with high (=proctor) density for stabilization and frost protection. This gravel layer is typical for Central Europe, whereas in countries without frost seasons such a layer is not necessary.

During road construction, the organic topsoil was either taken away or left buried beneath the gravel layer in depths of >1 m. The hard shoulder, built in the course of the road construction, measures about 1.5–5 m and is located directly along the asphalt edge. This part of the road is necessary to infiltrate the street runoff and consists of gravel-sand mixtures with high-saturated hydraulic conductivities. The 5–8 m of soil adjacent to the hard shoulder are mostly compacted and disturbed with little to no vegetation. After this distance the influence of the road slowly decreases and after 10–15 m predominantly original soil profiles are to be found.

Roadside soils often contain up to 30% technogenic materials and stones. These are calcareous (2–10%) and have a pH value of >7.0. Due to traffic emissions, trace elements at the soil surface (0–30 cm) greatly increase up to a distance of 20 m.

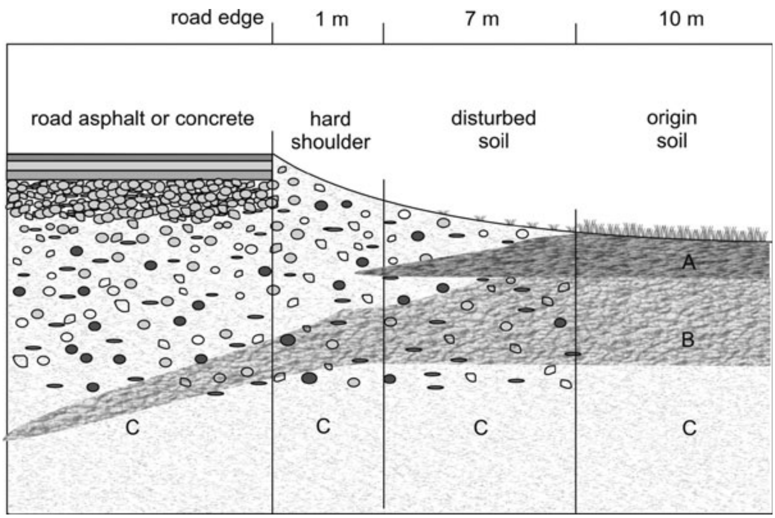

Fig. 4.14 Schematic cross section of a roadside soil

4.5.1 Sources of Pollution from Roads and Vehicles

The pollutants of the roadside environment originate from a variety of different sources, including:

– Automobile exhaust emissions
– Automobile component wear
– Road degradation
– Atmospheric deposition
– Discarded waste (litter)

Emissions from automobiles not only stem from the residues of complete fuel combustion (CO_2 and H_2O), but also from the residues of incomplete fuel combustion, oil leaking from engine and hydraulic systems, fuel contamination, fuel allowances, and wear of engine parts. A high potential source of pollutants is also the abrasion of the road surface itself, as well as the corrosion and wear of individual vehicular components such as the car body, tires, brakes, clutch or motor parts. A quantification of the release of individual building components is difficult because the composition varies widely depending on the manufacturer. Nevertheless, some studies have been carried out on the release and deposition rates of particulate pollutants from motor components and road degradation (e.g., Revitt et al. 1990; Muschak 1990).

Thus, a very complex mixture of pollutants is emitted in the area of the roadside soils. These are mainly:

– Carbon monoxide
– NOx
– Hydrocarbon (HC)
– Sulphur dioxide
– Methane (CH4)
– Lead, copper, zinc, cadmium, nickel, chromium and other heavy metals
– Organic pollutants such as PAHs.

4.5.2 Mechanisms of Dispersion

Most pollutants are emitted in a gaseous state or are deposited on the road as fine particles. Figure 4.15 shows a typical view of a road with pathways of dispersion by dry and wet depositions into the roadside environment.

The pollutants are transported across the road surface with the rain and then deposited as suspended or dissolved particles. Depending on the type of road and the inclination of the hard shoulder, spray and road runoff water can be transported as far as 10 m across the adjacent roadside area (Golwer 1991; Kocher 2007). With the additional influence of wind and airflow, very fine particulate matter can be transported up to a distance of about 25 m and deposited in the surrounding area

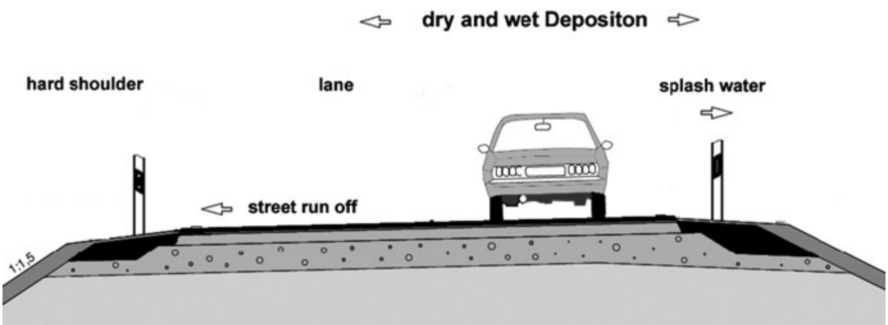

Fig. 4.15 Road with the pathways of dry and wet deposition

(Boller 2006). An analysis of studies on major roads and motorways (Golwer 1991) determined three different areas of pollution for roadside environments. These are:

– The range of 0–2 m, which is dominated by runoff water from the road and splash water
– The range of 0–10 m, which is partly influenced by splash water and partly by runoff water, depending on the inclination of the hard shoulder
– The range of 0–100 m, affected by airflow and wind

Dry depositions under the influence of traffic have shown higher concentrations of heavy metals and many organic contaminants, than comparable counterparts in rural environments. Wet depositions of urban areas, in the form of street runoff and also spray water, contain high concentrations of pollutants, in comparison to normal precipitation (Harrison et al. 1985; Makepeace et al. 1995; Wigington et al. 1986).

The composition and amount of dry and wet deposition depends on many factors, such as the particle size of the pollutant, traffic intensity, wind direction, wind velocity, rain events and intensity, previous dry periods, vegetation cover or construction of urban canyons and motorway design (Barbosa and Hvitved-Jacobsen 1999; Pagotto et al. 2001). In urban areas the construction and road design are important factors that influence the amount and the dispersion of soil pollution.

An example of the amounts of dry and wet depositions is given in Fig. 4.16. The study site is located on the motorway A7, north of the city of Hannover. The average daily traffic (ADT) is about 75000. The input of heavy metals is highest in the first few meters from the road's edge, and the decrease of depositions with distance is clearly visible. After 15 m the depositions return to the range of the background levels, even though after 100 m slightly increased heavy metal concentrations were measured in the upper centimeters of the soils (Kocher 2007).

4.5.3 *Wet Depositions: Run Off*

The composition of wet depositions is influenced by a variety of factors, including traffic, road catchment area, rainfall frequency and intensity, antecedent moisture

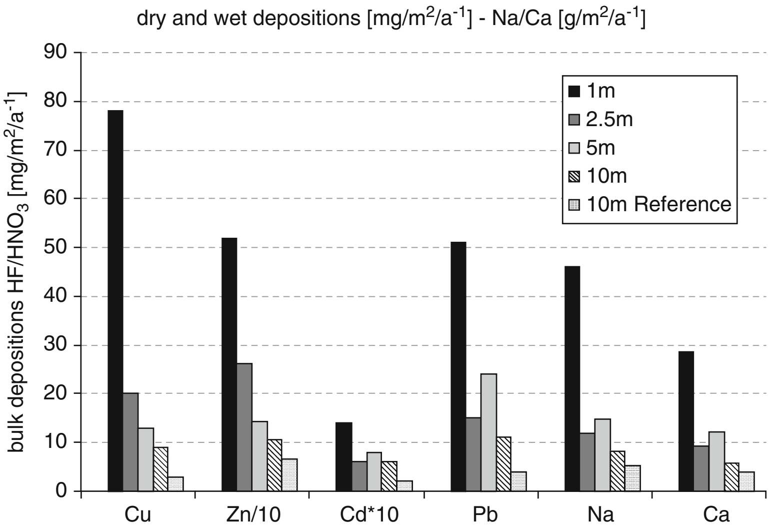

Fig. 4.16 Total depositions of Cd, Cu, Zn, Pb, Na and Ca at different distances from the roadside (A7, ADT 75000)

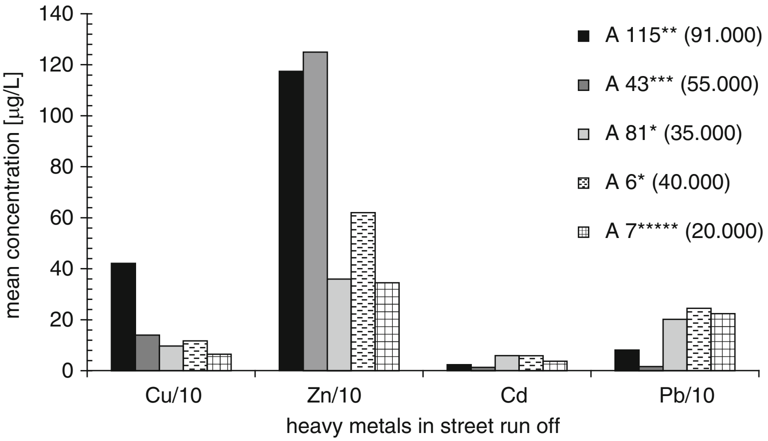

Fig. 4.17 Average concentrations of heavy metals in road runoff from different motorways in Germany (**Kluge 2010; ***Dierkes and Geiger 1999; * Muschak 1990; *****Diehl 2002)

conditions, road surface conditions and wind direction (Barbosa and Hvitved-Jacobsen 1999; Sansalone and Buchberger 1997; Polmit 2002; Kocher 2007; Göbel et al. 2007). However, a comparison of average pollutant concentrations in runoff of different motorways in Germany shows a similar range for the concentrations of Cu, Zn and Cd (in relation to vehicles) despite different sampling intervals and rain events (Fig. 4.17).

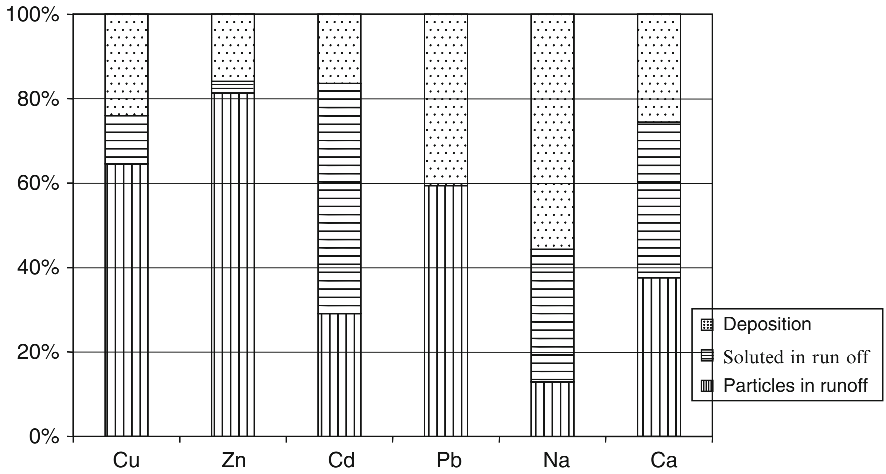

Fig. 4.18 Fractions of heavy metals of total depositions of a motorway (0–1 m distance, A7 – Hannover)

Figure 4.18 shows an example of the distribution of the deposited substances divided into dry and wet depositions (dissolved and particulate). Large fractions of Cd, Na and Ca were transported in a dissolved state, whereas Pb and Zn were mostly transported by airflow and solid fractions of road runoff.

4.5.4 Heavy Metal Concentrations in Roadside Soils

It is well documented that heavy metal contents in roadside soils decrease with distance to the road and with soil depth (e.g., Motto et al. 1970; Harrison et al. 1985; Turer and Maynard 2003; Li 2006). Figure 4.18 shows an example of heavy metal concentrations in roadside soils (0–10 cm) at the AVUS motorway. The AVUS motorway is located in the southwest of the capital Berlin. It was inaugurated in 1921 and is considered to be the oldest motorway in Europe; the ADT is about 100,000 vehicles with a high percentage of lorries.

In comparison to the mean natural, i.e., geological, background levels for the region of Berlin/Brandenburg, the concentrations of all heavy metals at the soil surface (0–10 cm) are greatly increased right up to the investigated distance of 10 m (Fig. 4.19). Zinc was the heavy metal with the highest levels in the soil, ranging from 8 to 804 mg/kg. Mean concentration at 2.5 m was 172 mg/kg, which is approximately ten times higher than the background level. Copper concentrations ranged from 2.9 to 565 mg/kg. The mean concentration at 2.5 m was 55 mg/kg. This value is about five times higher than the mean background concentration. Concentrations of lead ranged from 10.6 to 426 mg/kg. Mean concentration at 2.5 m was 177 mg/kg, which is eight times higher than the background level. Cadmium concentrations varied from 0.1 to 4.3 mg/kg. The mean concentration at 2.5 m

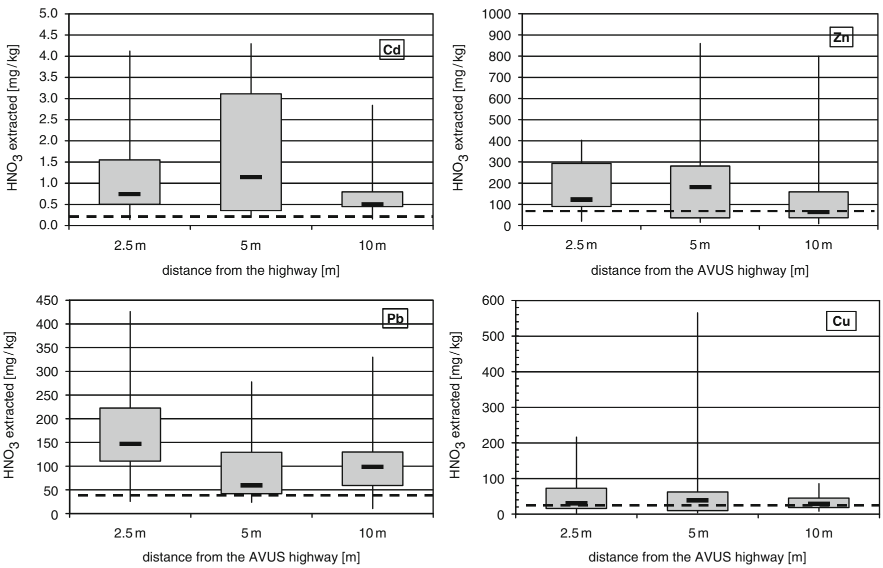

Fig. 4.19 Median concentrations Cd, Zn, Pb and Cu in the roadside soils at different distances from the roadside edge at the AVUS Highway, Berlin; soil depth = 0–10 cm; HNO3 extracted; $n = 60$ (Kluge 2010)

was 1.1 mg/kg, which is seven to eight times higher than the mean background value. At most sampling points this meant that concentration rates for all investigated heavy metals exceeded the precautionary values of the German Federal Soil Protection and Contamination Ordinance (BBodSchV) as much as tenfold.

4.5.5 Water Balance

The water balance of the road embankment, located directly next to the road (0–2 m), is mainly influenced by the road runoff water (Fig. 4.20). The annual infiltration rates at the roadsides of major streets or motorways that are drained over the hard shoulder are up to five times higher than the annual infiltration rates of sites not influenced by street runoff.

Measurements of the infiltration depth of percolation water at a motorway site in northern Germany (AVUS – A115, Berlin – precipitation 550 mm per annum) show that infiltrating water could reach soil depths of up to 12 m within 1 year. In the area that is influenced solely by spray water (up to 5 m), the depth decreased to 1–2 m. At a distance of >5 m from the roadside the annual infiltration of soil water is only influenced by rainfall and reaches depths of about 1 m (Kocher 2007).

Taking the runoff and splash effects into account, one can calculate the average percolation rate for the three parts of the road system: asphalt, hard shoulder and splash area. Note that evapotranspiration is drastically reduced compared to natural

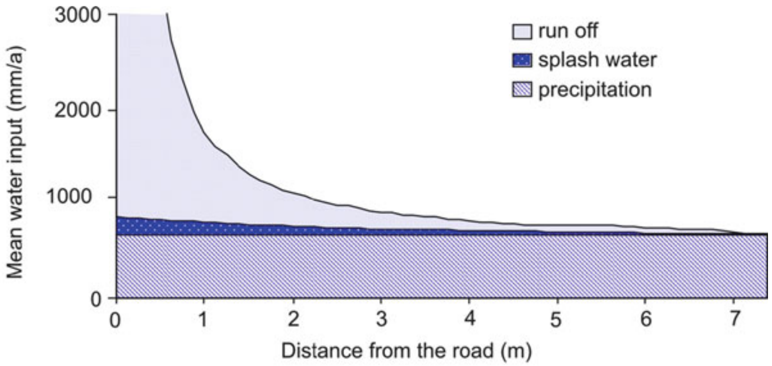

Fig. 4.20 Mean annual water input in roadside soils of runoff, splash water, and precipitation for various distances from the road

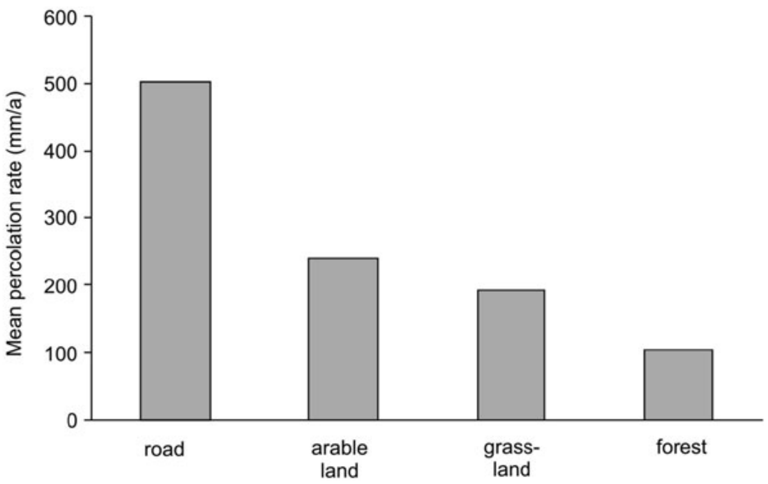

Fig. 4.21 Mean annual percolation rate in northeast Germany for different land use systems: roadside soils, arable land, grassland, forest

conditions because plants only grow sparsely beside the road. Figure 4.21 compares the mean annual percolation rates of a motorway with arable land, grassland and forest for the region of Hannover in the lower Saxony of Germany. Roads are lines with percolation rates more than twice as high as the rates of arable land and up to five times as high as the rates under forests.

4.5.6 Leaching of Trace Elements in the Vadose Zone: Cadmium

Figure 4.22 shows an example of the leaching of cadmium in the vadose zone beside a motorway as a function of the distance from the roadside. The annual

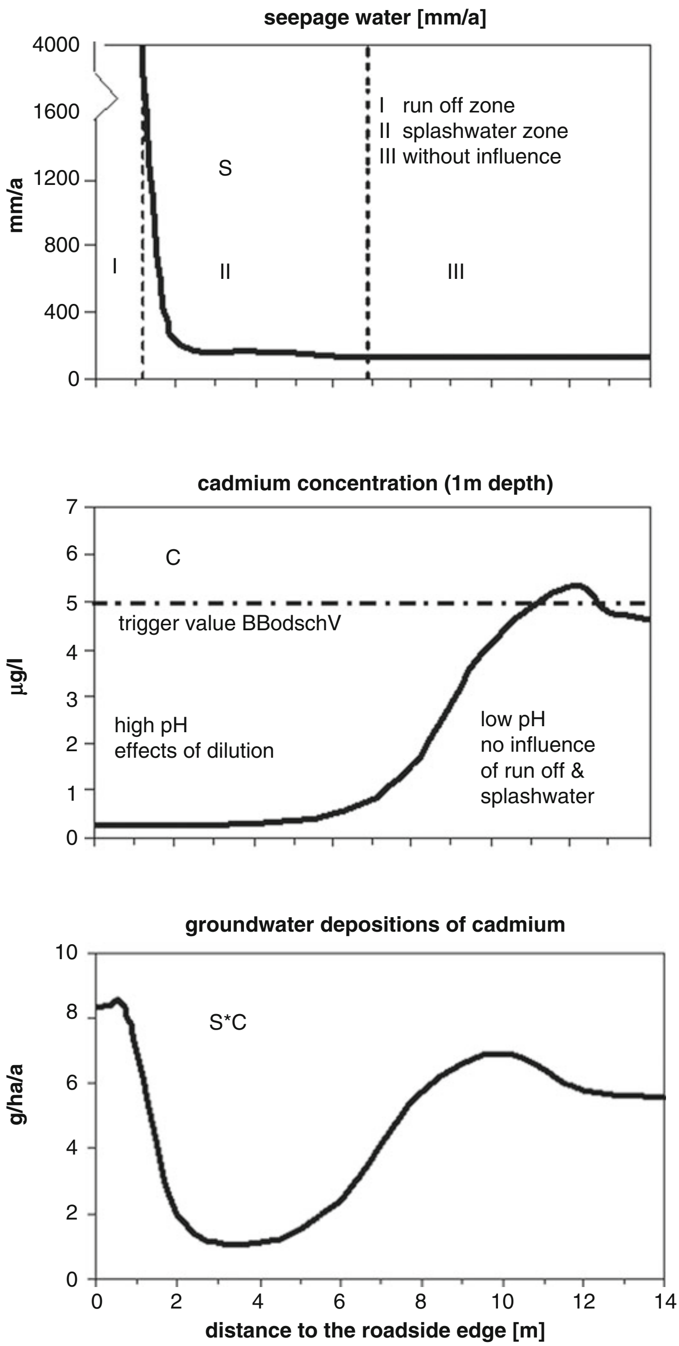

Fig. 4.22 Mean annual percolation rate (*top*), mean cadmium concentration in soil solution at 1 m depth (*middle*), and leaching rates (*bottom*) for various distances from the road

leaching rates (Fig. 4.22, bottom) were estimated by using the mean annual percolation rates (Fig. 4.22, top) multiplied with the average Cd concentration of the soil solution at 1 m depth (Fig. 4.22, middle). Due to high pH values and high infiltration rates in the first two metres beside the road only low concentrations of cadmium are to be found. Nevertheless, the high infiltration rates lead to high leaching rates. In contrast, a low pH value induces high solute concentrations at distances >8 m from the road. However, the percolation rates at these distances are low and not influenced by runoff and splash water any more. Thus the leaching rate is quite similar to the one of the hard shoulder of the road (BbodSchG 1998).

4.5.7 Leaching Scenario of Cd in the Vadose Zone over the Next 100 Years

Though most trace elements in roadside soils are relatively immobile, long-term leaching behavior is difficult to estimate. In order to predict solute and solid concentrations for long-term periods, numerical simulation models such as HYDRUS can be employed. For its use one needs trace element sorption/desorption characteristics of the roadside soils as well as information about the dry and wet emissions, such as the results shown in Fig. 4.16.

Figure 4.23 exemplifies desorption characteristics for Cd for two roadside soils with different pH (pH 6 and pH 4) values. At low solid concentrations of up to 3.5 mg Cd/kg, similar solute concentrations occur. However, at high Cd concentrations in

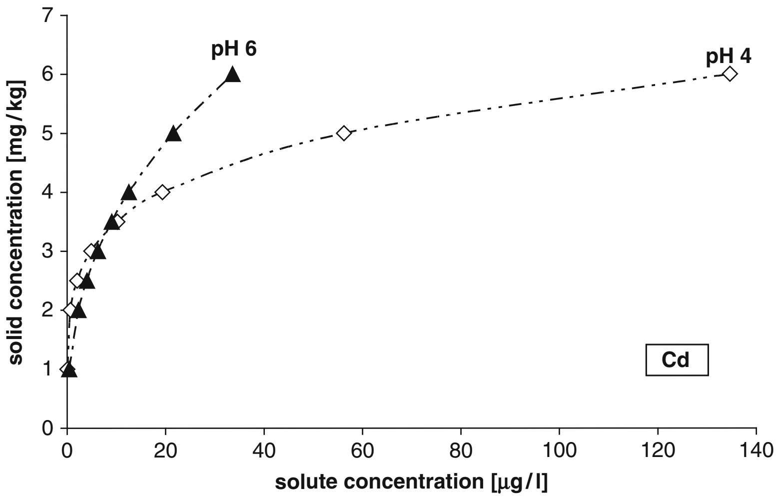

Fig. 4.23 Cadmium desorption characteristics of two roadside soils, one with pH 4 and the other with pH 6 (Kluge 2010)

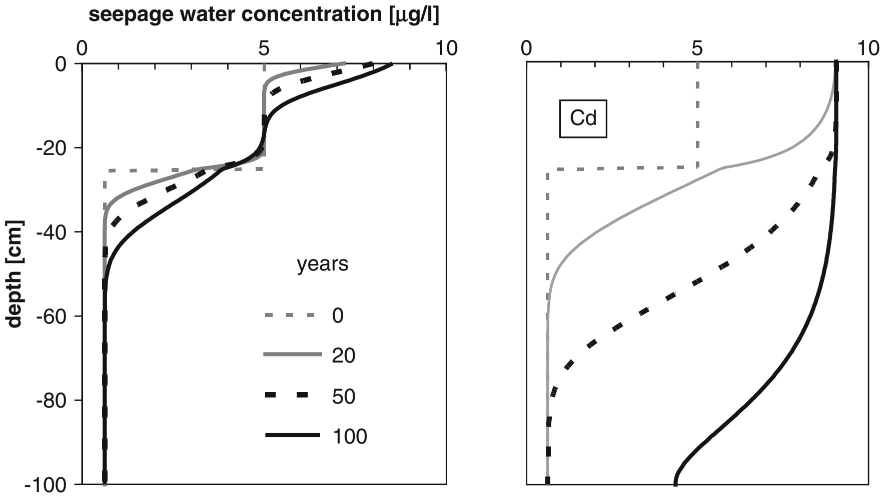

Fig. 4.24 Predicted Cd solute concentrations for two different motorway soils. The *left* part shows the solute depth concentrations at a distance of 10 m from the Avus motorway, the *right* part demonstrates a similar prediction, but for a recently constructed motorway with a low pH of 4.0 (Kluge 2010)

the soil matrix, the solute concentration of the soil with a low pH is increased greatly because of the decrease in sorption behavior.

Finally, Fig. 4.24 gives an example of long-term behavior of the heavy metal solute concentration for two different motorway soils. The left part of the Fig. 4.24 shows the predicted Cadmium solute depth concentrations at a distance of 10 m from the Avus motorway. The pH value of this soil is high because of high carbonate input from the long-term abrasion and weathering of the motorway surface. By contrast, the right part of Fig. 4.24 shows a scenario of a new motorway with low pH of 4.0, which is typical for the pedo-geological situation in northeast Germany. One can see the expected solute concentrations of up to a depth of 1 m for four time spans: at the beginning (0 years), after 20, 50 and 100 years. High values for the Cd solute concentration of the Avus are only to be found in the first centimeters for all time spans. In depths of >50 cm the concentrations are low because of the high sorption capacity of the topsoil. By contrast, we expect high Cd solute concentrations in the soils near the new motorway for the next 50 years, due to continuous traffic emissions and low sorption capacity of the topsoil at the beginning.

4.5.8 Conclusions

Roadside soils are strongly influenced by construction features and traffic emissions. Both result in disturbed and compacted soils with high concentrations of trace elements in the topsoil. The trace element concentration of the soil solution in the main infiltration zone of the hard shoulder is low because of high dilution. However, in these areas, high leaching rates might occur.

Though the input of heavy metals dates back to more than 100 years for some motorways, no study has observed a significant transport of trace elements deeper than 60 cm soil depth. Even for preferential flow conditions, particle transport is mostly limited by the depths of the transport fingers and cracks. We therefore conclude a low risk of groundwater pollution for the next 100 years. Potentially hazardous situations may arise for the soils of recently constructed motorways with low pH and low sorption capacity. As tested in a field and laboratory study by Kluge (2010), this potential risk was shown to be reduced by adding lime, clay or humic substances to the topsoil after construction work was completed. Potentially hazardous situations may arise for the soils of recently constructed motorways with low pH and low sorption capacity. This potential risk could be reduced by adding lime, clay or humic substances to the topsoil after finishing the construction work as it was tested in a field and laboratory study by Kluge 2010.

4.6 Visualizing the Vadose Zone

4.6.1 From Education to Creative Communication

Who bothers to look down at the sidewalk? More importantly, how can we successfully direct attention towards it, and to the significant role of soils in the city? In recent years knowledge transfer of soil scientific research to people without backgrounds in environmental studies has become increasingly important. In “The Future of Soil Science”, edited by Alfred Hartemink for the International Union of Soil Science in 2006, 55 top researchers from 28 countries highlighted issues such as soil degradation, food security, soil management issues, as well as traditional concerns such as soil classification and soil mapping. Fourty-nine out of the 55 authors also listed communication of soil issues as a top priority. The central idea is that better communication may not only lead to change in perception and behavior, but also to better resource management, and ideally a culture of conservation.

“Extending information about soils,” writes soil-communicator, Rebecca Lines-Kelly and Jenkins (2006), “is about making the invisible visible, helping people look beyond dusty, familiar surfaces into secret, hidden depths.” Lines-Kelly has authored numerous publications and educational materials, writes a regular “soil sense” newspaper column, and has organized workshops for Australia’s NSW Department of Primary Industries. Other publications have encouraged stronger integration of soil science in education from kindergarten through university (Herrmann 2006; Smiles et al. 2000), better public reference tools (Van Baren et al. 1998), consideration of social scientific research (Greenland 1991; Minami 2009; Winiwarter 2006) and the role of creative disciplines such as art, film, theatre and music in celebrating the beauty and cultural meaning of soil (Feller et al. 2010; Van Breemen 2010; Toland and Wessolek 2010). Furthermore, programs such as the German Soil Science Society's "Soil of the Year" campaign and museums such as the Underworld Exhibition in Osnabrück (Unterwelten Ausstellung des Natur und Umweltmuseums am Schölerberg) play a vital role in bringing soil knowledge above ground and into public view. Other educational exhibits include the ISRIC World Soil Museum in Wageningen, NL, the Underground Adventure at the Field Museum of Chicago, the Dig It! The Secrets of the Soil exhibition at the Smithsonian National Museum of Natural History in Washington D.C., and the Dokuchaev Central Soil Museum in St. Petersburg, Russia.

Museums and educational programs represent one type of environmental communication. These are, however, often gauged at particular target audiences (mostly school children) and do not usually incite or critically engage in cultural debate. According to some authors, such programs may not even foster lasting interest in youngsters. In his review article on soil education developments in Germany, Ludger Herrmann (2006) mentions a study of high school students interviewed in Osnabrück, Germany's "city of soils." Despite exposure to soil educational programs since childhood, not one interviewee chose to pursue a career or university degree in soil science (Anlauf and Rück 2005).

While education and public outreach programs initiated by scientific institutions are still crucial for the sensitization of future generations, a more intuitive cultural discourse can be observed in the arts and humanities, especially in cities where cultural enterprises thrive. It is to the creative disciplines that soil science might turn to find new allies in communication. And it is through cross-disciplinary collaboration between the arts and sciences that socially significant knowledge transfer and dissemination may take place. In the following, we outline our current investigation of the communicative potential of art as it addresses concerns discussed in other parts of this chapter: soil sealing, storm water run-off and rubble soils.

4.6.2 Storm Water Retention as Sculpture

A functioning vadose zone begins with ecosystems-oriented urban planning. This ranges from re-interpreting zoning laws, to on-site storm-water retention, site-specific water treatment and wetland mitigation. In city centers, where open space is usually scarce and contamination from run-off is higher, small-scale water-retention solutions include green roofs and facades, onsite infiltration strips around buildings and along roads, and the use of water-retention friendly materials. As these solutions are design opportunities as well as engineering tasks, they must be aesthetically pleasing as well as functional to gain acceptance. In recent years, a number of artists have taken on the vadose zone as subject and setting of their work, either by participating in wetland mitigation schemes, creating works that bring attention to threatened ground and surface water, or by creating custom works for newly created treatment wetlands. In this way, permeable pavements, bio-swales, berms and basins are used as formal sculptural media to bring attention to urban soils.

In the early eighties Gary Riveschl, for example, demonstrated in his “break out” installation (Fig. 4.25) the necessity for opening pavements in order to give nature and rainwater more space. At that time political proponents of the green parties started to demand the renaturalization of hydrologic systems in cities. Over the last 20 years it has become state of the art to design rainwater infiltration solutions for inner-city locations in order to close the hydrologic cycles. One such state of the art solution is the use of permeable pavements in non-risk green and residential spaces. In the ongoing work, Waterwash™ (Fig. 4.26), artist Lillian Ball has been working to rejuvenate degraded wetland sites in Mattituck, Long Island, and the Bronx by using Filterpave™ permeable pavements and native wetland plants. Integrating benches and interpretive signage, Ball’s work is educational, recreational and functional as it is aesthetic. With a grant form the National Fish and Wildlife Foundation’s Long Island Sound Futures Fund and construction and maintenance support form the Group for the East End, Ball’s goal as an artist is simply “to get green infrastructure out in the world” (Ball, in an email from 2009). Waterwash™,

Fig. 4.25 Gary Rieveschl, *Breakout*, Gütersloh, 1980

Fig. 4.26 Lillian Ball, *Waterwash*™, Mattituck Inlet Park, 2007–2009

Ball writes, is "…proof that multiple challenges can be solved with integrated functional aesthetics, improving the area both physically and environmentally…"

In another storm water retention project, artist Jackie Brookner created two sculptural works for the Roosevelt Community Center in downtown San Jose, CA. The project, *Urban Rain*, consists of two sculptures that collect and treat storm water from the roof of the LEEDs certified building. The *Coyote Creek Filter* adorns the south entrance of the building, using slate, stainless steel and amber glass to frame a filter that can process runoff from an area >2,300 m^2. A map of the Coyote Creek watershed is etched on to the face of the filter, which sits in a larger filter containing rocks and reeds. On the northern side of the building, stainless steel chutes gracefully direct storm water from the roof onto a giant stainless steel thumbprint that gently presses down on the surface of the soil. The water is filtered through 60 cm deep bed of rocks before flowing into a series of bio-swales, which curve around the side of the building. The Thumbprint Filter can process water from about 1,700 m^2 roof for a storm event of 1.3 mm/min (Figs. 4.27–4.29).

Melody Tovar (2009), deputy director of Watershed Protection for the City of San Jose Environmental Services, describes the environmental and communicative benefits of Brookner's work: "First, the stormwater system, integrated into the artwork, will reduce the volume an improve the quality of the water… Second, by providing demonstrations and monitoring, the artwork will expose and encourage these approaches to our community of developers and residents." In the words

Fig. 4.27 Jackie Brookner, *Urban Rain*, Roosevelt Community Center, San Jose, 2008

Fig. 4.28 Amy Franceschini and Future Farmers, *Victory Gardens*, San Francisco City Hall, 2008

Fig. 4.29 A. Toland and G. Wessolek, Spatial analysis of WWII rubble deposition in Berlin, under consideration of sulphate leaching, recreational quality and collective memory, Altes Museum Berlin-Neukölln, 2010

of the artist, however, an underlying conceptual layer provides the magic that differentiates *Urban Rain* from landscape architecture or hydrological engineering: "Whenever in this city we see rain, we see ourselves..." (Brookner 2009). Through the symbolic gesture of using a human thumbprint as the interface to the pedo-hydrological cycle, a personal relationship to the vadose zone is created in Brookner's water treatment sculpture.

4.6.3 Gaps in Knowledge Transfer

If soil science is the leading force in the pursuit or production of soil knowledge, visual art and its sister disciplines, design and the performing arts can be seen as articulating a *form* of soil knowledge (see also Kurt 2003). This in turn can generate interest, inspiration and action in a wider public. What do artists know about the soil? What could the artistic *form* of soil knowledge look like? With what creative gestures could a culture of conservation be visualized?

To address these questions, we carried out 15 in-depth interviews with artists who have worked with soil or soil conservation issues in urban and industrial areas (Toland 2010, in forthcoming). Artistic formats of the interviewees included sculpture, installation, illustration, painting, performance, video, participatory interventions, and landscape design. Environmental themes included moor degradation, acid mine drainage, rainwater harvesting, urban agriculture, pedodiversity, and coastal reforestation. Given this wide range of concerns and artistic approaches, the topic of didactic aesthetics was addressed in all of the interviews. Did these artists share a common goal of communicating or educating their audience? Although most of the artists answered that they thought about content first and then form, about half of the artists felt that art should inspire through innovative form, rather rely too heavily on informative texts or educational props. All artists described the importance of research in their work. Some had built up their own areas of expertise while others depended more on the expert input of others. All but one artist described instances of collaboration, which differed when working with other artists, scientists, city planners and educators. All artists described an interdisciplinary nature to their work and expressed interest in collaborating with scientists and engineers, if they had not already done so.

A second aspect that came up in the interviews points towards a highly personalized context of environmental protection. One artist described her art as a form of subservience – a service to community and environment. Other artists described their work as a moral, ethical or spiritual duty to nature. The point here is that art can and perhaps *should* communicate much more than facts or findings from scientific studies. To truly create awareness, art needs to address not only modes of aesthetic perception, but also bigger questions such as the human handling of soil, and the individual, cultural and political relationships with the earth. Such issues are often missing in the current paradigm of soil protection, and are generally taboo in scientific research.

Thus, if there is one thing that art is equipped to communicate, it is passion. While traditional soil communication tools can be used to inform city people about the history and science of soils, art may help people to identify with urban dirt as if their backyards and streetscapes were fertile valleys. It is in this sense that guerrilla gardening is becoming a new art form in cities worldwide. Projects such as Future Farmer's Victory Gardens on the lawns of San Fransisco's City Hall (Franceschini 2008); Haeg et al. (2008) "attack on the front lawn" and Nomadic Green's Prinzessinnengarten in downtown Berlin have attracted the attention of urbanites from all walks of life, turning food production into a cultural spectacle and community event.

Despite this recent boom in urban food production as creative public action, not much is known about the extent of knowledge these avantgardeners have about filtering and buffering functions, the dangers of glyphosate or the hydrological behaviors within the vadose zone. For farming, forestry or mitigation to function as sculptural or performative art, lasting partnerships with scientific bodies are necessary. Of the several artists interviewed who had either participated in or initiated community gardening projects, intensive time and work had been invested in experiences that didn't always yield fruit. To assist artists working with food production systems, long-term reclamation of degraded environments and social environmental justice, more research and practical guidelines are needed on knowledge transfer practices between soil science and the arts.

Bouma and Hartemink (2002) have emphasized the need for interdisciplinary research programs to support communication between soil scientists, planers, politicians, and other stakeholders. The cultivation of professional research partnerships is also necessary for accurate knowledge transfer between scientific and artistic disciplines. Organizations such as the Leonardo International Society for the Arts, Sciences and Technology (ISAST), and the Art and Science Collaborations Inc. (ASCI) attempt to bridge this divide. International environmental protection and communication projects such as Cape Farewell and the 350.org campaign have also brought together artists and scientists to raise awareness about climate change. Despite isolated examples, no equivalent interdisciplinary program yet exists to address soil conservation issues on a larger cultural scale.

4.6.4 Science Meets Art

The Department of Soil Protection at the TU-Berlin has been investigating several approaches to pedo-aesthetics in recent years. Projects have included: a soil and art group that was founded in 2000, the organization of several soil-art exhibitions, and a permanent collection of soil-art on display in the University. In 2007 and 2008, we led a series of creative field exercises in an overgrown urban lot near the TU campus. Landscape planning and environmental engineering students and staff were encouraged to paint their impressions of the site with materials found on or buried in the soil. Since 2002, several thesis papers and three student projects have also dealt with the topic of soil and art. For example, Andreas Vetter created plans for an urban soil park, including a sunken soil-auditorium for listening to the earth. Hardy Buhl installed a giant "soil cake" sculpture to demonstrate the remediation of a former wastewater-leaching field. In another example, Fritz Kleinschroth and the project group Soil Art on Urban Brownfields created an "ecological foodprint" in the shape of an oversized foot made out of kitchen scraps from a homeless shelter. A time-lapse video of the event illustrated processes of humification and mineralization. More student films can be found on youtube under: media, soil, tu-berlin.

In a latest effort, we participated in a three-week interdisciplinary workshop, "Science meets Art," initiated by Ping Qui for the Swiss Foundation for the Arts, Pro Helvetia. Eight artists met regularly with eight scientists and engineers to discuss research interests, methods, and the overarching cultural roles of science and art. Although points of contention came up in discussions on the funding and cultural contexts that define certain activities as "scientific" and others as "artistic," many parallels were also emphasized. Both are solution oriented. Both operate with a sense of a devotion and commitment to their work. Wilson (2002, p. 18) has highlighted other similarities of contemporary artistic and scientific practice: "Both value the careful observation of their environments to gather information through the senses. Both value creativity. Both propose to introduce change, innovation, or improvement over what exists. Both use abstract models to understand the world. Both aspire to create works that have universal relevance."

In an impromptu charrette, the group was given 1 week to create a formal interpretation of the previous weeks interactions in the former city museum of Berlin-Neukölln (Heimatmuseum Neukölln). We based our work on the ongoing research on WWII rubble. In a room with a low ceiling we sketched a map of Berlin on the floor and covered it with rubble, leaving only the waterways exposed. We placed 1 m-tall Plexiglas columns filled with rubble on the 13 points of greatest rubble deposition (such as Teufelsberg and Humboldthain Park) in Berlin. Drawn yellow curtains filled the room with a soft golden glow, symbolizing the yellow of sulphur, but also the contradiction of a domestic element (curtains) with the ruins of former residential buildings. Yellow is also a symbol of hope, loyalty, honor and new beginnings. In the opposite corner a desk of books, notes, maps, calculations, and other documents was illuminated with a desk lamp, representing the research involved in the department's work on WWII rubble soils. Historic maps and photographs found in the museum hung on the wall behind the desk. One map showed the planned deposition locations from Scharoun's post war urban plan, integrating the rubble moraines alongside garden colonies in the overall recreational green space planning. The installation was summed up as "a spatial analysis of WWII rubble deposition in Berlin, under consideration of sulphate leaching, recreational quality and collective memory."

Other than feedback from the workshop initiators and other participants, the reception of the work was limited due to the context of the exhibition. Rather than attract a large audience, the goal of the exhibit was to test out collaborative approaches and "translate" empirical experience into formal expression – interim results from a conceptual laboratory of knowledge gained. With a larger-scale public exhibition planned as a next step, several disciplinary and motivational ambiguities remain. In the words of one participating artist:

> "Questions about the motives of collaboration between art and (natural) science... and the internal and external conditions of such cooperation {remain}... Questions about the relationship between art and research, (research about art, research for art, research as art, {alternatively} art about research, art for research, art as research)... Questions about the cognitive value of science and art and ultimately a discourse on art and science on the horizon of sustainability" (artist George Steinmann, in an E-mail to other participants on the 14. September, 2010).

Such concerns are furthermore reflected in the interviews with artists working with soils. Of the interdisciplinary experiences mentioned during the interviews, not much is known about what was gained on the scientist's end. While artists can help communicate information and inspire interest in soil research and protection, Stephen Wilson (2010 p.16) suggests that "...artists can help researchers become aware of unrecognized perspectives and cognitive frameworks, as well as help establish connections with audiences outside the research community." The question remains as to whether scientific partners indeed recognize new perspectives and cognitive frameworks by working with artists. In what ways do scientists integrate creative insight into their research, and can this be influenced by inter- or cross-disciplinary collaboration? Finally, do such partnerships tend to emerge from individual personalities that seek out specific competences, or rather by institutional structures and funding opportunities for interdisciplinary research? While much has been written on art engaged with scientific questions (Wilson 2010; Ede 2005) more research is necessary on the role of artistic knowledge and creative practice in the sciences.

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Chapter 5
Plants in Urban Settings: From Patterns to Mechanisms and Ecosystem Services

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5.1 Introduction

More than half of the global human population is living in urban areas, and the trend towards further urbanization is strongly increasing (MEA 2005; United Nations 2008). Hence, the majority of people globally will experience "nature" and related ecosystem services primarily within the urban fabric (Gilbert 1989; McKinney 2002; Miller and Hobbs 2002; Miller 2005; Goddard et al. 2010). There is increasing evidence that urban land uses affect profound changes in all environmental components and that humans are the main drivers of change (Sukopp et al. 1979; Pickett et al. 2001; Alberti et al. 2003; Grimm et al. 2008). Urban growth has been identified as a major threat to biodiversity (e.g. Hansen et al. 2005), but at the same time, urban regions can harbour an array of species (Sukopp and Werner 1983; Gilbert 1989; Pyšek 1993; McKinney 2002) and contribute to the conservation of biodiversity. However, distinct urban ecosystems cannot replace totally the habitat function of (near-)natural systems (Kowarik 2011).

As plants provide an array of provisioning, regulating, and cultural ecosystem services in urban regions (Tzoulas et al. 2007), biodiversity is also of paramount importance from a social perspective, due to the simple fact that nature is here at the nearest proximity to people (Miller and Hobbs 2002). Exposure to natural systems has been found to positively affect human well-being and health (Kaplan and Kaplan 1989; Mitchell and Popham 2008). The biodiversity of urban green matters beyond the simple function of biomass. In green spaces of Sheffield, the degree of psychological benefit for people was positively correlated with species richness of plants and to a lesser extent of birds (Fuller et al. 2007).

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A better understanding of the ways in which biodiversity is affected by urbanization and how plant species may thrive in urban settings is needed to optimize strategies aiming at conserving and enhancing urban nature. Urban ecology has a long history, mainly in Europe (Sukopp 2002) and has developed rapidly over the last few decades, as illustrated by Marzluff et al. (2008). The Danish plant geographer Joakim Schouw (1823) described "Plantae urbanae" in the early nineteenth century and was among the first who found that distinct plant species have an affinity for urban conditions. A wealth of urban studies has revealed thus far an array of biotic responses to urbanization, including changes in phytodiversity patterns at different scales.

At the regional scale, cities appear to be hot spots of plant species richness with usually higher numbers of plant species compared with rural surroundings (Haeupler 1975; McKinney 2002; Hope et al. 2003; Kühn et al. 2004; Knapp et al. 2009). This holds surprisingly for both native and introduced species (Kühn et al. 2004). A common feature of urban floras is a high proportion of introduced species (Kowarik 1995; Pyšek 1998). Urban floras of 54 European cities have an average proportion of 40% alien species, ranging from 20 to 60% (Pyšek 1998). For some North American cities, a similar range (19–46%) and average (35%) has been reported (Clemants and Moore 2003). The richness of introduced species in urban regions has been explained by cities functioning as important points of entry and as foci for the secondary release of introduced species, with trade, traffic, and horticulture as most prominent dispersal pathways (Hodkinson and Thompson 1997; Dehnen-Schmutz et al. 2007; Kowarik and von der Lippe 2007).

Generally, the number of plant species increases with the size of the city and the human population (Klotz 1990; Pyšek 1993). Comparisons between the floristic assemblages of urbanized and rural areas in Germany revealed that floras of urbanized areas have a reduced phylogenetic diversity with a few species-rich lineages (Knapp et al. 2008a), and many species traits of urban plant species differ significantly from species assemblages of rural areas (Knapp et al. 2008b, 2009).

Changes in urban climate, hydrology, and soils due to urban land use have resulted in a heterogeneous mosaic of highly fragmented sites that add a range of dry, warm, and nutrient-rich habitats to the previously existing set of sites (Sukopp et al. 1979; Oke 1982; Gilbert 1989; Sukopp and Wittig 1998; Pickett et al. 2001). Correspondingly, grid comparisons show that urban regions harbour fewer species with hygromorphic leaves than rural areas, but more species with scleromorphic or succulent leaves and species that are indicators of nutrient-rich, warm, and dry conditions (Knapp et al. 2009). However, as the data from grid cells usually represent highly heterogeneous areas, it is difficult to scale down interpretations to habitat scale.

At the city level, variation in species richness and composition has been abundantly analyzed along urban-rural gradients (McDonnell and Hahs 2008). In one of the first gradient studies, Kunick (1982) found total plant species richness to peak in the transition zone between densely built-up inner-city areas of Berlin and the adjacent areas, while most non-native species have been found in the urban core. A few analyses of changes in urban flora over large periods of time revealed a significant turn-over in species composition, an increase in total species richness, and a decline in rare native species and archaeophytes (pre-1500 aliens) while the number of neophytes (post-1500 aliens) markedly increased. However, neophytes are generally less frequent compared to native species (cf. Kowarik 1990 for Berlin; Chocholoušková and Pyšek 2003 for Plzeñ; Knapp et al. 2010 for Halle).

Urbanization increases the fragmentation of habitats (Alberti 2005; Robinson et al. 2005) and integrating habitat features into analyses of large floristic data sets helps identifying the role of individual land use types for species richness (e.g. Celesti-Grapow et al. 2006 for Rome). Analyses at the habitat scale in Berlin showed that about two-thirds of native plant species were able to colonize sites subject to high levels of human-mediated disturbances, whereas the remaining species were confined to more natural sites. Numbers of introduced species peaked at profoundly changed sites, those of native species on sites subject to a medium level of human-induced disturbance (Kowarik 1990). At the community scale, introduced species were most prevalent in vegetation types that can be assigned to early succession stages or to naturally disturbed ecosystems such as pioneer sites in floodplains (Kowarik 1995). For an array of land use types in Berlin, ranging from (near-)natural to profoundly transformed by human agency, a wealth of studies, summarized in Sukopp (1990), illustrate the environmental conditions of various urban habitats and the corresponding species assemblages–revealing Berlin as one of the best-studied urban systems in Europe.

Characteristics of total urban floras and spatial patterns of plant species has been broadly analyzed in many cities, and a couple of studies suggest that biodiversity patterns in urban settings are deeply affected by human-driven mechanisms that lead to habitat changes but also drive the species composition by setting filters for plant selection and management of urban green spaces (Alberti et al. 2003; Grimm et al. 2008; Kowarik 2011). Analyses of large data sets at the city scale have revealed general trends in urban biodiversity patterns (e.g. Knapp et al. 2009), but it is yet challenging to disentangle the underlying mechanisms as different kinds of factors may interfere with each other at the habitat level.

The first three studies completed in the frame of the graduate program "Urban Ecology Berlin" aimed at a better understanding of patterns of urban phytodiversity by disclosing the functioning of possibly interfacing key mechanisms that are related to urban climate, human-mediated dispersal, and the effects of environmental parameters at different scales. Further ongoing studies address different approaches to enhance ecosystem functions on urban land.

5.2 Towards a Better Understanding of Mechanisms Underlying Biodiversity Patterns

Profound changes in urban climate with increased temperatures, less cold winters, and a longer vegetation period have often been hypothesized to affect the distribution of plant species (e.g. Sukopp and Wurzel 2003). As other than habitat-related factors could also drive the spatial configuration of species assemblages in urban settings, the first study aims at identifying consequences of the urban heat island on the performance of woody species that have become abundant in urban regions (Säumel 2006).

The occurrence of most plant species is strictly dispersal-limited, and the high fragmentation of urban habitats is supposed to profoundly affect the distribution of plant species (Bierwagen 2007). At the same time, the frequency of human-mediated dispersal processes is expected to peak in urban regions and could possibly counteract dispersal limitations of plants in urban settings. The second study thus addresses the question of to which extent traffic on urban motorways functions as dispersal vector of plant species (von der Lippe 2006).

Urbanization is multidimensional and key mechanisms cannot be combined into aggregated variables such as population density or total paved areas (Alberti et al. 2003). While the first two studies aim at identifying the functioning of distinct key mechanisms in urban settings, the third study addresses the complex interrelationships of different environmental and landscape parameters. Taking urban wastelands as model ecosystems, this study aims at disentangling the relative importance of environmental and landscape factors at the habitat and city scales that drive species composition and establishment (Westermann 2009).

5.2.1 Response of Urban Tree Species to Increased Temperatures

Global warming is expected to enhance invasions by non-native species (Dukes and Mooney 1999; Walther 2004) and effects of urban heat islands may anticipate impacts of global warming. Although urban heat islands have often been hypothesized to affect the survival, spread and distribution of non-native species in urban settings (e.g. Sukopp and Wurzel 2003), studies on the response of species to increased temperatures in terms of morphological and allocational traits are rare. Aiming to disentangle species' responses to changing temperature, we tested by experimental approaches the hypothesis that urban heat islands favour the growth of non-native species.

As model species, we used the native Norway maple (*Acer platanoides*) and two non-native tree species, tree of heaven (*Ailanthus altissima*) and box elder (*Acer negundo*). All are successful colonizers of urban habitats in Central European cities. However, only *Ailanthus altissima* is largely confined to metropolitan agglomerations, which has been hypothesised as being an effect of urban heat islands (Sachse et al. 1990; Kowarik and Säumel 2007).

In a field experiment, we exposed potted one-year-old saplings of the model species along an urban-rural gradient from the centre to the hinterlands of Berlin. Saplings of the same species have also been exposed for 2 years in climate chambers to assess their response to different temperature regimes: low temperature (10/05°C), elevated temperature (20/15°C), and control (15/10°C). We determined whether a moderate temperature increase or decrease alters growth and leaf display of the exposed saplings and analyzed more than 40 foliar, stem, and root traits to evaluate how temperature influences the plasticity of plant morphology. We here summarize the results by using a qualitative and quantitative classification approach (Table 5.1).

5.2.1.1 Intra- and Interspecific Variations

Our results illustrate the importance of temperature for growth and survival of tree species that successfully colonize urban habitats. The field experiment revealed the duration of frost periods and the amount of frost intensities as crucial factors for survival of the early developmental stages. Both *Acer* species performed higher tolerance to frost injury than *Ailanthus*, resulting in differing survival rates after field exposure during a strong winter. The survival rates in the *Acer* species

Table 5.1 Summary of interspecific variation in overall response of three tree species (*Ailanthus altissima*, *Acer negundo*, *A. platanoides*) due to warming (elevated temperature, ET) or chilling (low temperature, LT) compared to the control

Trait	Species					
	Ailanthus altissima		*Acer negundo*		*Acer platanoides*	
Phenology						
Bud break	LT	ET	LT	ET	LT	ET
Time from exposure to first bud break	+ + + +	− −	+ + +	− −	+ + + +	− −
Air temperature sum on day of bud break	+		− − − −		+/−	
Overall growth responsiveness						
Temperature sensitivity	LT	ET	LT	ET	LT	ET
Temperature sensitivity of leaf traits	● ● ●	● ● ● ●	● ●	●	● ● ●	●
Temperature sensitivity of stem and branch traits	● ● ● ●	● ● ● ●	● ● ● ●	● ●	● ●	●
Temperature sensitivity of belowground traits	● ● ● ●	● ● ●	● ●	● ●	● ●	+/−
Relative growth rate	LT	ET	LT	ET	LT	ET
Above and below ground	− − − −	+ + +	+/−	+/−	−	+/−
Above ground	− − − −	+ + + +	+/−	−	−	+
Below ground	− − − −	+ + +	−	−	−	+/−
Frost sensitivity due to seedling survival	High		Low		Low	
Temperature tolerance range	Narrow		Wide		Wide	
Seasonality of growth	No slowdown until late autumn		Slowdown in autumn		Slowdown in autumn	
Predicted response to global warming	High		Moderate		Low	

Original data from exposure of saplings in climate chambers were analyzed for amount and direction of parameter change due to warming (elevated temperature, ET) or chilling (low temperature, LT) compared to the control. The greatest response in each trait were set as 100%, given as (+ + + +) or (− − − −) for increase or decrease, respectively. On this base, value relative response of the other trait changes was calculated. Plus or minus indicates qualitative response (e.g. direction of trait change), and the number of plus or minus characterizes quantitative response. The symbol +/− was set for insignificant changes in the corresponding ANOVA. Plus or minus in square brackets indicates a significant change within this species. The overall temperature sensitivity of leaf, branch, stem, and root traits is given in quantitative values, with the number of points indicating quantitative response to temperature. The greatest response in each trait was set as 100%, given as four points decreased with declining influence of the urban climate, while all individuals of *Ailanthus* died due to early deep frost (von der Lippe et al. 2005).

In the climate chamber experiments, moderate increase or decrease in temperature altered saplings architecture and growth, morphology, and biomass allocation (Table 5.1). In general, the overall species' growth performance benefits from warming. In *Ailanthus*, chilling led to fragile saplings with a likely low competitive strength. Species differed significantly in temperature sensitivity of stem, branch, leaf, and root traits. Generally, *Ailanthus* showed the greatest response, while *Acer platanoides* showed a low and *Acer negundo* an intermediate level of response to temperature.

In *Ailanthus*, most traits related to size and number of plant modules tend to increase with increasing temperature and to decrease with decreasing temperature. Stem, branch, and leaf traits of both *Acer* species mainly decreased with decreasing temperature but did not change due to warming (Table 5.1). Exceptions of these general patterns were found in branch and leaf traits. In *Acer negundo*, branch traits and leaf number increased with decreasing temperature. Independently of the temperature regime, *Acer negundo* reached the greatest main stem height of all species, which suggests a high competitiveness.

In *Ailanthus*, the relative growth rate was markedly reduced due to chilling, while warming strongly enhanced related parameters. Chilling sensitivity was high in *Ailanthus* and low in both *Acer* species. Consistently, *Ailanthus* had a narrow tolerance range of temperature, while the *Acer* species acclimated to a wide temperature range (Table 5.1). Air temperature sum on the day of the first bud break was lowest in *Acer negundo*, intermediate in *Acer platanoides*, and highest in *Ailanthus*. Time to the first bud break was strongly shortened by warming in all species.

5.2.1.2 Phenotypic Plasticity

Phenotypic plasticity is the ability of an organism to express different phenotypes depending on the biotic or abiotic environment (Bradshaw 1965). A phenotypically plastic plant is able to optimize growth in an altered environment, while a phenotypically stable or fixed plant may suffer from a reduced growth rate. Many authors argue that a high level of plasticity enhances the invasion potential of introduced species (Davis et al. 2000; Yamashita et al. 2002; Durand and Goldstein 2001; Huxman and Smith 2001; Daehler 2003). Our study reveals a divergent plasticity of morphological and allocational traits in the focal species. All are invasive, but only *Ailanthus* performed a high level of plasticity, while *Acer negundo* showed an intermediate and *Acer platanoides* a low level of plasticity to temperature. We thus conclude that phenotypic plasticity may enhance the invasion of urban habitats by introduced species (cf. *Ailanthus*), but is no obligatory prerequisite for such a colonisation success (cf. *Acer platanoides*).

As a second important result, we found that the amount of plasticity depended on the direction of temperature change (i.e. chilling or warming). The maple species, but not *Ailanthus*, exhibited in most traits a significant higher plasticity to chilling than to warming. In allocational and growth traits, all species showed higher plasticity to warming than to chilling. The growth performance of *Ailanthus altissima* in the cold climate chamber highlighted that high plasticity not necessarily leads to higher fitness and invasiveness (see Scheiner 1993a, b; Via et al. 1995) and cannot be considered as adaptive (Sultan 1992, 1995).

5.2.1.3 Linking Experimental Results with Distribution Patterns

Our experimental results support the hypothesis that urban heat island effects favour the survival of juvenile trees in winter. That holds surprisingly also for the native Norway maple. In both maple species, an enhanced allocation of biomass to roots in the first growing period may support saplings to withstand frost injury and to take advantage of increased access to water and nutrients in the subsequent resprouting phase. Maple saplings exposed in the urban hinterland showed a decreased survival, but the whole cohort did not die-off as did *Ailanthus* saplings. This result corresponds well with the overall distribution pattern of both maple species, which are not restricted to urban habitats in Central Europe.

As *Ailanthus* is more sensitive to chilling than both maple species, mild winters seem to be a crucial prerequisite for its establishment. Hence, reduced frost periods and intensities due to the urban heat island are supposed to enhance population growth in this species and contribute to explain its confinement to urban centres in Central Europe.

The climate chamber experiments revealed significant differences in overall temperature sensitivity of the exposed species that can be well related to their distribution patterns. *Ailanthus*' growth is favoured by warming and strongly limited by chilling, while *Acer negundo* and *Acer platanoides* have a wide temperature tolerance (Table 5.1). Compared to both maple species, *Ailanthus* showed a substantial growth reduction due to chilling and a conspicuous increase in growth due to warming. In addition, a prolonged growing season as a typical outcome of urban climate will also favour the spread of *A. altissima*.

Water limitations and increased hydraulic stress as consequences of warming are supposed to hamper plant establishment. Our results provide strong evidence that *Ailanthus* meets this challenge much better than the *Acer* species. In the warm climate chamber, we found a reduced allocation to leaves as transpiring tissue, contrasting to an increased allocation to roots, and within the root system to fine and coarse roots. This will enhance the resource exploitation (water, nutrients) and reduce water loss by transpiration. The increased stem volume provides a larger cross-sectional area for vascular movement of water, and the positive correlation of cumulative foliar biomass and stem basal area indicates a better water supply for the whole plant. These findings amplify previous results on water-saving mechanisms (Trifilo et al. 2004) and deep below ground exploration (Pan and Bassuk 1986) in *Ailanthus*.

Due to a higher leaf turnover in the warm chamber, *Ailanthus* produced much more leaf litter than the other species. This might enhance its competitive ability because increased temperatures enhance allelopathic effects of the leaflets (Lawrence et al. 1991). While stem growth patterns in *Ailanthus* and *A. platanoides* can be attributed to the ontogenetic drift due to warming, the branching patterns of *A. negundo* might reflect a functional adaptation to chilling. Our results thus suggest a high adaptive capacity of *Acer negundo* across a broad range of temperatures, which contributes to explain its invasion success under both cold and warm climates.

The low responsiveness of *A. platanoides* to temperature clearly demonstrates the limits in generalizing positive effects of warmer temperatures as drivers of plant invasions. In summary, *A. platanoides* showed a low plasticity of morphological, allocational, and growth traits due to warming. Correspondingly, other factors than recent warming should have driven the successful spread of this species in North America and Europe. In Central Europe, increased nitrogen inputs are supposed to favour the colonisation of urban habitats and forests (Sachse et al. 1990). In North America, *A. platanoides* might benefit from more efficient light, water, or nutrient use compared to native broad-leaved species (Kloeppel and Abrams 1995) and of biotic interactions. The latter include a lower seed predation compared to native congeners (Meiners and Handel 2000) and reduced inhibitory effects of soil biota compared to its native range (Reinhart and Callaway 2004).

5.2.1.4 Anticipated Effects of Global Warming

To predict future effects of climate change on the abundance and distribution of species, a "space-for-time" approach has been used by linking current distribution patterns with actual climatic conditions (e.g. Iverson and Prasad 1998; Thomas et al. 2004). As cities actually show distinct urban heat island effects in different climatic regions (Arnfield 2003), they can be used as laboratories to analyze anticipated effects of globally increased temperatures on plant performance and resulting distribution patterns. Our results suggest that global warming will enhance invasions by some, but not by all, species that currently successfully spread in urban habitats. As a response to global warming, *Ailanthus* is expected to spread far beyond urban areas in Central Europe and to expand its range northwards. In contrast, the spread of both maple species will be less triggered (*Acer negundo)* – or not at all (*A. platanoides*) – by increased temperatures.

5.2.2 Vehicles as Dispersal Vectors of Plant Species

A dense road network is one of the most distinctive features that differentiate urban regions from their rural surroundings. The role of this omnipresent linear structure both for the fragmentation and connectivity of urban plant populations is still little understood. Distribution patterns of plants along roadsides suggest an important role of traffic as a dispersal vector. In particular, large gaps between newly established populations and the next known seed sources can frequently be observed during roadside expansion of plant species (Scott and Davison 1985; Griese 1996; Lavoie et al. 2007). This phenomenon points to a recurrent impact of human-mediated long-distance dispersal on population dynamics in this habitat.

Urban roadsides usually harbour a large number of non-native species. The flora of urban roadsides in Berlin housing areas contains 36% non-native species (Langer 1994), and roadsides on an urban to rural gradient in East Berlin contained 22% neophytes (Schmitz 2000). A similar percentage of 26% of introduced species was reported for the roadside flora in an urban area in South Africa (Cilliers and Bredenkamp 2000). Verges of high-use roads were shown to comprise more non-native species and a higher non-native plant cover than abandoned roads or unpaved roads of the same region (Parendes and Jones 2000; Gelbard and Belnap 2003), suggesting an impact of traffic density on roadside plant composition. Records of roadside invasions over time often revealed a very rapid spread along roadside corridors that by far exceeds the primary dispersal ability of the plant species involved (Ernst 1998; Pyšek et al. 2002; Heger and Böhmer 2005).

Although roadsides can be acknowledged as migration corridors this way, the vector, i.e. the underlying processes that cause these distributional patterns, can only be retraced indirectly. The possible processes leading to plant migration along roadsides can be divided into two main causes: (1) altered site conditions at roadsides that provide a suitable migration corridor and (2) seed dispersal by vehicles. The relative contribution of each of these mechanisms is hard to measure, as the outcome, that is, distributional patterns, integrates both of them. While the habitat characteristics of the corridor that facilitate plant migrations along roads are widely studied experimentally (Tyser and Worley 1992; Pauchard et al. 2003; Watkins et al. 2003; Johnston and Johnston 2004; Truscott et al. 2005), the key features of the main vector that possibly drives dispersal along roads, that is, dispersal by vehicles, are barely understood. The aim of this study was therefore to identify the mechanisms and properties of plant dispersal by vehicles and its role in plant migrations along roads. A focus was on the facilitation of plant invasions by this vector.

Adhesive dispersal by vehicles has long been suggested to play a prominent role in roadside expansions of plants (Ridley 1930). By taking samples of mud from the surface of vehicles, a handful of studies have demonstrated that adhesive seed transport by vehicles is actually possible and obviously correlates to the amount of unpaved surfaces a vehicle is driven through (Clifford 1959; Schmidt 1989; Lonsdale and Lane 1994; Hodkinson and Thompson 1997; Zwaenepoel et al. 2006). A different method for seed sampling was used by Wace (1977) who sampled the cumulative seed deposition inside a carwash by monthly samples of mud from the settling tanks. Although these studies revealed a high potential for human-mediated dispersal by vehicles, it is difficult to project the quantitative impacts on roadside plant populations from these data as both the rate of seed deposition and the transport distances remain unknown.

The limited knowledge about the effect of traffic as a dispersal vector is obviously due to the methodological limitation that seed *deposition* along roads cannot easily be separated in the shares that originate either from vehicle dispersal or from other adjacent seed sources. Simply exposing seed traps to roadsides would integrate both sources. A crucial prerequisite for this study was therefore to develop an experimental approach that could reliably estimate the magnitude of seed deposition by vehicles at roadsides as well as the spatial effectiveness and direction of this vector. Looking for sampling sites which are insulated from dispersal vectors other than traffic, we finally found a series of three long motorway tunnels in the north-western part of Berlin. To standardise the sampling procedure, a special kind of seed trap had to be designed, which could be mounted on the pavement of the motorway verges inside the tunnel (Fig. 5.1).

5.2.2.1 Seed Deposition at the Road Verge and Transport Distances

The seed deposition trapped at the road verges varies between 635 and 1,579 seeds per square metre and year, which is within the range of the seed rain in early successional stages, alpine turf, or acidic grassland (von der Lippe and Kowarik 2007a). Thus, within roadside habitats with sparse vegetation, the seed deposition of vehicles has the potential to add a similar proportion to the seed rain as the resident vegetation.

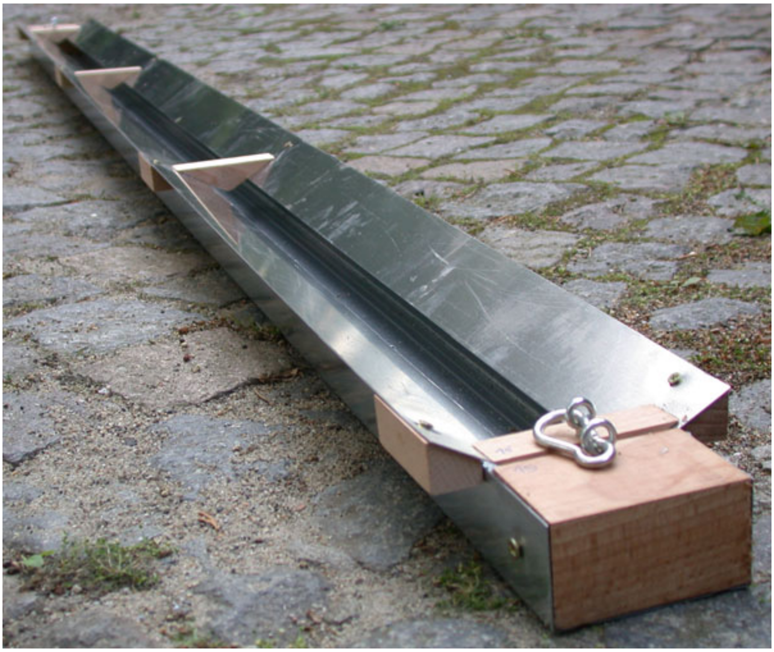

Fig. 5.1 Flat seed trap with a removable funnel construction for installation at the road verge of motorway tunnels

Within a transect of seed traps in the longest tunnel, seed deposition did not decline markedly with distance from the tunnel entrance (von der Lippe and Kowarik 2007a, Fig. 5.2), suggesting recurrent long-distance dispersal by traffic over the range of 550 m that was covered by the transect.

A comparison of the tunnel samples with the composition of the flora around the tunnel entrances revealed that long distance-dispersal over more than 250 m occurred significantly more frequent in non-native than in native species (von der Lippe and Kowarik 2007a). In individual cases, dispersal over several kilometres could be revealed, such as for the Australian annual herb *Chenopodium pumilio*, where the closest known populations are in a distance of more than 5 km from the tunnels.

There was a notable high proportion of rape and cereal seeds in the samples (24% of the total seeds), which can be attributed to transport losses (von der Lippe and Kowarik 2007b). The densities of each of these species in the seed samples were strongly related to one particular direction of traffic, probably tracing the major transport routes of the harvest.

5.2.2.2 Species Composition of the Tunnel Flora and Directed Dispersal

The species transported by vehicles represent 12.5% of the present flora of Berlin. Non-native species constituted 54.5% of all viable seeds in the samples and 50.0%

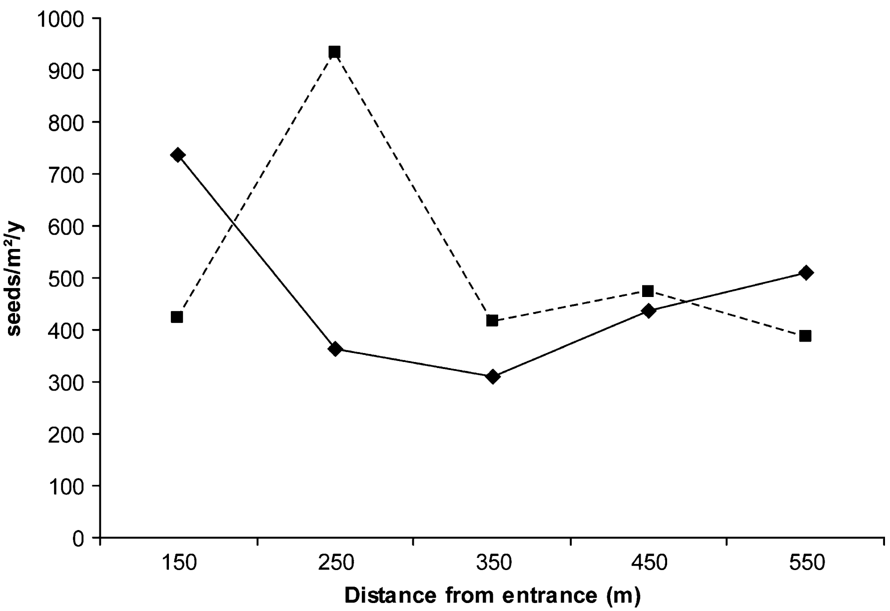

Fig. 5.2 Annual seed deposition along 400-m seed-trap transects in both lanes of an urban motorway tunnel. *Solid line*: outbound lane; *dotted line*: inbound lane

of the species. Compared to the city zones adjacent to the sampling sites, non-native species were over-represented in the samples (von der Lippe et al. 2005). In addition, 39 species (19.1%) of the tunnel flora proved to be problematic invasive weeds in some parts of the world, including *Acer negundo*, *Buddleja davidii*, *Lupinus polyphyllus*, *Solidago canadensis*, and *Robinia pseudoacacia* (von der Lippe and Kowarik 2007a).

The species that were transported by traffic come from a broad variety of different habitat types, including both elements of urban-industrial vegetation and semi-natural communities (von der Lippe and Kowarik 2008a). Among the habitat types, most species of the tunnel flora can be assigned to ruderal ecotones and grassland habitats. Also, species of woodlands, weed communities, and urban vegetation are overrepresented in the samples.

The spectrum of species found in the tunnels had a higher similarity with the Berlin roadside flora than with the species composition of the vegetation around the tunnel entrances. The frequency of the species in the tunnel traps is significantly correlated to their frequency in the roadside vegetation (von der Lippe and Kowarik 2008b, Fig. 5.3). This points to a strong feedback between roadside habitats as donors and recipients of seeds.

Overall, significantly more seeds were transported from the city towards the surrounding areas than vice versa, with a significantly higher proportion of seeds of

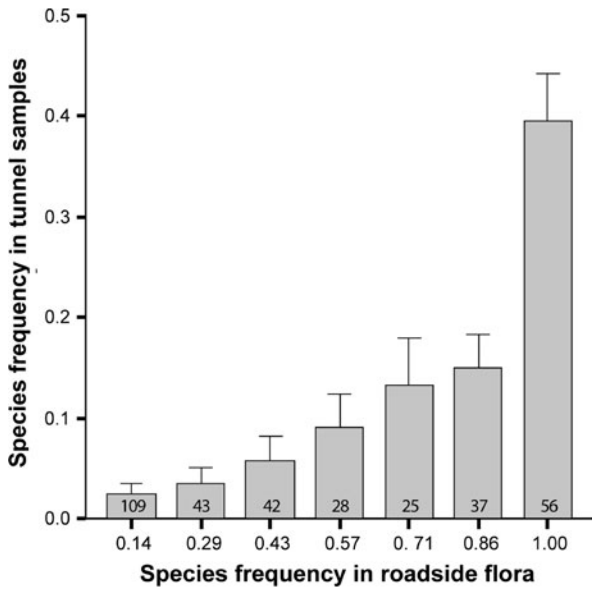

Fig. 5.3 Relationship between the frequency of species in the Berlin roadside flora in seven independent road sections (Langer 1994) and their mean frequency in the seed samples from 25 seed traps in five separate tunnel lanes of an urban motorway. Numbers within bars are sample sizes (species numbers within each group). The Spearman rank correlation is significant (rS $= 0.547$, $p < 0.001$)

non-native species in samples from carriageways leading out of the city. Indicator species analysis revealed that only few species can be confined to samples from lanes leading into the city, while mostly species of urban habitats were significantly related to samples from the outbound lanes (von der Lippe and Kowarik 2008a). The findings demonstrate that dispersal by traffic reflects different seed sources that are associated with different traffic directions and may thus exchange propagules along the urban-rural gradient.

5.2.2.3 Implications for Nature Conservation and Roadside Management

The observed dimension of seed deposition at roadsides suggests a strong impact of urban mobility on biodiversity patterns. Given its spatial effectiveness, human-mediated dispersal by vehicles may counteract urban fragmentation and the related habitat isolation. While this probably supports urban plant diversity in the short run, it also poses new risks of invasion and homogenization of urban floras.

Two outcomes of the study are of particular concern for nature conservation goals: first, the high share of non-native species deposited by vehicles and the large distances that can be bridged by this vector potentially support unwanted plant invasions along road corridors. Second, the directed transport of propagules in the direction out of the city may help to overcome dispersal limitation of isolated urban populations of invasive plant species and assist their migration to the countryside. The function of cities as centres of new introductions of plant species is thus combined with an effective vector that may lead to a quick “suburbanization” of these species. It is an open question, however, to which extent roadside populations of invasive species may function as foci for the invasion of habitats in the surrounding landscape. So far, effective invasions from roadsides to interior habitats were revealed for dry grasslands (Gelbard and Belnap 2003).

The management of roadsides can serve various purposes. Traditionally, erosion control and traffic safety were the primary goals but with an increasing road network, additional demands arose, like maintenance and development of roadside biodiversity and avoidance of biological invasions (Berger 2005).

The invasion of roadside verges by fast spreading non-native plants is not easy to control. Besides the difficulties of sustainable removing established populations of invasive plant species (Schepker and Kowarik 2002), the results of this study demonstrate the important role of recurrent introductions of a species to the same site with the help of traffic-mediated dispersal. Many approaches for the management of roadside invasions focus on local eradication of invasive species, often using chemical control (Berger 2005). Prior to this, however, an important implication of the findings about traffic as an important vector in plant invasions is to avoid invasion foci by roadside plantings.

If an invasion process is once in progress, efforts of eradication can be warrantable, if a species causes detrimental impacts and if success of the control measures can be expected. The results of this study suggest that management approaches on a local scale are unlikely to succeed in the control of invasive plants at roadsides. Even small isolated populations of invasive species at roadsides could act as invasion foci, which can rapidly negate control efforts. Therefore, roadside management of invasive plants demands for a perception of roads as a coherent dispersal network that affects distribution of propagules on a regional scale.

5.2.3 Environmental and Landscape Factors Shaping Species Composition on Urban Wasteland

Urbanization promotes the fragmentation of habitats (Alberti 2005; Robinson et al. 2005) and leads to a highly heterogeneous matrix, which is a distinctive characteristic of urban environments (Cadenasso et al. 2007). Thus far, only few studies addressed the question of how the spatial configuration of the urban matrix affects the floristic composition of urban habitat patches (e.g. Wania et al. 2006). As long-distance dispersal may counteract the effects of habitat fragmentation, the species-specific dispersal potential may strongly govern the colonization of fragmented habitat patches. In addition, environmental filters at the local scale are supposed to drive the composition of species assemblages of urban habitats, which are often different from natural ecosystems.

To better understand the mechanisms that shape urban biodiversity patterns, it is thus necessary to disentangle the relative importance of the spatial habitat configuration within the urban matrix, the local environmental conditions, and the dispersal abilities of individual species. A fuller understanding of the interplay between local factors and landscape parameters that affect urban biodiversity is also important for the management of urban habitats (Angold et al. 2006).

When urban wastelands remain unused for longer periods of time, initial successional stages are followed by herb- and shrub-dominated stages that finally develop into forests. Due to the frequency of disturbances in cities, early- and mid-successional stages are more common than late successional stages (Rebele 1994). Mainly in shrinking cities, however, larger woodlands can emerge on urban wastelands (Kowarik 2005). Up to now, soil, microclimatic, and land use predictors were used to explain the species assemblages of urban wastelands (Godefroid and Koedam 2007; Godefroid et al. 2007; Muratet et al. 2007). The question how these predictors govern successional mechanisms in urban habitats was however not considered explicitly.

We here aim at analyzing the relative importance of environmental and landscape predictors during the course of urban wasteland succession. Then, the predictability of the occurrences of species was examined with regard to their dispersal ability. To better distinguish successional effects from those of habitat heterogeneity due to strongly divergent starting conditions, one urban land-use type, i.e. abandoned railway areas, was studied. We analyzed species composition and measured directly microclimatic and soil parameters in stands that had been assigned to four

Fig. 5.4 Wasteland succession on urban railway areas (Berlin, Südgelände). The woodland stage is prevailed by a clonal population of the native poplar (*Populus tremula*), but also non-indigenous species can play an important role, e.g. the North American black locust (*Robinia pseudoacacia)*, here on the right side

successional stages, based on the dominance of annual, perennial herbs, shrubs, or trees (see Fig. 5.4 as an example). Landscape predictors (e.g. proportions of different habitats and sealed areas) within a 500-m buffer were analyzed using the Berlin Digital Biotope Mapping (SenStadt 2008). Data were analyzed by canonical correspondence analysis (CCA). To add the perspective of individual species dispersal ability, we compared the relative importance of landscape predictors to that of local environmental predictors. We then analyzed how strong landscape predictors improve the predictability of species occurrence (CCA) and how the change in predictability correlates to dispersal-related plant traits (regression tree). We hypothesized that the increase in predictability due to the inclusion of landscape predictors mainly occurs in species with a low dispersal capacity (see Westermann et al. 2011).

5.2.3.1 Relative Importance of Landscape and Environmental Variables

In a CCA including environmental and landscape variables, the most important predictors were PAR, C/N-ratio, and the proportion of ruderal and other habitat types (Fig. 5.5). PAR and temperature maxima exerted a significant and strong influence on species composition. This is likely due to differences in vegetation height and density during succession. The incoming radiation at the soil surface determines the surface temperature and thereby the air temperature near the surface (Stoutjesdijk and Barkman 1992).

The C/N ratio was the only significant soil predictor. In particular, plots in annual-dominated stages had high C/N ratios. The C/N ratios decreased during succession because the nitrogen content increased from annual- to tree-dominated stages. Correspondingly, in post-mining sites, the total nitrogen content increased in the course of succession (Frouz et al. 2008), thus showing a similar pattern.

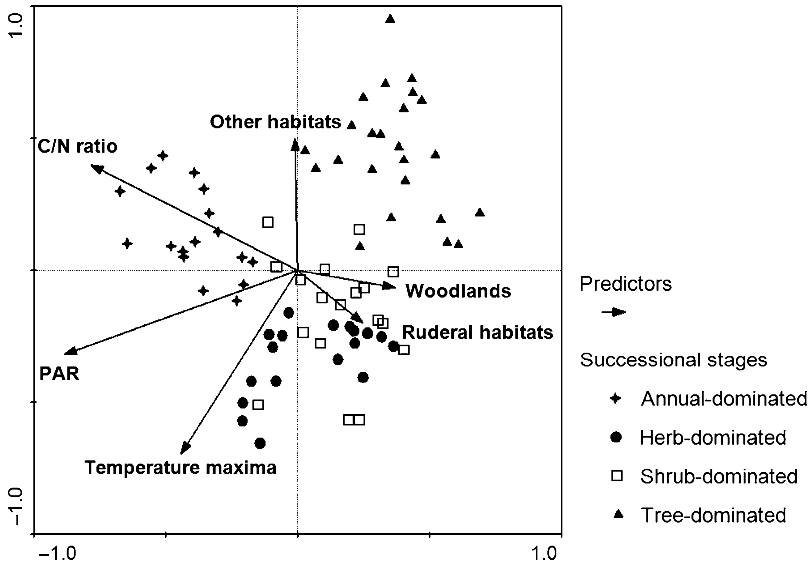

Fig. 5.5 Important environmental and landscape predictors driving plant succession in abandoned railway areas. Biplot of studied plots and predictors based on a CCA; eigenvalues of the first and second axes: 0.631 and 0.408. Significance of all canonical axes: 0.001

Hence, well-known mechanisms from non-urban successional series appear to govern also the succession in abandoned urban railway areas.

The proportion of ruderal and woodland habitats in the local vicinity of a plot exerted a significant and strong influence on the species composition. Muratet et al. (2007) argue that migration of species among large wastelands might have a significant impact on local species composition. Hence, the area covered with plants in the surroundings of a plot may act as propagule source and may thus affect the species composition of abandoned railway areas.

In a variation partitioning analysis, environmental predictors accounted for a higher portion of the variation in species data compared to landscape predictors. However, including landscape variables in a joint model together with environmental variables considerably increased the explained variation in the CCA (Westermann et al. 2011). These findings expand upon results from a study in Brussels, which found that density and function of built-up areas predominantly determine the urban plant assemblages (Godefroid and Koedam 2007). The present study also includes predictors that represent overgrown areas. In this case, the importance of built-up areas as predictor for the species composition is clearly lower but nevertheless significant. Built-up areas may function as dispersal barriers, preventing propagule exchange between fragmented habitats. Early successional stages on urban railway areas were often located in a close proximity to densely built-up neighbourhoods. In particular, propagules of short-lived species are able to reach these sites. This may be due to wind dispersal or due to human-mediated dispersal that favours small-seeded and lightweight species, as shown for traffic (von der Lippe and Kowarik 2008b).

5.2.3.2 Linking Landscape Variables with Species Traits

With a regression tree, we analyzed how the change in predictability due to the inclusion of landscape predictors in a CCA correlates to dispersal-related plant traits. The most important predictor in the regression tree model was the seed longevity index (SLI), followed by seed size, terminal velocity, and seed production. Species with a long-term persistent soil seed bank showed the largest increase in predictability due to the inclusion of landscape predictors in the CCA model. In contrast, species with higher wind-dispersal ability and a more transient soil seed bank had a significantly smaller improvement in predictability. Thus, the increase in predictability mainly occurs in species with low dispersal ability as hypothesized (Westermann et al. 2011).

The most important predictors, SLI and seed size, are more related to long-term persistence of a species on a given site than to dispersal, thus stressing the importance of a persistent soil seed bank in fragmented habitats (Bekker et al. 1998). With increasing isolation, the exchange of seeds between populations is hindered. In such cases, species with life-history characteristics that ensure a high persistence of the seed bank are promoted (Maurer et al. 2003). Such species traits foster stable populations once habitat patches have been colonized.

5.3 Enhancing Ecosystem Services in Urban Settings

Plants are known to mitigate negative features of urban environments, e.g. by reducing heat stress and pollution loads, and to offer multiple chances for urban residents to interact with natural components, with several feedback loops on human health and well-being (Tzoulas et al. 2007; Bowler et al. 2010). Contact with nature makes citizens also aware of the importance of biodiversity conservation and inspires human dwellers to interact with nature (Miller 2005). As the human population is markedly increasing, such ecosystem services become increasingly important. To strengthen them is thus a major challenge for urban planning. Hereby, a key question is to which extent ecosystem services rely simply on biomass or whether biodiversity matters as suggested for some psychological benefits in urban green spaces (Fuller et al. 2007).

Dust in the air is a prominent problem for urban health, and the function of vegetation to reduce this threat has been mainly analyzed for trees along roads or for distinct parks (e.g. Freer-Smith et al. 1997; Beckett et al. 2000; Endlicher et al. 2007). It is promising, however, to also consider the potential functions of the ground vegetation along urban roads, as this type of vegetation is directly exposed to both major pollution sources and the space where people move. Depending of the way of maintenance, vegetation along roads can also harbour an array of species (F. Weber).

While in strongly increasing cities green spaces are often limited and intensively used and managed, contrasting tendencies emerge in cities which are subject to shrinking (Kowarik and Körner 2005; Giseke 2007; Langner and Endlicher 2007). Here, new potentials for green spaces arise due to the reduction of built infrastructure, but often, the financial resources for designing new parks or later maintaining them are limited (Langner 2009). To date, ideas for developing aesthetically attractive green spaces in residential areas are of high practical relevance, in particular in areas where the density of housing estates has been reduced. With a field experiment situated directly in demolition sites, we aim at combining cultural ecosystem services with conservation interests by establishing attractive semi-natural meadows relying on regional provenances of native species (L. Fischer).

5.3.1 Regulating Services of Roadside Vegetation

Roads as key elements of the human society are omnipresent components of most landscapes throughout the world. Nowadays, the public awareness for the societal dependency on road traffic and for related environmental damages is growing and ecological impacts came into the scientific focus. The vast majority of studies on ecological impacts of roads have been developed in rural sites (Foreman et al. 2003).

Roadsides within urban landscapes differ widely in terms of shape, density, traffic, or adjoining usage compared to roads in rural landscapes (Van der Ree 2009). In particular, biotic and abiotic conditions on urban roadsides vary due to the location within the urban mosaic (Wittig 2002). Characteristic for habitats at road verges is a prevailing imprinting due to plant stressors like mechanical disturbances, de-icing agents, increased warming, dusts, heavy metals, and maintenance measures. Traffic also leads to the deposition of plant propagules at road verges (von der Lippe and Kowarik 2007a, b; see above). Generally, the growing conditions for plants next to roads stand for a well nutrient supply, at most slightly acidic to alkaline soils and rather droughty conditions (Langer 1994; Stottele 1995; Foreman et al. 2003). We use the term roadside vegetation in a broad sense relating to the entirety of plants growing on roadsides in urban landscapes. It includes all types of spontaneous and cultivated vegetation occurring in paving joints, at road verges, and tree planting sites (Wittig 2002).

In this chapter, we focus on the benefits people obtain from roadside vegetation, applying the concept of ecosystem services (MEA 2005). Roadside vegetation can give relief from environmental pollution in urban landscapes, first of all because it is situated very next to motor vehicle traffic. However, ecosystem services of roadside vegetation are an uncharted territory and nearly not considered in urban ecology research so far. Analogue to vegetation of other unsealed spaces, roadside vegetation mainly helps to sustain human health and quality of life due to services,

Table 5.2 Overview of regulating ecosystem services which can be related to roadside vegetation, and selected literature references

Services	Sources
Cooling effects	Shashua-Bar and Hoffman (2000)
Air filtration	Helbing (1973), Impens and Delcarte (1979), Beckett et al. (2000), Nowak et al. (1998), Langner (2007), Bealey et al. (2007), Jim and Chen (2008), Litschke and Kuttler (2008)
Noise abatement	Aylor (1971), Cook and VanHaverbeke (1977), Watts et al. (1999), Fang and Ling (2003), Szeremeta and Zannin (2009)
Biomonitoring[a]	Bargagli (1998), Mulgrew and Williams (2000), Djingova et al. (2003), Moreno et al. (2003), Ahmed and Ishiga (2006), Oliva and Fernández Espinosa (2007), Lehndorff and Schwark (2008)

Note: most work is on ecosystem services associated with tree species while research on effects of non-woody vegetation is underrepresented

[a]Biomonitoring based on roadside vegetation provides information on environmental pollution and can be addressed as an example of "provisioning ecosystem services"

which are due to the role of ecosystems in regulating climate and air quality. We here give a first overview on regulating services offered by roadside vegetation which are yet to be thoroughly valuated and made utilisable (Table 5.2).

In urban street spaces, people's health is seriously affected by traffic-related emissions (Samet et al. 2000; WHO 2006; UNEP 2007). Urban structure plays an important role as buildings form vertical barriers hindering the dispersion of particulates, leading to a higher particulate pollution within residential sites by local traffic compared to areas with high traffic surrounded by open space (Capannesi et al. 1993). Currently, the political pressure to act increases as established emission limits have been exceeded seriously in urban areas (UNEP 2007). By the need to improve air quality, the capacity of plants for particulate deposition, and as a result the filtration of dust-laden air, recently gained more scientific attention (Jim and Chen 2008; Litschke and Kuttler 2008). Particulate immobilisation and air filtration is a promising regulating service of urban roadside vegetation, although the effectiveness is still not proved. Proximity to pollution sources could lift removal efficiency of vegetation (Jim and Chen 2008). Freer-Smith et al. (1997) observed that the number of particles counted on leaf surfaces decreased as distance from the motorway increased. In order to maximize the efficiency of filtration, vegetation is required as near as possible to the emission source (Litschke and Kuttler 2008). A planting concept, or the existing vegetation, should provide as great a plant surface as possible near to the emission source without significantly reducing air exchange. Conceivable solutions could include loose ground-level vegetation with adequate spacing between the plants to minimize the effects on airflow, combined with façade greenery (Litschke and Kuttler 2008).

Additionally to urban climate effects, the heat release from traffic increases air temperature in streets canyons (Swaid and Hoffman 1990; Hong et al. 2009). Micro climate regulation and passive air quality melioration have been reported also for small urban green sites with trees (Shashua-Bar and Hoffman 2000).

Furthermore, roadside vegetation is beneficial to city dwellers concerning noise pollution. Vegetation does attenuate noise depending on the density, height, length, and width of vegetation barriers, which influence noise reduction by diffusion, whereas leaf size and branching characteristics have resonant absorption properties (Aylor 1971; Cook and VanHaverbeke 1977; Fang and Ling 2003). However, the actual acoustic effects are small if the vegetation belt is rather narrow (Kragh 1980). Vegetation in cities in general and roadside vegetation in particular could be beneficial to people in terms of coping with noise: Szeremeta and Zannin (2009) found that visual features such as vegetation or fauna contrasting the "grey" urban surroundings and acoustic conditions being different from traffic noise proved to be important factors influencing the perception of traffic noise within an urban park.

Roadside vegetation also offers biological monitoring with plants as a low-cost and effective method to estimate levels of environmental pollution and their impact on biological receptors (Mulgrew and Williams 2000; Oliva and Fernández Espinosa 2007). Biomonitoring by plants can be used as a standardized method (Bargagli 1998; Moreno et al. 2003).

It is widely acknowledged that green spaces and natural elements generally benefit people (e.g. Bowler et al. 2010). However, space for nature development in urban landscapes is often scarce. As roadside vegetation is in the immediate vicinity of people's everyday life, its potentials and services should be explored thoroughly and considered in urban planning decisions. Up to now, the filtration of airborne particles by plant surfaces was studied mostly for trees and some shrubby species (Beckett et al. 1998; Freer-Smith et al. 2004). First evidences suggest, however, that spontaneous vegetation may also contribute to the immobilisation of airborne particles (Jim and Chen 2008; Litschke and Kuttler 2008; Weber et al. unpubl. data). Further research should thus also consider ecosystem services of herbaceous roadside vegetation.

5.3.2 Urban Meadows: Linking Conservation Goals with Cultural Ecosystem Services

Being widely established in the city, urban meadows originate and sustain due to a wide array of uses and objectives. As grassland covers about 5% of the city's surface (SenStadt 2008), these areas are of high relevance for Berlin's residents in terms of recreation, sports, and experience of nature. Also for plant species, urban meadows such as in old parks can be a "refuge" (Maurer et al. 2000; Peschel 2000). Some reasons are that gaining a good yield is unimportant for landowners here, and with the continuance of the sites such as in historic parks, they are often maintained over long periods of time in a traditional way (Wilhelm and Andres 1998).

The potential of urban grasslands becomes especially interesting for biodiversity conservation when considering the remarkable decline of extensive grasslands in agriculture (Wesche et al. 2009). Here, grassland extent and quality change due to intensification of agriculture (Reidsma et al. 2006) but also with the abandoning of unproductive sites (Henle et al. 2008). Additionally, urbanization leads to the fragmentation of many grassland areas in the cultural landscape (Ricketts and Imhoff 2003; Antrop 2004; Wittig et al. 2010). However, it is uncertain to which extent grasslands occur in urban settings today, and if they are of similar quality to agricultural – i.e. traditional – grasslands. In addition, aesthetically attractive grasslands are integral parts of designed and semi-natural green spaces, where they may contribute to human well-being as a part of aesthetic experience. Aesthetic experiences often lead to direct actions or generate feelings like that of identity as found for European agricultural landscapes (Gobster et al. 2007).

It is thus challenging to consider both conservation value and cultural significance of urban grasslands. Combining both functions could strengthen the potential to maintain or establish species-rich grasslands in urban settings. Taking Berlin as an example, we here first present an overview of the function of different urban land use types in harbouring legally protected grasslands and then illustrate an experimental approach in establishing species-rich grasslands in residential areas.

5.3.2.1 Protected Grasslands in Urban Settings

With analyzing the Berlin Biotope Mapping (Senstadt 2008), we performed a first area-wide GIS-based analysis of quantity and quality of urban grassland biotope types (Fischer et al. unpubl. data). We hereby compared legally protected and non-protected grasslands in agricultural areas to that of typical urban land use types (airports, historic parks, other urban areas). We determined that of all grassland cover in Berlin, 43% are legally protected grassland types. Only one-third of these grasslands are located in agricultural areas but the majority of more than 70% lies in other land use categories. Covering just 2% of Berlin's surface, airports and historic parks contain one-third of all protected dry grasslands.

Largest grassland patches with a high connectivity on different scales were determined for airports and partially for agricultural areas. Grassland patches in urban green spaces outside of historic parks and airports are least connected with other grassland habitats. In airports, grasslands of special conservation interest are highly connected as the areas themselves are large and other biotope types are less common due to the land use type itself. With that, airports represent core areas for grassland habitats in the inner city. Also, the smaller grassland patches in historic parks may contribute to the inner city habitat network, as patches are highly connected with other non-sealed surroundings, whereas their small patch size might originate from the landscape garden design.

These results demonstrate the prominent role of urban land use types to harbour grassland habitats of special conservation interest outside of agricultural areas. In parts, urban grassland may compensate for the high decline of traditional grasslands in the cultural landscape. As our analyses also showed that most of the protected grasslands are located outside of conservation areas, the results suggest that private and public landowners need to be involved in strategies to conserve urban grassland. Especially within the next years, when both inner city airports in Berlin are being changed to green spaces and housing areas, aims of biodiversity conservation and options for recreation of urban dwellers need to be balanced. This offers an excellent opportunity to “conserve biodiversity where people live and work” (Miller and Hobbs 2002).

5.3.2.2 Establishing Species-Rich Grasslands in Residential Areas

In dense residential areas, usually more intensely managed grassland types such as lawns prevail. In shrinking urban regions where residential houses and associated infrastructure are demolished, the evolving green space offers the chance to establish meadows oriented on extensive grassland types. Here, establishing new meadows might match objectives of nature conservation, planning, and aesthetics. The initiation of grasslands on demolition sites requires careful consideration of various background factors, though. For example, an important issue for planners and landowners is the question about financial advantages of meadows compared to traditional landscape design with frequently cut lawns. Not only the initiation but also the later maintenance needs to be a cheap option for large-scale greenings (Giseke 2007; Langner 2009). It is equally important that the created meadows have an appealing character to residents whilst being appropriate for their daily use. These social and psychological benefits associated with biodiversity (Fuller et al. 2007) are especially important for residents who rarely have the possibility to experience nature (Miller 2005; Samways 2007).

For nature conservation, we can determine two distinct advantages of creating extensive meadows in shrinking residential areas. First, species that are on the decline in the cultural landscape may be at least partially supported in these areas – considering that the importance of urban green spaces for biodiversity generally grows (Goddard et al. 2010). Second, a positive interaction is to be expected for residents interested in nature and its conservation (Miller 2005; Dunn et al. 2006).

The establishment of extensive grasslands on urban demolition sites has to meet several requirements: (a) technically, as dispersal limitations of native grassland species need to be overcome, and target species have to be established over time. Limitations linked to abiotic, e.g. soil characteristics, need to be incorporated. (b) The new meadow type has to withstand the typical pressure of use in residential areas. (c) The meadows have to be perceived as an attractive alternative to common landscape design but also to non-maintained wasteland.

Our study area Marzahn-Hellersdorf in the north-eastern part of Berlin is a large-scale residential housing area of the 1980s, when about 100,000 apartments were built. Especially young families moved in back then, resulting now in an oversupply of kindergartens and schools due to severe demographic changes – e.g. the proportion of elderly people is predicted to increase another 190% within the next 20 years (Bezirksamt Marzahn-Hellersdorf von Berlin, n.d.). The area is a part of the program ‘Stadtumbau Ost’ (Senstadt 2010), meaning that apartments were torn down within the last years (Bezirksamt Marzahn-Hellersdorf von Berlin 2007).

Nevertheless, shrinkage of the quarter is still apparent with various demolition and wasteland areas, and evolving free spaces of no future or interim use.

In these surroundings, we test different treatment types which involve strategies of reintroduction of species and assisted migration (Ricciardi and Simberloff 2009; Vitt et al. 2010): (a) seed mixtures of regional provenances, (b) the same seed mixtures combined with a mycorrhiza inoculation, and (c) seed transfer (*Heudrusch*®) from species-rich grassland communities of nearby conservation areas. For the first treatment, we composed seed mixtures oriented on comparable grasslands in the cultural landscape outside of Berlin. The mycorrhiza inoculation should give a start up aid for the vegetation, especially in dry times, and increase soil stability (Rillig and Mummey 2006; Chaudhary et al. 2009). With seed transfer, we apply a traditional method which transfers not only target species but also species of other functional groups such as mosses. These methods are known as robust treatments for extreme sites (Kirmer and Tischew 2006; Tischew et al. 2010; Kiehl 2010; Kiehl et al. 2010), but have not been tested in urban settings yet.

We randomly applied the three treatment types on tilled soil in $4 \times 4\ m^2$ plots in fall 2008 on 11 sites in Berlin-Hellersdorf. Each site also has a control plot. Plots were neither marked nor fenced, as we wanted residents to use these areas just as normal. In the following 2 years, we studied the success of our target species and the spontaneous vegetation (mapping of all species, their cover, and reproductive potential), and analyzed environmental parameters (e.g. soil stone content, potassium, pH, frequency of dogs and people).

First results show a significant increase in species richness in the treated meadow plots already after the first 2 years, e.g. species number increased from 28 species on average in control plots to over 40 species in both seeding treatments. The highest species numbers were found in plots where regional seeds were sown and mycorrhiza was inoculated. Many target species are already abundant. In those variants where seeds were applied, of the 26 sown species, in average, we found 11 (seed mixture only) and 14 (seeds combined with mycorrhiza) target species. Nine of the target species were among the most frequent 20 species found in the seed mixture treatments. This shows that spontaneous vegetation and target species are nearly equally present. Seed transfer had a lower rate of target species (on average 4 of 16 target species). In all treatments, target species richness was increasing in the second year of establishment. Blooming aspects were changing throughout the course of the year (Fig. 5.6).

Statistical modelling which incorporates environmental variables showed that the abundance of target species is strongly depending on abiotic parameters such as the stone content in the soil. In contrast, human-mediated disturbances by recreational activities or walking dogs had less influence on the occurrence of target species in the non-fenced plots. This latter surprising result suggests promising chances of establishing species-rich grassland vegetation in residential areas.

In the long run, we anticipate the emergence of novel grassland types in residential areas, which are characterized by a mixture of typical grassland species (target species) and ruderal species that colonize the plots from adjacent seed

Fig. 5.6 New types of urban grasslands are initiated in large-scale housing areas in Berlin. Blooming aspect of marguerite *Leucanthemum ircutianum* in summer of the second year of establishment

sources or the propagule bank. Further monitoring should test the successful establishment of target species over longer periods of time.

A future part of the study will aim at the perception and preferences of the experimentally established grasslands by the neighbourhood. It will be of high relevance for application which meadow type they prefer, and if simple methods such as seed mixtures on tilled soil are sufficient to create meadows which appeal to residents. If this could be proved statistically, our project could be a new impulse to combine cultural ecosystem services with nature conservation interests.

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Chapter 6
New Directions in Urban Avian Ecology: Reciprocal Connections between Birds and Humans in Cities

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6.1 Introduction

Ask any urban person what type of animal they see on a daily basis and the response will likely be "birds". Whether it is their increased mobility due to flight compared to other animals, or a particular ability to adapt to changes in the environment, certain species of birds live in relatively high densities in human-dominated landscapes. Indeed, some species apparently thrive in urban habitats. The connection between birds and human settlements is not a recent one. For example, the house sparrow (*Passer domesticus*) is estimated to have begun its commensal relationship with humans between 400,000 and 10,000 years ago in the Middle East (Anderson 2006). Despite this ancient connection between people and birds the reciprocal nature of our interactions is just beginning to be investigated (e.g. Marzluff and Angell 2005).

The study of avian ecology in urban areas has steadily grown in the last decade (see Fig. 6.1), but the vast majority of this research documents the hazards of humans to birds. We affect ecosystem dynamics by changing land cover, producing waste, using resources, and changing communities of fauna and flora (Marzluff 2001; Liu et al. 2007). The major factors negatively affecting bird species are habitat alteration (loss, fragmentation, small patch sizes, vegetation changes) and introduced/exotic species (predators and competitors; Chace and Walsh 2006). These factors, however, are mostly indirect. Humans can also have direct negative effects on birds, such as disturbance (Evans et al. 2009; Fernandez-Juricic et al. 2003;

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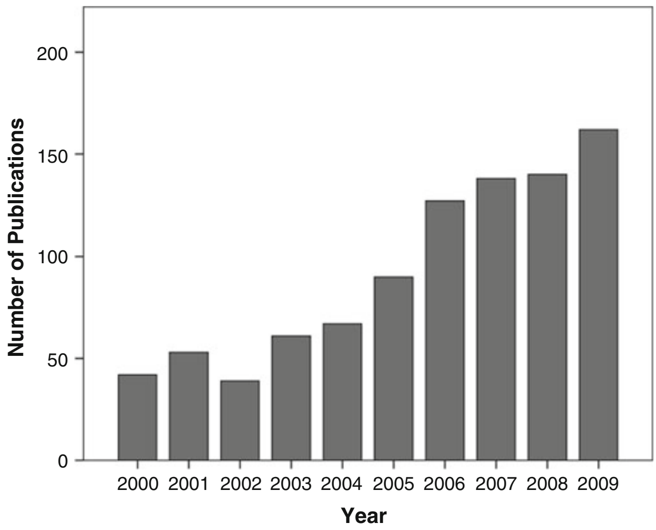

Fig. 6.1 Number of publications by year found when searching "urban and birds" and "urban and avian" on Web of Science

Möller 2008; Schlesinger et al. 2008). Humans may unintentionally negatively affect birds in urban areas simply by passing by a nest or walking in a foraging area (Fernandez-Juricic et al. 2003; Campbell 2006; Möller 2008). Human visitation to parks and other natural areas can disturb birds' foraging, breeding, and nesting behaviour (Chace and Walsh 2006).

The effects of humans on birds, while profound (Marzluff 2001, 2005; Chace and Walsh 2006; Robb et al. 2008; Chamberlain et al. 2009; Evans et al. 2009), is not only negative. A positive influence on birds is the supplementary resources provided to them by people. Our plantings, buildings, structures, and birdhouses provide novel nesting sites. Our direct (bird feeders) and indirect supplementary foods (e.g. garbage) can profoundly affect birds. In fact, up to 43% of households in the United States and 75% in the United Kingdom feed birds (Robb et al. 2008), and 48% of urban households in the UK provide food for birds (Evans et al. 2009). The effect of supplementary feeding on birds in urban areas has the potential to be substantial (Lepczyk et al. 2004; Chace and Walsh 2006; Fuller et al. 2008; Robb et al. 2008; Chamberlain et al. 2009). Positive effects include increased winter survival, larger population sizes, and for raptors, a greater prey base (Chace and Walsh 2006). Most studies on the influences of feeding birds have been conducted in rural areas (see Evans et al. 2009); nevertheless, feeding birds is also common in urban areas. There are potential negative consequences of providing food for birds, including reduced diet quality, inadequate diet for nestlings and increased disease transmission, predation risk, and spread of exotics (Chace and Walsh 2006; Chamberlain et al. 2009).

Supplementation of resources is a defining feature of urban ecosystems that may also affect community dynamics, essentially increasing the community carrying capacity, favouring some species, and disconnecting trophic dynamics from in situ productivity (Hairston et al. 1960; Menge and Sutherland 1976, 1987; Fretwell 1987; Oksanen 1991; Polis and Strong 1996; Chesson 2000). In this way, supplementation of resources from outside the urban ecosystem (Polis and Strong 1996) modifies the ways in which competition interacts with predation, facilitation, mutualism, colonization, recruitment, and the productivity and stress of the physical environment to determine diversity (Menge and Sutherland 1976, 1987; Wootton 1994; Jones et al. 1997; Hacker and Gaines 1997; Chesson 2000; Crain et al. 2004). Supplementation may disproportionately advantage birds the scavenge, eat seeds, and nest in cavities, but these effects may ripple throughout urban bird communities as some predators, parasites, excavators, or strong competitors are positively or negatively affected by human supplementation.

Just as humans can affect birds, birds influence humans. Due to the abundance and diurnality of certain species in urban areas, birds are often the most visible wildlife in human-dominated areas. It is possible that just the presence of birds can positively affect human health and well-being (e.g. Fuller et al. 2007). Research has demonstrated that viewing nature can decrease recovery time after surgeries; improve blood pressure, cholesterol levels, and outlook on life; reduce stress and mental fatigue; and improve concentration (Bjerke and Ostdahl 2004; Maller et al. 2005). Birds can also perform certain ecological services for humans, such as decreasing pest arthropod numbers (Blockstein 1998).

The negative aspects of birds living in proximity to humans are mostly indirect – damage to property (including homes, vegetable gardens, and fruit trees) and nesting and defecating in undesirable places; however, birds can transmit disease and some species will even attack humans (e.g. corvids and gulls; Marzluff et al. 1994). The banning of hunting in cities may select for an increased propensity in birds to attack people in urban areas (Knight 1984; Knight et al. 1987).

The interactions between humans and birds in urban areas are influenced by various factors. First, characteristics of the urban environment, such as city age (Marzluff in press), size, geographic location, and habitat type can influence relationships. For example, in comparison to European cities, North American cities are relatively young and species compositions of birds may include species that are currently adapting to urban life or being driven to extinction whereas older European cities may include more adapted species (Martin and Clobert 1996; Marzluff in press).

Human interactions with and attitudes towards animals can be influenced by human demographic, socioeconomic, and cultural factors. For instance, age, gender, and education can affect whether landowners feed birds, and occupation and relative house size can influence if they use pesticides or herbicides, which can harm birds (Lepczyk et al. 2004). In addition, people in deprived areas are less likely to feed birds (e.g. Fuller et al. 2008). Human interest and concern for animals have been shown to vary with age, gender, and education level (see review in Bjerke and Ostdahl 2004). An increase in education corresponds to an increase in positive attitudes towards animals, and there are subtle species preference differences between children and adults and between females and males (Bjerke and Ostdahl 2004). Cultural differences also exist among countries where human attitudes and actions towards animals were surveyed (e.g. USA, Germany, and Japan; Kellert 1994).

Birds' relationship with humans can also vary according to life history and morphological, physiological, and behavioural traits. Habitat use, degree of specialization (e.g. diet), local history (native or exotic), activity patterns (e.g. nocturnal vs. diurnal), migratory and reproductive behaviour, intelligence (e.g. degree of innovative behaviour), physiological tolerance, and personality (e.g. risk adverse or explorative) have all been shown to affect whether bird species are urban adaptors or avoiders (Jerzak 2001; Chace and Walsh 2006; Bonier et al. 2007; Croci et al. 2008; Möller 2008; Marzluff in press).

As interest in urban ecology generally, and urban avian ecology specifically, increases we urge researchers to fully investigate the positive and negative, reciprocal linkages that couple human and natural elements of urban ecosystems (Liu et al. 2007). Here, we describe recent research in avian urban ecology conducted through the Urban Ecology program at Humboldt University in Berlin, Germany (Perspectives on Urban Ecology III – Optimizing urban nature development) that begins to more fully examine human-natural connections. We start with some examples of birds that are adapting to urbanization in Berlin: one an endangered songbird, the other an urban-savvy bird of prey; we then present a comparative study of human–avian interactions in Berlin and Seattle, Washington, USA.

6.2 The Northern Wheatear (*Oenanthe oenanthe*) in Berlin

The Northern wheatear is a widespread but endangered bird species (Baillie et al. 2004; Südbeck et al. 2007). Whereas populations of natural habitats like alpine meadows and tundra do not show a long-term decline, those in man-made habitats like pastures, vineyards, stone pits, or mining areas have shown a severe decrease since about 1870 (Glutz von Blotzheim and Bauer 1985; Bauer et al. 2005). Wheatear populations declined dramatically since the 1990s in Germany as well as in other countries in Europe (BirdLife International 2004; Baillie et al. 2004; Südbeck et al. 2007). The main cause of decline is land-use change. As an insectivorous, long-distance migrant wintering south of the Sahara desert, the wheatear suffers also from drought and overgrazing in its winter habitat (Bauer et al. 2005).

A study on habitat requirements and breeding success of the wheatear in Berlin, Germany, found that residential human population was negatively correlated with wheatear's occurrence, but that increasing impervious surfaces (sealing) encouraged settlement by wheatears (Meffert et al. in prep.). These relationships existed only within 50 m around the plot, whereas the broader urban context of a 2-km scale human activity did not influence occurrence probability. In accordance with previously described habitat requirements of this species, it favoured high proportions of sand cover and very short grass. Wheatears avoided any tree or moss cover and tolerated only very few shrubs. Plot size emerged to be a crucial factor, with occurrence probability being much higher on sites larger than five hectares.

Most pairs settled on wasteland often former railway properties. Almost a quarter of the pairs were found on a former airport site that was transformed to a country park containing a nature reserve that was grazed by sheep. A minor portion of the pairs was found at construction sites, on railroad properties, in storage yards, and in a so-called “meadow park”.

Overall breeding success was high: in 73% of the nests, young fledged. Breeding success did not vary between the 2 years. Approximately half of the nest losses happened on construction sites, where heaps of rubble and stones were altered. Predation rate was comparatively low (seven percent of nests were preyed upon). Compared to other artificial habitats like vineyards (Buchmann 2001) or heathlands (Tye 1980), breeding success was considerably higher in wastelands; natural habitats show approximate similar values (Moreno 1989).

Meffert et al. (in prep.) only found a weak influence of direct disturbance by humans, since plots were large enough for the wheatear to avoid encounters with humans and dogs. Field observations showed that proximity of nest locations of a few metres to railroad tracks, walkways, or benches did not prevent the birds from nesting and feeding chicks. That contrasts to observations of other authors. Possibly, urban populations adapt their behaviour as known for other species (e.g. Luniak and Mulsow 1988).

Our findings show that wheatears are able to cope with or even profit from the urban habitat. The wheatear, settling and successfully breeding on wasteland is an example of an early successional species that, with little direct effort from people, can thrive in urban settings. This might hold true also for other endangered open-land bird species such as tawny pipit *Anthus campestris*, linnet *Carduelis cannabina*, tree sparrow *Passer montanus*, and crested lark *Galerida cristata* that were also found on the study sites.

To maintain habitats, novel approaches in wasteland management and landscaping are needed. Two of the studied areas in Berlin are already transformed to parks, and show that recreational usage and habitat requirements of the wheatear can be balanced.

6.3 The Common Kestrel (*Falco tinnunculus*) and House Sparrow (*Passer domesticus*) in Berlin

The kestrel is the most common bird of prey in Berlin. There are approximately 200–250 breeding pairs in the whole city. From 2002 to 2004, the feeding ecology of kestrels was studied in Berlin across an urbanization gradient, as well as several life history and behavioural traits such as reproductive success and nesting location (Kübler 2006). Data was also collected from 2004 to 2010, however, not systematically.

Kestrels had high reproduction success at all sites in Berlin across the urbanization gradient, if they bred in special nest boxes (about 4.7 young/brood, Kübler 2006). However, effects of the urban gradient are clearly visible in regards to the composition of food kestrels prey on. The diet of kestrels was studied by pellet analysis and the remains of plucked feathers. Birds were found to be the main prey item in the city centre (mainly house sparrows) but this decreased towards the outskirts (Kübler et al. 2005). Rodent prey items (e.g. mice and shrews) follow an opposite pattern, becoming increasingly present in the kestrels' diets when moving outside the city centre. Perhaps the most striking finding was anthropogenic food items, for example bones of human-processed meats (steaks, chops, ribs), found in many nest boxes in the city centre, which shows the adaptation to humans (Kübler and Zeller 2005; Kübler 2006). Some exotic prey birds were found predominantly in the central area, notably budgerigars. Another remarkable behavioural adjustment found in kestrels is their decreasing fear of humans (e.g. foraging on a schoolyard for sandwiches, hunting of pigeons on main streets, nesting on high rise buildings).

The nesting locations of kestrels in Berlin also demonstrate adaptations to living in an area of high human-made structures. Indeed, the German name "Turmfalke", translated literally means "tower falcon". Apart from the common breeding sites (nest boxes/aids, niches of buildings), several very extraordinary nesting sites were documented in Berlin, for example, breeding in a flowerpot. This flexibility in breeding locations has also been observed quite frequently in Tel Aviv, Israel (Charter et al. 2005).

A positive aspect for kestrels living in the highly dense areas of Berlin is the high density of its most common prey item: the house sparrow (*Passer domesticus*). The population of house sparrows in Berlin is estimated to be 100,000 to 200,000 breeding pairs (Otto and Witt 2002) respectively 119,000 breeding pairs (Böhner and Schulz 2007) and their abundance depends on building structures and food resources of human origin. The highest densities were recorded in high-rise apartment building areas (Kübler 2006) confirming their strong attachment to humans. House sparrows also use nesting material of human origins (e.g. thread, wool, plastic, foil).

The population of house sparrows in Berlin is not endangered by the kestrel (or other predators). Both species are thought to enrich the city life and are well-liked by the Berlin inhabitants (Kübler 2005). The two species are also protected by the Environmental Protection Authorities and the German Nature Saving Law ("Deutsches Bundesnaturschutzgesetz"). But, it has to be emphasized that especially in a metropolis like Berlin, there is always need for further research, because the synurbization (adaptation to urban environments) progresses permanently. It is important to understand the developing mechanisms and adaptations in a city, so that one can conserve and protect the avifauna in the long run.

6.4 Human–Avian Interactions in Berlin and Seattle

6.4.1 Methods

We conducted a human survey of attitudes and actions towards birds in Berlin, Germany, and Seattle, Washington, USA, to quantify the level of human engagement with birds. We also quantified bird diversity and nesting behaviour in both cities so that we could determine how human attitudes and actions might influence birds. We conducted the human and bird surveys across an urbanization gradient (see below) to capture various types of habitats, human socio-economic status, and bird communities. Here, we will outline the methods of the study and present some preliminary results and discussion.

6.4.1.1 Study Areas

Seattle, Washington, USA (47°36′35″N, 122°19′59″W)

The area of Seattle was originally settled by persons of European descent around 1850, and in 1889, Washington was declared a state. The population around that time was 80,671 inhabitants (Dryden 1968). Currently, the Seattle metro area covers approximately 21,200 km^2 and has a population size of 3,344,813 inhabitants.

The human survey was conducted in Seattle from October 2009 to February 2010.

Berlin, Germany (52°30′2″N, 13°23′56″E)

The area of Berlin was originally settled by Slavic tribes around 720, but it was not until 1244 that the city of Berlin was founded. By 1400, the population was around 8,000 inhabitants, and by 1709, Berlin had 55,000 inhabitants (Taylor 1997). Currently, the Berlin metro area covers approximately 891.82 km^2 and has a population size of 3,700,000 inhabitants.

The human survey was conducted in Berlin from August 2008 to December 2008.

6.4.1.2 Study Sites

We selected two study sites for each site type along an urbanization gradient: (a) Heavy Urban (city centre, apartments), (b) Medium Urban (suburban, detached family-housing), (c) Medium-Light Urban (suburban, detached family-housing), and (d) Light Urban (village/rural, detached family housing, farms) (see Table 6.1 for study site characteristics, Fig. 6.2 for maps, and Fig. 6.3 for images of study

Table 6.1 Study site characteristics

City	Study site	Urban level	Human density (average resident/ha)
Seattle	Belltown	Heavy	129
	Capitol Hill	Heavy	129
	Ravenna	Medium	37
	Laurelhurst	Medium	24
	Somerset	Medium-light	14
	Westwood	Medium-light	11
	Maltby	Light	2
	Duvall	Light	8
	Lee Forest	Forest	0
Berlin	Moabit	Heavy	350
	Kreuzberg	Heavy	400
	Mariendorf	Medium	45
	Karlshorst	Medium	77
	Rudow	Medium-light	49
	Dahlem	Medium-light	22
	Lübars	Light	15
	Blanken-felde	Light	9
	Stadtforst	Forest	0

sites). We also conducted point counts (see below) at a forested site in each city to represent bird diversity and abundance in a less anthropogenic habitat.

6.4.1.3 Human Surveys

We attempted to conduct approximately 30 personal interview-style, door-to-door surveys at each site (see Table 6.2 for sample sizes). We posted flyers either in mailboxes or in public places about a week before surveying to notify residents of the survey. We first gave each participant information about the study and then asked questions from four sections: A, B, C, and D. Appendix A includes a sample survey of the English version used in Seattle. In Berlin, a German version of the survey was utilized.

Section A consisted of general questions about the respondents' actions and attitudes towards birds (see Appendix A; e.g. do they feed birds, how often they watch birds, if they are bothered by the noise birds make, did they do any actions to discourage birds from their home or yards). This section was designed to measure the level of engagement the participant had with birds and their general opinions of birds.

Section B included specific questions pertaining to the participants' perceptions of two contrasting bird species: finches and crows. Greenfinches (*Carduelis chloris*) and hooded crows (*Corvus corone cornix*) were used in Berlin and house finches (*Carpodacus mexicanus*) and American crows (*Corvus brachyrhynchos*) were used in Seattle (see Fig. 4). These species are found across all sites in each city. We chose these species to obtain a range of attitudes and actions people exhibit towards birds.

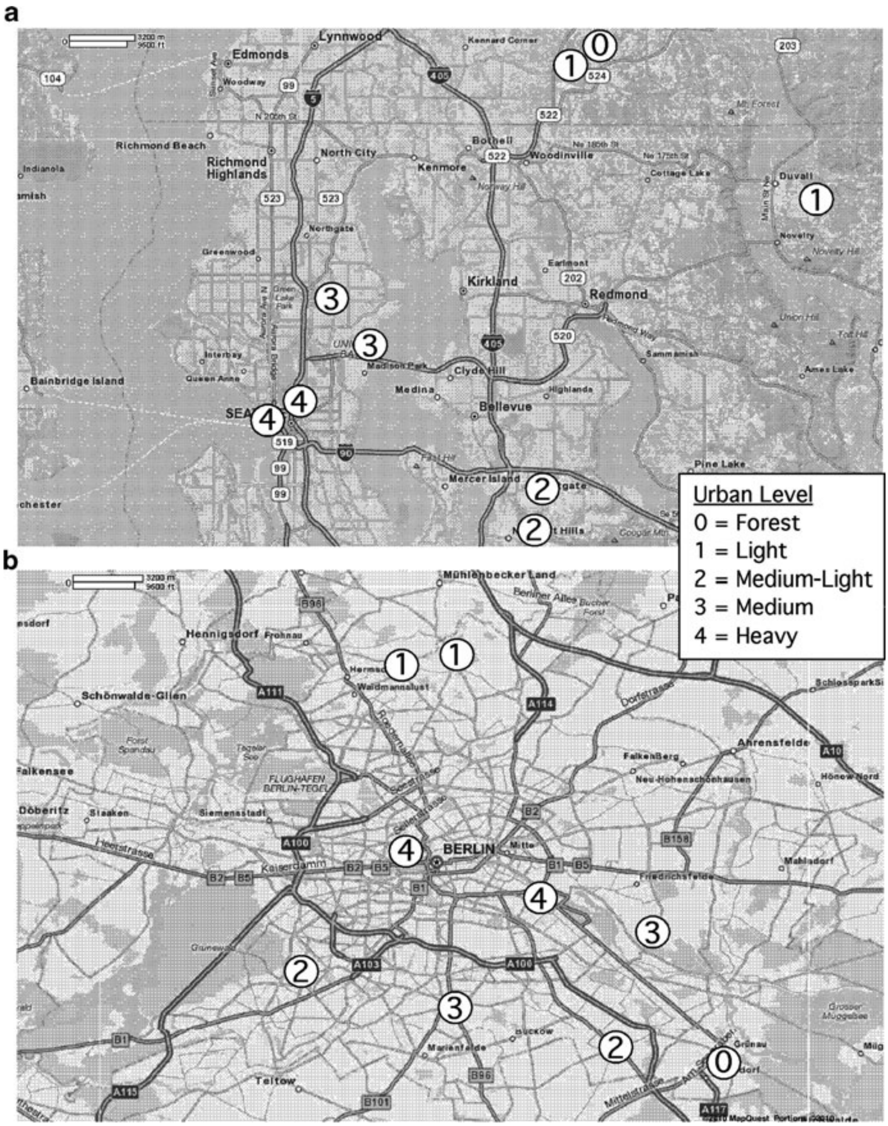

Fig. 6.2 Maps of study site locations in (**a**) Seattle, Washington, USA, and (**b**) Berlin, Germany

We expected that most people would have positive or neutral opinions about the finch species due to their charismatic coloration and vocalizations (finches produce melodic songs). In contrast, we expected most people to have neutral or negative opinions of the crow species because of their negative reputation (e.g. getting into trash) and relatively harsh vocalizations (“caws”). At the beginning of this section, the participant was shown a colour photograph of one of the species (finch or crow, see Fig. 6.4, order was varied across surveys) and asked if they recognized the bird

Fig. 6.3 Photographic images of study sites in (**a**) Seattle, Washington, USA, and (**b**) Berlin, Germany. From top to bottom: Heavy Urban, Medium Urban, Medium-Light Urban, and Light Urban (photograph credits: Seattle: Jacob Clifford; Berlin: Helena Franke)

Table 6.2 Human and bird survey information

City	Study site	Number of surveys	Percent feeding	Percent nest box	Number bird species
Seattle	Belltown	26	11.5	0	8
	Capitol Hill	25	24.0	4.0	13
	Ravenna	28	42.9	17.9	18
	Laurelhurst	25	28.0	16.0	32
	Somerset	25	64.0	48.0	28
	Westwood	29	53.6	13.8	28
	Maltby	25	72.0	24.0	28
	Duvall	26	65.4	30.8	39
	Lee Forest	0	0	0	24
Berlin	Moabit	52	28.8	5.8	16
	Kreuzberg	50	14.0	0	17
	Mariendorf	50	70.0	48.0	16
	Karlshorst	50	76.0	48.0	30
	Rudow	50	62.0	42.0	16
	Dahlem	50	62.0	36.0	20
	Lübars	31	67.7	38.7	28
	Blanken-felde	26	57.7	46.2	31
	Stadtforst	0	0	0	19

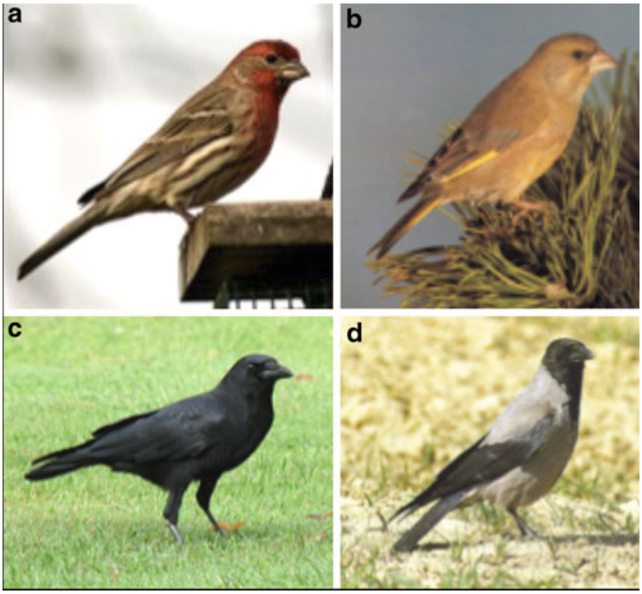

Fig. 6.4 Photographs of bird species used in the human survey: (**a**) house finch, (**b**) American crow, (**c**) greenfinch, and (**d**) hooded crow

(if they recognized the bird, they were also asked if they recognized its vocalization) and then were asked a series of questions that addressed the participants' attitudes and actions towards the species (e.g. how pleasing they found its visual appearance, if they encouraged or discourage it from their home or yard; see Appendix A).

In connection with Section B, Section C asked about willingness to pay for management efforts for finch and crow species (see Appendix A). Based on the participants' responses in Section B, they were asked if they would pay to conserve (positive responses in Section B) or reduce (negative responses in Section B) the species' population in the city. If the respondents' responses were neutral, they were asked both how much they would be willing to pay to conserve or reduce the species' population.

Finally, Section D consisted of demographic questions (gender, age, own or rent housing, schooling, income, etc; see Appendix A).

6.4.1.4 Bird Species Diversity and Nesting/Feeding Behaviour

We determined bird species diversity and abundance by conducting point counts of birds at each site using standard methodology (e.g. Donnelly and Marzluff 2006). Briefly, counts were conducted at three locations 250 m apart per site four times across the breeding season (once a month from April–July, in 2009 for Berlin and in 2010 for Seattle). A count lasted for 10 min and every bird seen or heard within a

50-m radius was recorded on a map of the location. Point counts conducted in the forest sites were done at least 500 m from human structures.

Bird species were categorized into groups based on nesting and feeding behaviours. Categories for nesting behaviour were open nester, primary cavity nester (excavates hole itself), or secondary cavity nester (utilizes a pre-existing hole). We characterized birds as those that forage on bird feeders provided by humans (including consistent to occasional use) and those that do not.

6.4.2 *Results*

6.4.2.1 Human Attitudes and Actions Towards Birds in Berlin and Seattle

We surveyed 209 residents in Seattle and 356 residents in Berlin. There were no significant differences in the number of males and females surveyed in either city; however, the age structure of Berlin residents was slightly skewed towards an older age (Fig. 6.5). The mean age of people surveyed differed between the two cities with Seattle having a mean of 49.64 years (±1.97 SE) and Berlin having a mean of 54.51 (±0.956 SE) (ANOVA: $F_{1,563} = 9.90$, $p = 0.002$). We found that a majority of respondents in each city watched or identified birds on a daily basis (Fig. 6.6) but that Berlin residents were more likely to watch or identify birds than were Seattle residents (Chi square: $X^2 = 19.37$, df = 5, $p = 0.002$). Residents in both cities rarely reported being concerned with disease transmission from birds (9.8% were somewhat to very much concerned) or bothered by the noise birds made around their homes (12.5% were somewhat to very much bothered).

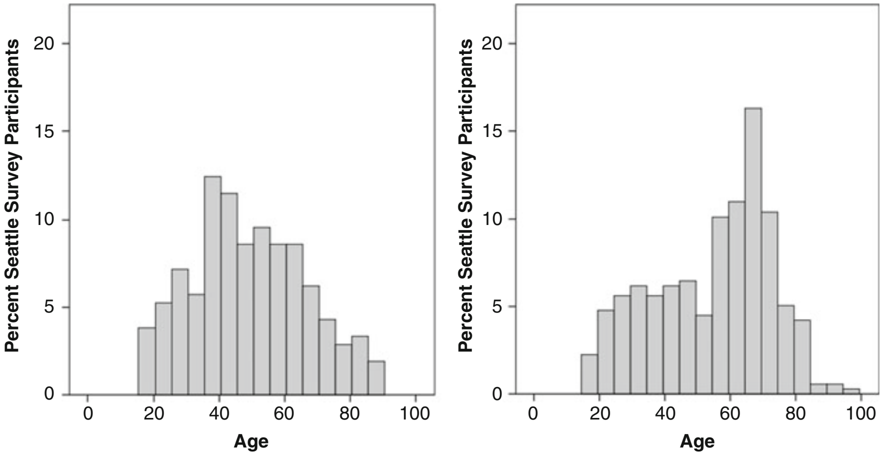

Fig. 6.5 Age distribution of survey participants in Seattle and Berlin

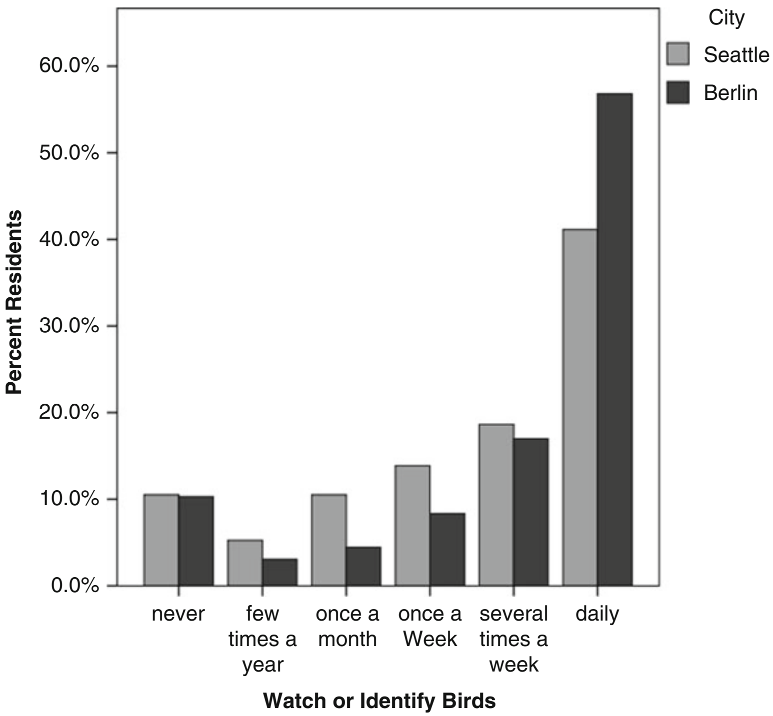

Fig. 6.6 Degree to which survey participants watch or identify birds in Seattle and Berlin

Table 6.3 Factors influencing bird provisioning (feeding and nest boxes) in Seattle and Berlin (Logistic Regression; asterisks indicate significant factors)

	B	S.E.	Wald	df	Sig.	Exp (B)
Percent residents feeding birds						
City*	0.442	0.206	4.609	1	0.032	1.556
Urban gradient*	−0.234	0.042	31.423	1	0.000	0.792
Age*	0.029	0.006	25.535	1	0.000	1.030
Own	−0.445	0.229	3.762	1	0.052	0.641
Constant	−0.620	0.368	2.836	1	0.092	0.538
Percent resident providing nest boxes						
City*	0.920	0.235	15.332	1	0.000	2.510
Urban Gradient*	−0.224	0.051	19.195	1	0.000	0.799
Age*	0.025	0.007	13.828	1	0.000	1.025
Own*	−1.154	0.284	16.500	1	0.000	0.316
Constant	−1.794	0.442	16.492	1	0.000	0.166

The percentage of respondents that fed birds was influenced by several factors: city, location on urbanization gradient, and age of respondent (Table 6.3). First, Berliners feed birds slightly, although significantly, more than Seattleites. Second, respondents living in heavy urban sites feed birds less than those living in medium

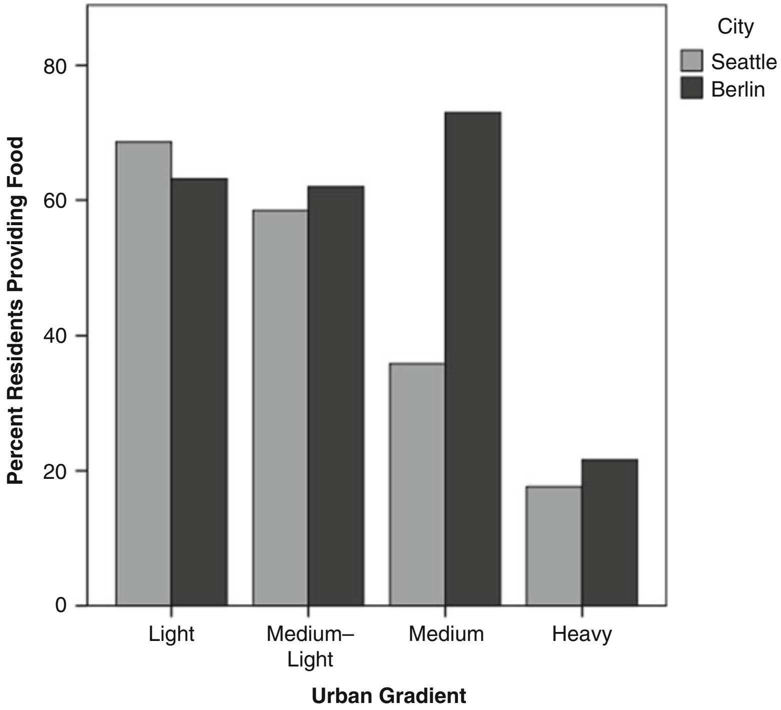

Fig. 6.7 Percent survey respondents that feed birds across the urbanization gradient in Seattle and Berlin

to light urban sites (Fig. 6.7). Finally, older respondents were more likely to provide food for birds than younger respondents. We found similar results for the percentage of respondents that provide nest boxes (Table 6.3, Fig. 6.8); however, there was a significant effect of housing type. Respondents that owned their homes were more likely to provide nest boxes than those that rented (Table 6.3).

Respondent perceptions of finches and crows differed dramatically (Fig. 6.9). In both Seattle and Berlin, survey participants thought the physical appearance and vocalizations of finches were more pleasing than the crows (Chi-square: appearance: $X^2 = 309.5$, df = 20, $p < 0.0001$; vocalizations: $X^2 = 52.32$, df = 25, $p = 0.001$; note that only a subset of respondents recognized the vocalizations of finches and/or crows; therefore, these results are 107 for finches and 457 for crows). We also found that respondents differed in whether they encouraged or discouraged crow versus finches (Chi-square: Seattle: $X^2 = 30.6$, df = 8, $p < 0.0001$, Berlin: $X^2 = 443.8$, df = 15, $p < 0.0001$). Respondents directed more discouraging behaviour towards crow species in both Seattle and Berlin (American crow = 19.6%, hooded crow = 10.8%) than finch species (zero percent for both house finches and greenfinches). Discouraging behaviour towards crows did not, however, differ across the urbanization gradient (Chi-square: Seattle: $X^2 = 36.00$, df = 32, $p = 0.287$; Berlin: $X^2 = 29.25$, df = 28, $p = 0.400$).

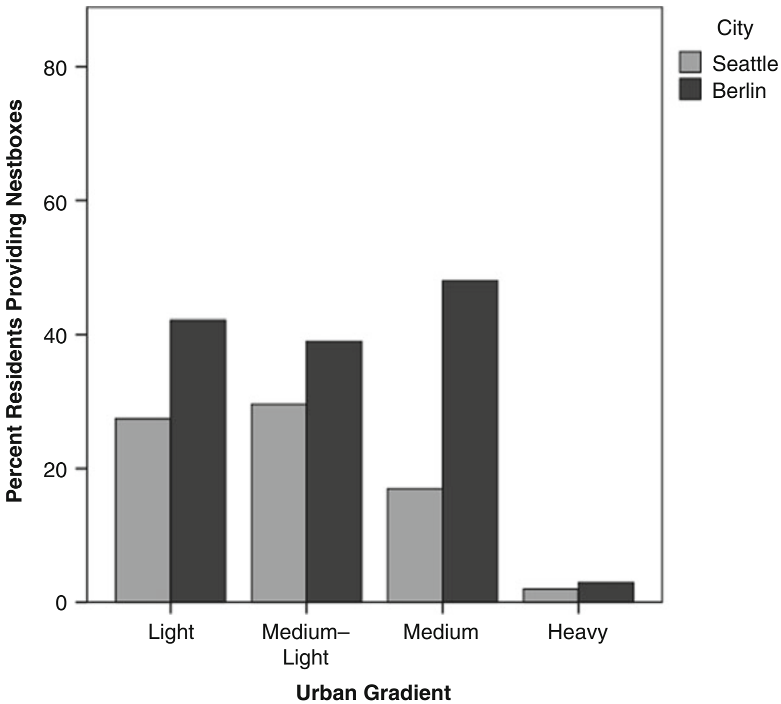

Fig. 6.8 Percent survey respondents that provide nest boxes for birds across the urbanization gradient in Seattle and Berlin

6.4.2.2 Human Influences on Bird Species Diversity and Nesting Behaviour

We counted 1,954 and 2,156 birds in Seattle and Berlin, respectively, across all sites and a total of 58 species in Seattle and 52 species in Berlin. Species diversity (number of total bird species) varied across the urbanization gradient (Fig. 6.10). The lowest species number was found in the city centres (heavy urban) and the highest number in the rural areas (light urban) (Fig. 6.10). Species diversity tended to increase from the city centre out to rural areas; however, there was a slight drop in the forest sites, a trend that has been previously been shown (Marzluff 2005). Interestingly, there was greater species diversity in the city centre sites in Berlin than in Seattle (Fig. 6.10). These relationships held for all species and when only considering secondary cavity nesting species (Fig. 6.11).

Supplementation was correlated with the number of bird species, and to a lesser extent with the number of individuals that use such provisions. The number of bird species that will eat at bird feeders was positively related to the percent of survey participants that feed birds (Pearson Correlation: $r = 0.564$, $p = 0.015$; Fig. 6.12). The number of secondary cavity nesters was also positively correlated with the percent of people that provide nest boxes (Pearson Correlation: $r = 0.756$, $p < 0.0001$; Fig. 6.13). The number of individual birds that use bird feeders was

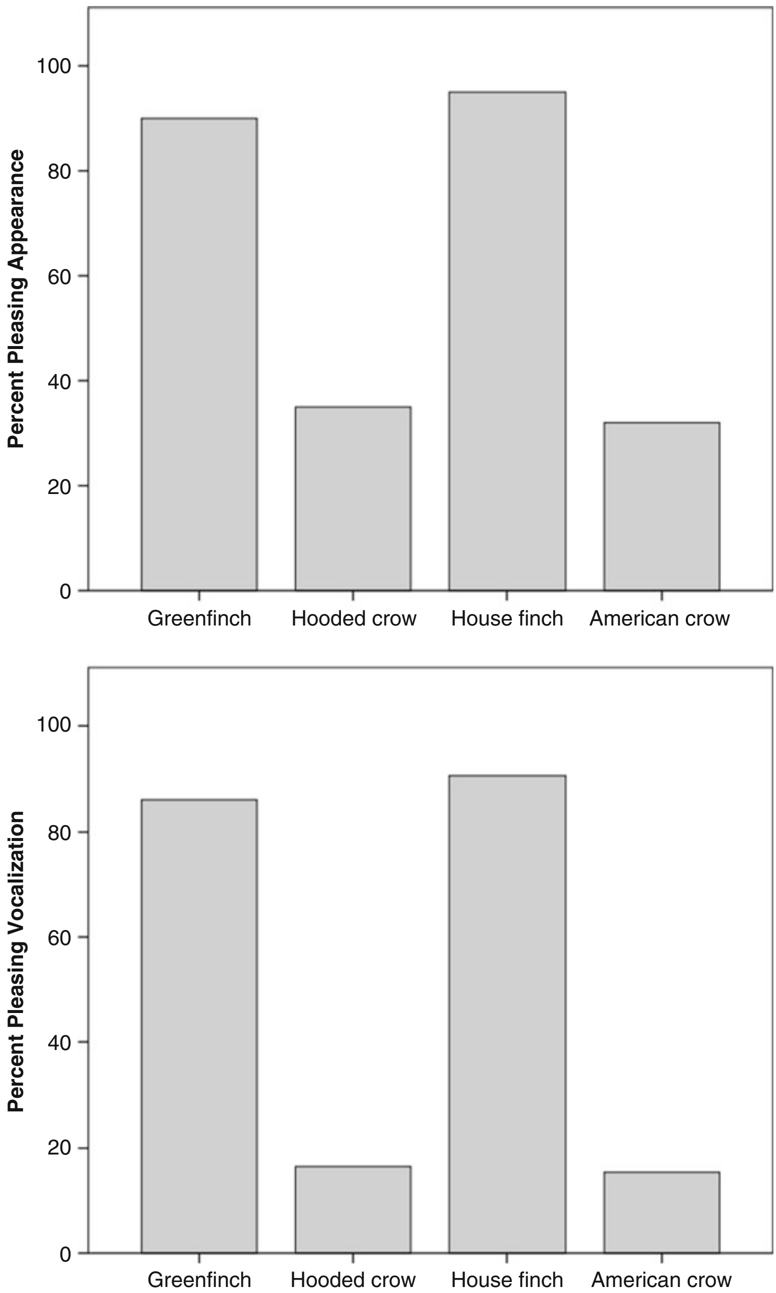

Fig. 6.9 Respondent perception of visual and acoustic characteristics of finches and crows in Seattle and Berlin

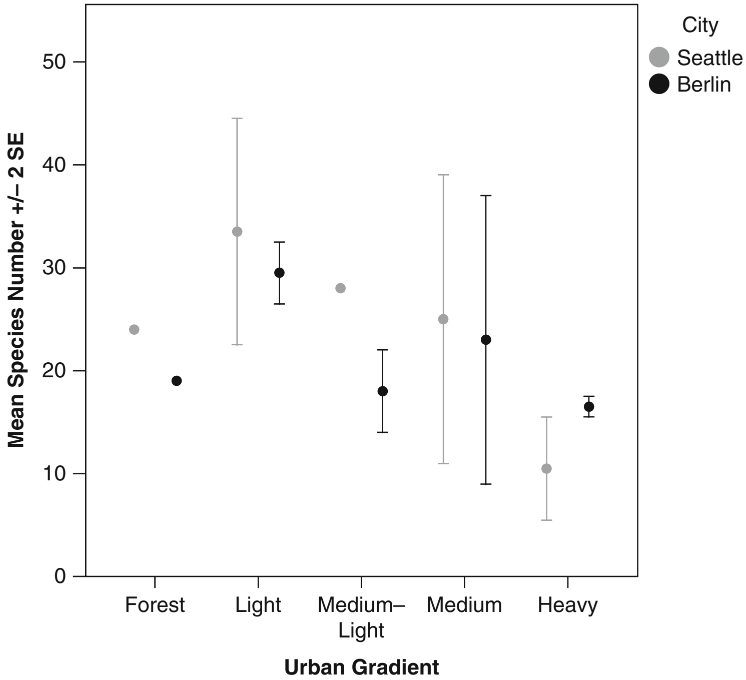

Fig. 6.10 Mean number of bird species across the urbanization gradient in Seattle and Berlin (error bars represent standard errors)

also correlated with the percent of residents providing feeders (Pearson Correlation: feeders: $r = 0.555$, $p = 0.017$). However, the number of individual secondary cavity nesters was not significantly correlated to the percent of residents providing nest boxes (Pearson Correlation: feeders: $r = 0.344$, $p = 0.162$).

6.4.2.3 Human Influences on Finches and Crows

Abundances of finch and crow species (house finches and American crows in Seattle, greenfinches and hooded crows in Berlin) varied across the urbanization gradient (ANOVA: Urban Gradient: $F_{3,16} = 10.24$, $p = 0.001$; Fig. 6.14). However, this response to urbanization differed among the different species (ANOVA: Species: $F_{4,16} = 6.63, p = 0.001$) and there was a significant interaction between species and urbanization gradient (ANOVA: Species*Urban Gradient: $F_{12,16} = 2.68$, $p = 0.034$). American crow numbers in Seattle increased linearly moving from forest and rural areas to heavy urban areas while hooded crows were not found in the forest site in Berlin and had similar numbers in light to medium urban areas, spiking in heavy urban areas (Fig. 6.14). House finches in Seattle had the greatest numbers in medium to medium-light urban areas and greenfinches in Berlin in

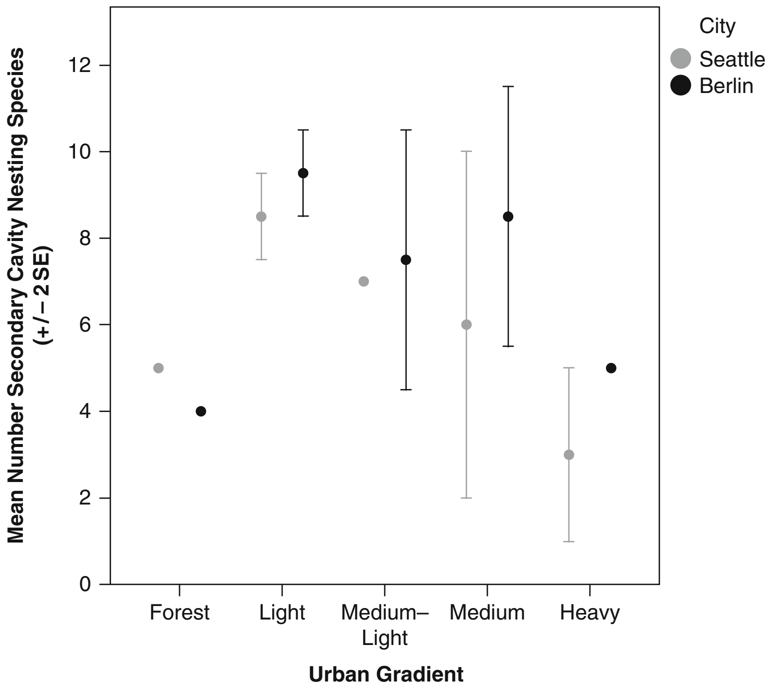

Fig. 6.11 Mean number of secondary cavity nesting species across the urbanization gradient in Seattle and Berlin (error bars represent standard errors)

medium to light urban areas but both species had relatively low numbers in heavy urban areas (Fig. 6.14).

We also found that abundances of greenfinches in Berlin were positively correlated with the percent of residents providing food for birds (Pearson Correlation: $r = 0.814$, $p = 0.004$) while this relationship did not exist for house finches in Seattle or either crow species. Discouraging behaviour towards crows did not have an effect on the abundances of crows in either Seattle or Berlin (Pearson Correlation: Seattle: $r = 0231$, $p = 0.550$; Berlin: $r = 0.019$, $p = 0.962$).

6.5 Discussion

As the number of avian ecology studies conducted in urban areas has increased (see Fig. 6.1), our understanding of urbanization's effect on native bird populations and biodiversity has improved. Notable factors that negatively affect birds are habitat alterations and fragmentation and the introduction of exotic species (Chace and Walsh 2006). However, we remain ignorant about how human behaviour can affect urban birds (but see Fuller et al. 2008), especially how humans affect the cultural

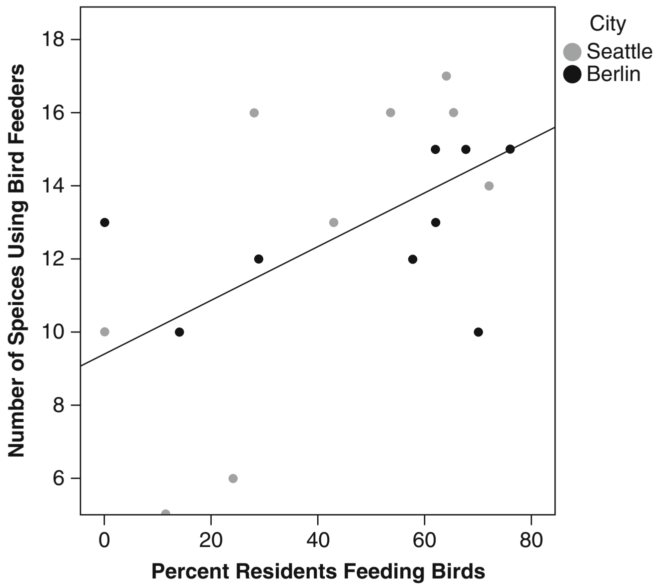

Fig. 6.12 Relationship between percent of survey participants that feed birds and the number of bird species that eat bird from feeders

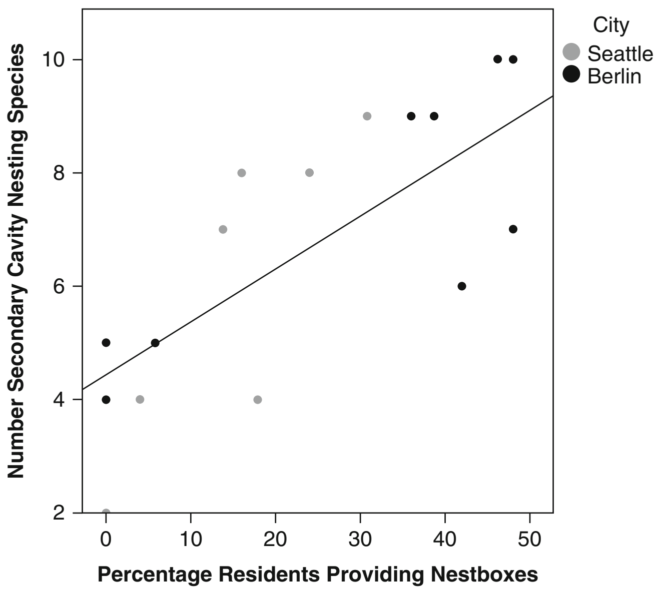

Fig. 6.13 Relationship between the percent survey participants that provide nest boxes and the number of secondary cavity nesting species in Seattle and Berlin

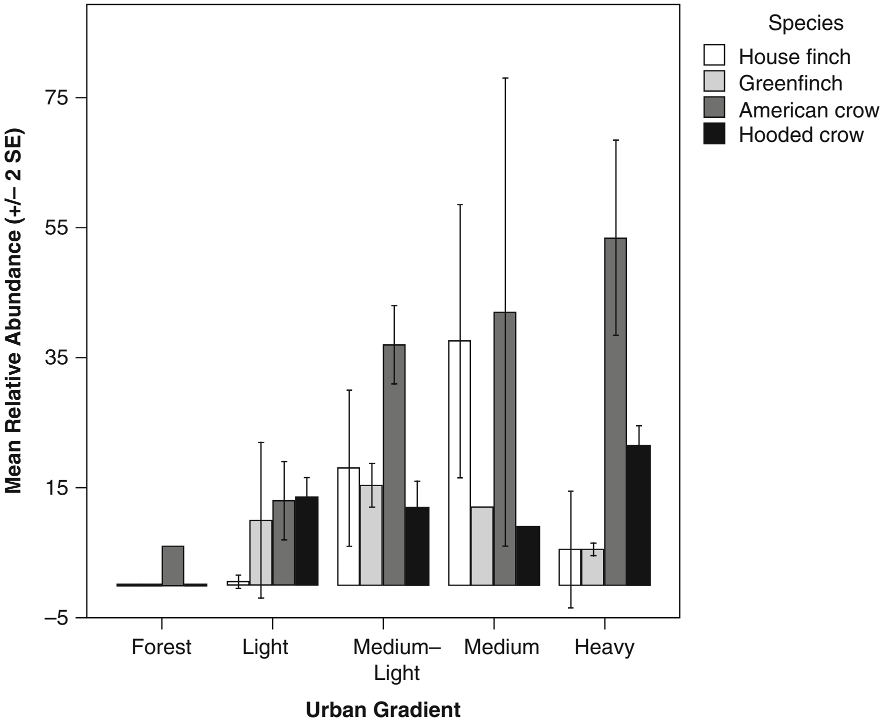

Fig. 6.14 Mean relative abundances of finch and crow species across the urbanization gradient in Seattle (house finch and American crow) and Berlin (greenfinch and hooded crow). Error bars represent standard errors

and genetic evolution in birds (Marzluff in press). We suggest that rather than focusing simply on how humans influence birds, we should study the reciprocal relationships between human and birds. The evidence for coupled human-avian relationships in urban areas suggests that such interactions can produce positive feedback loops (Clucas and Marzluff in press). Humans can promote the conservation or creation of bird habitat and feeding opportunities (e.g. Chamberlain et al. 2004; Fuller et al. 2008) and in turn, birds can provide a window into nature (Fuller et al. 2007). Thus, it will be important for urban avian ecologists to not only look at structural changes in the environment but also include humans (and their behaviour) as components of urban ecosystems. Moreover, researchers should also consider the effects of decreases in urban biodiversity on human well-being. A full understanding of these reciprocal relationships will increase our understanding of, and ability to conserve and restore, urban ecosystems.

Our research in Berlin and Seattle shows that not all native species are negatively affected by urbanization. Novel habitats such as abandoned fields and wastelands enable sensitive grassland species such as the wheatear to exploit cities. Novel subsidies such as the cavities in old buildings and food waste also enable predators such as the kestrel to flourish in cities. These species have adapted their behaviour to live in proximity to people.

These examples of individual species' adjustments to urbanization are mirrored at the community level. In both Seattle and Berlin, we found that species diversity varied across a gradient of urbanization. Light settlement (exurban to suburban, single family) was associated with increased bird diversity relative to no or to extensive settlement (Fig. 6.10). This beneficial influence of human settlement on bird species richness likely results from increased habitat heterogeneity (Marzluff 2005) and increased supplementation of resources (Figs. 6.7 and 6.8). While the pattern of bird diversity and human settlement was similar in both cities, there was slightly higher species diversity in the city centre of Berlin than Seattle. It is possible that the large difference in the time since first human settlement and urbanization of these two cites (at least 200 years) may have allowed more species in Berlin to adapt to heavy urban conditions (see Martin and Clobert 1996). In addition, that Berlin's birds are closely attuned to the actions of humans is also indicated by the positive relationship between abundance of greenfinches and bird feeding by humans. This was not the case in Seattle, where house finch abundance was not strongly correlated with bird feeding.

6.5.1 Importance and Influence of Ex Situ Supplements

We found that Berlin residents supplement birds (by providing food and nest boxes) more than residents in Seattle. Nevertheless, the percentages of residents providing food in both Seattle and Berlin were relatively high (55% in Berlin and 45% in Seattle). Thus, the urban systems we studied had substantial ex situ inputs (meaning inputs from outside the natural ecosystem). These inputs affect at least two conspicuous guilds of birds: seed eaters and secondary cavity nesters. The provisioning of seeds appears to increase the number of seed-eating species and the provisioning of nest boxes appears to increase secondary cavity nesting species. Compared to forested control areas without supplementation, the diversity of secondary cavity nesters is nearly doubled in the light to moderately settled neighbourhoods we studied where provisioning of nest boxes was greatest. In addition, similar to results found in Sheffield, United Kingdom (Fuller et al. 2008), we also found that the abundance of individuals of species that eat from bird feeders increased with the percent of residents supplying food. However, we are uncertain that this is the entire story. Certainly, resources drive bird population increases, but it is also conceivable that as cavity nesters and seed eaters become more frequent in people's yards, the experience of seeing birds may also drive human behaviour to provision more. Birds and humans likely affect each other in a reciprocal manner.

6.5.2 Supplementation Couples Human and Natural Systems

The reciprocal nature of the relationship between birds and people was evident in both Seattle and Berlin. In both cities, people typically watched or identified birds on a daily basis (Fig. 6.6). People typically reported birds as pleasing aspects of their environments and rarely reported discouraging them from their yards and residents. Thus, in our study, the positive feedbacks between people and birds such as the connection between provisioning, increasing diversity, and pleasure of watching and observing birds appear more important than negative feedbacks such as attracting birds to garbage, fear of disease, annoyance of noise, and

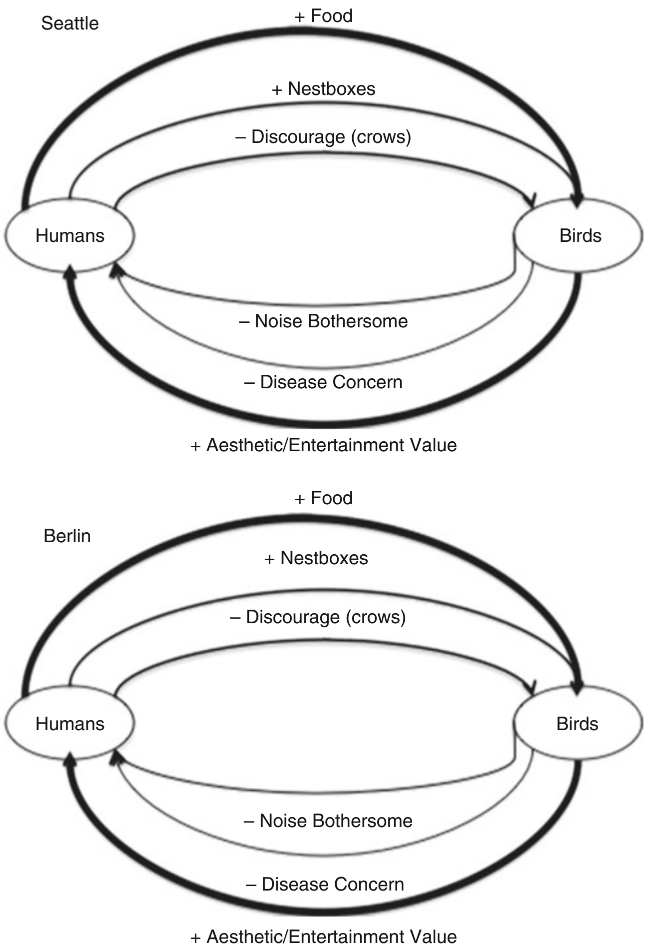

Fig. 6.15 Connections between humans and birds in Seattle and Berlin. Positive connections are indicated by "+", while negative connections are indicated by "–". The thickness of the connecting lines depicts the magnitude of the connection (thicker lines = stronger connection)

reducing population size. The relative importance of positive and negative feedback loops in Seattle and Berlin is similar (Fig. 6.15), but in need of greater elucidation. For instance, supplemental feeding may have positive effects on some bird species (e.g. greenfinches) but may create negative impacts for other species sensitive to disease transmission or interspecific competition (Robb et al. 2008).

The relationship between birds and people is not consistent along the gradients of urbanization we studied. In both Seattle and Berlin, residents in city centres who typically rented rather than owned their homes provided few subsidies for birds and encountered few species of birds. Such "ecological poverty" is typical of city centres (Lehrman and Warren in press), although the cause and effect nature of the relationship is not clear. We suggest that increased subsidies in city centres, especially in the form of nest boxes and well-maintained bird feeders could increase the diversity of birds and the resultant ecosystem services and health and well being benefits (e.g. Fuller et al. 2007) they provide to urban people.

Appendix A

Number of questionnaire--------------.
Date..
Day of the week................................….
Time of day.........................
Study site..
Street and street number.............................

Human-Bird Interactions in Urban Areas

Hello, my name is …and I am from the University of Washington here in Seattle. You may read a flyer about the survey we are conducting in your neighborhood. This survey is part of a research project aimed at better understanding how people and animals interact around their homes. In particular, we are interested in your opinions about birds. We would greatly appreciate if you could take 20 minutes of your time to complete the survey.

A. Our first set of questions is designed to understand your basic interactions with birds at your home

1. How often do you notice birds around your home?
- ☐ Daily
- ☐ Several times each week
- ☐ About once a week
- ☐ About once a month
- ☐ A few times a year
- ☐ Never

2. How often do you watch or try to identify birds around your home?
- ☐ Daily
- ☐ Several times each week
- ☐ About once a week
- ☐ About once a month
- ☐ A few times a year
- ☐ Never

3. 3. Do you try to attract birds to your home with food, plants or nesting materials? Yes No *(If no, go to 4)*
If yes,

3.a. Do you provide food? Yes ☐ No ☐ (If no, go to 3b)

3.a.1. Do you feed them
- ☐ in the winter
- ☐ in the summer
- ☐ all year round

3.a.2. For how many years have you done so?

3.a.3. What foods do you provide?
- ☐ Basic bird seed
- ☐ Suet balls (or the like)
- ☐ Bread
- ☐ Kitchen scraps
- ☐ Special food for finches
- ☐ Special food for insect eating birds
- ☐ other

3.a.4. (If you buy food) How much do you spend on bird food per month (per winter/per summer)?

3.b. Do you provide nesting material (including bird houses)? Yes ☐ No ☐ *(If No, go to 3c)*

3.b.1. How many bird houses do you provide?

3.b.2. For how many years have you done so?

3.b.3. How much do you spend per month (per year) on nesting material? (If you can't estimate an amount of money, then how often to you purchase materials, how much do you get, and what type do you usually get?)

3.c. Do you provide plants to specifically attract birds?

Yes ☐ No ☐ *(If No, go to 3d)*

3.c.1. What kinds of plants?

3.c.2. For how many years have you done so?

3.c.3. How much money do you spend per month (per year) to improve your garden (balcony/windowsills) for birds?

3.d. Are there other activities you do around your house for birds (e.g., bird baths)?

4. Do birds do any damage to your home or yard? Yes ☐ No ☐ *(if No, go to 5)*

4.a. Which of the following problems have you experienced from birds around your home?

☐ Damage to landscape plants
☐ Damage to fruits or garden
☐ Droppings on house/car
☐ Damage to house
☐ Other

4.b. Are you concerned about damage done by birds to your home? Yes ☐ No ☐ (if yes…)

4.b.1 How much money do you spend each month (per year) to repair damage by birds?

4.b.2 How much time do you spend each month (per year) repairing damage by birds?

5. Are you concerned about disease carried by birds in your backyard/around your home?

☐ Very much
☐ Somewhat
☐ Not really
☐ Absolutely not

6. Are you bothered by the noise that birds make around your home?

☐ Very much
☐ somewhat
☐ not really
☐ absolutely not

6a. If you are bothered, what is it about the bird song that is bothersome (for example, time of day, volume, tone)

7. Do you have a cat(s) that go(es) outdoors? Yes ☐ No ☐

7.a. How often do you observe your cat(s) catching birds around your house:

☐ Never
☐ Several times each year
☐ About once a month
☐ About once a week
☐ Several times each week

7.b. Do you have a dog(s)? Yes ☐ No ☐

7.c. How often do you observe your dog(s) catching birds:

☐ Never
☐ Several times each year
☐ About once a month
☐ About once a week
☐ Several times each week

8. Have you found birds injured or killed by windows at your home?

Yes ☐ No ☐ *(If No, go to 9)*

8a. If yes, how often (can you estimate how frequently per year or how many birds?)

9. Do you use methods to try to keep birds from your home, for example scarecrows? Yes ☐ No ☐ *(If No, go to 10)*

9a. If yes, which methods?

9b. If yes, for how long have you done so?

10. How important are environmental or conservation issues to you, relative to other issues like health care, national security, education, and the economy?

☐ Most important
☐ Very important
☐ Moderately important
☐ Least important

11. Do you belong to any organizations that support bird conservation? Yes ☐ No ☐

11.a. If yes, which ones?

11. b. For those you belong to, what do you do?

☐ donate time
☐ donate money
☐ attend meetings
☐ committee work

B. B. Now we would like to ask you a few questions about 2 common birds: ***Show photos (order <u>randomly</u>)***

1. Please name this bird, if you can.

------------------------- -------------------------

☐ House finch ◯ American Crow

<u>If person did not know the bird, tell them now…</u>

2. Do you know its song or call?

Yes ☐ No ☐ *(If no, go to 3)*

Yes ◯ No ◯

2.a. Do you find its song/call:

☐ very pleasing ◯

☐ pleasing ◯

☐ neither pleasing nor displeasing ◯

☐ displeasing ◯

☐ very displeasing ◯

3. Do you think this bird's coloration is:

☐ very pleasing ◯

☐ pleasing ◯

☐ neither pleasing nor displeasing ◯

☐ displeasing ◯

☐ very displeasing ◯

4. Do you

☐ strongly encourage ◯

☐ encourage ◯

☐ neither encourage nor discourage ◯

☐ discourage ◯

☐ strongly discourage ◯

this bird from your home?

5. 5. If this bird comes to your feeder or nests on your house it would be?

☐ very enjoyable ◯

☐ enjoyable ◯

☐ do not care ◯

☐ a nusisance ◯

☐ a strong nusisance ◯

Please indicate the degree to which you agree or disagree with the following statements about this bird:

6. This bird increases my stress.

☐ strongly agree ◯

☐ agree ◯

☐ disagree ◯

☐ strongly disagree ◯

☐ no opinion ◯

7. This bird helps control insect pests.

☐ strongly agree ◯

☐ agree ◯

☐ disagree ◯

☐ strongly disagree ◯

☐ no opinion ◯

8. This bird brings good luck

☐ strongly agree ◯

☐ agree ◯

☐ disagree ◯

☐ strongly disagree ◯

☐ no opinion ◯

9. This bird is a bad omen.

☐ strongly agree ◯

☐ agree ◯

☐ disagree ◯

☐ strongly disagree ◯

☐ no opinion ◯

10. This bird eats baby birds.

☐ strongly agree ◯

☐ agree ◯

☐ disagree ◯

☐ strongly disagree ◯

☐ no opinion ◯

11. FOR THOSE WHO ANSWER QUESTION 4 ABOVE as Neither Encourage or Discourage, Encourage, or Strongly Encourage:

Different cities are actually concerned about declines in this species' abundance. They are considering local and regional restoration programs to improve urban parks and greenspaces for the birds and even considering feeding programs, breeding and release programs. We are investigating this issue in Seattle. If Seattle was to initiate a program to increase this species' population it would cost the city. We estimate that this program would cost an additional $…. in your taxes .

Choose at random from the following annual cost schedules. (for example, if schedule 1 is selected, you as first would you be willing to pay $60 to reduce the species, if they answer yes, then you ask, would you be willing to pay $120, but if they answer no, you ask would you be willing to pay $15.

Would you support a program with that (mid level in random selection) cost to increase this bird species?

Yes☐ No☐

Yes◯ No◯

IF yes, would you support a program with higher (upper amount in random selection) cost to increase this bird species? Or
IF no, would you support a program with lower (least amount in random selection) cost to increase this species?

Yes ☐ No ☐
Yes ○ No ○

1. 15, 60, 120
2. 15, 60,150
3. 15, 90, 120
4. 15, 90, 150
5. 45, 60, 120
6. 45, 60, 150
7. 45, 90, 120
8. 45, 90, 150

12. FOR THOSE WHO ANSWER QUESTION 4 ABOVE as Neither Encourage or Discourage, Discourage, or Strongly Discourage:
Some American cities are concerned about the damage this species does to populations of other native birds and human well-being. We are investigating this issue in Seattle. If Seattle was to initiate a program to reduce this species population by cleaning waste grain and garbage from our streets, and even by trapping and removing birds (Tokyo, for example has hired professional bird exterminators to reduce some birds) it would cost the city We estimate that this program would cost an additional $….. in your taxes (the value you state here is the mid value from the selections below, read on for directions)

Would you support a program with that (mid level in random selection) cost to reduce this bird species?

Yes ☐ No ☐
Yes ○ No ○

IF yes, would you support a program with higher (upper amount in random selection) cost to reduce this bird species? Or
IF no, would you support a program with lower (least amount in random selection) cost to reduce this species?

Yes ☐ No ☐
Yes ○ No ○

C. Now we are almost at the end of the questionnaire. It will help our analysis if record some basic information:
1 a: Gender:
1 b: How old are you? ☐ [If they don't want to answer, estimate: 18-29 30-59 >60].

2. Do you rent or own your place? 2.a. How many people live in the household?

3. How long have you resided here? 3.a. How long have you lived in Seattle?

4. If have or had children, have you involved them in observing or learning about birds? Yes ☐ No ☐ no kids ☐

5. What is your education?

- ☐ High School
- ☐ Community College/Technical College
- ☐ University/College
- ☐ Higher (e.g., masters, Ph.D, professional degree)

6. What part of the country were you born (circle)?

Pacific Northwest West Coast (California) Central West East Coast Southwest Midwest South Southeast Other:

7. Where you raised in a rural or urban environment or both?

- ☐ Rural
- ☐ Urban
- ☐ Both

8. What is your employment status?

- ☐ Full time
- ☐ Part time
- ☐ Retired
- ☐ Unemployed
- ☐ Others:

9. What is this household's annual income? (over the last year)

- ☐ 25, 000 or below
- ☐ 25,001- 50,000
- ☐ 50,001- 75,000
- ☐ 75,001 – 100,000
- ☐ 100,001 - 150,000
- ☐ 150,001 – 200,000
- ☐ 200,001 or greater

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Chapter 7
Urban Economy

Elmar Kulke, Maike Brammer, Benjamin Otto, Daniela Baer, Julika Weiß, and Betka Zakirova

7.1 Introduction

The limitations of our resources and the effects of economic growth were first brought to a wider public consciousness in the 1970s report of "Limitations of Growth". Since then, a broader discussion has started about how to save resources and how to reduce the negative ecological impacts of economic activities. In 2010, the BP oil-drilling catastrophe in the Gulf of Mexico showed us once again the fragility of eco-systems; the unappeasable hunger for cheap oil as the blood of our economic corpus continually leads to highly problematic events. And, our daily behaviour of using fossil fuels not only reduces the richness of resources but also leads to permanent pollution of the environment; global warming is only just one catchword which highlights these problems.

On the macro-level, more and more attempts are made to reduce the conflicts between economy and ecology. The most important approach is the "internalisation of external effects", which means that all kinds of human activities, and especially economic activities, have to pay for the removal or compensation of the negative environmental effects they have induced. Pollution certificates, environmental standards, eco-labels, or legal frameworks are private or public elements of a

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more sustainable economy. Most advanced economies have today developed several laws to reduce the negative environmental effects of economic activities. In Germany, the “Bundes-Immissionsschutzgesetz” or the “Lärmschutzverordnung” are only just some examples of this legal framework.

While there is an intensive macro-discussion with attempts to a certain kind of standardisation of the approaches, there is still a heterogeneous situation on the local level – which means land use and spatial development on the micro-scale. In Germany, all new developments of land use have to undergo an evaluation concerning the environmental impact (“Umweltverträglichkeitsprüfung”). This has contributed to the reduction of land consumption, to the development of ecological compensation spaces, and to the reuse of older built-up areas (e.g. brownfield sites, vacant buildings). In urban agglomerations and in built-up areas, the leading models of the “compact and mixed city” or of the “city of short distances” are now influencing the planners’ and politicians’ decisions of urban development. The limitations and perspectives of these models have delivered guiding ideas for the subprojects of urban economy in the graduate school of urban ecology. In general, these subprojects have analysed possibilities of economic development in built-up areas of the urban agglomeration of Berlin in the context of business development, consumer behaviour, planners’ policies, and ecological impact.

The following article will first draw a picture of important recent changes of structures and locations of the urban economy. In the second part, the research design and the most important results of the subprojects will be characterised. Finally, some remarks will highlight some general findings.

7.2 Changes in the Urban Economy

Urban agglomerations in advanced economies are strongly influenced by the general trends of structural change of the economy and of growing international linkages connected with the globalisation process (Kulke 2010). The industrial society, which was dominant in the middle of the twentieth century, has now changed to a service society (Fig. 7.1). In advanced economies, more than two thirds of the labour force is working in the service sector; in urban agglomerations, the service sector has an employment share of more than 75%. There is still important industrial production, but the manufacturing sector shows a high labour productivity and an orientation towards knowledge-intensive products. Industrial production and manufacturing industries show a tendency to close their activities in the high-density urban agglomerations; sometimes, they are moving either to suburban locations or even to other countries. These trends are opening spaces for new kinds of use. In economically strong agglomerations, new activities will immediately reuse these locations; if there is a less dynamic development, it might be interesting to find temporary forms of use; sometimes, the out-movement is so strong that tendencies of a shrinking city might appear.

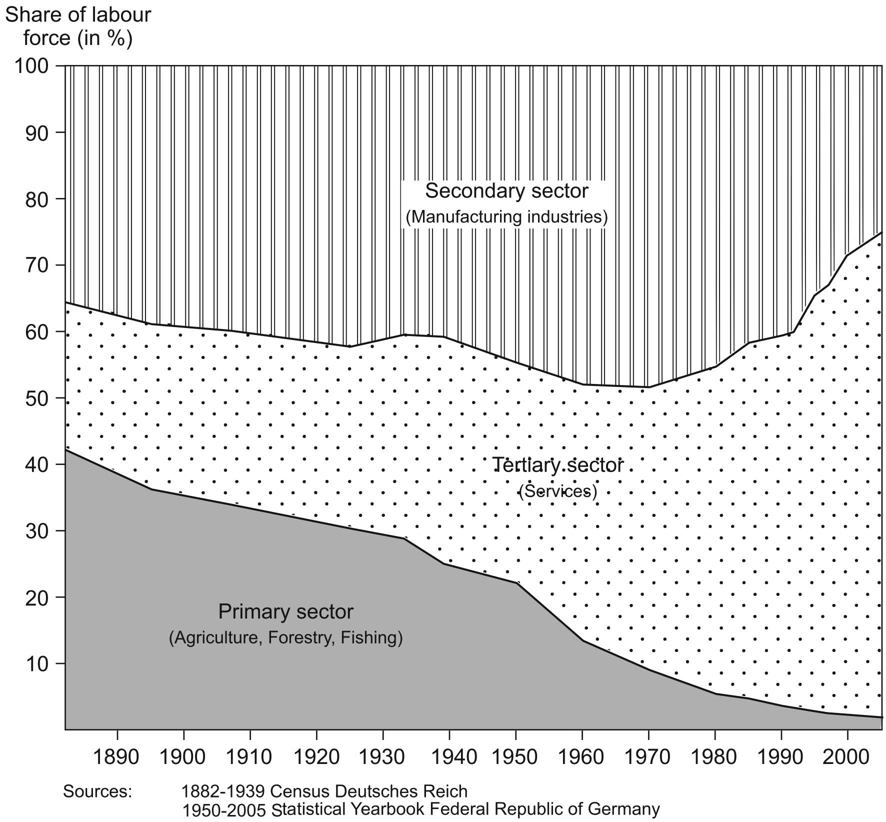

Fig. 7.1 Sectoral change in Germany
Source: Kulke 2009

During the last decades, a much diversified service sector was developing in most of the agglomerations (Fig. 7.2). For a long time, urban agglomerations already possessed all parts of the classical consumer-oriented service sector (e.g. retailing, personal services), of the distribution service sector (e.g. transport, wholesale, public traffic), of public services (e.g. administration, government, theatres, museums), and of the finance sector. With these services, the agglomerations fulfilled functions as central places for a wider area. The developments of the last decades – in terms of employment and turnover – were dominated by modern services. In particular, high-ranking enterprise-oriented services (defined by a high human-capital intensity; e.g. research and development, consultants, advertising, marketing), the so-called FIRE-sector (finance, insurance, real estate), and the cultural economy (production and distribution of media products like arts, music, movies, and television) were expanding very fast (Kinder 2010; Krätke 2002; Mossig 2010).

The growth of these sectors can be explained not only by the classical reasons for sectoral change, which are the different increase of labour-productivity in the sectors and the income increase which leads to a stronger demand for services.

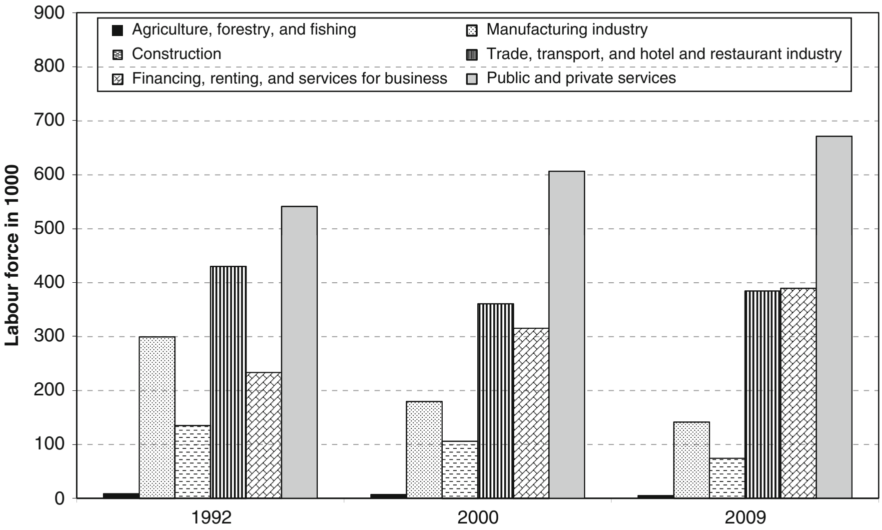

Fig. 7.2 Sectoral change in Berlin
Source: State Statistical Institute Berlin-Brandenburg. Own draft and layout

Some new factors – externalisation-, interaction-, and innovation-hypothesis – are explaining in more detail these new developments (Kulke 2009). According to the externalisation-hypothesis, services, which were before done by production-enterprises themselves, are now given to specialised service enterprises; they are either able to provide these services cheaper or are more flexible in delivering them or possess a higher competence. The interaction-hypothesis describes that in general, the demand for enterprise-oriented services is increasing; shorter product life cycles, international interactions, global location systems, and stronger competition are increasing the demand for research/development, transport/logistics, advertising/marketing, or consultant work. The innovation-hypothesis explains that new kinds of services are developing and are generating with their supply new demand (e.g. mobile-phone provider, sun studios, media industries/cultural economy).

One additional factor is that in advanced economies, more and more former state-run services are privatised and several suppliers are now serving the market. Communication services, transport infrastructure (e.g. ports, airports), transport services (e.g. railways), or medical care (e.g. large hospitals) were former often run by the state and are now opened to private competition.

Different services are showing different spatial distributions (Fig. 7.3). Classical consumer-oriented services (e.g. grocery stores, hairdresser) and public services (e.g. elementary school) are more or less in every settlement available; these services are showing a spatial distribution which is similar to a grid or net pattern. Services of the same kind but with differences in the quality are forming an hierarchical system; in the catchment area of a higher ranking service unit (e.g. a high-school), several service units of the same kind but with simpler supply (e.g. an

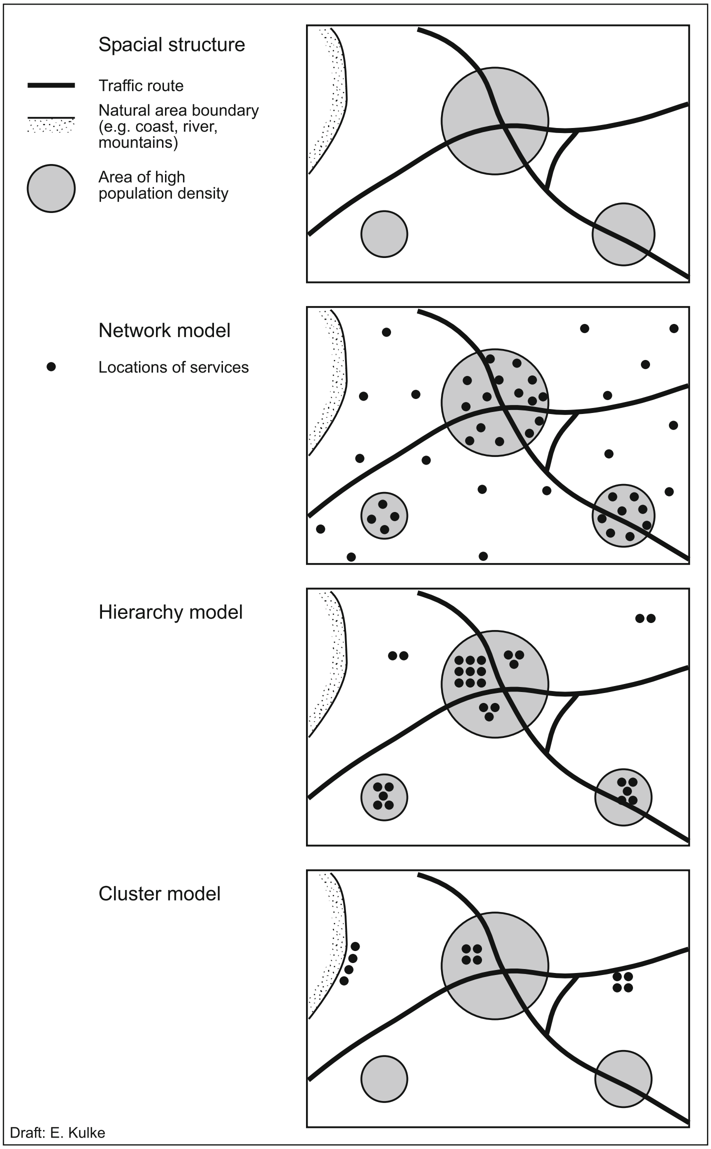

Fig. 7.3 Locational systems of services
Source: Kulke 2009

elementary school) can be found. This locational system of services contributes strongly to the hierarchical system of settlements and towns and was the major study object of Christaller's theory of central places.

The modern services show a different spatial distribution; they have a strong tendency to concentrate in few places, especially in the large agglomerations.

Due to their large marketing areas, they are able to serve clients from these places, because they are usually offering good transportation links. And, they gain advantages from proximity to other services. On the one hand, it is often favourable that places with concentrations of a certain kind of services are then well known by clients and consumers. On the other hand, services often co-operate and are forming clusters. In particular, “project co-operation” is important for the spatial concentration of services. Project co-operation means that for a certain project, independent services enterprises are working together and are contributing to the project with their special skills or knowledge. During the project, they develop routines and trust between each other. If after some time a similar project is started, those enterprises with good experience in co-operation will work together once again; this reduces the transaction costs for co-operation.

The described spatial distributions are not only found between settlements/towns but also in the agglomeration areas (Kulke 2009). And, the sectoral change strongly effects locational developments in the agglomerations. The moving out of manufacturing industries opens disposition spaces for new forms of land use, often for the development of modern services. Older areas for larger manufacturing units were very often located in central parts of the towns; during the foundation of these enterprises, they showed an orientation towards classical transportation infrastructure – mainly railway and water-ways – which were at that time the most important means of transportation. Now, these areas are available for new uses. Smaller manufacturing and handicraft enterprises were often found in mixed land use with housing; they either used ground floors or backyards of condominiums or manufacturing buildings with several storeys. Both locational types, railway/water-way manufacturing areas and ground-floor handicraft use, are very typical for Berlin especially in the so-called “Wilhelminian Circle”. And, in this area during the last two decades, many units were closed, opening disposition spaces for new (service) activities.

7.3 Results of the Subprojects

All subprojects of the research on urban economy tried to identify interrelations between the changes in the urban economic landscape (sectoral and spatial developments) and the possibilities of finding new more environmentally friendly forms of (re-)using available locations. Taking the sectoral structures and sectoral developments into consideration, the subprojects of the urban economy were primarily analysing recent developments in the service sector. All projects were considering the influence of different actors on the structural and spatial development; actors are coming from the major groups of enterprises (supply), consumers/users (demand), and planners/politicians (planning).

In the first phase, changes in the retail sector and on the consumer side towards more ecological products were studied, taking the interrelation between available supply and consumer behaviour into consideration. In the following phases, the availability of brownfields, empty spaces, and vacant buildings was the focus of the studies. The general observation in Berlin – and other agglomerations – is that due to the sectoral change – with the out-movement of manufacturing industries – and due to the general tendencies of shrinking, spaces are available for new forms of use. The behaviours of planners/politicians, of owners, and of enterprises concerning possibilities and strategies of the re-use of these spaces were analysed. Of special interest were possibilities to use it for the strongly expanding sector of enterprise-oriented activities and of the cultural economy.

7.3.1 Subproject: "Environmental Friendly Shopping Behaviour" (Julika Weiß)

The influence of nearby shopping opportunities for environmentally friendly food on the shopping behaviour was the topic of this study (Weiß 2006). Thereby, a contribution was made to a closer characterization of spatial differences regarding opportunities and purchase, as well as the connection between both. The environmental impacts considered exceed the choice of products and include shopping mobility behaviour and the choice of shops. Regarding environmental impacts, the question in how far shops further away will be visited by consumers if nearby opportunities are missing is of special interest.

The study inquires these questions using food shopping in six residential areas of Berlin as an example. The study is based on qualitative methods (interviews) and quantitative methods (mapping, inquiry). The results demonstrate considerable distinctions between the shopping opportunities for eco-friendly food in different survey areas. The supply situation in the inner-city areas with tenement houses from the Wilhelminian time generally surpass the supply in the areas with high blocks of flats and detached family houses in the outskirts. In particular, natural food stores – concentrating in the inner-city areas – are of importance for these differences, as the supply of environmentally friendly food in the conventional food retail stores is rather limited and little known.

Differences between the survey areas were also identified for the purchase of eco-friendly food, shopping behaviour of the areas with tenement houses from the Wilhelminian time being most environmentally friendly. This discrepancy is strongest for organic food. Nearby supply has been shown to have an important impact on the purchase of eco-friendly food. Besides, socio-demographic characteristics and attitudes of the interviewees also showed relevance of their shopping behaviour. As an obstacle to the purchase of environmentally friendly food, poor knowledge of consumers could be identified by the study. Knowledge gaps have been found especially concerning the relevance of environmental impacts of different product characteristics, as well as shopping opportunities for eco-friendly products.

Several types of "environmental shoppers" were generated, demonstrating the relevance of different shopping orientations for their shopping behaviour. In how far further distances are travelled if nearby supply is absent also differs depending on major shopping orientations. Normally, shopping opportunities further away are not visited to buy environmentally friendly food. On the contrary, persons who buy eco-friendly food to a high degree behave particularly environmentally friendly in the field of shopping mobility as well. Thus, the present study reveals positive interrelations between environmental behaviour in the different fields of food shopping: choice of product, shopping mobility, and choice of shop.

7.3.2 Subproject: "Services as After Use on Urban Potential Sites in Shrinking Cities: The Example Berlin" (Daniela Schüler)

This project deals with the subject of the re-use of potential sites with services. Due to structural economic changes, an increasing number of inner-urban potential sites develop within the city. Simultaneously, a shift of emphasis within the urban economy takes place towards the service sector. The study investigates the re-use of inner-urban potential sites with services, using the example of Berlin. With regard to the demand for potential sites with services, ten types of potential sites could be identified using a statistical cluster analysis. As a result of the distinction in knowledge-, commercial-, and technology-based services, the respective location factors and spatial patterns could be considered. The data revealed a consistency between the patterns based on the theory assumed and the actual spatial patterns. Using the case study of Spree-area Friedrichshain-Kreuzberg, an in-depth analysis was made to identify the influencing factors on the location of knowledge-based services at potential sites. Some of the characteristics of the potential sites are crucial for the location of knowledge-based services at potential sites. The consideration of the micro-level and specifically potential sites was disregarded for a long time in empirical location research. Finally, the findings were integrated into an evaluation instrument, which indicates the suitability of a potential site for a re-use with services. This approach provides the basis for a development of potential sites, which is adjusted to the need of the demand.

7.3.3 Subproject: "Challenges for Urban Planning and Ecology: Analyses on, and Strategies for, the Shrinking Urban Fringe" (Betka Zakirova)

The main research topics of this study are suburban shrinkage and regeneration strategies in respect of urban studies and urban ecology. Shrinkage is discussed as being a major social problem only at levels above the local, and only in areas which are *not* expected to grow, such as outside suburbs. During shrinkage,

- Formerly used land is abandoned
- Tax bases and incomes shrink

- And this decline adversely affects social services, city sustainability (for example infrastructure maintenance), and the economy at the national and city levels.

At local levels, almost every social group has interests that are affected by city shrinkage:

- Politicians are afraid to lose votes.
- Communities experience declining tax bases and incomes which makes communities less attractive from citizens' points of view.
- Urban planners seldom discuss negative growth – shrinkage is usually regarded as a failure although it can open up new options.
- Residents have a lower quality of life, fewer jobs, and infrastructure problems – hence they will seek to out-migrate.
- Businesses head for an outright failure and get a smaller customer base.
- Although shrinkage is an interesting subject, social and physical scientists state that there is a lack of studies on this subject.
- Environmentalists see an opportunity for restructuring land and policies.

Research on urban shrinkage is multidimensional and significant (1) from different stakeholders' viewpoints (such as communities, urban management, real estate/city marketing, and joint regional planning) and (2) in the field of urban planning, urban sociology, urban studies, as well as human geography.

Most of the general research has been focussed on shrinking processes and redevelopment in the inner cities and cities' cores, rather than in the suburbs in general. The paucity of work about shrinkage in suburbia probably reflects the difficulties in studying urban shrinkage because it is driven by a complex mixture of processes, and in addition to this, there are many variables within a spatial parameter "suburbia" (cf. Howe et al. 1998). Consequently, no clear-cut strategies have been proposed or implemented to deal with the problem (or advantage) of shrinkage (in suburbia).

No studies of shrinking suburbs have been conducted on Berlin and its metropolitan area. Worldwide, most studies on shrinking suburbs focus on only the first (=inner ring) suburbs,[1] meaning the city's older or mature surrounding region directly beyond the city boundary. Such research usually consists of case studies of suburban areas in the USA.

The goals of my study on the communities in Berlin's suburbs were to determine (1) whether there are underlying general principles governing when, how, and why these communities shrink and (2) if and how they recover. My third and final goal was to find out which development and planning strategies are most suitable for particular shrinking areas on the urban fringe. Appropriate strategies for the fringe are probably quite different from those most suitable for the core city (more exactly, for the "inner city").

[1]The older suburbs can be found as outer city's area in Berlin, which begins approximately beyond the encircling surface railway route and ends at the city boundary. Some of the city's districts, such as those with prevailing large housing estates, have been subject to shrinkage after 1990.

In the initial phase of shrinkage, shrinkage is *actively overlooked* by almost all urban designers, urban planners and local officials. Most of the personnel who must recognise and then deal with shrinkage have never been trained to do so. Generally, planners and designers learn how to cope with growth only – there is a significant deficiency of applied and theoretical knowledge (and training) to handle shrinkage. When shrinkage *is* acknowledged, it is seen as an illness to be cured, either by taking actions or by inaction (that is by allowing the illness to run its course). The significance is that by ignoring or misunderstanding city shrinkage, (1) governmental actions are taken (often at great expense) that are either useless or actively counterproductive; (2) cities miss opportunities to turn an apparent problem into assets for the longer-term functioning of the cities, such as using brownfields as a resource to increase green space and ecological liveability of the city.

7.3.3.1 Suburban Shrinkage and Urban Ecology

Defining city shrinkage is a difficult task because the term comprehends multi-dimensional and complex processes. I will measure it by including decline in population, decrease of economic dynamics (indicators: decline of employment and gross domestic product – GDP), and deterioration of urban functions (indicator: areas – their use and potentials to be developed).

The research area considered in this paper will be the *urban fringe*, defined as that edge of developed land which begins beyond the city boundary and "ends" as it blends into open space or landscape (Evert 2001: 577; Fachhochschule Nordhausen 2004: 1). The centrepiece of my research will be the former "Brandenburg's part of the sphere of mutual influence of Berlin and State Brandenburg[2]" – the Berlin suburbs – which was defined in 1998 and comprises 0.8 million inhabitants on 4,480 km^2 (MLUR's Development Plan).

One of the major sustainability goals of European Spatial Planning has been efficient land use (European Council 2006). This particular goal is a big challenge in suburban areas because (1) there are numerous potential and undeveloped/greenfield areas and (2) inner cities have higher chances of achieving redevelopment since the demand for land and pressure for redevelopment are higher than in suburban areas. Even declining core cities have better assets than suburbs do (Swanstrom et al. 2006: 161). For example, the former include central business districts (CBDs), tourist attractions, and urban amenities (such as parks, museums, and universities); they also have professional staff and greater policy attention. Furthermore, the distances within the core city might be short in contrast to the long distances from suburbs to core city and within the suburbs, and hence, the use of energy and resources required for transport might be lower in core city than in suburbs.

[2]This is a translation of the German term "engerer Verflechtungsraum (abbr.: eV)" therefore an apostrophe is used here.

Suburban land is relatively low-value, and local development regulations in suburban areas are usually less restrictive than those in the core city; thus, suburban land is often seen as not worth the cost of redevelopment. In fact, if there is a serious problem with suburban areas (such as contamination or pollution), the costs of clean up may be higher than the value of the land, making the land "negative" in value for redevelopment. This negative balance seldom pertains in inner or core city areas where land is at a premium and value is high and the added expense of clean up can be absorbed into the value of the finished project. Recent studies (Difu 2007) found that even new developments of commercial and light industry, as well as housing areas, on the urban fringe in German growing regions do not bring increased tax incomes. Thus, the perspectives for redevelopment and the economics thereof depend on the position of the sites in the suburbs, suburbs in the metropolitan region, or the region in the (inter-)national territory.

Research on brownfields in East Germany and Berlin shows that there are more potential sites in suburban areas than in the core cities [see BBR (2004) research on brownfields in East Germany and Berlin]. This phenomenon could explain the ever-increasing land development in Germany despite shrinking processes (2006: 20), a situation which also occurs in other countries (cf. van den Berg et al.'s 1982 phase of deurbanisation). The changes in the built-up area on the urban fringe affect many parameters of urban ecology, such as soil, water quantity and quality, biodiversity, city climate, traffic flows, air quality, and ultimately health and living conditions of the local inhabitants (Graduate Research Programme [GRK] 780/II 2005). Direct ecological consequences of suburbanisation are increased land consumption and ecological footprint on the soil, air, plants, and animals, and influencing (usually disturbing) of the water cycle. Indirect consequences of suburbanisation present the correlation between land consumption and material or energy cycles (e.g. change of city climate, increased danger of natural hazards or disasters such as floods).

Suburbanised areas have lower environmental pressure – at the local level – than do densely urbanised areas (Breheny 1992). Surprisingly, biological diversity is higher in urban areas with moderate densities than in agricultural areas, because urban environments (with moderate building densities) are much more heterogeneous (Kowarik 1992). Yet, a lot of domestic animals are disturbed or displaced by the invasive foreign sorts, since the corridors and their environments are built-up, disconnected, or demolished (Theobald et al. 1997). Among all human influences on soil, building-up causes the most radical ecological effects (SRU 2000) for soil's natural functions are permanently lost.

Investment in existing built-up land and accompanying infrastructure (land recycling) might be appropriate for (1) avoiding new developments beyond the existing settlement fringe and (2) efficiency (particularly cost efficiency). Investing in existing infrastructure/developed sites compared to developments on greenfield sites is more efficient because there is "existing infrastructure, a large working force, proximity to city core, local entrepreneurs, and advantage of moderate density" (Wiewel and Persky 1994: 473). Furthermore, once an area is built-up, this is a permanent condition and many resources are needed to renaturalise it; even if renaturalisation does take place, this makes the development inefficient from an ecological perspective. If one is aiming for sustainability, the resources that might go into new developments should rather be redirected into existing developed sites or districts. Lee and Leigh (2005) discuss suburban decline through the lens of the "smart growth" concept, which includes setting a high priority on reusing existing resources in already built-up areas. Hence, the importance of reuse not only of inner cities' areas but also of areas in the (first) suburbs is demonstrated.

7.3.3.2 Methods

Underlying questions in my research are

1. How and why do shrinking processes occur on the urban fringe?
2. Do the communities in the suburbs deal with shrinkage at all, and if so, how and to what extent?

In order to answer these questions, the first step was to choose, as case studies, communities and towns which are affected most by shrinking of population (1992–2008) and of employment (1994–2007). To determine these case studies, statistical and geographical spatial analyses of socio-economic and demographic indicators were assessed using SPSS, MS Excel, and ArcGIS/ArcView. The criteria for choosing case studies were declining size according to one or both of the variables from 1994 to 2005 and having a small or middle-sized industry as a significant sector before 1990.

My analysis and interpretations of the reasons for shrinking, major factors of redevelopment, planning strategies, and measures for further development will be mainly based on the results of personal guided qualitative interviews I conducted with experts and with people closely (often professionally) involved in planning and development. Qualitative research based on interviews is commonly used in the human geography and planning sections. To choose people to interview, I began with the heads or comparable experts in communal planning offices, sometimes supplemented by staff in private planning companies. After that, I continued by interviewing relevant stakeholders from companies managing state or private real estate, other users, registered associations, research institutes, investors, and project developers, as well as other initiators of redevelopment (see Fig. 7.4). The interviews were interpreted using Mayring's method (2007) for qualitative content analyses.

7.3.3.3 Results

The suburbanisation of Berlin is unique and therefore not comparable with "typical" western patterns of development. The conditions in which Berlin's suburbanisation happens are very different from other cities, e.g. the Wall and political regulations about home ownership in the GDR until 1989, increased migration flows after "the Wende", existing demographic change, population and economic stagnation (Herfert 2006), large subsidies by the state for the industrial development before 1990, and the

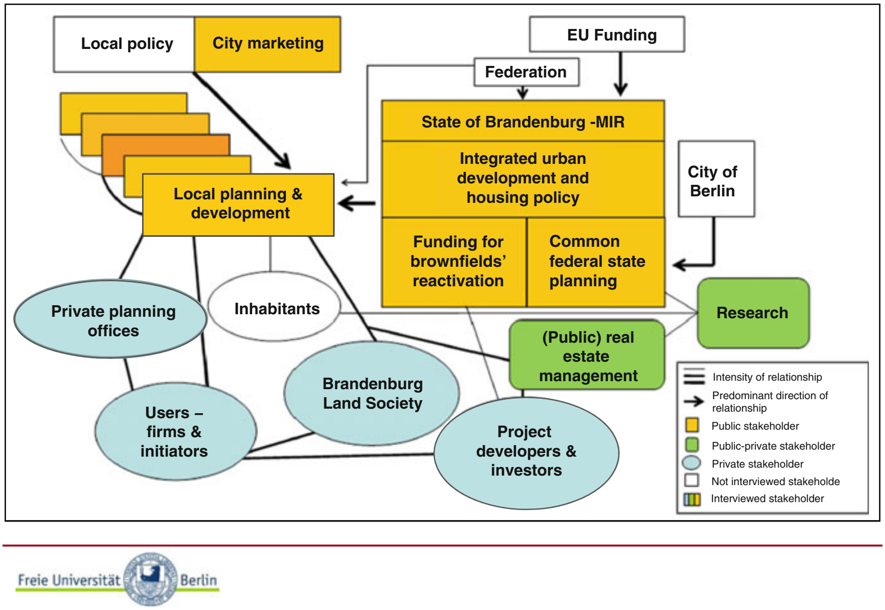

Fig. 7.4 Stakeholders and their correlation
Source: Zakirova, original figure

significant importance of the military until 1994. The initial lack of regulations in the 1990s, state grants for purchasing homes, low land prices, and rather rural, low-density areas were beneficial for housing and economic developments in the suburbs.

Yet, after 1998, these driving forces decreased, and suburbanisation slowed down abruptly without achieving a mature stage in the terms of the centrality and urbanity of suburbia. The Berlin suburbanisation slowed down due to many reasons – e.g. decelerated or shrinking economy; increase of empty-nesters; improved attractiveness of inner cities for students; young professionals and DINK (double-income, no kids) households; change of life style from suburban to urban; and the often expensive, exhausting, and complicated suburban life style/living standards due to increased energy costs – which stands in contrast to the popular view of life in suburbia. Predictions are that the shrinking processes will speed up and spread in the Berlin suburbs (BBR 2005; PFE 2006).

One interesting phenomenon is that in Berlin's urban region (as in Germany as a whole), shrinkage and growth are taking place next to each other simultaneously, revealing a fragmented and patchwork pattern of developments. Due to this differentiated distribution of growth and decline, I agree with Matthiesen (2002) that the region surrounding Berlin is not 'a continuously suburbanised commuter belt' ("Speckgürtel"), but rather a space characterised by 'suburbanised patches' (own translation, "Speckwürfel"), not all of which are identical.

Eight shrinking communities in the Berlin suburbs (1994–2007) were chosen for study here: they are situated in the semicircle from north to south-east (see Fig. 7.5).

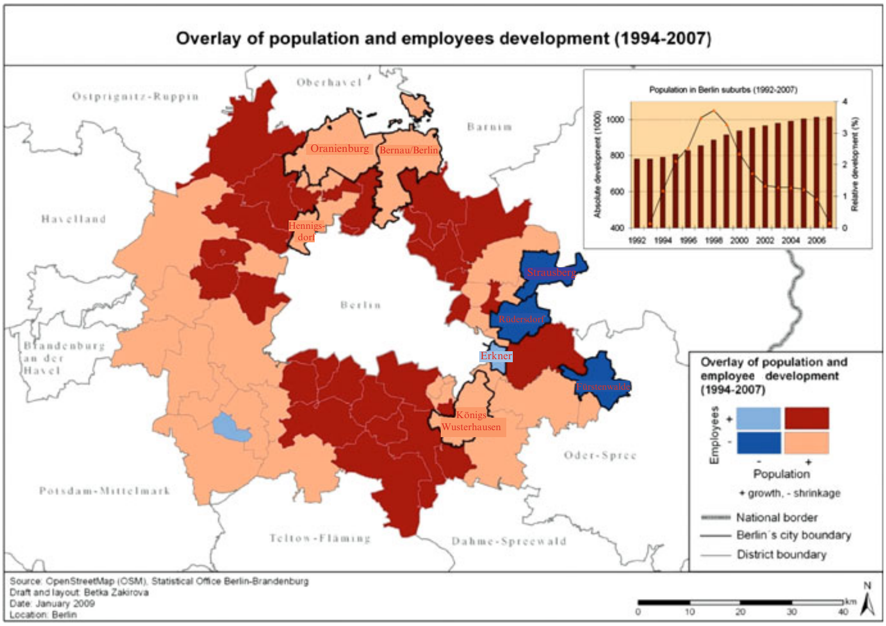

Fig. 7.5 Development in Berlin suburbs (1994–2007)
Source: OpenStreetMap (OSM), State Statistical Institute Berlin-Brandenburg. Draft and layout: Zakirova

Only a small fraction of communities (that is, 10%, $N = 6$) shrank in population by as much as 10% from 1992 to 2008 – but more than two thirds of them experienced a decline in jobs between 1994 and 2006. Most of the communities have experienced demographic changes. Note – we did not have data for the first years after "the Wende" when the population and the job decline in the suburbs were very significant. Apart from the population or the employment decline, another factor for choosing the case studies was the importance of the old manufacturing industry to the community before 1990. The reason for choosing this indicator has been that the decline of jobs happened mainly due to decline in the manufacturing industry after the Wende and that we expected to find sufficient supply of potential sites.

Causes of shrinkage were contrary to invisible forces such as lack of investments, increased costs of energy and transport, change in people's housing preferences, and selective population in- and out-migration. Not only that shrinking suburbs experience a significant lack of demand, but they can also decline because of scarcity of the open space for new developments. The transformation processes[3] such as loss of industrial, military, and agricultural land uses and accompanying jobs have been specific in the Berlin suburbs. The problems of shrinkage have been

[3]There are no overall theoretical explanations for transformation processes due to their spatial parameter.

closely related to the general transformation and globalisation processes which happened very rapidly and disrupted some sectors and places. These were not fast enough in adapting to the new political, economic, social, and spatial realities. Hence, it seems increasingly important to consider the influence of global forces on regional and local developments (Pallagst et al. 2009).

"Negative images" of the shrinking communities and disadvantageous locations (e.g. uniform housing structure, bad transport connections, and access) relative to modern social needs have often been a serious disincentive for the investigated communities. A strong negative image about the shrinking communities (e.g. industrial or military use in the past) exists, which is very tenacious (i.e. persistent through the time) and sometimes significantly removed from reality (changeable situation through processes in time). The negative public images of shrinking communities are in strong contradiction to the (pre)dominant positive perception of local stakeholders inside the researched communities. Scientists argue that the cause for shrinkage is not a negative outside image but having no image at all. Shrinking areas appear as empty grey places in human perception.

Surprisingly, shrinkage is not acknowledged at the local level in Berlin's shrinking suburbs. The common attitude by local governor officials and planners is "This cannot be happening, not in my town!" With such a view, the problem of shrinkage might escalate and lead to devastating results for planning. By neglecting shrinkage, local stakeholders formulate plans and measures which may work during growth but fail during shrinkage. For this reason, they are incapable of improving the situation in their shrinking community. A proposed shift of paradigm from "perpetual growth" to "cycles that normally include periods of shrinkage" is essential. The future goal is to study how a shift of paradigms can be implemented so that such accurate thinking is acceptable (or required) at every level.

The formation of suburbs and city shrinkage have both been viewed as some kind of temporary "diseases/ailments" for which urban scientists and experts have been trying to discover "remedies". However, to a large degree, these processes are constant forces of urbanisation and should be considered as "normal" (Hesse 2008) – they are not necessarily indicative of "problems", "illnesses", or other "malfunctions".

7.3.3.4 Conclusions and Outlook

The phenomenon of shrinking suburbs is unlikely to disappear but will remain a consistent part of urban regions. One might argue that if the shrinking of suburbs continued for a long time, the medieval idea of the so-called "European compact city" might be realised. However, that is unrealistic, since growth and shrinkage, suburbanisation, deurbanisation, and reurbanisation are taking place simultaneously. These forces are constant in the formation of a polycentric heterogeneous urban region – which seems to be an advantageous condition regarding ecological parameters and quality of life, such as living conditions.

The shrinkage in Berlin's suburbs is unique and different from that in Western mature suburbs where decline happens due to the spill-over affect from the core city and from on-going urban sprawl and decentralisation (Orfield 2002; Hudnut 2003; Puentes and Warren 2006). In contrast, suburbs of many East German cities (Köppen 2005) and Berlin do not extend and grow in the above sense. Existing explanations for shrinkage are inadequate. Berlin's suburbanisation happened very rapidly and selectively. Without reaching a mature stage [van den Berg's phase of deurbanisation (1982)] and independent functional status, partial shrinkage is emerging in the suburbs.

We do not know how long the phase of urban shrinkage will last, but it is certainly a temporary feature of the cities' general life cycle. Since linear growth in future seems improbable, the shift of paradigms from growth to shrinking is essential. We do not know how to make that shift. The new non-linear understanding of urban development might help communities to comprehend other dimensions of development. Urban history gives clear evidence that neither too vigorous growth nor strong shrinkage is good for cities – both present powerful problems for urban planning and the cities' balance.

There has been a range of attempts to stop shrinkage, e.g. to keep declining urban areas functioning by means of artificial support (e.g. external aid) but all present attempts are failing in the long term (cf. Gatzweiler and Milbert 2009). The aim of external artificial support is not only to stimulate activity by local stakeholders, i.e. the bare certainty that communities deal with shrinkage at all, but rather that grants help cities to develop their potentials, positive/productive ideas, concepts, and approaches which might have strategic middle- and long-term effects and enable the cities to remain (or return to being) self-supporting. External funding and subsidies are limited, temporary, and sometimes inefficient resources: they make cities dependent – not strong enough to take care of themselves.

The studied Brandenburg communities mainly lack an active and aggressive approach – there is an obvious shortage of initiative because they simply neglect shrinkage. Instead of "waiting for better times" and for more external support, they need to learn to actively cope with shrinkage by recognising and implementing their potentials (e.g. human capital, quality of nature and environment, available space, and ecological quality). The top-down measures are not efficient if the bottom-up initiatives are not sufficient. The public grants are used best and most efficiently by helping the shrinking areas survive shrinkage in the middle term and thus become independent of external help in the long term.

Since competition on the market and between communities is taking place and both the decline of fiscal and the lack of demand emerge at the same time, the local officials in shrinking communities act under pressure – they feel they must accept any investment or development that is offered, regardless of consequences. There is not only competition between communities, but also between suburbia and the core city and between Berlin-Brandenburg and other regions: all these leads to an ongoing over-supply of sites and to the co-existence of growth and shrinkage on small scales. This finding agrees with Nuissl and Rink (2005) who argue that shrinking communities in suburbs will act in a rather unsustainable way by extending beyond the settlement's fringe (they call this "urban sprawl"). Thus, preferring new developments to redevelopments makes the national goal of reducing land consumption to 30 ha per day until 2020 a Utopian dream.

Despite increasing competition among communities during shrinkage, some co-operation between them has been established, due to demands made by the federal state and European Union. Some communities realise that collaboration with their neighbouring communities can improve redevelopment and save costs on infra-structure. It seems clear that it is better to keep the potential taxpayers nearby (that is, next-door) rather than losing them entirely to a distant location. Once communities realise such things, they can cooperate, for instance, by marketing their potential sites together and develop common inter-communal strategic plans.

Growth occurred in those suburban communities which could deal quickly with problems of restructuring, i.e. turning "problems" into alluring developments. During transformation processes, both extremes – growth and shrinkage – are evident in the Berlin outskirts since the systems are unstable and changing rapidly. But strong, fast growth often leads to problems in the communities (like lack of social services, poor public transport). If the growing communities do not deal effectively with these problems, they might shrink in the future. In contrast, the shrinking communities that I studied have plenty of developed land, social services, and amenities, plus good transport access. Hence, the *first* scenario for future development of shrinking suburbs is that they might grow since the growing communities experience disadvantageous conditions owing to too vigorous growth.

The *second* scenario might be the trend of decreasing rates of suburbanisation and smaller growth rates in single communities after 1998 continues: back-to-the city movements may grow further, while parallel, the in-flow capacity from the periphery to the suburbs may decrease. If so, then suburban shrinkage might become widespread. Although the studied shrinking communities do not perceive their development as "a problem", outside experts disagree – in the future, shrinking processes will expand all over the Berlin suburbs, which seems obvious from the slow-down of growth since 1998.

The *third* scenario is that the patterns of developments will be even more differentiated in the future and the gap between growth and shrinkage will become larger – hence, the patchwork pattern of development will become even more 'variegated'.

The future focus in urban studies should be to propose efficient strategies for shrinking suburban communities. Here, I chose three recommended strategies for helping research communities to deal with shrinkage. If shrinking communities recognise the reality of decline, first, they might deal with shrinkage by preferring redevelopment before a site becomes vacant. Since any land use is better than none, the local planners need a great variety of flexible and informal instruments to enhance reuse of potential sites. Hence, to concentrate development with preferable moderate densities or implement developments in the gaps speaks for modern social and housing needs. These tendencies were seen on examples of Fürstenwalde or Strausberg.

The second strategy of shrinking suburbs might be that they use their vacancies or brownfields for producing renewable energy. This would not only ensure the self-supply of costly energy for local manufacturing industry (such as steel work in Hennigsdorf) but also mean to converge function with the core city. After all, an advantage of shrinking suburbs is having land and vacant areas. On the contrary, having no land can cause shrinkage. Aiming to increase competiveness of shrinking communities, they might network with their neighbouring communities and establish so-called strategic inter-communal alliances with a motto "together we are stronger". A good example is a community Rüdersdorf with prevailing industrial land use. This community lacks space and conditions for residential land use. Lack of areas for new developments could cause shrinkage in the future; that is why housing land use has been preferably shifted in the neighbouring community (In exchange, the neighbouring community could send new industrial investors in Rüdersdorf. "It is better to keep potential user near-by than lose an opportunity of investment completely").

In conclusion, we refer to Clapson (2004) who says that it does not matter whether core city or suburbs (or both) will provide good housing conditions, social opportunities and job supply, and freedom from any decay, overcrowding, and despair – being a main reason for suburbanisation. The shrinking suburbs have two great opportunities: (1) space where they can realise new ideas and develop population densities adjusted to human needs and can provide direct access to green or even waterfront surroundings, and (2) improved environmental parameters (water and air quality, fauna and flora diversity, etc.). The latter factors offer good quality of life and might also provide opportunities for future development (residential, tourism, and recreation). These resources are scarce on the global level; hence, their value will increase in future.

7.3.4 Subproject: An Urban Ecology Perspective on Micro-enterprises in the Cultural and Creative Industry in Berlin (Maike Brammer)

7.3.4.1 Introduction

In Germany, Berlin is one of the international centres of creative and cultural production. The cultural and creative industries have grown enormously in the past decades; therefore, they received growing attention in the scientific community. The concept of cultural and creative industries has been transformed in the last decade with scores of new definitions. The statistical definition of the term is interpreted in many different studies. In Germany, the discussion recently reached an agreement to combine economies of being valued as cultural and creative industries. This research is based on the definition of the European commission for cultural and creative research in which the field of cultural and creative industry encompasses an industry complex of eleven sub-markets. The essential criterion of definition is the profit-character of the company. Nine of the eleven sub-markets are subsumed under the term “cultural industries”. These are *music and book market, art market, film industry, broadcasting industry, performing arts, design, marketing, architecture market,* and *press market*.

Additionally, the two sub-markets *advertising market* as well as *software/games industry* as so-called “creative industries” are included in the definition (Söndermann et al. 2009). In the following paper, the term cultural and creative economy is used synonymous for the term cultural and creative industry.

About 75% of the cultural and creative economies in Germany are small and micro businesses. Some observers find evidence for a closer local integration of small firms than large firms (Koschatzky and Zenker 1999), because these firms tend to locate in spatial proximity and influence the neighbourhoods in which they settle. This paper is going to evaluate the externalities which micro businesses contribute to the local development in a deprived area of Berlin. I argue that the different markets and branches of the cultural and creative economy have diverse ecological, social-cultural, and economical effects on the local neighbourhood development. Based on the concept of embeddedness in a spatial perspective, the central element of this paper is to reveal the various effects of the different markets in cultural and creative economies in relation to their level of spatial embeddedness and whether there are differences depending on the locations on micro scale levels such as a store front level or upper level.

To discuss the impact of cultural and creative industries on neighbourhood development, my research questions are

What effects do the different markets of the cultural and creative industry generate within the local neighbourhood development? Does it matter where the firm is located (store front level or upper level)?

What interactions occur between creative neighbourhood development and the embeddedness of the cultural and creative industry to the local environment?

In my dissertation, I will furthermore examine new evidences in economic geography by discussing the relationship between network behaviour and micro location. The approach emphasises also the concept of project organisation. The temporary character of project-based inter-firm relations of micro businesses is going to be characterised for the design, art, and film markets. Projects have become typical in the cultural and creative economies. Grabher described the work of the creative scene as project ecologies and emphasised the temporality and network-based work of the “cultural and creative economy” (Grabher 2004). Therefore, my research questions are

What impact does the spatial concentration have on project organisation and the network interactions?

Where are the differences between the markets of the cultural and creative industry addressing the network behaviour? And how does that differ from the micro scale where they locate?

This paper focuses on the first research question which emphasises the impact on neighbourhood development of cultural and creative economies. The second research questions are not going to be discussed furthermore in this paper.

7.3.4.2 Spatial Concentration, Network Approaches, and Drivers of Urban Restructuring

Micro businesses and self-employed freelancers tend to locate and concentrate in undeveloped areas of the city centre not just for the simple reason of space and money. Florida argues that they concentrate in cities or in particular districts where they like to live. Such places embody a place-based environment that is open, diverse, and tolerant (Florida 2002).

In the literature, several theoretical concepts are discussed that describe different forms of spatial concentration of economic activity. To name a few concepts which underline the fundamental issue of this work, I want to mention the notions about positive externalities of spatial concentrated economic production developed by Alfred Marshall in his work "Principles of Economics" in 1890. Marshall emphasised that the spatial proximity between firms creates an "industrial atmosphere" that generates gains in productivity (Schätzl 2001). Industrial districts are characterised by mostly locally owned small and medium-sized companies which have minimal linkages to firms outside the district (Schamp 2000; Markusen 1996).

The GREMI group (Group de Recherche Européenne sur les Milieux Innovateurs), introduced in 1980 the concept of the "innovative" or "creative" milieu. They have defined a creative milieu as "the set, or the complex network of mainly informal social relationships on a limited geographical area, often determining a specific external 'image' and a specific internal 'representation' and sense of belonging, which enhance the local innovative capability through synergetic and collective learning processes" (Camagni 1991).

The term cluster was popularised by Porter's studies of national competitive advantage. Porter defines a cluster of economic activity as a "geographically proximate group of inter-connected companies and associate institutions in a particular field, linked by communalities and complementarities" (Porter 1991).

Personal and organisational agglomeration approaches have received as "networks" growing attention. Constitutive elements of networks are spatial proximity, cultural proximity, as well as institutional and organisational proximity (Kulke 2009). For the development of a regional or project-orientated network the embeddedness in a corporate human, cultural, social, or political environment can be important for the formation of the network. With Mark Granovetter's notion of embeddedness, the network concept opened up a relational view of the social context of economic action. 'By embeddedness I mean that economic action, outcomes, and institutions are affected by actors' personal relations, and by the structure of the overall network of relations. I refer to these respectively as the relational and the structural aspects of embeddedness' (Granovetter 1990). Granovetter's idea of embeddedness catalysed a numerous body of research on economic networks.

The industrial district stresses the intense co-operation of firms along the same value-added chain while the creative milieu approach describes the institutional embeddedness of firms in similar and related industries. Porter's cluster approach emphasises the generation of competitive advantages through competition as well as co-operation among co-located firms. The concept of embeddedness emphasises the importance of relations and the structure of relations.

As spatial concentration and network configurations can bring positive effects as drivers of innovation, growth, jobs, and urban restructuring for regional development, there has been growing political interest. In particular, the cultural and creative economy has become prominent in reference to revitalise urban districts. The re-urbanisation and the Renaissance of the inner city districts are recognised all over the world, and are often related to the growth of the “cultural and creative economy”, especially in districts where working and living can be combined (Ebert and Kunzmann 2007). Scott even argues that cultural and creative economies tend (though not always) to be environmentally friendly and generate positive externalities. They contribute to the quality of life in places where they locate and improve the image of the local area (Scott 2004). Besides the influence exerted by the creatives as an economic factor, they make a major contribution to local development by local bonding, as a location factor, and with an impact on tourism, real estate, and social integration (Heider 2007).

7.3.4.3 Methodology

The analysis is based on a quantitative and qualitative case study. To examine the research area, I took the characteristics of creative economies into account by analysing deprived inner city districts of Berlin, which tend to be potential locations for the creative and cultural economy. For the area of research, I chose the deprived district Reuterquartier in the northern part of the borough Neukölln. To provide a complete picture of the cultural and creative economy of the Reuterquartier, I conducted a standardised survey of creative micro-entrepreneurs. The quantitative case study is based on a statistical census of the cultural and creative economy of the Reuterquartier. A total of 165 companies were identified from the creative core. Overall, 83 questionnaires for the evaluation are considered. This represents a response rate of 50.3%. The data collection was completed in August 2009.

To provide further useful elements that help to characterise the nature of Neukölln’s creative economy agglomeration, network behaviour and effects on the local neighbourhood development, an explorative, qualitative case study has been done. The qualitative approach had been focused on the three dominant markets in the cultural and creative industries of the research area Reuterquartier: the design, film, and art markets. For the qualitative case study, a semi-standardised interview has been conducted, primarily using the technique of face-to-face dialogues. Within the design, art, and film markets, 18 firms have been interviewed. In addition, 12 experts from planning institutions, government, and scientists have been interviewed.

7.3.4.4 Preliminary Results

The local embeddedness of firms relates to the impact of culture and creative industries. Particularly social and cultural impacts are related to the level of local embeddedness, although ecological and economical impacts can be characterized and differ by branches and by the micro scale of location. The impacts of cultural and creative industries on neighbourhood development are classified in ecological, social-cultural, and economical impacts. These three major impacts are characterised as follows (see Fig. 7.6).

Ecological impact: City of short distances and neighbourhood greening

The quantitative analysis reveals that 60.1% of the interviewees live in the neighbourhood (Reuterquartier) of their workplace, 17% live in the borough where they work, and just 22% reside in other parts of Berlin. There has been no difference in branches or according the location of a firm; all interviewees in the qualitative analysis said that they use their bike or go by foot to work and run their errands mostly in the neighbourhood. This finding stresses the argument of Scott, in which he argues that the creatives tend to be environmental friendly as they get to work by bike or by foot.

> 'I have to pass the kitchen to get to my studio. But Thomas gets here by bike. And if we have a big order we do "car sharing". We do not have our own car.' Interview ABS 05

The tree collar "Baumscheibe" is an important aspect of "greening the streets" and contributes to the natural development of the districts. It also emphasises the encouraging image of a neighbourhood and has positive externalities to the real

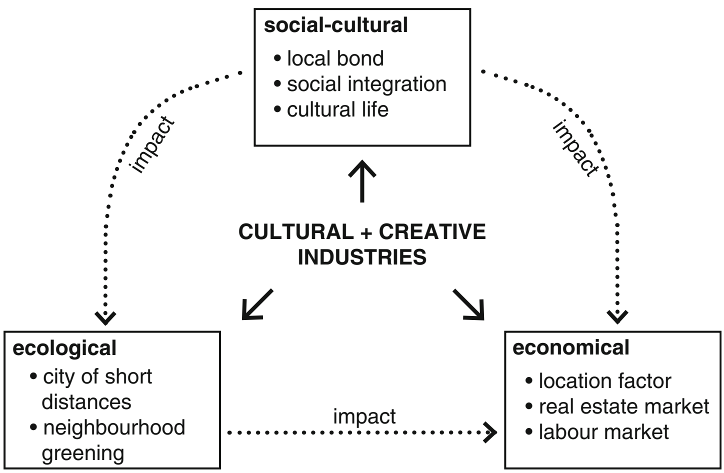

Fig. 7.6 Impacts of cultural and creative on neighbourhood development
Source: Brammer, original figure

estate market. Fostering of the tree collar and greening of streets are clearly linked to the floor where the firm is located. Almost every firm which is located in the store front level is engaged in “greening” the Reuterquartier. In contrast, firms located in upper floors of creative lofts and warehouses in the research area are not typically involved in “greening”.

Social-cultural impact: Local Bond, social integration, and cultural life

The theoretical concepts of clusters, industrial districts, and creative milieus stress on co-operation and collaboration among certain firms as a major element of spatial concentration. Many cultural and creative goods are mainly aligned to a local or regional network. In this case study, design and in particular art businesses are more embedded in their local environment and collaborate more with other co-located businesses than film businesses do. About 80% of the art businesses are taking part in temporary neighbourhood events like the art festival “48 Stunden Neukölln or Nacht und Nebel”. It is also noticeable that more than 60% of the firms who locate in storefront level are involved in temporary neighbourhood events. They generate cultural attributes and improve the cultural atmosphere in the neighbourhood by also having open studios, art sales, and design markets in the area. The qualitative analysis reveals that design businesses and art businesses located in store front studios often are strongly bonded to their local and regional neighbourhood. That is for the reason of spatial and cultural proximity and social embeddedness. As well as that, their economical development is heavily linked to their direct surrounding.

The quantitative analysis also exposes that around 15% of the art, design, and film businesses are involved in local city development processes by being part of a local committee.

> ‘It’s is planned that we are focusing on Neukölln’ Interview PW 01

> ‘For us, spatial proximity is very important. . . . In the future, we like to work together with the company “common works”. They are located right around the corner . . . and we know they do fair business and pay fair wages.’ Interview TA 06

Only a small fraction of interviewed design and art businesses located in store front studios improve the social integration by offering workshops or other social cultural projects. Culture here is used directly as a social tool to improve the life of the poorest members of the neighbourhood.

> ‘I offer “talks” about my job. I also work with school in the neighbourhood’ Interview PW 01

7.3.4.5 Economical impact: Location factors, real estate market, and labour

The image of the location is significant as a location factor as well as the creative, social, and cultural atmosphere. This is further stressed by the high significance of proximity to other businesses in creative and cultural industries. Therefore, the creative business can be seen as a location factor itself. In real estate development, the cultural and creative industries gained growing attention in different perspectives. The rising rental prices and therefore a growing gentrification affect the real estate market. Many creatives put major energy in the renovation of run down store front studios. The rental of store front studio spaces to the creative also has an impact on the rental of an apartment in the house.

> 'We really enhanced the house by a major renovation we did in our studio. Although the landlord of Klaus and Denise (artists) said that he has from now on no problems to rent the apartments in the houses. In the past, he had to do much advertising. Also, he paid the artists to remodel the façade of the house.' Interview LK 12

Even small firms employ staff. Although this employment tends to be on a freelance/project basis, it also contributes to the labour market. The quantitative and qualitative analysis reveals that the design market and particularly the film industry are employing obviously more people than the art market. Also, the film market does offer more internship positions.

7.3.4.6 Conclusions and Outlook

The aim of this paper has been to outline an urban ecology perspective of my work on cultural and creative industries. Therefore, this article answered in general the question what impacts the creative and cultural industries have on the social dimension of urban ecology. This study has demonstrated so far that cultural and creative industries generate particular externalities to the local neighbourhoods and districts. It has shown that ecological, social-cultural, and economical impacts on the neighbourhood are linked to the micro scale of location and to the branch of cultural and creative industries. Spatial and cultural proximities provide a sticky environment with a social-cultural impact like local bond and social integration. In the research area, three sub-markets – design, art and film markets – have been compared. It has shown that particularly art and design businesses which locate in store front studios are more embedded in their local environment. Empirically, these firms generate more social-cultural attributes and improve their neighbourhood. The businesses which are located on the store front level imply more ecological impacts like neighbourhood greening. Therefore, the film industry, which mostly concentrates in warehouses and loft locations, does bring more effects to the labour market.

This paper could not yet address the conclusions for a sustainable local and regional policy with respect to small firms in the art, design, and film industries in deprived areas. But, it made clear that we need detailed analysis to address regional policies. This question will be discussed in the future approach. The forthcoming research will also argue to what extent the findings support or discredit the applicability of spatial agglomeration and embeddedness in relation to utilisation to a local network. Furthermore, the approach will emphasise the concept of project organisation in the art market, the film industry, and the design industry of Berlin. Finally, I will outline the relationship between network interactions and the impacts of creative and cultural industries on local neighbourhood development.

7.3.5 Subproject: "Planner and Owner Interrelations in Temporary Use of Vacant Spaces" (Benjamin Otto)

7.3.5.1 Introduction

Temporary uses of brownfield sites and vacant buildings have been a topic in urban planning and politics since the beginning of the 1990s. The growing interest in this subject arises from fundamental social changes such as the increasing acceleration and flexibility in urban (and as well in individual) time patterns and the socio-economic transformation from Fordism to Post-Fordism (Breitfuß 2003; Kohoutek and Kamleithner 2006). As a result of industrial decline and arising service society, both the supply of (temporary) brownfields and the demand for these areas have increased. At a theoretical level, temporary uses may be considered as a new form of spatial production and spatial use. At a more applied level, it can be argued that these temporary uses have a high relevance for a sustainable urban development in all dimensions (economical, ecological, and social sustainability) which should not be underestimated (BBR 2008; Urban Catalyst 2007). In the best case, all stakeholders can benefit from temporary uses: The user can rent space for a low amount of money, the landlord can reduce his maintenance costs, and the municipality can avoid the negative effects of extensive vacancy and decay in certain areas.

The research on temporary uses is mainly applied. In particular, legal and economic problems and obstacles with landlords and municipalities in the practical implementation of temporary uses are the focus of attention. Usually, case studies are examined at the local level to derive policy recommendations and best-practice solutions (e.g. Gallenmüller 2004; Heydenreich 2008). There is a lack of more critical approaches and attempts at a theoretical classification. This research project will try to reduce this research deficit. Starting with the motives and objectives of the stakeholders (landlords, users, municipalities, and intermediaries), the phenomenon "temporary use" will be examined in the larger context of social change to obtain a sound theoretical explanation for its growing importance in scientific and political discussion. Special emphasis will be given to the landlords and the municipalities because despite all the advantages temporary use should have for them, these uses are still a niche phenomenon. In particular, the landlord's reservations are often strong, so that only a small fraction of all the unused land is used for temporary activities.

In the following chapter, at the beginning, the term "temporary use" is defined. Then, it will be clarified how these uses can contribute to a sustainable urban development and why there can be advantages for all stakeholders. Following this, the research questions are derived and choice of study area and methodology are explained. Afterwards, one aspect is discussed in more detail, namely, which obstacles prevent landlords and municipalities from establishing temporary uses.

7.3.5.2 Definition of Temporary Use

Two characteristics of temporary use are particularly important for the distinction between temporary (or interim) and permanent uses: the temporality of a use and the change of a use. Of course, in the long run, all uses are temporary. So, the decisive criterion is that the use is seen as temporary from its beginning and by all involved stakeholders (Haydn and Temel 2006: 17). However, this also applies, e.g. for most commercial leases. Therefore, the second criterion is a change of use: An area or building is temporarily used for another purpose than it was originally intended to when it was erected. The previous use has ended and a new permanent use has not yet started. Normally, the landlord has certain ideas and plans about the future use of his property. But, these plans cannot be implemented yet for various reasons like a lack of funding or prolonged planning procedures. During this time, a temporary use can take place which does not meet the long-term expectations of the landlord's wishful thinking: Mostly, the generated returns are too low, or if the land is owned by public authorities, there is different use planned (Overmeyer 2007: 45).

The most common types of temporary uses are gastronomic uses such as beach bars, green uses such as community gardens, and sport and leisure uses such as beach volleyball fields. Most temporary uses arise in residual and in-between areas in or near the urban centre because a good infrastructure and an attractive locality are necessary for their success (Urban Catalyst 2007: 275).

7.3.5.3 Temporary Uses as Part of a Sustainable Urban Development

Temporary uses are often considered as an important element of sustainable urban development (BBR 2008; Overmeyer 2007) because "they have a capacity to create maximum effect with minimum resources" (Hentilä and Lindborg 2003: 20). Temporary uses per se possess an element of economic and ecological sustainability, as they always recycle previously used land and buildings, save resources, and match the planning principle of internal development instead of exterior development. Through interim use, buildings and areas like former industrial estates, obsolete transport infrastructure, (e.g. harbours, freight depots), and unused offices are maintained, which would otherwise expire. And, temporary uses may offer additional benefits for urban development (BBR 2008; Urban Catalyst 2007): They can generate a new image for disadvantaged neighbourhoods and stimulate economic development there which has a positive impact on the redevelopment of these areas. They offer the possibility of participation to realize the citizen's wishes quick and non-bureaucratically and establish grass-root urban development processes.

Fig. 7.7 Temporary use of an inner-urban brownfield for urban agriculture in Berlin
Source: Photo taken by Katharina Winter

In particular, green temporary uses such as intercultural and neighbourhood gardens have a very sustainable component, since they provide green spaces in often highly compacted areas and achieve in this way both socially and ecologically sustainable effects (Rosol 2008, see Fig. 7.7). Furthermore, a research project showed that wasteland left to itself in the city is often of high ecological value (Strauss and Biedermann 2006). But, such areas are often not accepted in residential neighbourhoods and are uses as dumping area and for dog walking so that the ecological value is reduced (Heydenreich 2008: 236).

For the successful implementation of temporary uses, not only the municipality but all stakeholders must gain benefits through them – especially the landlord. Possible advantages include protection from vandalism and decay, lowering maintenance and security costs, forming a new image for the property, and attracting tenants and/or investors (Hentilä and Lindborg 2003: 17). Finally, temporary uses have also advantages for the users. Normally, the rent is much lower than the market rates for comparable spaces. Due to this and shorter contract terms the risk of failure is reduced for start-ups and small entrepreneurs (BBR 2008: 116).

7.3.5.4 Research Questions, Study Area, and Methods

From the above considerations, the following research questions arise:

- What are the motives of landlords to allow temporary uses on their property? Can certain types of landlords be identified who are more likely willing to establish such uses?
- What are the motives of temporary users and what kind of user types exist?

- How big is the influence of the municipality on temporary uses on privately owned land?
- Has the general acceptance of temporary uses in the context of real estate and urban development processes increased? Is there an institutionalization of temporary uses?

Berlin is chosen as study area because in this city, “the temporary always had a very strong influence on urban development” (Overmeyer 2007: 45), due to many radical changes in the city’s history (cf.: Oswalt 2000). As a result, on the one hand, there are a lot of inner-city open spaces which can be used for temporary activities. On the other hand, there are also enough young and creative people who want to use these brownfields. Accordingly, temporary uses are more common in Berlin than in any other German and European city.

Methodologically, a qualitative and exploratory approach is taken to answer the research questions. This is necessary because the research topic is very dynamic and only little scientific literature exists so far. The first step is a registration of the temporary uses in Berlin and creating a map which shows their geographical position. Since there are no statistics on this subject besides one publication (SenStadt 2007), this is done mainly through own primary research on location and desk research in newspapers, existing literature, and the Internet. Furthermore, explorative expert interviews are conducted with people who have studied in theory and practice with the issue temporary use. In the second step, from the recorded temporary uses, case studies are selected. For each case will be sought to speak with the user, the landlord and other key actors involved like municipal authorities, to get a comprehensive picture about the stakeholder’s motives and assumptions to answer to the overriding question. In addition, in-depth interviews with the planning offices of the districts and landlords conducted, as little attention was paid to these two groups of stakeholders in previous studies.

7.3.5.5 Obstacles Despite Benefits

Despite the benefits temporary uses have apparently for all stakeholders, the number of unused wastelands and empty buildings exceeds significantly the number of temporarily used areas. This is true even in Berlin, which can be considered a centre of creative, temporary uses. The concerns and barriers to this kind of exploitation appear to be larger than suggested by many authors.

One problem is that an interim use is rarely profitable from a purely business point of view. The rental or lease income is usually low and often does not even cover the administrative and organizational effort – which for a temporary use is the same than for a permanent use and sometimes even higher (Dransfeld and Lehmann 2008; Hentilä and Lindborg 2003). Only in the consideration of additional, usually not precisely quantifiable effects, the landlord can come to the conclusion that such use is worthwhile for him. These “soft” effects include, for example, protection against vandalism or a certain promotional effect by an interim use that facilitates the marketing of the property. But, even in these cases, there remains another major obstacle: The landlord's fear of an unintentional continuation of the temporary use (BBR 2008: 117). This is especially true for property which the owner expects to be developed or sold short term:

> '... and then I have probably problems to get them [the temporary user] out again. No matter what kind of contract you have, if they sue you, they can stay for the moment. This is too uncertain. [...] No, [one year] is too short and we do not want to have any trouble, so we leave it vacant' (interview with a manager of a medium-sized real estate development firm).

In this question, it also makes no difference whether the landlord is a small landlord, a big real estate fund, or a municipality:

> "[The temporary users] went there as long as the plans of the city were not ready yet. And now, the city has the problem to get rid of them. And that's the biggest fear for many [landlords]: How can I handle the situation that someone with his bar, with his beach volleyball, etc. will not go away, although I progressed in my plans [for the property]" (interview with a manager of the Berlin Senate Department for Urban Development).

Of course, no temporary user is able to occupy permanently a property without the landlord's permission. But, a delayed clearance of a site causes additional costs and any delay can deter potential investors. Thus, a special relationship of trust between a temporary user and the landlord is crucial for a successful temporary use – in addition to a good contract design. Often, the negotiation and cultural behaviour of property owners and temporary users differ so much that intermediary institutions are necessary to achieve an agreement (BBR 2008: 122).

7.3.5.6 Conclusion

Temporary uses will be more common in following decades than today; because of their flexibility, they cope better with the changing social conditions than traditional uses. Furthermore, they have the potential to support the sustainable development of cities in all dimensions. But, if they should be become an integral part of urban development processes and more than a niche phenomenon, landlords and municipalities have to be convinced that temporary uses offer them more advantages than disadvantages. There is a need to take seriously the concerns of the landlords and the local authorities, overcome their prejudices, and establish temporary use as a normal form of land use.

7.4 Final Remarks

The subprojects show that integrating economic development and improvement of the urban ecology is a difficult and heterogeneous project. The simple idea of "internalisation of external effects" is convincing but problematic in its realisation. Especially, if the global approach is transferred to the local level, many obstacles and factors of influence become obvious. Many actors with different aims, ideas, or approaches are taking influence and have to be integrated. Therefore, it is not really surprising that the subprojects have developed interesting results in detail, but are not yet delivering a general model or strategic approach. But, bringing the analysis and results together, some general observations can be derived:

- All subprojects documented that urban agglomerations are breathing objects; this means that the urban agglomerations do not have a permanent character concerning economy, planning strategies, buildings, and land use. Instead of this, the built-up-areas face a permanent change. And, breathing means that there is no continuous growth; instead of this, the urban landscape shows at the same time parallel trends of expansion – with new built-up areas – of shrinking – with former used and now vacant land – and of change – with transformation of the kind of land use.
- These changes are very much influenced by economic developments or transformations. All large agglomerations in developed economies are facing a sectoral change towards service activities; especially, modern high-ranking services and cultural economy are expanding and are forming new spatial concentrations or clusters. Manufacturing activities are moving out and we are facing a transfer from a Fordist industrial economy to a post-Fordist flexible economy; this tendency is especially strong in Berlin where the post-socialist transformation resulted in a strong de-industrialisation process. The economic change delivers vacant land and buildings in central areas and even at the outskirts, which opens opportunities for new uses, often by establishing service activities.
- These processes of change open the possibility of improving the environmental situation of the landscape of the agglomeration and on the local level. But, to realise these environmental improvements, strong land use planning and management influences are needed. The realisation is quite difficult because of the many actors involved, their differing aims, sometimes lacking consciousness, and limited planning instruments.
- Generalised there are three major groups of actors – the enterprises, the consumer/clients, and the planner/politicians – involved in the developments. But, these groups can be subdivided into many smaller groups in detail. Their different aims and strategies must be integrated for a comprehensive development approach. Interesting for developing new forms of land use in vacant locations is especially the group of land-owners. They – of course – try to maximise their income and land value; this strategy sometimes is in conflict with improving the ecological situation and opening the spaces for temporary forms of land use. And often, enterprises are not really aware that integrating ecological aspects into their locational design can be an element which not only just improves the environment but in addition might be a positive factor in competition. The case study of cultural economy shows that for modern services, this element already possesses a certain kind of importance.

– In general, there is a need for all actors to raise the awareness for ecological elements in their behaviour. Consumers can change their spatial and article behaviours towards more ecological friendly products (see the case study of environmentally friendly shopping), planners/politicians can utilise the land use changes for improving the ecological situation in the agglomerations (see the case study of challenges in planning), and enterprises may design their locations in a more environmentally friendly way (see the case study of cultural economy).
– The case studies show that the instrument of temporary use can be a good tool for improving the landscape development in a breathing agglomeration (see the case study on temporary use of vacant spaces). Up to now, shrinking and change seem to have a negative connotation; but these processes are opening possibilities to improve the urban landscape and temporary use might be a short-term bridge for long-term improvements.

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Chapter 8
Remote Sensing and Spatial Modelling of the Urban Environment

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8.1 The Urban Environment: A Remote Sensing and Land Use Modelling Perspective

With the beginning "urban millennium" (UNESA 2007), our interest in the societal, economic, and ecological functioning of urban systems is rapidly increasing (Pickett et al. 2001). Half of the world's population inhabits cities, with an increasing share of megacity dwellers or people living in mega-urban regions (Kraas 2007). Urban agglomerations steer processes from the local to the global level and urban ecological science needs to develop a deeper understanding of how matter and energy flows driven by urban ecosystems function across scales (Grimm et al. 2008; Kaye et al. 2006). While a city's physical footprint is limited, the ecological footprint of our increasingly urbanized world is rapidly expanding. Urban agglomerations are estimated to extend on an ecological footprint of up to 200–300 times their actual physical size (Folke et al. 1997). The sustainable provision of urban ecosystem services and maintaining urban biodiversity is hence closely connected to mitigating effects of imbalanced rapid urbanization (McGranahan and Satterthwaite 2003). Accordingly, urban ecology is becoming more prominent and will determine how sustainable future cities will develop from an environmental perspective. There is an urgent need for in-depth process understanding and a more profound knowledge of land use decisions that drive the urban structure and thereby heavily impact the urban environment and the provision of ecosystem services. Actually, urban regions offer the most intense interaction of humans with ecosystems and

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thereby a wealth of opportunities to gain a deeper understanding of related land use processes and impacts on urban ecosystem services. However, urban ecology is intrinsically complex; it exhibits many different research facets and an overarching theory is still to be developed. A methodologically sound basis is mandatory to lay the foundation of such theoretical frameworks and to provide input for model-based research to test hypotheses in urban ecology and land use change (LUC) impacts on urban ecosystem services (Alberti 2005; Pickett et al. 2008).

The importance of spatially explicit analysis and modelling in the context of urban ecology has been pronounced by numerous authors (Alberti 2005; Cadenasso et al. 2006a, 2007; Grimm et al. 2000; Pickett et al. 2008). Essentially, all consolidated findings in urban ecology are based on spatial observations and a conceptual understanding drawing to a large extent from spatially explicit research and models. Remote sensing techniques provide spatially explicit information on the urban environment at different spatial and temporal scales and in a consistent and reproducible manner. Spatial analysis and modelling of an integrated urban environmental dataset – including remote-sensing-derived and additional environmental and socio-economic data – allows the exploration of land use processes and likely impacts on the urban environment in urban areas from a human-environment system's perspective (Rutledge et al. 2008; Van Delden et al. 2007).

To assess the state of the urban environment, in recent years urban remote sensing has gained tremendous interest which may be due to two reasons: the advent of very high spatial resolution sensors and the increased interest in urban ecology. The latter is partly triggered by long-term ecological research (LTER) in the urban context (Hobbie et al. 2003; Wu 2010) and by the ever-increasing concern for urban ecosystems in a steadily urbanizing world. Related literature includes numerous special issues in remote sensing journals (Gamba et al. 2003; Gamba and Chanussot 2008; Weng and Quattrochi 2006b) and also a variety of book publications (Jürgerns and Rashed 2010; Netzband et al. 2007; Weng and Quattrochi 2006a). This wealth of new research is invaluable, as urban remote sensing covers a wide range of topics, including analyses of vegetation differentiation, urban climate, and energy fluxes (Gluch et al. 2006; Hung et al. 2006; Kaufmann et al. 2007), biodiversity (Cohen and Goward 2004; Seto et al. 2004), imperviousness (Phinn et al. 2002; Ridd 1995; Yang et al. 2003) or also the generic problems of urban growth (Griffiths et al. 2009; Herold et al. 2003; Schneider et al. 2005).

To explore the processes and likely impacts of urban land use on the environment and the provision of urban ecosystem services, one powerful instrument is LUC modelling. It enables one to uncover the many relationships, driving factors, and underlying causes contributing to urban change (Batty 2007). LUC models are primarily used as learning tools to gain knowledge of changing mechanisms and causal relations within complex systems such as cities. Furthermore, LUC models can also be powerful to explore scenario-based future trends and to explore hotspots of likely LUC and the respective impacts on urban ecosystem services (Rutledge et al. 2008; Van Delden et al. 2007). LUC models contribute to the communication between researchers and decision makers (Verburg et al. 2006) and allow new insights to preserve and improve the existing urban environment and particularly its services in an urban context. In recent decades, a variety of LUC model applications have been carried out. They exhibit considerable differences in complexity, modelling techniques, drivers, spatial resolution and scale (local to global) and finally in regards to the investigation of land use type itself (Batty 2003; Haase and Schwarz 2009; Koomen and Stillwell 2007; Lakes et al. 2009; Pijanowski et al. 2006).

The aim of this paper is to illustrate the contributions of sophisticated and up-to-date technologies to an improved understanding of the urban environment, the provision of urban ecosystem services, and the underlying processes of LUC. We therefore begin with the need for information on the urban environment from a scientific and decision-maker point of view based on the already available information for our case study Berlin. We then present initial insights from two case studies on (a) very high resolution remote sensing techniques for assessing the urban environment and (b) land use modelling techniques to assess likely future LUC and its impact on the urban environment.

8.2 Availability of and Need for Information on the Urban Environment in Berlin

Land use change caused by human decisions as well as by climate and demographic changes affects the urban environment and the provision of ecosystem services in Berlin to a significant degree. It is particularly the case for Berlin that a mosaic of continuous growth, change, decline, and restructuring exists (White and Engelen 1993). Assessing and modelling these processes of land use change and modification is a major task to gain an improved understanding of the present and likely future city of Berlin. In addition to this focus on urban development under different scenarios of demography or climate change, a variety of environmental formal and informal planning and decision-support instruments exist to preserve and develop the environment within the urban area of Berlin, such as Preparatory Land-Use Planning, Zoning Ordinance, the Water Framework directive, the Fauna Flora Habitat directive, or the Environmental Impact Assessment Directive. The Strategic Environmental Assessment has developed to a key tool for sustainable development (Jones et al. 2005; Dalai-Clayton and Sadler 2005). This European guideline requires an environmental assessment of the effects of formal plans and programs which set a framework for subsequent planning levels.

To address these challenges of decision-making and urban ecosystem service preservation and development, the crucial prerequisite is the availability of reliable information on the present situation of the Berlin urban environment which is spatially explicit, sophisticated, and user-friendly. Also in Berlin there is an increasing interest in generating scenarios on likely future changes and potential impacts on the urban environment. In recent years, the amount and heterogeneity of available spatial information on the urban environment has rapidly increased. Different information technologies for assessing and analyzing environmental information are applied, including a growing variety of remote-sensing sensors and products (Hostert 2007; Schneider et al. 2007). Remote sensing techniques have augmented additional acquisition methods and have been a fundamental information source, including the assessment of the sealing degree (Haag et al. 2008) and the vitality of tree species (Damm 2009). They have been particularly valuable for the field of nature conservation, where a significant demand for area-wide and up-to-date data exists, for example with biotoptype and NATURA 2000 mapping.

As well as the increase in data acquisition techniques of the urban environment, the number of users and data providers is steadily growing so providing a sophisticated management system environmental information and spatial data in general is now one of the major challenges. The concept of the spatial data infrastructure is to explicitly address this issue of data provision in a transparent and user-friendly way (De Man 2006). In Berlin, the Spatial Data Infrastructure (SDI) is brought forward by a joint committee of Berlin and Brandenburg stakeholders (http://gdi.berlin-brandenburg.de). An online geo-portal provides information on the available data in the two federal states with state-of-the-art standards and technologies. These include a Web-Map-Service, a Web-Feature-Service, and a Web-Catalogue-Service all of which allow user-friendly access to available information, and even more importantly, allow access to relevant metadata on available geodata, and data on the urban environment, respectively. Access to a large number of environmental datasets exists with the Environmental Atlas as one of the most important, maps of land use planning or a soil pollution register (please see http://gdi.berlin-brandenburg.de). Berlin was actually one of the first cities in Germany to implement such an environmental information system which since then has been further developed and migrated into a broker that allows access to a large amount of Berlin data for several application fields. With this new generation of Environmental Information Systems, the aim is to allow information, communication, and transaction of environmental data (Schneider et al. 2007).

Studying the urban environment with regard to LUC and ecosystem service provision requires the integrated analysis of different environmental data as well as socio-economic data independent from the method of data acquisition. New technologies open up new application fields on the one hand, such as the growing spatial and temporal resolutions of remote-sensing data (van der Linden and Hostert 2009), the increasing capacities of internet-based access (Schneider et al. 2007), or the spatial analysis and modelling techniques. The use of these newly available techniques for a specific aim requires a profound knowledge on the user needs and on the benefits as well as challenges of available data such as shown for the example of urban habitat networks in Berlin (Lakes and Pobloth 2005). On the other hand, it is the actual question arising in science and decision-making such as assessing ecosystem services from very high resolution remote sensing or local impact analysis of LUC on ecosystem services driven by demographic change which requires new approaches, selecting the most appropriate available data, and spatial modelling techniques.

8.3 Very High Resolution Remote Sensing for Urban Ecosystem Service Analysis

8.3.1 State of the Art

The urban space has increased in significance as a field of concentration and spatial attraction of human capital (Seto 2009). Its dynamics, either waxing or waning, is driven by a variety of social, economical, and ecological factors causing disparities within the urban environment. Consequently urban space is categorised into different spatial units such as those with social disparities, economic centres, and areas providing large shares of ecosystem services. Science will not address challenges of ecosystem services in urban areas if the urban space is taken as a single unit while intra-urban analysis still lacks detailed studies (Troy et al. 2007). As today's significance of the urban space increases, the field of urban ecosystem services becomes more important (Cadenasso et al. 2006a). Up to now, services such as air filtration, micro climate regulation, carbon storage, noise reduction, rainwater drainage, sewage treatment, provision of food, recreational, and other aspects have been barely addressed in the urban context (Bolund and Hunhammar 1999; Oberndorfer et al. 2007). In contrast to earlier approaches, the urban environment, and in particular vegetation analysis, is now – from an anthropocentric point of view – one important indicator to assess and approximate the state of urban ecosystem services. The major question will be what are interactions between the urban structure and the vegetation derived ecosystem services? (Cadenasso et al. 2006a; Pickett and Cadenasso 2008) This then allows the identification of the range and ecosystem services and the identification of those groups that benefit and those that do not. As Phoenix (Arizona, USA) and Baltimore (Maryland, USA) serve as case studies on urban ecosystem services, they address fluxes, relationships, and linking of ecology and socio-economy over time in particular (Benton-Short and Rennie-Short 2008; Cadenasso et al. 2006b).

Major challenges for urban ecosystem service analysis are access to appropriate data, a patchwork of multisource datasets, different levels of aggregation of vegetation, limited spatial coverage of data, differences in data acquisition time, a lack of updates, as well as missing volume data on vegetation. Multi-spectral remote sensing can be used to derive features of physical parameters such as vegetation coverage, multi-temporal datasets offer change detection and updates of the earth's surface. Remote-sensing-derived classification of urban vegetation has been addressed in many ways, but, up to now, has most often been limited to only few classes such as grass and trees. In-depth analysis of one vegetation class was limited by the availability of appropriate sensors and the heterogeneity of the urban surface. Analysis of ecosystem services which may be linked to a specific vegetation species have hence also been restricted. This remotely derived vegetation information however may serve as an objective, statistical measure and as an additional parameter for multi-variate analysis of ecosystem services by linking physical features of remote sensing and spatial information on socio-economics.

Conventional remote sensing analysis has used space-borne systems such as Landsat which offers high coverage (swath width of 185 km), but low spatial resolution of 30 m within the spectral range for vegetation analysis (Eurimage 2007). Other systems with very high spatial resolution (<1 m) as spaceborne systems such as Quickbird have very limited coverage (swath width of 15 km) (Eurimage 2009). New sensors such as RapidEye proceed in between and offer high spatial resolution data (6.5 m) as well as a swath width of 77 km with continuous observation coverage up to 1,500 km. Hence, the benefits of high spatial resolution remote sensing and comparability of data for area-wide vegetation analyses can be explored (Hostert et al. 2010). High temporal resolution with the additional inter-annual vegetation information of remote sensor systems such as RapidEye may provide important information for vegetation differentiation on the one hand as well as add new insights into changes within ecosystem service provision throughout the year on the other hand. For example, intra-annual dynamics of leaf unfolding or leaf fall will cause recurrent variations in physical parameters over time and will differ between vegetation types (Morin et al. 2009; Nilsson and Källander 2006; Wesolowski and Rowinski 2006). In result, ecosystem services such as retention of rainwater and air filtration will be affected. Further benefits for ecosystem services may be derived from additional height information such as shown for a vegetation classification based on spectral mixture analysis of a Quickbird image and additional LIDAR height information (Tooke et al. 2009). Fusion of multi-temporal and multi-spectral data analysis with large coverage and high spatial resolution on the one hand and height and volume data on the other hand indicates a successful approach in assessing the urban environment for ecosystem service analysis.

8.3.2 Case Study

In Berlin, a huge variety of environmental information is available already, such as information on vegetation in the Environmental Atlas or a LIDAR-derived 3D model of buildings (Berlin Department of Urban Development 2009). However, for sophisticated ecosystem service analysis, these datasets are missing important information on current changes; since area-wide updates are rare. Furthermore, the location and specification of vegetation is based on combinations of different methods of assessment which limits the comparability across Berlin (Berlin Department of Urban Development 2009). Furthermore, vegetation has been excluded from remote sensing based urban 3D and seasonality analyses up to now (Fig. 8.1).

For the stated challenges of urban ecosystem services, our remote-sensing approach aims to tackle the challenges of up-to-datedness, comparability, and urban vegetation volume information in the city of Berlin, Germany, (Fig. 8.1):

1. Vegetation differentiation for urban ecosystem services: it is necessary to create up-to-date information on the urban environment city-wide. In-depth analysis can then identify and compare differences within urban vegetation beyond the

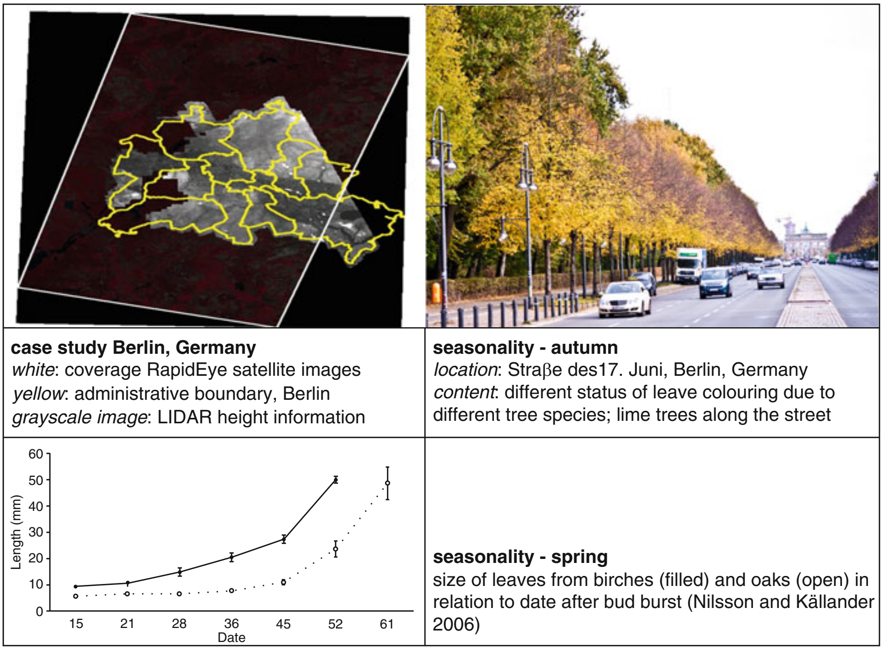

Fig. 8.1 Case study Berlin – seasonality

most frequently assessed classes of grass and trees are needed. Hypothesizing that different vegetation offers different types and/or values of ecosystem services, the results can then be used to calculate ecosystem service provision.

2. Quantification and interaction between urban ecosystem services and socio-economics: 2D outputs do not offer a realistic quantitative measure on ecosystem services, because many ecosystem functions correlate to vegetation volume and connectivity in a 3D space. Linking those environmental and socio-economic data will raise two important points of view: first, the availability of ecosystem services for different socio-economic groups, and second, the socio-economic groups' views and actions to urban ecosystem services.

8.3.2.1 Research Questions

The aim of this case study is to address these challenges by exploring large coverage, high-resolution, multi-temporal data on vegetation and height information to analyze the urban environment and extract parameters relevant for ecosystem service assessments.

Research questions concerning vegetation differentiation are:

1. How does an intra-annual, multi-temporal dataset of RapidEye images support the classification of urban trees?

   (a) Which improvements can be identified by a multi-temporal intra-annual dataset compared to a standard summertime mono-temporal multi-spectral approach?
   (b) What is the effect of further spectral information from the red edge band?
   (c) How does illumination correction by LIDAR data improve the classification of multi-temporal data featuring differences in illumination?
   (d) Which correlations exist between remotely sensed intra-annual trajectories of trees and data of phenological gardens offering high-resolution phenological timelines?
2. How does a multi-sensor approach of RapidEye images and additional LIDAR derived height information support the classification of urban trees?
3. Which urban ecosystem service gains substantial information from remote sensing derived vegetation information including height information?

The research questions concerning quantification and interaction of a specific urban ecosystem service are:

1. How does the selected urban ecosystem service vary in space and volume?
   (a) What are limits of analysis of summertime bio-phytomass derived by wintertime LIDAR and RapidEye data?
   (b) How does illumination-corrected and non-corrected classification differ in location and volume measurements of each tree species?
   (c) What are the minimum mapping unit and limits of different resolution of ancillary (census) data and tree volume data derived by remote sensing?
2. How does the specific urban ecosystem service affect humans?
3. How can findings of socioeconomic disparities of urban ecosystem services be addressed by different socio-economic groups?

8.3.2.2 Data

To answer these research questions, this study focuses on urban trees within Berlin as they are one of the major urban green sources in Berlin (Berlin Department of Urban Development 2009). A multi-temporal dataset of high-resolution RapidEye satellite images (6.5 m) from 2009 and very high resolution LIDAR (0.5 m) is used to improve classification details of urban tree species as a unique reference base (RapidEye AG 2010) (Table 8.1). Additional socio-economic information on social status is retrieved from the Senate Department of Urban Development.

RapidEye images provide high coverage, high repetition rate, high spatial resolution, and extended multi-spectral features. An intra-annual dataset of five images provides additional phenological information which can be used for in-depth vegetation analysis to benefit from seasonality of vegetation as shown in Fig. 8.2 (Schwartz 2003). Colours of Fig. 8.2 indicate differences in vegetation characteristics for the surrounding of the former Berliner Schloss (Berlin castle). The possible differentiation within the vegetation by a multi-temporal, intra-annual dataset becomes already apparent by visual interpretation (Fig. 8.2).

Table 8.1 Dataset

Multi-spectral	*System*: RapidEye, spaceborne *Geometric Resolution*: 6.5 m; 5 m resampling *Spectral Resolution (nm)*: 450–510 (blue) 520–590 (green) 630–685 (red) 690–730 (red edge) 760–850 (nir) *Swath Width*: 77 km	*Date of acquisition*: 13 April 2009 27 July 2009 16 August 2009 09 October 2009 19 October 2009 *Coverage*: City of Berlin, Germany
LIDAR	*System*: ALTM GEMINI, airborne *Geometric resolution*: Digital Surface Model, 0.5 m Digital Terrain Model, 1 m *Spectral resolution (nm)*: 1,064	*Date of acquisition*: Winter 2007/08 *Coverage*: City of Berlin, Germany

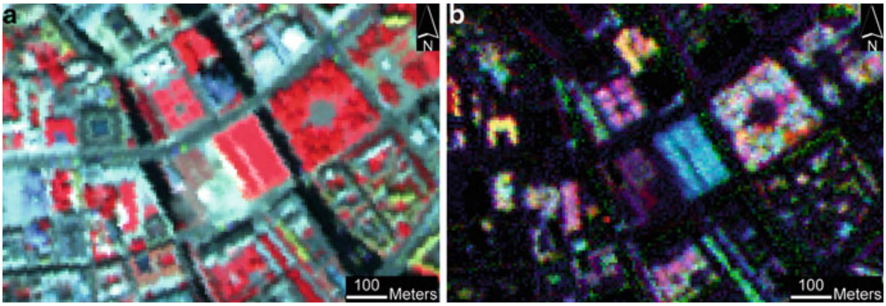

Fig. 8.2 Mono-temporal (*left*) and multi-temporal (*right*) RapidEye satellite image, Berlin.

Differences in height and volume of vegetation are derived by the digital elevation model as shown in Fig. 8.3. The centre of Fig. 8.3 depicts the building "Neue Wache" which is surrounded by chestnut trees.

8.3.2.3 Methods

As a first step, the literature review concentrates on urban remote sensing, tree physiology, volume modelling, urban ecosystem services, and spatial statistics combining social census data with parameters derived by remote sensing. Furthermore, a field survey is conducted to map reference data on urban trees in the city of Berlin. Homogeneous structured patches of the same tree species are identified and

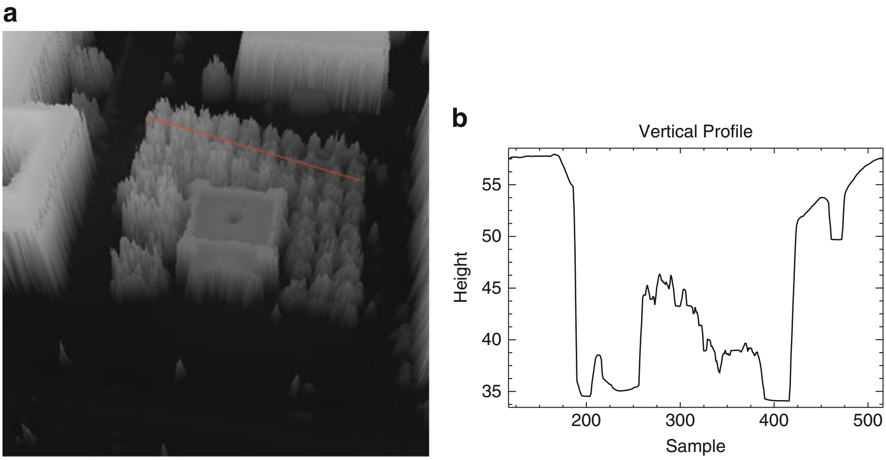

Fig. 8.3 Digital surface model (*left*) with vegetation height profile (ROI), Berlin

located. For each vegetation patch, additional attributes such as a visual assessment of the understory and the degree of mixing of different types of vegetation and impervious surface are mapped to account for their manipulation of the spectral reflectance of the vegetation.

Pre-processing of the multi-spectral and LIDAR data includes geometric and illumination corrections. A high-resolution digital surface model of 0.5-m spatial resolution is used for orthorectification of each RapidEye image. Secondly, each image is co-registered in space using airborne orthofotos of 0.1-m spatial resolution. Further, solar illumination correction is conducted by an IDL-programmed module called c-correction which is based on the slope-aspect correction of multi-spectral scanner data by Teillet (Canty 2010; Teillet et al. 1982).

For the automatic classification of trees, an iterative process is applied using support vector machines (SVMs) (Fig. 8.4) (compiled by the author Tigges). The RapidEye image from summer is used as a reference line since this is a standard period of time for remote-sensing-based classification of vegetation. Additional images of different phenological phases are then added one by one to evaluate potential improvements in the classification process. Additional information of the red edge is added as a final step to identify the effect of further spectral information on multi-spectral remote sensing. SVMs are used as classifiers for image analysis since they proved to be able to handle high data dimensionality of multi-temporal data stacks as well as to adapt to the urban environment regarding small patches of vegetation.

Volume data of vegetation is then derived by a difference model of a LIDAR digital surface model (first return) and a digital terrain model (last pulse) (Hyyppä et al. 2000; Wagner et al. 2004). Small inner crown holes as part of the DSM data are filled by convolution filters. Further accuracy assessment and correction derive true summertime bio-phytomass above ground. Remote-sensing derived

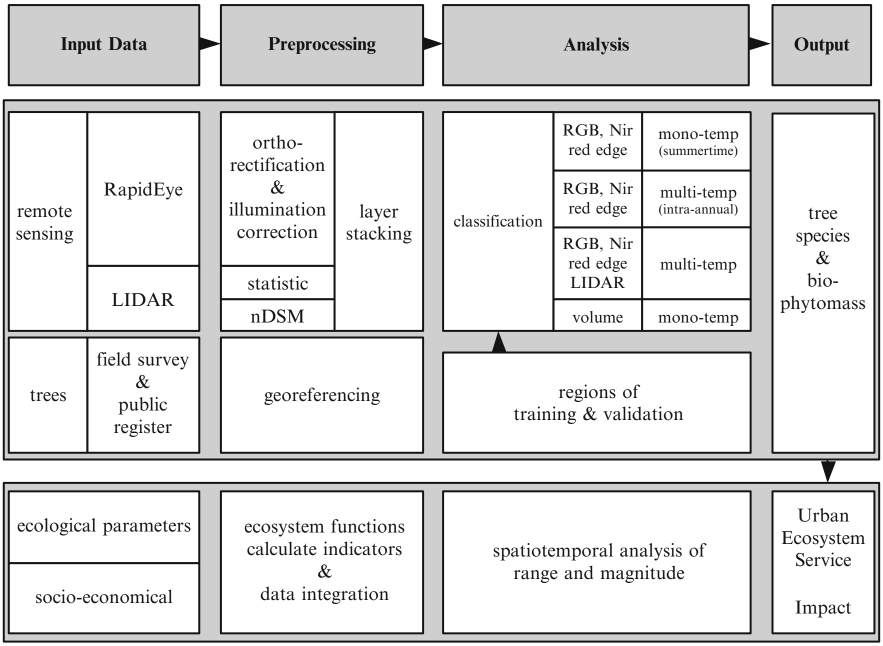

Fig. 8.4 Workflow

information on tree species and bio-phytomass is then augmented by additional ecological parameters to identify indicators for ecosystem functions of trees. In a next step this information on ecosystem functions of trees is analysed with socio-economic information to define indicators for ecosystem services. Spatial statistics and analysis are then conducted using geographical information systems to derive the spatiotemporal characteristics of range and magnitude of the urban ecosystem service.

8.3.2.4 Preliminary Results

To explore the possibilities of the above-described RapidEye data in terms of differentiation of tree species, a separability test of different tree species has been conducted. Results are illustrated by a test site located at the Kottbusser Damm in Berlin. The site is characterized by a set of honey locust, plane trees, and chestnut trees, with each set covering an area of approximately 2,500 m^2. A transformed divergence separability measure for Gaussian statistics is used as a statistical measure where values above 1.9 indicate good separability while values below 0.5 indicate insufficient separability (Richards and Jia 1999). The test is applied to two datasets. First, a mono-temporal RapidEye layer stack of July is used for testing, which includes the red, green, blue, and nir-infrared channels. This time period and selected channels stand for a traditional dataset used for vegetation analysis in remote sensing. Secondly, a multi-temporal, intra-annual RapidEye layer stack is used for separability testing (Table 8.1).

Results indicate a high variability concerning a mono-temporal dataset. The transformed divergence value of chestnut trees and honey locust is likely to be highly insufficient for classification purposes. A strong increase in value is shown (Table 8.2) in class honey locust, plane trees, as well as chestnut trees using a multi-temporal approach. These results reach the transformed divergence value of above 1.9 for good separability. The results underline the advantage of using a multi-temporal and intra-annual dataset for vegetation separability of tree on a species level.

The possibility of achieving a deeper understanding regarding the level of tree species by using a multi-temporal intra-annual dataset are also underlined by the identified exemplary trajectories of plane tree, chestnut tree, and honey locust (Fig. 8.5). All of them show similar trajectories in terms of increasing reflectance till summer (date 2 of Fig. 8.5) and decreasing till October (date 4 and 5 of Fig. 8.5). Nor do they indicate significant differences in reflectance due to differences in illumination and nor in understorey and degree of sealing. In result, spectral divergence in time is most likely due to differences in species which will be further explored to improve vegetation classification.

Table 8.2 Separability test of selected tree species

Class 1	Class 2	Transformed divergence, mono-temp	Transformed divergence, multi-temp
Gleditsia triacanthos (honey locust)	Platanus × hispanica (plane tree)	1.2	**2.0**
Platanus × hispanica (plane tree)	Aesculus hippocastanum (chestnut tree)	1.3	**2.0**
Aesculus hippocastanum (chestnut tree)	Gleditsia triacanthos (honey locust)	0.4	**2.0**

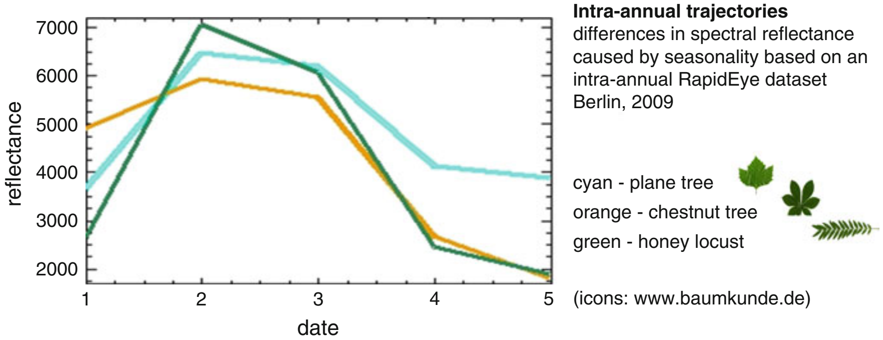

Fig. 8.5 Intra-annual changes in spectral reflectance of tree species

8.3.2.5 Benefits and Challenges

Preliminary results on the possibilities of a multi-temporal, multi-spectral, and high-spatial-resolution dataset for a differentiated classification of urban vegetation on the level of tree species seem very promising. Additional information gained from the third dimension out of the LIDAR data will most likely add a substantial component for precise information for differentiating urban vegetation. In a next step, the derived information will then be used to map ecosystem services, in particular those, which are heavily influenced by the vegetation volume, such as air pollution filtering.

Results derived by remote sensing, however, have to be discussed regarding their spatial resolution, their comparability across space, and changes in time. As vegetation parameters are derived by an intra-annual dataset of spectral information, spatial differences in phenology of the same vegetation species might affect the classification process. This was indicated in a field survey of vegetation phenology in Berlin 2006 where significant phenological differences of the same trees species were found, which were related to microclimatic characteristics of the urban heat island effect (Henniges and Chmielewski 2007; Mimet et al. 2009). Furthermore, the dataset of this case study is limited to very few stages of the phenological cycle of vegetation. Another challenge in the field of remote sensing will remain shadow and mixed pixels due to spatial resolution and differences in solar illumination. The spatial range of a specific ecosystem service will be limited to the nearby surrounding of trees, because long-distance impact will need a more complex modelling approach and information. Furthermore, long-term changes of climate as well as demographic change cannot be considered in this study. While climate change will most likely modify intra-annual dynamics such as leaf fall or leaf unfolding, the demographic change is expected to modify the urban population's perspective on ecosystem services. Only an interdisciplinary perspective will allow approaching the question of access to ecosystem services among different socio-economic groups and the transfer of the derived new insights into locally adapted decision-making.

8.3.2.6 Outlook

One reason for differences in spectral reflectance of trees is seasonality. This will produce specific trajectories of spectral reflectance. Are these intra-annual changes similar to ground-truth trajectories of phenology gardens? Positive results would be a first step to a generic approach which might be transferred to other regions and types of trees. Inter-annual data supports an improved classification up to the level of tree species. Further improvements are expected by including the above-introduced LIDAR data, which will support the differentiation of vegetation according to their height. Area-wide, comparable and up-to-date results on a species level and bio-phytomass may then be an indicator for air pollution filtering, carbon storage or pollen emission. Particularly in urban areas, this could be of high interest for epidemiological studies; for example, allergic reactions to birch pollen or secondary organic aerosol can cause respiratory symptoms. An analysis could reveal new insights on spatio-temporal patterns of urban ecosystem services for different socio-economic groups. Furthermore, the aim to reduce CO_2 emissions could be supported by a measure of urban CO_2 storage of trees since the physiology of tree species shows differences on CO_2 storage dynamics. Beside other factors such as climate change, soil condition, and irrigation, a generic classification on a species level a remote sensing approach could provide information for monitoring CO_2 storage dynamics on a large scale. Thus, Berlin and its different tree species could serve as a laboratory relevant for different ecosystem services at the human-environment interface in urban areas.

8.4 Modelling of LUC and Ecologic Impacts

8.4.1 State of the Art

LUC – as a major influence on the urban environment – has been analysed in the past by a variety of different modelling techniques, out of which we in the following will concentrate on the predominant urban models, namely system dynamics (SD), cellular automata (CA), and multi-agent systems (MASs).

SD in an urban context was firstly applied in the 1960s (Forrester 1969; Lowry 1964) with rather simple assumptions, such as housing develops in relation to the place of work, however it was pioneering work. Within SD, the system-describing components are interlinked by differential equations in the form of stocks and flows and show a nonlinear behaviour. While SD are generally not spatially explicit, their strength is the dynamic behaviour due to implemented feedbacks between the system components (Dhawan 2005; Sterman 2000). SD represents a qualified tool to reproduce population dynamics and respective decisions and behaviours. Today, system dynamics play an important role in modelling ecological parameters under inclusion of (socio)economic parameters, such as biodiversity, soil functions, or carbon cycle, which is particularly relevant in terms of ecosystem services and environmental impact assessments (Costanza and Voinov 2004; Seppelt 2003).

Spatially explicit models for urban land cover and land use change gained importance in the 1980s when computer-based processing became more accessible and affordable and increasingly remote sensing techniques were applied to derive data on the urban land cover and land use. These “newer” models of both, cellular automata and multi-agent systems, frequently use raster information to describe the spatial organisation of land use within a city or urban region.

The basic idea of cellular automata (CA) is that cells holding discrete numbers of land use states depend on neighbouring cell states (Engelen et al. 1997). All cells change their state simultaneously for each time step according to the same rules. The dynamic behaviour of CA models result from implemented transition rules in form of neighbourhood functions. In doing so, all cell states are incorporated to determine the probability for a cell transition. Contributing factors are physical conditions, proximity to transportation networks, and restrictions due to planning standards (Barredo et al. 2003). Neighbourhood effects regarding different land uses are integrated as distance-decay functions defining attraction or repulsion (White and Engelen 1993). The neighbourhood for each cell is equal and predefined. Since Tobler (1979) proposed the use of CA as a tool for geography, CA has been widely used and continuously improved towards user-friendly urban simulation tools like the software package Metronamica (Riks 2007). In fact, CA models are predominant for LUC simulations. They are very suitable to simulate the spatial allocation of LUC due to the possible integration of diverse spatial factors affecting LUC, such as political constraints, economical conditions, and physical characteristics. However, CA models are mostly lacking the representation of dynamic behaviour based on the causal relation between drivers and LUC. Frequently, they rely on quantification of change in land use classes (the driver for CA) by simple methods such as trend exploration or regression-based trends (Ti-yan et al. 2007) while individual or group-specific behaviour of city dwellers is still not detailed enough considered in CA.

MASs explicitly address the agents who act and organize themselves within a spatially explicit urban environment. Originating from artificial intelligence (AI) (Bousquet and Le Page 2004) agents in MAS are autonomous and defined as individuals, interest groups, or organizational units (such as households, landowners, or farms). Each agent or agent group has specific characteristics or preferences to solve the predefined problem of the MAS (Loibl and Toetzer 2003). Decision-making by agents, such as the choice of a land use cell, is based on interactions with other agents and their environment. In this way, agents are able to enlarge their knowledge of the environment by communication and learning. The environment is often described by a grid, in which cells define the spatial conditions (Batty 2007). MASs are powerful tools to address human decision-making in a spatial context, especially in small-scale considerations of only few land use classes. MASs address, for example, residential relocations of households affecting residential land (Haase et al. 2010; Loibl et al. 2007) or shifts of arable land due to different behaviours of farmers (Valbuena et al. 2008). MASs quickly become too complex for integrated LUC modelling with a detailed land use classification

We conclude that different model approaches imply different advantages and disadvantages for LUC modelling depending on the research question. Combining the approaches seems promising for improving the reproduction of real LUC processes, especially in terms of an integration of demographic, social, economic, political, and ecological driving forces. A few recent model approaches benefit from combining different techniques (Batty 2007; Fang et al. 2005; He et al. 2008). However, studies on ecosystem services and ecological impacts due to LUC are snap shots in time rather than a dynamic time series study. Existing models interlinking dynamic LUC and ecosystem services or ecosystem functionalities are leading the way for an integrative citywide perspective on urban ecology (Rutledge et al. 2008; Van Delden et al. 2007).

Numerous inductive investigations on urban ecology on the small scale (as shown in this book) prove the effects on the environment due to structural differences in the same land use. Especially, in residential areas, ecological effects vary greatly depending on the structure and density of land use. Consequently, a more detailed differentiation of urban land use classes is needed. Further, the development of European cities proves the imperative of a wider perspective of LUC. Shrinking cities and the comeback of urban nature have to be considered and unilateral growth models have to be enhanced to adapt LUC models to the current needs (Buzar et al. 2007; Kabisch 2005; Kasanko et al. 2006).

8.4.2 Case Study

8.4.2.1 Research Questions

The aim of this project is to tackle the above-mentioned challenges by applying a combined model approach based on system dynamics, cellular automata, and an ecological impact model. We intend to uncover the functional chain of demographic change, LUC, and consequential ecological impacts. Furthermore, we are interested in how those effects might influence LUC decisions again. By improving the causal relation of LUC through integrating a residential choice algorithm, we expect more adaptable and dynamic model behaviour. Due to the use of finer residential land use classes, a housing market perspective is enabled, a deeper insight into LUC effects is offered, and finally, land use patterns are reproduced more accurately. Furthermore, we aim to integrate a mechanism enabling growth and shrinkage for our model in Berlin. Appropriate model scenarios help to identify possible future paths for Berlin. These objectives lead to the following research questions:

1. How does the model quality improve by combining system dynamics and cellular automata model approaches and integrating sophisticated population dynamics?
   (a) Which are the main drivers of LUC and how sensitive are they?
   (b) How do household shifts due to demographic change influence urban LUC in terms of growth and shrinkage?
2. Which impacts on selected ecosystem services due to LUC are identifiable and how might they affect LUC and vice versa?
   (a) How do food providing land uses develop and where do changes take place?
   (b) Are changes in green space provision affecting land use decisions?
   (c) How is the sealing rate going to develop?
3. How does LUC express for Berlin's metropolitan area under consideration of growth, shrinkage, and baseline scenarios for the year 2022?
   (a) What development of urban-suburban relations can be predicted under consideration of different scenarios?

(b) Are the increase in detached and semi-detached housing in the outskirts and the development of inner-city brownfields proceeding? If so, in which intensity?
(c) Which developments are expectable on the former airport sites Tempelhof and Tegel and how might the surrounding of the new international airport in Schönefeld be affected?
(d) How do recent planning constraints address identified LUC processes?

8.4.2.2 Study Area

In order to improve the understanding of urban-suburban interrelations, the study area is defined by the metropolitan area of Berlin. Thereby, the administrative border of Berlin is exceeded and parts of the federal state of Brandenburg are involved (Fig. 8.6). In total, the case study involves an area of almost 5,370 km^2 and includes almost 4.3 million inhabitants (SOBB 1991–2008). Berlin as one of the biggest European agglomerations represents a city where urban development trends of socialist and western cities occur and contrasting processes of simultaneous shrinking and growth are revealed.

LUC since the reunification of Germany is characterized by an increasing demand to be “living in the green”. Numerous developments of detached and semi-detached houses have displaced former arable land, accompanied by an outward-directed migration of family households towards Berlin’s hinterland. Against this, the population numbers of Berlin declined rapidly and vacancy rates of inner-city block structures and prefabricated multi-storey houses (from socialist time) increased. The collapse of the GDR economy was accompanied by the abandonment of industrial sites and the increase in inner-city brownfields. New commercial areas, however, emerged on valuable green and arable land. In the last decade, Berlin has transformed into a smart growing city not least due to its favourable living conditions (a relaxed housing market, low living costs) and its cultural meaning. Young people especially, are attracted across national borders and form a new reurbanisation trend, which is supported by the positive net migration.

Land-use patterns as depicted in Fig. 8.6 show a dominance of forest and arable land in the study area in 2007. Only 25% describe built-up areas, of which 32% depict detached and semi-detached houses. All listed land use classes are integrated in the presented LUC model. The city of Berlin is used for model calibration, whereas the total study area is used to assign the model quality. Different land use maps for Berlin and the metropolitan area (ranging from 1992 to 2008) are derived from satellite images (own interpretation of IRS_P6 image) and aerial photographs (Berlin Department of Urban Development 2009; Brandenburg State Office for Environment 2010). Besides, census data, economic parameters, and spatial planning information is used (Berlin Department of Economy Technology and Women 2010; Regional Planning Department Berlin Brandenburg 2010; Statistical Office Berlin Brandenburg 2010).

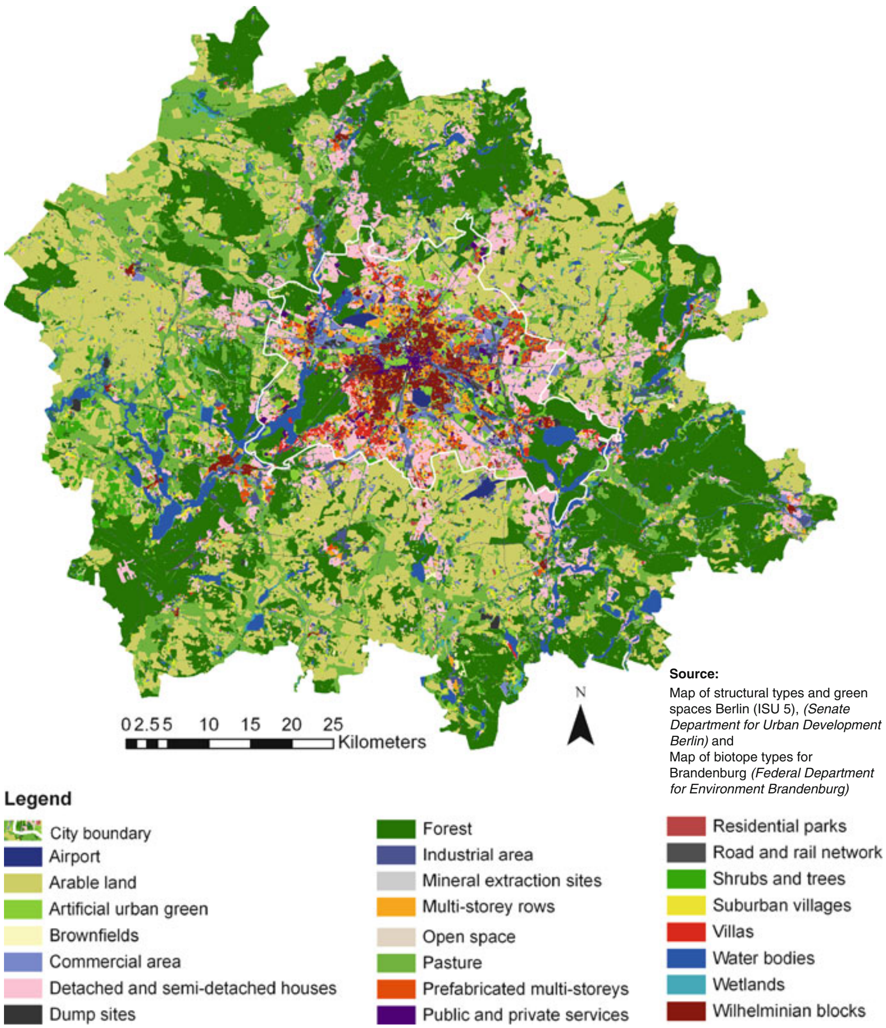

Fig. 8.6 Land use map of the study area in 2007

8.4.2.3 Methods

Figure 8.7 gives an overview of the introduced model structure, its components, their relations and content, plus the model inputs. By changing the parameters of the input data, different scenarios are implemented, such as population growth or shrinkage. The quantitative LUC is calculated using system dynamics and the spatial allocation then is determined by cellular automata. Spatial effects on the urban environment are finally identified in the ecological impact model. Feedback loops are implemented to additionally measure the effects on LUC as a consequence of its ecological impacts (c.f. broken lines).

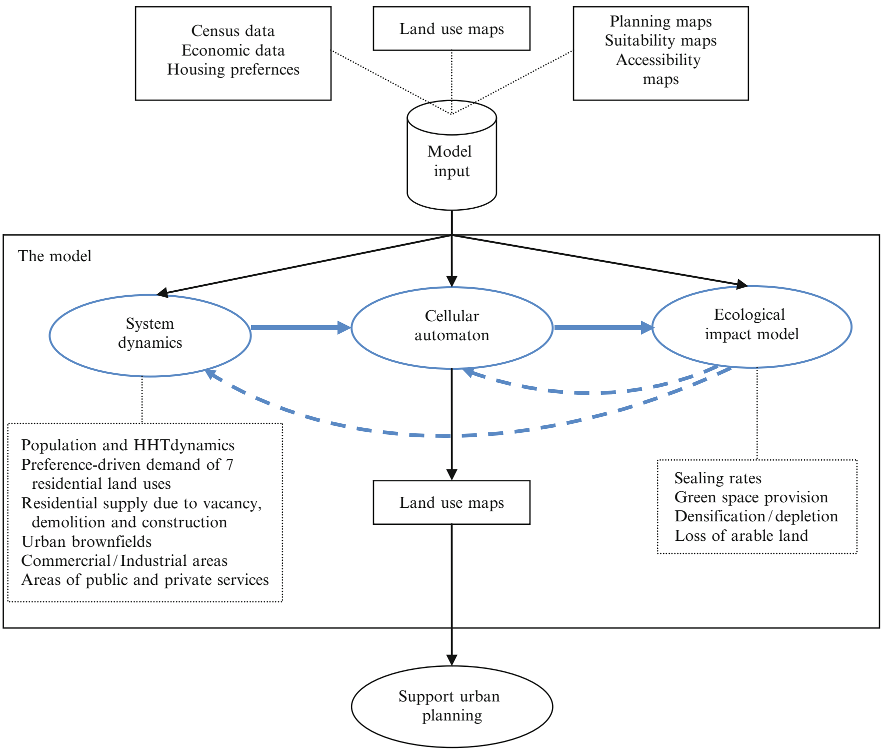

Fig. 8.7 Model approach

System Dynamics

We use system dynamics to calculate the demand for living space in each residential use including population dynamics with regard to the second demographic transition (Kaa 2004). Therefore, population shifts of eight age cohorts are determined by the demographic variables fertility, mortality, and migration. Using a dynamic transition matrix, the population of each cohort is distributed over seven household types. Respective housing preferences are used to determine the residential choice with reference to varying residential uses in terms of structure and form. The demand for living space in each residential use is calculated by the mean living space per capita and household type and the number of housing demanders. For the calculation of living space supply, we integrated the construction rate, vacancy rate, and demolition rate as a function of demand. The given site conditions for each residential use depend on demand and supply shifts. These affect residential choice, which starts a closed feedback loop. As well as using seven residential use types in the model approach; commercial area, industrial area, and public and private services are derived as a function of population and the economic variables GDP and employees by economic sectors. Further, we calculate the shifts of (urban) brownfields within system dynamics.

Cellular Automaton

We use CA to compute the spatial allocation of LUC with respect to neighbourhood effects between land use types, which are formalized in transition rules. Planning decisions, local suitability, and the availability of infrastructure are integrated in form of raster maps using a uniform grid as used for the initial land use map. All maps were prepared in GIS. We implemented a cell size of $50 \times 50\ m^2$ for the challenging study area size to capture local dynamics in detail. The simulated changes of the SD model for 11 land use classes constitute the input for the CA. Those 11 active classes affect LUC of 7 passive classes, representing the potential sites for urban growth, which are (1) artificial urban green, (2) forest, (3) shrubs and trees, (4) pasture, (5) arable land, and (6) open space. The remaining four classes are constant uses, such as water bodies. The regional development plan giving back the protected green areas and the suggested development axes for built-up areas as well as zoning plans protecting inner-city parks are integrated. For the spatial characterization of accessibility, we integrated the road network of federal streets and freeways, the network of regional and city trains, and all local rail stations.

Ecological Impact Model

This part of the model describes the spatial analysis of impacts on the urban environment due to LUC. The simulated land use maps of the CA are imported into GIS and evaluated with respect to the scenario implications. At this stage the analysis focuses on quantitative changes and spatial dynamics in terms of the degree of sealing, the green space provision for city dwellers within the neighbourhoods, the loss of arable land, and the developments of urban densification versus depletion. Those indicators are further used to identify changes regarding the provision of ecosystem services, such as food provision, recreation, and climate regulation. The output of the model contains risk maps detecting local impacts and losses of services. As used in preventive planning, we will incorporate those maps in the preceding model components (SD and CA) to include the feedback and analyze resulting effects on LUC.

8.4.2.4 Selected Results and Discussion

Several simulation runs provided a better model quality regarding land use patterns due to the underlying SD implications which is described by statistical accuracy measures. Effects of demographic change on LUC are measurable, especially the change in the household composition with decreasing family households versus increasing single households; this expresses obvious demand shifts in certain residential uses. Residential choice is sensitive to changed demand-supply relations, affecting the side conditions of the residential uses, such as living costs and green space provision (Lauf et al. in press). Due to the detailed residential land use classification, the associated inclusion of construction, vacancy and demolition rates and the integration of the class urban brownfields, shrinkage processes in Berlin are reproducible, as seen in the housing stock of prefabricated multi-storey houses from socialist times (Fig. 8.8 and Table 8.3).

The following results refer to a simulation run from 1992 to 2022 under baseline assumptions: a low population growth is determined especially by immigration of younger age cohorts. The increasing number of single person households leads to a growing demand for accommodation in inner-city (Wilhelminian) block structures. Despite a decline of family households, the space consumption of detached and semi-detached houses increases. The vacancy in prefabricated multi-storey houses increases at 7%, whereas the vacancy in Wilhelminian blocks continuously decreases.

A closer look at Fig. 8.8 reveals five major significant trends:

1. Inner-city consolidation
2. Spreading of detached houses
3. Massive changes caused by airport developments
4. Renaturation in prefabricated multi-storey neighbourhoods and
5. Increase in commercial areas and public and private services.

Table 8.3 gives a detailed overview of the land use development until 2022 and shows which land use transitions occurred in the model run. Focusing on the green and open land use, a loss of over 6,400 ha is shown. Of these, almost 53% is arable land; 12%, pasture; 2%, shrubs and trees; 13%, forest; and 20%, open space. The number and area of brownfields, however, increase. This is due to the massive changes in the surrounding area of the airport Tempelhof, with the consequence of a tremendous amount of released land. This is in the first instance, defined as brownfields. Still, this fact should be kept in mind when valuable soils are transformed to built-up areas.

8.4.2.5 Outlook

Future work will focus on scenario simulation and the assessment of land use changes on the urban environment in particular on urban ecosystem services. With extreme scenarios, model consistency will be tested. Implications defining a growth and shrinkage scenario will be realized under integration of different planning constraints. Furthermore, land use effects on before-described ecosystem services will be analyzed and evaluated within risk maps. These maps will then be reintegrated in the SD and CA model to obtain a full response model by which the likely shift of land use decisions as a consequence of its own impacts on the environment can be determined. Finally, the results will be discussed with local authorities to integrate the findings into current decision-making processes.

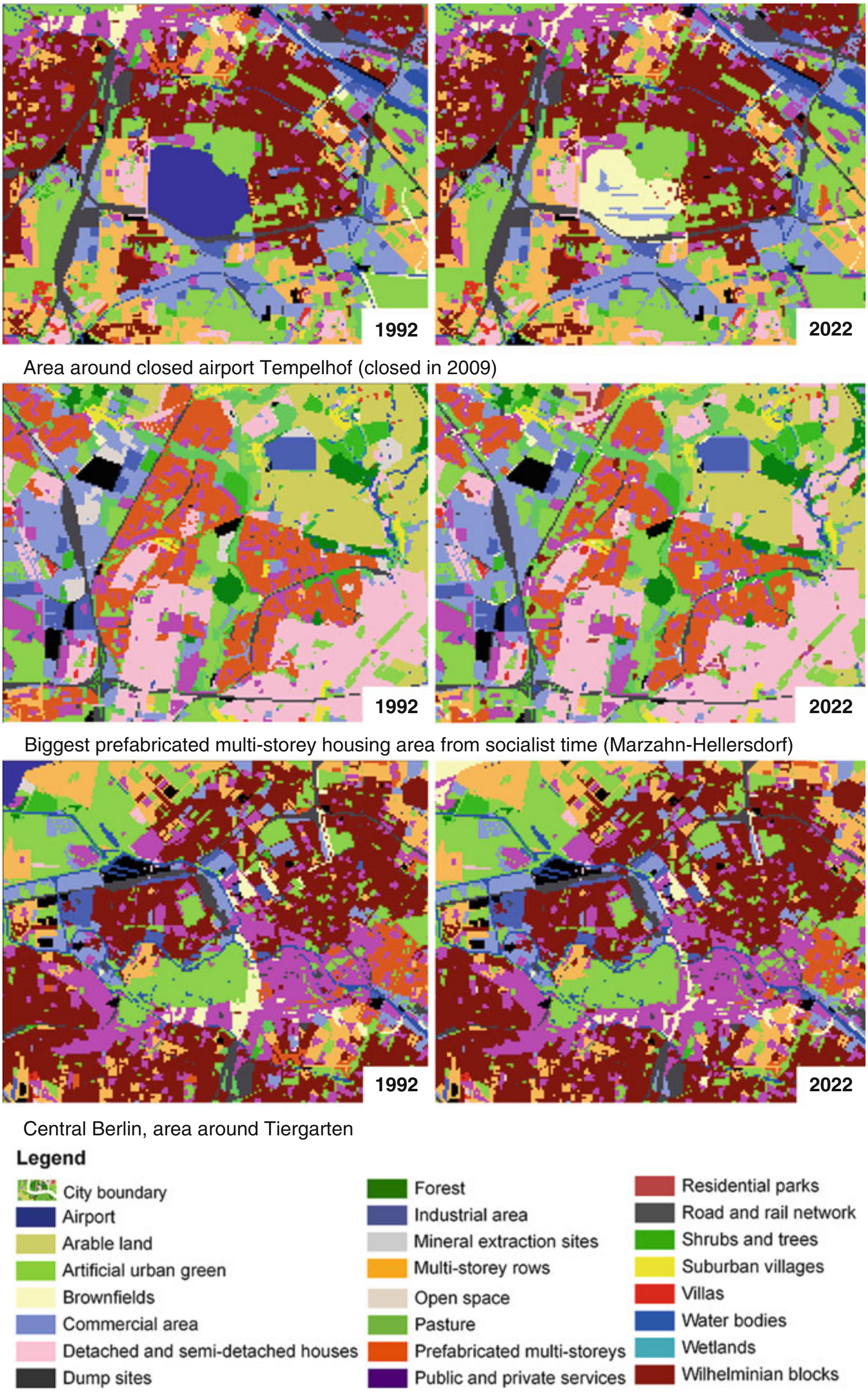

Fig. 8.8 Land use change for selected areas of Berlin's metropolitan area in 1992 (observed) and 2022 (simulated) for a baseline scenario

Table 8.3 Cross table of cell transitions for selected land use classes for a simulation run of 30 years (1992–2022) under baseline assumptions

Map 1992/ Map 2022	Artificial urban green	Brown fields	Multi-storey prefab	Post-war rows	Pre-war blocks	Villas	Detached houses	Residential park	Services	Commercia l area	Cell count LU map 1992
Arable land	354	244		52			13,183	5,401	178	2,030	527,543
Pasture	96	352		77	349	347		35	134	1191	293,690
Shrubs and trees	15	67		13	98	26	1	2	6	177	34,205
Forest	277	319		86	6	47	2	137	237	1625	684,934
Open space	5,182	29		1	18	23	9	2	37	239	5,565
Artificial urban green	81,580	3			12		943	18			88,959
Brownfields	26	1,181		68	72	20		312	680	765	3,208
Multi-storey prefab	1,241	542	12,005	27	460		1	581	18	23	14,951
Post-war rows	251			29,234			1	1	4		29,611
Pre-war blocks	500	34		32	28,422		50	75	26	117	29,375
Villas	168	18				17,746				9	18,001
Detached houses	33						153,585			1	153,660
Residential park											0
Services	291	194		5	67		85	45	20,430	260	21,956
Commercial area	3	63			38				12	47,126	47,499
Industrial area	30	86		52	7	21	5	312	34	349	26,710
Suburban village											21,747
Airport	125	2,637		21	31	2	75	15	255	272	5,196
Cell count LU map 2022	90,172	5,772	12,005	29,668	29,580	18,232	167,940	6,936	22,051	54,189	3,868,800

8.5 Conclusions

Starting with the high relevance of the environment, and in particular, ecosystem services in urban areas (McGranahan and Satterthwaite 2003); (Alberti 2005; Cadenasso et al. 2006a; Cadenasso et al. 2007; Grimm et al. 2000; Pickett et al. 2008), we have pointed out the need for augmenting already existing information on today's ecosystem service provision and for modelling urban land use processes to assess likely future impacts on ecosystem services.

We have presented two studies that investigate the potential of sophisticated and up-to-date technologies in remote sensing and spatial modelling. The overall goal of these two studies is an improved understanding of the provision of urban ecosystem services and the underlying processes of land use change. Our studies are focused on the city of Berlin as an example for a densely populated city; however, we believe that the investigated techniques and methodical approaches are to a far degree transferable to similar urban systems.

Initial insights of these studies reveal the following findings: (1) High-temporal and spatial resolution remote sensing data combined with height information can add an additional perspective on urban vegetation for further analysis of ecosystem service provision; (2) Human choices on urban land use heavily impact the provision of urban ecosystem services; and most importantly, (3) Sophisticated and up-to-date technology in the two fields of remote sensing and spatial modelling may offer a large benefit for the analysis of the urban human-environment system when they are integrated.

Thus, we want to conclude that the integration of environmental and socio-economic data, acquired by different methods including remote sensing, is already a major field of research in urban ecology and particular in urban ecosystem service analysis (Pickett et al. 2008). In the future, this will most likely or rather hopefully continue to further develop into the integration of not only data but also methods and concepts to address today's challenges in the urban environment, such as assessing and analysing urban ecosystem service provision driven by land use changes.

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Chapter 9
Social Dimensions of Urban Restructuring: Urban Gardening, Residents' Participation, Gardening Exhibitions

Miriam Fritsche, Martin Klamt, Marit Rosol, and Marlies Schulz

9.1 Introduction

The conditions for urban development have changed considerably in the last decades. This can be attributed to social and economic changes encompassing the processes of globalisation, deindustrialisation and demographic change. The corresponding economic, social and ecological impacts pose new challenges on urban development and planning. Especially those cities which have undergone a transformation from a socialist planned economy to a social market economy in the last 20 years are affected from these new challenges. The "shrinking city" is a phenomenon which sets up a new dimension in urban development. Shrinking leads to a substantial reshaping of urban structures. It is causing urban decline and decay, vacancy and underuse of lots and buildings. The effects and problems resulting from a loss of function include the rise of urban brownfields, depopulation, empty apartments and unused social infrastructure such as schools and kindergartens. This calls for new forms of action, planning and controlling of urban development processes. Urban restructuring requires measures which provide opportunities to adapt existing structures to meet the needs of a changing society and a changing economy. Urban brownfield sites and vacant buildings offer potentials for a sustainable urban development and innovative temporary uses. These potentials provide

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a variety of options to improve natural und built environments for the inhabitants on varying spatial scales.

Urban development is a social process. Political-administrative actors are increasingly confronted with private sector actors (e.g. private investors and housing companies) and civil society (e.g. tenant associations). The various actors have different power resources, motives and logics of action. This affects participative processes, which play an increasingly important role within the planning and controlling of urban development, especially with regard to the objective of sustainable development. It is important to integrate all actors into these urban development processes, including a civic participation. This is the basis for a collaborative form of political control, which includes different objectives, spatial and social levels.

Within the Graduate Research Programme (Graduiertenkolleg) the subject area of “Urban geography and planning” is covered by three subprojects which are dedicated to empirical research on urban restructuring. The projects are concerned with three specific aspects of sustainable urban development and design. They are considering the changing conditions and deal with community gardens, urban restructuring and gardening exhibitions. In each case the research focus is on the social dimensions of restructuring processes and participation in the coordination and control of the examined projects. In order to analyse past and present social processes, all three projects are using qualitative methods. The research includes three different spatial levels of the city:

– Micro level: Brownfield sites in diverse structured housing areas (subproject 1)
– Meso level: Urban restructuring in a large housing estate with prefabricated housing units (subproject 2)
– Macro level: Gardening Exhibitions as an opportunity for a sustainable urban development (subproject 3)

For subprojects 1 and 2 Berlin has been elected as a study area. The city is a prime example for the changing conditions urban development has to deal with. Berlin has undergone a radical structural change in the last 20 years due to economic and social changes, the reunification of the formerly divided city and the political and economic transformation of the eastern part. Berlin is characterised by a stable population, a relatively high unemployment rate and an extraordinarily high level of debt. It is not a shrinking city, but there are parts of town which are characterised by large-scale industrial sites which turned into urban brownfields. These sites offer opportunities for a sustainable urban development. Especially in the large housing estates (Großwohnsiedlungen) in the eastern parts of Berlin measures for substantial restructuring have been carried out. These measures have modified the urban structures in these areas considerably. Formerly used sites have been abandoned and turned into urban brownfields. At the same time, however, the measures taken for restructuring provide new opportunities for urban regeneration and an improvement of living conditions for the inhabitants. Thus, many new options are available for the design of urban nature and a sustainable land use.

The three subprojects cover very different fields of research within the research areas of urban restructuring measures and sustainable urban development, namely the constellation of actors, their motives and logics of action. The results provide interesting insights into details of the research projects. Strategies for urban ecology as temporary or long-term uses are pointed out. Moreover, the following reports provide evidence for urban governance and new forms of control in urban development. They reflect the changing requirements for policy and planning on the one hand and the problems of participative processes on the other. The implementation of sustainability in urban development is a difficult and diverse project which needs to be adapted to local conditions in order to be successful.

9.2 Results of the Subprojects

9.2.1 Subproject 1: Community Gardens in Berlin – A New Form of Citizen Participation? (Marit Rosol)

9.2.1.1 Introduction

Berlin, as a stagnating city, has many brown fields and empty lots. Alone in the inner city, there exist about 1,000 empty lots (ca. 150 ha). They can be found especially along railway tracks, the former wall-strip, and on former industrial estates and graveyards. As consequence of economic and demographic change, locations of social infrastructure such as Kindergartens and schools are being, or will be, abandoned, especially in districts in the outer city such as Marzahn-Hellersdorf (c.f. Beirat Stadtforum 2020 2005). This is a result of a decreasing population, decreasing number of jobs due to de-industrialization, and global economic and social changes, events, which are followed by the demolition of vacant houses, social infrastructure, and industrial areas.

At the same time, there are still qualitative and quantitative deficiencies regarding the provision of urban public green spaces. A study by the Berlin government (the *Senat*) calculates a quantitative lack of 210 ha of public, near-residential green space for all of Berlin. Studies on the quality of public green space show, furthermore, a deterioration both in maintenance and in equipment in recent years (cp. konsalt et al. 2000; SenStadt 2001). This neglect of the public green sector is in contrast to the enormous social, ecological, and economic importance stated in studies about urban green space (e.g. Bochnig and Selle 1992; Nohl 1993; Selle 1993).

This situation needs, and allows new and innovative, solutions for empty lots. Not surprisingly, thus we find an increasing number of calls from municipalities for more civic engagement or general civic participation in maintaining and governing urban green spaces (EA.UE 1992; Schröder 2000; Krug-Gbur and Preisler-Holl 2004). Therefore, I will focus on a specific form of residents-lead transformation of empty lots into public green space.

In recent years, quite a number of local initiatives in Berlin have turned former empty lots or brownfields into publicly accessible open (green) spaces, some only temporarily, others on a more permanent base. A few of those projects – often inspired by those created in New York City – can be identified as Community Gardens. Collective gardening, in the form of community gardens, is still a rarely known form of creating, shaping, and using public space. In the German context, it has been analyzed thus far primarily in the context of urban agriculture (Lohrberg 2001) or their potential as interim uses (Bauhardt 2004; Eißner and Heydenreich 2004; BBR 2004; Rosol 2005). In this paper, I want to analyse this recent development in the context of citizen participation in urban (green space) governance. Thus, I ask, in how far does Community Gardening in Berlin represent current forms and problems of public participation in urban green space governance, and thus exemplifies important shifts in the role of citizen participation over the past 20 years?

In order to contribute to answering this question, I will present results from a case study of nine community gardens in Berlin.[1] After a brief introduction into Community Gardening in Berlin, I will discuss important shifts in the role of civic participation and volunteering. In the fourth section I will present motivation and requirements of gardeners before I close with some reflections on what made possible the emergence of community gardening in Berlin, its possibilities and limits, and how to analyze it in the context of a changing character of civic participation.

9.2.1.2 Community Gardening in Berlin

The term “community garden” is in Germany mostly known from New York City and other cities in North America, but until now has rarely been used in Germany. The phenomenon, however, does exist. The Berlin, community gardens differ in size (from 700 m^2 to 4.5 ha), target group (local residents, migrants, children), and appearance (landscaped park, organic vegetable garden, brown fields with spontaneous vegetation). What they share in common is that they differ from both uniform institutionalized public green spaces and other forms of urban gardening. In contrast to city parks, they are community-managed, i.e. they are collectively designed, built, and maintained by local residents. In contrast to other forms of urban gardening, like the well-known – private – German allotment gardens (*Schrebergärten*), they are, at least, sometimes open to the general public. They heavily

[1]The case study is based on 44 semi-structured in-depth interviews and another 24 shorter interviews – some of them as group interviews - with community gardeners from 14 garden projects ($N = 26$) and support organizations ($N = 12$), local politicians and administrators ($N = 16$), academics ($N = 6$) and environmental organizations ($N = 8$) conducted in 2003/04 and analyzed with MaxQDA qualitative data analysis software. The sampling followed theoretical, not statistical logic. Least similar cases of existing, and more or less successfully operating, gardens were selected in order to explore different perspectives. Further sources are participatory observation and analysis of secondary literature, media coverage and policy papers [for detailed information on methods, see Rosol (2006)].

depend on voluntary work and reflect the needs and ideas of the volunteers in both management style and appearance. In contrast to other forms of voluntary engagement, as, for example, stewardship for existing green spaces or sporadic volunteers' days, the involved residents create new green areas according to their own ideas. Moreover, community gardening implies the steady and more or less long-lasting commitment of residents through different stages of green space production (concept, creation, maintenance).

Although some of the gardens are only temporarily open to the general public, they can fulfill important social or other functions, which are relevant for a broader group of people or for the whole neighborhood. Most of these gardens have both an economic function (food provision) and a social function (social contact), irrespective of the geographical region in which they are situated. Often urban gardening projects are also political battles around the power of disposition over (urban public) space.[2] In contrast to North American community gardens (Saldivar-Tanaka and Krasny 2004; Baker 2004; Meyer-Renschhausen 2004) though, the Berlin gardens mostly do not serve productive functions. Flowers and shrubs are more commonly planted, and vegetables are planted for demonstration purposes, not as agricultural crops. Most gardens have collective areas as well as individual beds. The community garden groups are organized in different ways, ranging from loose groups to formally registered associations. The groups get funding from different sources: member fees and member donations, donations from outside, or prize money. Most of them get public funding as well, sometimes only for the creation of the gardens, sometimes also for maintenance costs.

Community Gardens fulfil important social functions, because they provide a space to meet and get in contact with other neighbours. They offer open green spaces to city dwellers and this way alleviate lacks of urban green in neighbourhoods with inadequate provision with public green open spaces. Different to conventional parks, they provide more appropriation possibilities, because people can use and change these spaces according to their wishes and ideas. Community gardens present, at the same time, an alternative to private gardens also in dense inner city districts. In a community garden, the garden as a traditionally very private form of green space can become an experimental ground for urban society.

The importance of the diverse functions of a community garden differs according to the needs in the specific neighbourhood. Generally, the public accessibility will be more important in dense inner city districts with a higher lack of public green space, whereas in the outer and periurban areas no full public access all the time may be needed due to better provision with private green spaces and other forms of urban green such as forests.

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[2]This is especially well documented for New York City (Hassell, 2005; Schmelzkopf 2002, 1995; Staeheli et al. 2002; as another example see e.g. Lebuhn 2008). Here the guerilla gardening movement stands out, which became famous in New York City in the 1970s (Meyer-Renschhausen 2004; Reynolds 2008).

9.2.1.3 Shifts in the Role of Civic Participation and Volunteering

But in how far does community gardening represent a new form of citizen participation, and what kind of chances and problems does this reveal? Theoretical and empirical research (e.g. Elwood 2002; Geddes 2006; Ghose 2005; Herbert 2005) have shown how changes in urban governance over the last 20 years has shaped citizen participation at the local scale in the following five respects:

1. There is a growing responsibility of citizens and civic institutions – corresponding to the neo-liberal goal of greater institutional efficiency – which is usually not accompanied by increasing resources, influence and power (Ghose 2005)
2. Outsourcing and privatization of state services towards the profit-making and the non-profit sector and to volunteering citizens has become more common (Bondi and Laurie 2005)
3. There is the emergence of a discourse of collaboration that "has the potential to de-politicise urban governance practices and effectively discipline community organizations into forms of participation that are more manageable for the state," (Elwood 2002: 123)
4. There is co-optation of energy, time, and agendas of participating citizens (Elwood 2002) and
5. Competitiveness among community groups has increased, as they, for example, compete for grant funding, at the expense of co-operation (see e.g. MacKinnon 2000: 298).

Crucial for the following discussion of community gardens is the rising significance of, "governance-beyond-the-state" (Swyngedouw 2005), i.e. the increasing participation of non-state actors in (local) state decision-making and the transformation of roles, responsibilities and institutional configurations of the (local) state and citizens in urban spatial politics. In many cases, this inclusion of non-state actors is less geared at citizens' participatory rights, but rather at the outsourcing of traditional state functions to civil society organizations (see e.g. Fyfe 2005).

This is especially obvious in the shift of responsibilities for service provision towards the profit-making and the non-profit sector and to volunteering citizens (Bondi and Laurie 2005; Mayer 2006a, b; Milligan and Conradson 2006; Milligan 2007; Kearns 1992; Fyfe and Milligan 2003).

9.2.1.4 Motivation and Requirements of Gardeners

Within this larger context, I take a closer look at a specific example of civic participation in urban green space governance: community gardening.

Running a community gardens requires a lot of commitment – it needs time, labour, and money. Why do people do it nevertheless? It is revealing to study the motives of people who are community gardeners, i.e. who do commit their time and energy to running public green spaces. Generally, it can be said that their motivation does not stem from calls for volunteering or an abstract sense of civic engagement. Instead they participate for specific personal reasons. Motives vary a lot and range from self-serving motives to political claims far beyond the actual gardens.

Analyzing the in-depth interviews, I found four motives to be the most important ones. First, most of the community gardeners enjoy the gardening itself. Second, most of the garden members want to be part of a group, socialize with others, and get into contact with their neighbours. An aspiration of some, for others a nice surprise, the gardens have become important local meeting places where neighbors get to know each other. Third, they are not satisfied with the number and appearance of existing parks and green spaces and wish to improve the situation of the lot or the neighborhood, beautify them and make them accessible to themselves and the public. And fourth, many of them also want to provide a safe and enjoyable outdoor space for their children.

Other motives mentioned by some gardeners were: recreation and fitness through gardening, exploring one's own creativity, affinity to nature and environmental concerns including the questioning of corporate (global) food systems. Last but not least, there are pedagogical motives (teaching children about nature in the city or demonstrating organic gardening techniques combined with the joy of cooking), economic reasons (because private or allotment gardens are not affordable for many), the desire to promote a co-operative form of working together, and this way transforming the city. Some gardeners also expressed the feeling of responsibility for their neighborhood and the future of a gardening project.[3]

Not surprisingly – if familiar with other empirical research concerning volunteering (e.g. Braun and Klages 2000: 76–85; Klages 2003: 92–93) – "having fun" is the factor that predominates and combines all other motives for the commitment of the community gardeners. In other words: If it does not bring fun, they don't engage in it. Therefore, the gardeners seek those activities that are most likely to be enjoyable for them – be it the actual gardening, be it fund raising, public relations or designing the garden, negotiating with local politicians or organizing a garden party. It is these motives that drive residents to green and maintain small lots and take on responsibility for them. However, they do not: (a) take on responsibility for a whole existing park or parts of it by joining a registered association or the like; and (b) assist the parks department more than sporadically through labor intensive, executive work such as garbage and leaf collection. This is simply because, "just cleaning, picking garbage and so on, that cannot be the fun." (Gardener, Interview 12b/2003).

Moreover, the gardeners ask for basic conditions and provisions from the local state concerning funding and support in bureaucratic and legal issues. Without financial assistance, many of the gardeners could not afford the costs for the sites. Furthermore, the gardeners typically see funding for gardening material as an

[3]Food production for self-sufficiency or as self-help in the face of poverty is, as mentioned earlier, in contrast to many other cities (Domene and Sauri 2007; e.g. Buckingham 2005; Johnston and Baker 2005) not an important factor. The motives listed above confirm results of other community gardening studies (e.g. Armstrong 2000; Gehl 1987; Hanna and Oh 2000; Stone 2009).

appreciation of, or compensation for, their voluntary work: "because we do the work and they give the money." (Gardener, Interview 12a/2003). Another one requests from local authorities:

> Well, the only thing we really ask for is that they should give us the site at no cost. And really, at no cost. And they should make their contribution in the form of ensuring safety and paying other costs. So they should still fulfill their public duties. And even then, we would still give more than enough work in maintaining (. . .) the sites. (Gardener, Interview 47/2004)[4]

They also ask for minimal interference in the design and their way of running the lots. The self-determination, the voluntary nature of their engagement, and the openness of the process are important factors for many of the gardeners. This does not mean that the gardeners would completely abstain from support from the outside or be ignorant towards other needs and critique. However, they would not work in a hierarchical project, controlled and managed from outside, e.g. the city's park department. Thus, representatives of the garden "Dolziger Straße," for example, approve of an expansion of community gardening projects, but nevertheless doubt that it would work with a master plan imposed upon them from above (Interview 8/2003).[5] Another gardener answers to the question whether he favored an expansion of community gardens that it would become dangerous if local authorities obliged people. In his view, local authorities should act according to the motto: "We don't cede work, we cede decisions." (Gardener, Interview 17/2003).

9.2.1.5 Conclusions

In this last section, I will summarize what made possible the emergence of community gardening in Berlin, its possibilities and limits, and how to analyze it in the context of a changing character of citizen participation.

Many of the studied gardens on public land became possible only because of the appalling budgetary situation of the City of Berlin. Because the City was not willing or able to fund the foreseen collective infrastructure, land fell vacant. This opened up a possibility for interim uses like gardens. As a result however, the gardens will have to go as soon as the eventual use – like a kindergarten in case of the Kids' Garden – has obtained financing and will finally be realized. Gardens on private land, on the other hand, became possible due to the specific situation of the real estate market in Berlin. The lots are empty because development is currently not profitable enough. In this case too, these gardens have no long-time guarantee. In

[4]One project, the "Kids' Garden" however, highly values the financial independence of the local authorities because of fears of too much influence from their side. However, this garden is more membership focused and yields only limited access to the general public. Public access for anyone at anytime is a precondition for public funding in the other projects.

[5]Stone similarly argues regarding the New York City Green Thumb project that many benefits provided by community gardens depend on the gardener's autonomy and self-governance (Stone 2009).

their contract, the community gardeners had to agree that they will clear the land as soon as private investors show interest and, subsequently, a building permit is issued (Garden Dolziger Straße).

Insofar as this new acceptance of community green spaces is not a general appreciation of independently run green spaces and the support is only for temporarily uses of urban brownfields, the tenure of community gardens in Berlin is fragile. The current arrangements are only valid until "big investors" come back into the city. Comments by Berlin officials and their insistence on the term "interim use" suggest that gardens are seen mostly as a stop-gap measure or a second-best option in times of slow real-estate development. This is also related to the fact that the gardens meet certain aspirations of the municipality, but do not tackle the real problem: the maintenance of larger existing parks.

However, even if only temporarily, support from urban planners, which stems from limited financial resources and from a reorientation towards community responsibility and volunteering, has changed the possible fields of action of community greening projects. Therefore, a second series of questions is: What possibilities and problems does the new acceptance or even support of self-organized use of open space by the local state imply? Does it open up new opportunities? Is self-help the only chance for deprived urban areas to get any public green space? The study of the history of Berlin community gardening projects shows that the new situation leads to a complex outcome providing both opportunities and problems.

The acknowledgement and support of community gardens, on the one hand, make possible the emergence of new spaces with other uses, other designs and styles, with or without regulations. Also the gardens initiated and supported by the municipality open up former private and offer self-determined space, decentralized and non-bureaucratic solutions. These spaces are appreciated and used by local residents. In some cases, the gardens function as an important social meeting point of a neighborhood, and even if they were originally thought of as being only for interim uses, there is a good chance of securing them after they have successfully operated for a while and won enough support from residents and others.[6]

However, although the support of community garden projects opens up opportunities, this new acceptance of community groups is very ambiguous: it is both functional and fragile, given that only temporary uses are encouraged. Gardening groups have to acknowledge these new circumstances. They can use this support to promote their own cause, but have to be aware of the administrations differing interests.

If we look at the historical changes of community gardening in Berlin (Rosol 2010), we can find a shift from community gardening with strong connections to urban social movements towards community gardening as a form of voluntarism or the provision of social services. This, of course, has important implications for the question of participation. The changes discussed earlier of the character of civic

[6]See the longevity of the "interim" allotment gardens in Berlin, which have been in existence for more than 100 years now (Gröning 2000).

participation are relevant here. The withdrawal of funding from public infrastructures and the resulting outsourcing and privatization of state services as well as the responsibilization of citizens for the provision of services are especially obvious in the green space governance of Berlin today. Also, the increasing competition for public funding between different groups can be detected, although also new funding sources are opening up. The discourse of collaboration and participation as co-optation (see Sect. 9.2.1.3) are less important in the analysed cases.

This means that in the general discussion on civic participation and volunteering, we must be historically and geographically specific. Furthermore, I argue for an analytical rather than a normative approach towards questions of participation. With this, we are able to see how participatory experiences change with changes in society in general, and how this must lead to very different theoretical and political evaluations of the projects themselves.

9.2.2 Subproject 2: A Network of Interests: Civic Participation Within "Urban Restructuring East" in Berlin (Miriam Fritsche)

9.2.2.1 Participation Within the Framework of *Stadtumbau Ost*

That participation is in style can be regarded as commonplace within recent planning theory as well as within political and social sciences. Several contributions to research on German local politics, having been published during the last years, show an upturn of participative approaches on a local scale (cf. Haus 2002; Haus et al. 2005; Geis 2005; Greiffenhagen and Neller 2005, for a research overview see Vetter 2007). According to these authors, not only the extent of participation is increasing, but there is also a shift occurring in the relation between citizens and local authorities. Under the label of "co-operative democracy" (cf. Bogumil 2002; Holtkamp et al. 2006), a duplication of roles in local politics intended for citizens is established: No longer do local political interests just focus on citizens as constituents and voters, but also as recipients, clients, and co-producers of local goods and services. Against this background, local politics is not only bound within the city hall anymore, but manifold "new governance spaces" (Taylor 2007) are set up, enabling state authorities, entrepreneurial actors, and citizens to take part in political decisions.

The following remarks analyse how the denationalization of urban planning interacts with public participation in a specific urban neighbourhood within the current German federal subsidy programme *Stadtumbau Ost* ("Urban Restructuring East"). Over the last few years, the shrinking of cities in the former eastern German states has become a hot topic in German urban development politics, and *Stadtumbau Ost* is likely the most ambitious current programme, envisaging the demolition of about 350,000 housing units in more than 340 municipalities. It is the goal of *Stadtumbau Ost* to remove the vast number of vacant tenements, as well as to alter the course of urban politics by fitting east German cities to population decline. *Stadtumbau Ost* is of specific significance because unlike traditional state programmes of urban development, it is much more shaped by a co-operative approach. *Stadtumbau Ost* supports procedures of civic participation as well as a strong involvement of the housing industry in order to define the targets of urban development. The Federal Government as well as the Federal States (*Länder*) and their authorities have made both aspects as a precondition for granting subsidies. Accordingly, all *Stadtumbau Ost* municipalities are experiencing a boom in participation approaches (such as discussions, planning workshops, or advisory committees). At the same time, big housing companies are engaged in elaborating on the concepts of urban development to an extent previously unknown in Germany (cf. Hunger 2003).

Almost every *Stadtumbau Ost* programme document emphasises the necessity of comprehensive civic participation. For example, in the call for proposals of *Stadtumbau Ost,* it demands that, "participants from urban planning, the housing industry, and all affected citizens should be involved, from the beginning, in decisions concerning the necessary measures of restructuring" (BMVBW 2001: 3; own translation). Furthermore, the "concepts aimed for specific areas have to be examined in close coordination with affected property owners, users, and residents," (ibid.: 8f.; own translation).

The national German *Urban Development Report* of 2004, released by the former Red-Green Federal Government, likewise acknowledges the commitment of civil society as decisive for a successful urban development. For example, it says, "Economy, citizens, and local authorities are called upon to define together the aims and goals for their city. This is the basis for a comprehensive and consensual strategy of realisation," (BMVBW 2005: 8; own translation).

The same arguments are used by urban development politics at the level of the Federal States. According to the *Brandenburg Department for Building and Construction*, even the general success of *Stadtumbau Ost* is closely tied to the comprehensive participation of affected inhabitants – as the following quotation illustrates: "The successful realisation of 'Stadtumbau Ost' depends on the quality of public relation as well as upon the participation of residents," (MSWV Brandenburg 2002: 6; own translation).

Participation does not only enjoy a good reputation among politicians. The national umbrella organisation of housing companies in Germany also alerts its members to the fact that, "without the commitment of citizens as those being affected as well as co-designers of a public community, 'Stadtumbau Ost' cannot be afforded," (vhw 2003: 67; own translation). Similar quotations can also be found from other actors. The responsible Federal department, the *Länder* administrations, the housing industry, and public agencies all agree that *Stadtumbau Ost* needs participation.

At the same time, *Stadtumbau Ost* is characterised by an extreme fragmentation of decision-making structures. The Federal Government outlines the framing design, whereas funding guidelines are defined by the Federal States, and approval is given by local authorities. Yet, *Stadtumbau Ost* is only workable if landlords and homeowners are involved. Because of instruments of legal protection of property they are able to veto every proposal to dismantle – it is up to them whether they want to see their properties demolished, rebuilt, or renovated. Hence, each project of the *Stadtumbau Ost* relies on the co-commitment of the housing industry.

Tenants in the areas affected by *Stadtumbau Ost* can also influence the process, because a high number of vacant tenements does not necessarily mean that any particular building is fully unoccupied. Remaining tenants have to be persuaded to move before demolition starts. Therefore, residents' willingness to take part is likewise essential for realising any measures of the *Stadtumbau Ost* programme. The position of residents towards *Stadtumbau Ost* is shaped by comprehensible interests (cf. Kabisch et al. 2004, 2007; Hagemeister and Haller 2009). In contrast to the presumptions that prevailed during the early stages of the *Stadtumbau Ost* programme, most residents are not against demolition in general. Rather, they attempt to preserve existing qualities of their residential area and – in case their removal is caused by a demolition – to gain control of the removal conditions in the greatest possible extent. Demolition of only parts of a building, renovations or upgrades easily find acceptance among residents. However, residents often refuse total demolitions. Affected tenants demand that housing alternatives are provided that do not differ from their previous apartments in terms of floor plan, rent, and fittings.

Here, a paradox becomes apparent: Although all participants appreciate co-operative procedures, the affected inhabitants experience a decline in their opportunities to influence the procedures when actors from the housing industry become involved. A cost of co-operation with economical players comes at the cost of democratic participation.

In order to explain this observation, the example of a large housing estate in the Berliner district of *Marzahn* serves as an illustration of civic participation in the *Stadtumbau Ost* programme. Taking the local *Stadtumbau Ost* as an example, the following paragraphs show what the handing over of communal liabilities means for the scope of participation.[7]

9.2.2.2 *Stadtumbau Ost* Between Residents' Participation and Housing Corporation's Interests: The Case of *Marzahn-Nord* in Berlin

Marzahn-Nord is the youngest part of East Berlin's large housing estate *Marzahn*, where about 60,000 prefabricated housing units (*Plattenbauten*) were built between 1975 and 1989. In 1989, the district of *Marzahn* had about 160,000 inhabitants. After 1990, the status of this housing dramatically shifted: House building in Berlin and its environs and increasing rents in *Marzahn* produced internal migration processes that led to a population decline, leaving behind a vast number of vacant tenements, and a change in population structure (cf. Schulz 2004).

Between 1992 and 2000, the population of *Marzahn* declined by 20%. Within the neighbourhood of *Marzahn-Nord*, directly adjoining the city limit, the loss was

[7]The following case study draws in parts of Fritsche (2008) and Fritsche (2010).

particularly dramatic. The population, which was once around 29,000 inhabitants, decreased by a third (cf. Weeber and Partner 2003). Accordingly, the number of unoccupied tenements increased. Hence, the neighbourhood was designated by the Berlin *Stadtumbau Ost* programme as a main area for demolition (cf. Cremer 2005). Besides the complete demolition of 170 housing units, the concept envisaged a partial reduction of eleven-story high-rises in the middle of the neighbourhood down to 3–6 floors. This meant a demolition of another 1,300 housing units, as well as the modernisation of the remaining 450 tenements (cf. BMVBW/BBR 2003: 64–67).

In *Marzahn*, civic participation did not start with *Stadtumbau Ost*. From the beginning of another federal subsidy programme, *Soziale Stadt*, in 1999, the district has been one of the areas designated under the "Neighbourhood Management" (*Quartiersmanagement*) planning programmes (cf. Abgeordnetenhaus von Berlin 1999). The professional neighbourhood managers, according to their own estimations, did not find any organised interests of residents, who were suitable to include into the process. Therefore, in addition to various single events, they initiated a residents' advisory committee (*Bewohnerbeirat*) that has been meeting on a monthly basis since mid-2000. The neighbourhood managers then consulted with this committee concerning all matters of relevance to the neighbourhood.

With the emergence of *Stadtumbau Ost*, the *Bewohnerbeirat* got into a changed situation: Relevant questions were no longer presented and discussed within the residents' advisory committee. Instead of intensive discussions simple and quite short-termed information was released. Just 14 days after affected tenants had learned from Berlin newspapers exactly which buildings were destined for demolition (cf. Berliner Morgenpost 2002), the state-owned housing corporation began their clearance. This information politics mobilised protest against *Stadtumbau Ost*. Voices in the neighbourhood's newspaper and at hastily summoned meetings criticised how ignorantly and disrespectful affected tenants were treated by the housing corporation.

In order to reach a broad public, a circle of protestors, organised around the existing residents' advisory committee, got active. It published a position paper (cf. Bewohnerbeirat Marzahn NordWest 2002) that demanded information on standards that underlie the planned demolitions. Furthermore, the residents demanded more consideration of their needs as well as clarifications as to the social, juridical, and financial implications of *Stadtumbau Ost*. At the beginning of the year 2003, a turbulent information event with about 350 participants was held that dealt with local *Stadtumbau Ost* process. It turned out that the holding back of information was a result of disagreements between the Berlin Senate Department for Urban Development *(Senatsverwaltung für Stadtentwicklung*) and the housing corporation. They were unable to reach an agreement about the financing of the modernisation procedures for those apartments remaining within the buildings that were designated for reduction (cf. NORDWEST 2003). Unlike the demolition, which was financed by *Stadtumbau Ost*, assistance for modernisation had to be granted by the State (*Land)* of Berlin. However, the responsible *Senator for Urban Development* was reluctant to provide benefits for *Marzahn-Nord* because he regarded it as a residential area with weak future prospects and therefore favoured a complete demolition of the eleven-story high-rises. Due to this mixture of divergent interests, unstable financing, uncoordinated strategies of *Stadtumbau Ost,* and restricted deliveries of information, the original plans, that had hoped for ambitious civic participation, fell behind.

Members of the *Bewohnerbeirat*, who were meanwhile convinced by proposals of partial demolition linked with modernisation, founded a rent control initiative (*Mieterschutzinitiative Marzahn-Nord*) and circulated leaflets with the header "Nobody Has To Move" into the letterboxes of affected buildings. The committee thereafter recorded a significant increase in the number of people who attended its meetings.

However, the fact that the financing of demolition remained secured while the modernisations remained further uncertain had not changed. In May 2003, since the Senator reacted neither to the position paper nor to an invitation to visit the neighbourhood, the residents' advisory committee decided to go public. They wrote to the mayor of the neighboured municipality of *Ahrensfelde* (located in *Brandenburg*) and asked for support. After a devastating account of the situation ("the residents' advisory committee cannot help thinking that *Marzahn-Nord* is already written off and – visually spoken – buried by the capital", Bewohnerbeirat 2003; own translation), the advisory committee requested the mayor to check if it was possible to incorporate *Marzahn-Nord* into the local authority of *Ahrensfelde*. Copies of this letter had been sent to various newspapers in Berlin together with a press release. This, "attempt to escape to Brandenburg," (Preußing 2004) generated a broad media coverage in the following days. Local TV stations reported from the neighbourhood and gave inhabitants a chance to speak. Mobilisation led to success (cf. Cremer 2005). In December 2003, the Senate assured grants for modernisation, thereby enabling the realisation of the *Stadtumbau Ost* project, that became known as *Ahrensfelder Terrassen* (Figs. 9.1 and 9.2).

But already in springtime 2007, the constraints of the local negotiation structure that was established during the first period of *Stadtumbau Ost*, were becoming obvious. *Stadtumbau Ost* in *Marzahn* was planned for a second round, initially putting another 200 housing units in the neighbourhood of *Ahrensfelder Terrassen* up for consideration of reconstruction (cf. Fritsche and Lang 2007). Due to the problems during the first phase of *Stadtumbau Ost*, the neighbourhood managers initiated a participation procedure in good time. It was supported by the local neighbourhood advisory board (*Quartiersbeirat*)[8] and the steering committee for *Stadtumbau Ost*, and it included representatives of the Senate, the local authority of the district *Marzahn-Hellersdorf*, the housing corporation, and the neighbourhood

[8]The neighbourhood's advisory board, established in spring 2006 as a new committee of the local implementation of *Soziale Stadt* programme, includes representatives of the residents as well as of third sector agencies, associations, educational institutions, and housing companies. It decides on the allocation of all funds from the *Soziale Stadt* programme. In Berlin, the distribution of assistance from *Soziale Stadt* for all areas of neighbourhood management is meanwhile in the responsibility of the particular neighbourhood advisory board (cf. Fritsche 2008).

Fig. 9.1 Marzahn-Nord before reconstruction

Fig. 9.2 Marzahn-Nord after reconstruction

managers. An external applicant, who proposed to hold a *Charrette*,[9] was selected to realise the procedures of participation. The *Main Charrette* was held during several days in March 2007 amidst the affected area.

At the same time, a smouldering conflict over the extent of forthcoming demolitions broke out. During preparation of the planning workshop, it was communicated that the volume was restricted to the complete demolition of 132 housing units in two eleven-story high-rises. However in the meantime, the housing corporation had

[9]A *Charrette* is an open planning workshop that should carry on at least 4 days. On the basis of a question concerning urban development or public spaces, an interdisciplinary group including various interest groups, affected residents, policy makers, and experts elaborates on a common solution that should be articulated as a development concept or master plan (cf. Kegler 2005).

altered its plans – to the surprise of all other local actors. Another 3 six-story buildings (with almost 130 housing units) were scheduled for complete demolition. Originally, they had been designated for reduction with complementary modernisation in the manner of the *Ahrensfelder Terrassen*. This enlargement of the demolition setting burdened the whole participation procedure. The residents' advisory committee and the rent control initiative together accused the housing corporation of abusing the workshop, seeking for pseudo-participatory legitimation, and disregarding the agreements and communication channels established during the first period of *Stadtumbau Ost*. Residents protested against the housing corporation's decision with open letters, press releases, and their pointed absence from the *Charrette*. The planning workshop was eclipsed by developments, which let it now appear as a starting point of expanding demolition.[10] The *Charrette*, intended to plan the further development of the area, initially had the support of all actors of the neighbourhood (including representatives of residents as well as the housing corporation). However, now this participation instrument came into fatal difficulties.

This was due to the solo effort of the housing corporation torpedoing cooperative agreements. It defined its decisions as a consequence of a renewed evaluation, dealing with the business-oriented strategy of *Stadtumbau Ost*. Because this consequence should not be up for any public consideration, further debates were completely unfounded. The housing corporation's view was implicitly supported by the *Senate Department for Urban Development*, whose responsibility was to control the programme and to provide benefits. In 2005, it laid down that, "decisions on demolition, renovation, or selling of the housing stock (. . .) are to be made by the management of the housing corporation on its own responsibility," (Abgeordetenhaus Berlin 2005: 2; own translation).

As a result, a divided participation policy was established. On the one hand, the local authority welcomed the involvement of affected residents. On the other hand, it did nothing to ensure that the state-owned housing corporation would stay on the uncomfortable path of participation in case of conflict. Participation therefore turned out to be an "act of grace" that the housing corporation would afford. When hard decisions are on the agenda, "goodwill-cooperation" barely withstands. The inhabitants interpreted the housing corporation's approach of simply casually and belatedly informing them of altered demolition decisions as an attempt to overwhelm them. As they saw it, the housing corporation not only wanted to create a *fait accompli*, but also attempted to give it a participatory air by joining the planning workshop.

[10]This view was widely shared by people outside the residents' advisory committee – which was seen when a head teacher decided to withdraw his promise that the pupils of his school would participate at the *Charrette*. He criticised that the changed demolition setting turned the procedure into an "alibi-participation, abusing any commitment".

9.2.2.3 Conclusion: The Participation Paradox of *Stadtumbau*

Marzahn-Nord experienced a long forerun of participation before the beginning of *Stadtumbau Ost*. Procedures and structures of participation had been already established under programmes such as *Soziale Stadt*. As a consequence, active groups of inhabitants had already existed for years, being engaged in the interests of their neighbourhood where they are well-known and rooted. Various participation procedures were adopted in the course of *Stadtumbau Ost*, based on approaches that had been tested already. The range contained public meetings, planning workshops, advisory boards, and regular platforms for discussion.

But this participation always has had a subordinated status. Inhabitants were neither involved into the conception nor informed about the plans in time. Against this background, it is daring to speak of a broad cooperative approach within local *Stadtumbau Ost*. It can be rather emphasised, that existing platforms of participation were excluded whenever sensitive issues affecting the housing problem were under discussion. The above-mentioned "disregarding" and attempted "overwhelming" of the residents' advisory committee shows this.

Reasons for this are easy to detect. Since the housing corporations began to be crucial for the operability of *Stadtumbau Ost*, they brought in a higher veto power to the negotiation table than did the residents. The unequal distribution of resources is immediately reflected by the different chances that residents and housing companies have in profiting from cooperative procedures. This situation can be described as *participation paradox of Stadtumbau Ost*. On the one hand, *Stadtumbau* Ost is much more cooperatively oriented than previous programmes, including players from the housing industry in the process of defining targets and implementing them afterwards. On the other hand, this stronger involvement leads to a loss of opportunities for citizens to decisively influence the programme.

Neither a shortage of grassroots participation culture nor a lack of willingness, on the part of the administration, is crucial for the failure of participation procedures – at least, not in the presented case of *Marzahn-Nord*. It is equally valid to suggest that failure is caused by the choice of wrong participation techniques. It is rather problematic that the scope of participation within *Stadtumbau Ost* depends on a specific network of operating necessities on the part of housing companies. When citizenry and state start establishing cooperative solutions within the framework of participation events, they are in danger of reckoning without the host. The course of *Stadtumbau Ost* is not determined by the model of a cooperative democracy (however it is shaped), but rather by the logic of practical constraints. It is an incidental mixture, differing from place to place, and resulting from an interaction of distribution of property, assistance policies, and situations of mortgage – giving important control capacities to housing companies.

In summary, one has to draw a disillusioning image of cooperative democratic approaches within *Stadtumbau Ost*. The scenery of a harmony of interests, shared between housing corporations, administrations and citizens, that enables them to just sit around a table, to speak openly about problems and to actually find a broad consensus obviously does not mirror reality of local politics. Wherever conflicts of interests occur, procedures based on participation concepts are quickly annulled – like in the case of the *Charrette* being held in *Marzahn-Nord*.

The few existing evaluations that deal with *Stadtumbau Ost* and its concrete measures underpin these results. Already the first analysis of integrated concepts of urban development, having been elaborated in a nationwide contest, contains rather sobering findings:

> "The concepts [were] partly presented at panels and also partly discussed with residents during workshops. Whereas in the sensitive area of determining the reduction of specific objects, local authorities and housing societies often shared the legitimate concern that a public involvement, especially with the affected tenants, starting too soon could make the realisation of the plans more difficult," (BMVBW/BBR 2003: 25; own translation).

In contrast to "common definition of goals", "closed coordination" and "early inclusion", like it was intended by the programme, the practice is rather dominated by one-dimensional information events, where residents learn about decisions, which nevertheless had been already made. While the programme acknowledges citizens as co-deciders and partners, during realisation, they are positioned as the shy deer that could be scared up by too much information. The 2006 status report of *Stadtumbau Ost* came to a similar conclusion (cf. BMVBS/BBR 2006). It showed that the fear of civic participation from the preparatory period of *Stadtumbau Ost* has continued during its realisation:

> "As a result, in many cases information about ongoing negotiations and necessary measures of reduction was held back for a long time. Nevertheless, they were often brought on public focus by using 'intricate paths', what understandably caused resentment among persons affected. (...) Participation regularly happened as information after planning came to an end, without keeping the possibility open to take part or even to object," (ibid.: 79; own translation).

Due to these findings, an appropriate civic participation within *Stadtumbau Ost* can be considered as wishful thinking.

Considering that *Stadtumbau Ost* is a significant policy field of urban development in Germany, with benefits of about 2.5 billion Euros and more than 340 participating communities, the often met positive opinion of "cooperative democracy" seems to barely correspond with reality. Moreover, an interesting paradox is emerging. Although all actors want more involvement, the reality of participation falls back far behind.

From this, a shift of perspective within the field of urban research and especially for studies of urban neighbourhoods within political sciences is arising. Instead of taking a crypto-normative position that considers participation as good by definition, it should be examined who is participating, for which purposes they take part, who is able to enforce his or her interests, and by which means. The example of *Stadtumbau Ost* in *Marzahn-Nord* shows clearly that interests of private enterprises or interests of those players acting along the requirements of private economy are of crucial importance within such a context.

9.2.3 Subproject 3: From Brownfield to Blossom? Sustainable Urban Development Through Gardening Exhibitions (Martin Klamt)

9.2.3.1 Effects of Gardening Exhibitions on Cities

It's not about flowers. Gardening exhibitions, based on a tradition of more than a century in Germany (Preisler-Holl 2002: 161), have become major events and prominent instruments of urban development in recent decades. In this article, I will draw on the development of gardening expos and their effects on urban sustainability in terms of implementation of planning principles, city image production, and participation.

When the first horticultural exhibitions started in the early nineteenth century, for about a hundred years their predominant function was to show exotic plants and gardening art (Panten 1987: 9 ff.). The early federal expos, set up as a biennial event after the second World War in Germany (*Bundesgartenschau*), were used to repair destructions caused by war and to establish urban green strips (Meiberth 2002: 9). In the 1970s and 1980s, a more economic function came to the fore in terms of city marketing and tourism. The 1990s brought an additional emphasis to the expos: against the background of German reunification, political, economic, and demographic changes, horticultural exhibitions displayed their function as instruments of sustainable urban development, of urban resilience and transformation in bright light.

While community gardens work as places of social integration on micro-scale level and while urban renewal projects are often meso-scale urban phenomena, large-scale urban areas demand their very own instruments regarding transformation processes of the city. At first glance, gardening exhibitions are likely to be associated with landscape planning, botany, and horticultural design. Yet, their role, in fact, is of a broader political, economical, and social character, that deeply affects the prosperity of cities and greater regions.

For the city, winning an expo also means winning large amounts of public subsidies and private investment (Häußermann et al. 2008: 262). Like the Olympic Games (Garcia 1993) it means gaining media attention and attracting tourists (Häußermann et al. 2008: 260). Additional funds are generated in the prospects of developing large-scale urban free space and housing areas in an aesthetic and sustainable way, which would otherwise simply not have been possible. Furthermore, setting up an expo venue speaks to the needs of creating urban parks, producing or even changing the image of the city, and accelerating urban renewal (Meiberth 2002: 9). In the end, the expo vision has a disciplining effect on the political and economic stakeholders of the city who concentrate their power on this single project (Härtig 2002: 44; Klamt 2009: 37). Of course, there might be also consequential problematic effects because less prominent problems and projects might simply be overridden by the sole planning of the big event (Häußermann et al. 2008: 265). Therefore, it should be examined whether, and to what extent, there are sustainable effects of the exhibition after its 6 months of ephemeral "show time" (cf. Härtig 2002: 41).

The German federal gardening expos are held every 2 years and are organised not only in major cities but also in smaller and less attractive cities and regions. In other words, horticultural exhibitions are not only well adapted to a city's functional needs in terms of the subsequent use of the site, in aiming at long-term development of large-scale urban areas, they also entail easier application processes, in particular for cities dealing with serious structural and social problems that would otherwise have little chance of hosting other major events. The venue itself is often planned for an inner-city park for *everyday* use afterwards. For these reasons, gardening exhibitions could be seen as an exceptionally fitting instrument of sustainable urban development.

To sum up, horticultural expos are large-scale urban projects with far-reaching effects on the city's ecology, economy, and quality of living. Currently, there are three federal and two international exhibitions planned in Germany (Koblenz 2011, Hamburg 2013, the Havel region 2015, Berlin 2017, Heilbronn 2019), as well as four to eight exhibitions every year at the regional level of the federal states of Germany (cf. Hauser 2010). Other countries like Austria, China, the Netherlands, Japan, Taiwan, and the UK have been aiming at similar goals with their own gardening expos. Yet despite its impact on urban development, the phenomenon of federal and international horticultural exhibitions has only rarely been investigated systematically (but see Theokas 2004). Hence, this is the initial point for this research project.

In this article, firstly the main objectives of research as well as the case studies of the federal gardening exhibitions of Munich and Schwerin will be introduced. Against the background of the theoretical framework, empirical methodology is explained secondly. Main results derived from empirical research are shown in terms of the general function of the expo for urban development in these cities as well as of city image, planning principles, and participation. Finally, a conclusion is drawn, also sketching some future perspectives.

9.2.3.2 Objectives and Case Studies

Still, while the goal of sustainable urban development is the same, the outcomes might be different in each city. Löw has stated that knowledge about which strategy works best in which city has not been systematised yet (2008: 11). It shall be analysed then how the same instrument of sustainable urban development is interpreted by the main actors of each city government, economical players, and civil society. What are the plans, the goals, and the outcomes as appraised from different perspectives of these actors?

The main objectives of this analysis of the sustainable factor of gardening expos are: what are the effects of gardening exhibitions regarding urban sustainability in terms of a city's image, planning principles and outcomes, public spaces and participation? According to this, one main field of research is to examine the effects of a gardening exhibition on *city image* (as external perception and city marketing product) and identity (as perception of citizens). City images serve as soft locational factors with high relevance in contemporary urban politics. A second main aspect is to study the specific *planning principles* of each city and the role of the gardening exhibitions to enhance them in practise. Regarding the problem of how (sustainable) *public spaces* such as parks, city squares, and open spaces in housing areas should be and can be designed, the question arises as to whether or not the horticultural expo is a proper instrument here. Furthermore, the process of planning and the influence of *participation* are to be investigated.

There are two central case studies to be analysed. First, there is Munich as a major German city of growth. Here the federal gardening exhibition of 2005 was used to develop a former airfield as a whole new urban district with large housing, business, and park areas based on planning principles of sustainability. As a contrast, Schwerin, a shrinking eastern German city, implemented the federal gardening exhibition 2009 in the very heart of the City to recreate a new and attractive eco-city profile to stop degradation and to manage structural transformation by enhancing urban resilience. The comparison of these quite different case studies is to be completed in the broader research framework by further examples of future venues in Germany as well as of Asian cities.

9.2.3.3 Theoretical Framework: Sustainability, Festivals, and Urban Politics

The theoretical framework is provided by analysing the paradigm of *sustainability*, as well as the phenomenon of urban "*festivalisation*", and the urban politics of *aesthetisation*. These theoretical approaches shall be introduced here briefly.

Sustainability is generally seen as being based on the three pillars of economy, the socio-cultural, and ecology. Gardening exhibitions playing a role as an instrument of urban development and setting free political, financial, and specific local resources, are affecting all three of these pillars (cf. Härtig 2002: 49). Yet, the research project focuses mainly on the socio-cultural aspect of sustainability. It includes a comparison of the politician's and planner's view with the outcomes shaping everyday life of urban residents as well as (seemingly) soft factors such as urban images, and questions concerning the influence of participation (Cranz and Boland 2004; Preisler-Holl 2002: 163). There are many faces of sustainability and the term is used in almost every context. For this reason, it has to be sharpened (cf. Zeemering 2009) to get a tangible term that is suitable for empirical operationalisation. In this context, sustainability shall be defined as long-term optimisation of urban images and socially successful implementation of planning visions and building measures.

Festivals have become important instruments in pushing urban planning projects and city marketing (Häußermann and Siebel 1993). There are two main challenges cities have to face and can accept by implementing horticultural exhibitions as an instrument. On the one hand, some cities have to deal with shrinking and degradation processes, as well as declining economies and lower tax revenues due to fundamental industrial and political transformation. Cities and regions in eastern

Germany were struck particularly hard by this development. On the other hand, against the background of globalisation, cities increasingly have to compete with other (and more) places (Häußermann et al. 2008: 263; Löw 2008: 12 f.). In this regard, both shrinking and prospering cities are affected by competition (while the specific impact and the city's potentials to shape it positively are quite different, of course). As a consequence, urban politics often aims at sustainability in terms of creating characteristic attractions and distinctive urban spaces. To that end, festivals are used as an instrument.

The aspect of festivalisation is therefore paralleled by urban politics of *aesthetisation* which means that city governments are increasingly aiming at urban improvement measures to refurbish and *clean out* the city, and to compete with other cities of comparable rank e.g. by means of image production (Paul 2004: 573; Rutheiser 1996) and tourist attractions (cf. Löw 2008: 118 ff.). But generally, aesthetics is not quite the same comparing a planner's and a layman's view which Tessin (2008) has shown. In addition, within this framework of city improvement the less wealthy may have to give way to rising rents and gentrification processes in an aestheticised neighbourhood (Häußermann et al. 2008: 277 f.; Garcia 1993: 257 ff.). Gardening exhibitions do have an impact on both of these scenarios and therefore have to be analysed empirically in this regard.

Due to this assumption, a gardening expo might work as an instrument here. When it comes to planning the future of urban areas available as a result of deindustrialisation, or developing urban brownfields (Meiberth 2002: 11) and former airfields, applying for a federal or international horticultural expo seems to be a proper option. Still, the applicant cities do have to deal with quite different challenges. Hence, I will have a look at if and how this instrument works in terms of urban sustainability in different cities.

9.2.3.4 Methodology

The perspective of experts and urban residents is evaluated with qualitative and quantitative techniques of empirical social research. The main method was to conduct qualitative interviews with experts of the exhibition management, urban governments, and economy, as well as with residents of (former) exhibition areas and everyday users of these urban landscapes. So far, 50 persons have been interviewed, among them representatives of city governments, exhibition management, different political parties, nature conservation organisations, tax-payer associations, real estate management, urban planning and landscape architecture. Additional interviews were conducted with experts of future expos in Germany and of contrastable projects in Japan and Taiwan. The function of these interviews was to find out about the different motives, strategies, influence, and aims of the stakeholders and managers on the one hand. On the other hand, subjective perceptions of the situation, evaluation of the planning and its outcomes by laymen can be found by analysing and interpreting their interview's transcripts. As can be seen, planning large-scale projects like gardening expos is a matter of key players of urban society while the outcomes are observed best through the eyes of the persons affected by the project as users of city spaces in their everyday routines.

In addition, a quantitative survey with citizens in Munich and Schwerin was completed in 2009. The questionnaire covered three pages of questions, which were presented to residents of each city in a face-to-face situation. Its function was to mirror the findings resulting from other methodology. This proved reasonable in particular when it came to finding out how the image of the city was influenced (cf. Rutheiser 1996) by means of the horticultural exhibition and to what extent the specific planning principles can be regarded sustainable in terms of a high resident's acceptance of the parks. Until now, more than 520 people have taken part in the survey, approximately half of them in Munich and half of them in Schwerin. From the findings based on this empirical research, both the critical factors of success as well as the specific outcomes in different cities and the problems created by this kind of planning shall be derived, with an eye on applicable solutions for future exhibitions in different cities.

9.2.3.5 Results

From these data sources first results can be derived. The focus here is firstly the general role of gardening exhibitions within urban development processes, secondly sustainability in terms of city image and urban planning, and thirdly the aspect of participation.

The General Function of Gardening Exhibitions for Urban Development

Especially from the perspective of planners, expo managers, and politicians, federal gardening exhibitions are clearly used as an instrument of urban development. Their objectives are – at least ostensibly and regarding German expos – to establish sustainable urban structures both by means of the built environment and the economy, as well as to address issues such as social integration, political participation, and city image. It was, arguably, a consensus among the interviewed experts that the exhibition is not a proper instrument to *compass* urban planning strategies. It should rather be a means to advance and accelerate already *existing* and *consistent* planning visions. In other words, gardening exhibitions work as motors rather than as initiators of urban development. Recently, aiming at sustainable urban development through gardening expos in Germany points to long-term economical and socio-cultural effects on city and region rather than above all reaching for short-term economic success and a maximum of visitors. Urban renewal, management of structural change, optimising infrastructure and public spaces were important objectives, too, within a planning period that began usually about 5–10 years in advance of the expo.

Gardening exhibitions are therefore a fitting instrument for developing urban areas that are large-scaled and of high relevance in the context of urban ecology. In some cases of course, organising an expo may politically lead to unforeseen conflicts, and economic problems to be solved (Theokas 2004: 264 f.): where there is no sufficient basis for cooperation of the leading actors, where the residents are not widely supportive of the project, or where financial calculations are all too optimistic or short-sighted. The international gardening expo in the maritime eastern German city of Rostock in 2003 (cf. Preisler-Holl 2002: 166), with its large and expensive exhibition halls, is one of the examples where planning seemed to be focused mainly on setting up the venue for the exhibition itself due to available financial support, and less on the probable uses of the area afterwards (see Thwaites et al. 2007: 5ff.). Thus the City was left not only with a deficit after the event but with permanent future costs of maintenance. This also emphasises the political scope of horticultural exhibitions, interrelating the issues of sustainability, urban development, and major projects with social and monetary aspects.

Urban Sustainability in Terms of Image and Planning Principles

A main research objective was to find out about the effects of the gardening expo on urban sustainability in terms of a city's image and implementation of guiding principles of urban planning.

Munich 2005

There are cases where the effects of the event as a motor are not as strong and as positive as they probably could have been. The *Bundesgartenschau* of Munich in 2005 accepted the challenge of promoting an attractive image for the whole new urban district of the *Messestadt Riem* which was established on the former airfield on the urban fringe, and to set up a modernly designed landscape park.

The findings of the survey documented that creating a positive image of sustainable urbanism by using the gardening expo turned out to be quite demanding. Indeed, the gardening exhibition helped gaining media attention to the new district and its park surroundings. Nevertheless, 4 years after the exhibition only 23% of the people asked continued to associate the Messestadt with the gardening expo. In this regard, the initial effect of 2005, promoting newly set up real estate projects near the park, can not be seen as sustainable.

Furthermore, it seems surprising that the character of the image itself does not refer to the positive connotations of the city's planning principles and the gardening exhibition as green, liveable, urban, ecologically sustainable, and economically successful. Instead, only 17% characterise the image of the former exhibition venue as positive. This result seems to be even worse in comparison with the image of the City of Munich itself which obtained 88% positive votes, a remarkably high value. Hence, the federal exhibition of 2005 neither constituted a *lasting* positive label for the new urban neighbourhood and it remained more or less irrelevant for the City of Munich in general. That is why subsequent long-term economic effects for the location probably cannot be derived from the event itself, but rather from the new Munich fair located close to the housing area.

Still, the Messestadt is, according to the interviews, quite a liveable neighbourhood especially for young families and older residents. As the last phase of construction of the district has not even been finished yet, it will still need some time to establish stable identity structures (Koch 2006). There is a discrepancy between a positive perception of the former venue from the perspective of inhabitants (and planners as well) and a negative perception from people living outside Messestadt.

Planning and outcomes in Munich have to be analysed differentiated and not only from the perspective of the gardening expo itself, but in a broader context of the city's development policy. The city government of Munich implemented its planning principles for sustainable urban development – compact, urban, green – building an exemplary new district for 16,000 dwellers and a location of 13,000 jobs at the eastern city limits. Since the airport had already closed in 1992 and moved to a larger area out of the city, the planning visions for the subsequent use of the former airfield, with an area of 550 hectares, started long before the vision for a horticultural expo became tangible there. However, the federal expo then appeared to be a perfect instrument for transforming the vast area into a new city park, and for enhancing the development of a new and sustainable urban district.

Yet, a closer look at the urban conception as well as the contrast between the interviews conducted with planners on the one hand and with residents on the other hand reveals that the planning principles have led to antagonistic rather than integrative outcomes. While the compact city aims at sustainability in terms of shorter routes and urban density, it is, at least partly, interrupted by nice, but (to this end) interfering, spacious green areas. Urbanity should have been created by mixed use, but the chosen scale instead led to separated use in fact: the business area of the Munich fair is located in the north, spatially separated from the housing area by a mall, while the housing use in turn separates the vast landscape park in the south which in turn doesn't constitute an urban linkage to the surrounding districts. Furthermore, the architecture of buildings and streets is perceived as monotonous and therefore composes an improper framework to create urbanity. Ecological urban sustainability requires less car use. Yet, providing all too little parking space unfortunately did not seem to be the right planning tool here. Instead of resulting in less car use and less traffic, it increased the frustration of residents in the first place. These issues also point to the question of participation in urban development which I will discuss below. However, the federal gardening expo did not help to solve these issues of planning conceptions.

Schwerin 2009

Although the initial issue – managing transformation processes by developing inner-city areas in a sustainable way – was similar in the City of Schwerin, the background situation and outcomes were quite different. The venue of the federal expo of 2009 geographically covered the very heart of the formerly shrinking city – a promising, yet quite challenging location. The planning concept was based on opening the city to the lakeshores which frame the centre district (*City at the waterfront*) (Fig. 9.3), and to put the meaning of the city's attractions like the castle, the historic centre, and historic parks to the forefront of both the constructions works and of all marketing measures. By doing so, conflicts with civil society groups and nature conservation organisations were inevitable. However, in the end the plans of the exhibition management and the city government became widely accepted, and paved the way for refurbishment measures visible throughout the cityscape (Fig. 9.4), bringing forward economic resilience, too: the survey and the interviews clearly indicate that Schwerin created a new profile as a tourist destination and regional cultural centre. The gardening exhibition is, to this end, particularly suited as it carries the image of a tourist attraction by labelling itself as aware of urban ecology and sustainable development. In accordance with that, 68% of the people asked confirmed that Schwerin got a new and positive image, while none of

Fig. 9.3 New perspectives on the city from the lake (Schwerin 2009)

Fig. 9.4 Urban renewal in the wake of the expo (Schwerin 2009)

them associated their city with the former characteristic of a “degraded” and “grey” city. A vast majority was even “proud” of hosting the *Bundesgartenschau*.

As an explanation, the plans for Schwerin focused successfully on the City’s genuine geographical characteristics, placing emphasis on the urban lakes and on the historic city centre, with its famous buildings and existing parks. The gardening expo worked as a promoting tool for urban renewal measures, and for managing economic transformation processes. In other words, the expo of Schwerin tied in with the city’s specific potentials, enhancing them to create new urban spaces now positively to be experienced for the citizens. Secondly, a new urban profile as a tourist destination and cultural centre linked closely to the surrounding natural landscapes was pushed. In combination with a coherent financial calculation, investment, and successful long-term planning measures put into effect, the federal expo of 2009 seems to have provided for promoting a process of sustainable urban development (cf. Klamt 2009).

Participation

Of course, even the best plan probably will not work out well in every detail. Participation might be particularly important here for two reasons. Major events like federal and international gardening exhibitions are always a bone of contention. They attract main attention by conflicting interest groups and shape everyday life of citizens by their built and social consequences. The latter is especially true in the case of gardening expos as they affect vast urban areas, which have proven to be particularly sensitive objects in terms of image, ecology, economy, and belonging.

Participation is therefore a proper instrument to firstly identify (future) needs of residents and to conceptualise urban and landscape design on this basis. This in turn is a crucial indicator of sustainability (cf. Cranz and Boland 2004: 114). Last but not least, it is also a question of democratic fairness (Hester 2006: 77). Secondly, there is a soft but nevertheless highly important effect of real participation. People not only get informed but *feel* that their perspective is needed and that there actually is a stage for them within the big project. This is ambivalent of course as this *feeling* might be exploited when participation is only a superficial proscenium without any influence on the outcomes. Meanwhile, the deals are made backstage by the stakeholders. The so-called communicative turn in planning strategies (Häußermann et al. 2008: 260) is therefore not enough.

Managing gardening expos to success means uniting those involved in, and affected by, the project – a task difficult enough, and to be handled by experts only. As participation has been recognised as an important factor that must not simply be overridden, a series of city governments as well as expo managers are trying to inform the public about the project at an early stage and to moderate between conflicting parties.

This approach is accurate yet not sufficient as the real influence of citizens is widely limited in most cases. The organisation of the international expo in Hamburg-Wilhelmsburg 2013 is worth mentioning here as special attention is paid to the multiethnic interest groups in the district. A specific agency for participation and process management has been institutionalised within the organising company, especially taking care of the demands of citizens for useable and liveable public spaces (cf. Cranz and Boland 2004). Still, even efforts like that may not be fair enough to countervail the residents' fear of gentrification, or to even solve the problem itself. Still, it indicates the importance of the interplay of the protagonists here once again.

Regarding the federal exhibition of Munich 2005, the real influence of participation is not quite clear but the survey shows that about 40% people could declare to have been informed well, and that there was an opportunity to actively participate (which was actually taken by only about 10%, however). Despite these figures, the new landscape park cannot truly be named sustainable due to its (perceived) very modern design, vast geometric free spaces, and lack of convivial public space. In other words, the concept was not well-understood by its users, did not realistically seem to aim for social integration, and therefore now is not socially sustainable (see Ostermann 2009; Cranz and Boland 2004). However, the park was not a failure. Some parts remain quite frequented, the design is distinctive, and it will still require some years to fully develop its potentials. The question therefore is rather if it could have been done better and more in accordance with the user's perspective (Tessin 2008), and finally, if the effects and resources of the federal gardening exhibition could have made a more sustainable contribution to this.

Further problems of top-down planning are reflected in monotonous streets, buildings, and spatial arrangements of the new Munich district. Yet, not only the (green and grey) built environment caused arguable perceptions. The social pillar of sustainability in the new Messestadt included social housing and a diverse neighbourhood of multiethnic residents. This is one of the reasons why some Munich residents who live outside the Messestadt perceive the young district, despite this socially sustainable objective and its modern urban layout, as degrading already. The example illustrates that integration cannot simply be built even if planning principles and spatial framework are designed to that end. Still, it is not proven if a greater extent of participation could have helped to avoid such problems (cf. Hester 2006; Theokas 2004: 258). The case of Munich's former airfield nevertheless might serve as an ambivalent guide for the international expo planned for Berlin-Tempelhof 2017.

While the organisers of the federal expo of Schwerin 2009 managed to get some critics to join and to arouse high acceptance from the citizens, the sound of some voices was absorbed by the stakeholders, and even more by the success of the expo itself. Among them, some owners of small garden plots now fear removal due to planned real estate projects promoted by the dynamic expo effect. Another bone of contention is the relationship of the gardening expo and the preservation of nature. It comes as no surprise that the federal association for the protection of nature (*BUND, Friends of the Earth Germany*) even filed law suits against the building measures taken at the city lake of Schwerin as a preparation of the federal exhibition in 2009, and against the cutting down of trees, finally achieving an agreement in court.

Last but not least, there are two more aspects with a view to participation which will have to be analysed further in this project. Participation may also mean that private persons join the process of refurbishing the city by supporting it financially or even practically. Secondly, aesthetisation and refurbishment may lead to raising rents, displacement of the not so well-off, and to long-term gentrification processes as well (cf. Garcia 1993: 257 ff.). The international Flora exhibition 2010 in Taiwan's capital Taipei might become a striking example here: *Cleaning out the city* and *green washing*, as some experts call it, could probably mean that some owners will have to leave their homes due to dynamic real estate projects enhanced by a politics of making the city more beautiful in the wake of the expo. This constitutes the other side of the coin of using gardening exhibitions as an instrument of urban aesthetisation, economic success, and international recognition. In Germany, inner-city, neglected, and multiethnic neighbourhoods are by trend especially "endangered" by *expo urban renewal*. Less prominent need for action and "smaller" problems may be overshadowed by the big exhibition project. Hence, it is right that growth and integration are competing goals of postmodern urbanism (Häußermann et al. 2008: 277). Nevertheless, participation and sustainability mean to ensure that socially deprived residents will also profit from the benefits of the activated urban potentials rather than being crowded out or simply forgotten. Yet, the positive effects of such urban politics of renewal are not to be forgotten either. In the end, gardening exhibitions are thus about spatial justice, too (see Soja 2010).

9.2.3.6 Conclusion and Perspectives

As shown, horticultural exhibitions are more than just major events. They are deeply affecting social, ecological, economical, and political dimensions of the city (Meiberth 2002). Gardening expos might serve properly to develop large-scale urban areas. For these reasons, they constitute a specific subject of urban geography in general, and of urban ecology research in particular (cf. Cranz and Boland 2004). Despite a long tradition and a major function for urban development, the effects are not quite clear in detail yet. With the present project, I therefore analysed these main effects theoretically and empirically in the context of urban sustainability. The empirical data collected can be used to explain the effects of horticultural expos on urban planning and on the image of the city as well as the question why and how this works specifically in different cities.

Gardening expos work different according to the specific location of its venue chosen *within* the city, and according to the specific problems and structures of the city (Hauser 2010). Different forms of management and governance produce different outcomes. However, directly referring to the historic, built, and natural potentials of a city that can be activated and positively valued by the expo is a main criterion not only for a successful expo (Härtig 2002: 41) but for sustainable effects on urban development in a broader sense. Another important aspect is to analyse the planning principles applied in each city and how these are enhanced by the expo.

The advancement of already existing plans by the expo is acknowledged as basis for long-term success after the festival (Theokas 2004: 262).

Finally, participation is a complex subject intimately connected to success and failure both of horticultural exhibitions and long-term urban development processes. As a result, expert stakeholders are crucial for the execution of the event as well as for enforcement of the planning concepts. The success of expos is therefore closely related to individual expert knowledge of key actors. Apparently, both cooperation of the experts and integration of civil society at an early stage is an essential factor, too.

At least from the perspective of the German Association of Federal Horticultural Exhibitions (*Bundesgartenschaugesellschaft*), the cities of Cologne and Essen have established outstanding sustainable parks in terms of user's acceptance, tourism, and an eminent function of these green areas for their urban context (cf. Zeemering 2009). Thus, the cities were recently awarded the association's sustainability prize. Recently, the International Flora expo in Taipei 2010/11 strongly campaigned for introducing more *ecology* in the daily life of urban dwellers by using the instrument of the exhibition – at first glance, this seems reasonable. Still, it is arguable whether or not setting up urban parks and dissemination of plants or greening walls all over the city is adequate enough here. It has to be examined further how gardening expos bring forward sustainable urban structures and at the same time cause issues of incorrect planning and social deprivation. In the end, it is not all roses.

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Chapter 10
From L. Wirth to E. Wirth: Integrating Effects of the Organizational Division of Labour into the Study of Urban Life

Harald A. Mieg

10.1 Introduction

The Chicago school of sociology introduced urban ecology as an approach to study urban phenomena from a sociological point of view. The core idea of urban ecology was to understand cities as environments like those found in nature with a struggle for scarce urban resources and a division of the urban space into niches. In their magnum opus *The City*, Park et al. (1925) – founders of the Chicago school – proposed a concentric zone model of the city, with areas of social and physical deterioration concentrated near the city centre, followed by more prosperous areas in the suburb. The zones are subject to succession by different *social groups*, succession being a term borrowed from plant ecology. This concentric zone model and its derivate are widely used in urban planning until today.

There has been intense research on how specific social groups shape the urban zones. The focus so far has been on ethnic and social segregation; on families and the disadvantaged; on socio-spatial processes such as gentrification or tertiarisation; and last but not the least, on the influence on the urban fabric of specific urban businesses or industries such as, most recently, creative industries. The aim of this chapter is to present a contribution to research on the core factor of urban social differentiation: *the division of labour in large modern urban organizations* such as banks, city administrations, or universities. We would like to know whether the socio-spatial influence of this division of labour goes beyond the obvious commuter problem.

The presented study – called the Planning-Horizons Study – is linked on the one hand to organizational research and on the other hand to the work by Lynch (1960) and others on mental mapping. Mental maps show how people view and make sense of a city. In general, mental maps distort the physical relations of the city's layout: they are both representations and guides of behaviour. The presented study had an experimental character: it tested *whether the abstract, hierarchical organization of*

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work exerts any influence on how work-related neighbourhoods are perceived and used.

Any confirmation would open new pathways for the interdisciplinary study of urbanism. The sociologists Georg Simmel and Louis Wirth revealed the institutional "grammar" of modern urban life, Simmel with a focus on money (Simmel 1903), Wirth on organized social groups (L. Wirth 1938). In a similar vein, the psychologist Stanley Milgram (Milgram 1970) argued that the information overload of a city leads to cognitive and behavioural adaptations such as information selection or the use of institutions. In geography, this approach would create new theoretical connections for the research on the determinants of mental maps and spatial behaviour. As we will see, the geographer Eugen Wirth provided bridging concepts in his theoretical geography (E. Wirth 1979). Our line of argumentation, however, is going to start with his namesake Louis Wirth, a sociologist.

10.2 Louis Wirth – Eugen Wirth

Louis Wirth was one of the representative scholars of the Chicago school. His paper on *Urbanism as a Way of Life* (1938) became a classic in urban sociology. According to Wirth, urbanism defines a way of life based on a high density and heterogeneity of people. Urban life is characterized by the "substitution of secondary for primary contacts" (p. 20). "The contacts of the city may indeed be face to face, but they are nevertheless impersonal, superficial, transitory, and segmental" (p. 12). In general, urbanism results in a reduction of personal interactions and a weakening of traditional ties, and it highly depends on the division of labour:

> Characteristically, urbanites meet one another in highly segmental roles. They are, to be sure, dependent upon more people for the satisfactions of their life-needs than are rural people and thus are associated with a greater number of organized groups, but they are less dependent upon particular persons, and their dependence upon others is confined to a highly fractionalized aspect of the other's round of activity. (L. Wirth 1938, p. 12)

To gain any influence, the urban individual is "bound to exert himself by joining with others of similar interest into organized groups to obtain his ends" (p. 22). Therefore, L. Wirth speaks of "urbanism as a form of social organization" (p. 20).

The geographer Eugen Wirth was interested in the study of spatial processes such as the diffusion of epidemics or the evolution of traffic systems. In his theoretical geography (E. Wirth 1979), he distinguishes three spatial fields or zones:

(a) The *information field* – refers to areas about which a person or organization has any information
(b) The *contact field* – refers to areas of daily personal contacts of a person or organization;
(c) The *interaction field* – refers to areas in which a person or organization exchanges information, for instance, via email or telephone.

In general, the information field is the most expanded field; the contact field, the narrowest one. The contact field is often also addressed as the action area or action field. E. Wirth emphasized the intermediate role of the interaction field. For instance, according to E. Wirth, inner-urban migration is guided by the interaction field – and not by the information field (p. 222). Similarly, industrial exchange and expansion processes follow the paths of an organization's interaction field.

To summarize: whereas L. Wirth stated the important role of the *organized* individual within modern urban life, E. Wirth conceptualized interactions as the principle determinants of this socio-spatial organization. The fact that E. Wirth's field concept has lacked wider recommendation might be due to the success of the network concept since the study by Granovetter (1973). However, L. Wirth's field concept shows a certain elegance in explaining spatial processes. For instance, we can ask for the comparative influences of the information and interaction fields on the contact field. The study presented will profit from the conceptual work of L. Wirth and E. Wirth.

10.3 Core Assumptions and the Hypothesis of the Planning-Horizons Study

The reported study was intended to assess work-related planning horizons and their relation with the contact field. This conceptual outset is based on the following assumptions:

1. Role of work: Everyone (who is working) has a work-related interaction field (besides his/her private interaction field).
2. Division of labour: There are basic differences in the structure of the work-related interaction fields that correspond to different managerial levels.
3. Impact on contact: These differences in interaction fields result in different work-related contact fields.

The second assumption can be explicated within the organizational theory by the psychologist Eliot Jaques (1976, 1988). He claimed that the management of any considerable organization is based on a hierarchy of levels of abstraction with a rising number of organizational units and more and more extended planning horizons. The core factor is the increasing organizational complexity that requires abstract governance structures and increasing time spans for discretion. For instance, the work of a typical teller or clerk in a supermarket has a time span of one day, which means the following: by evening, his/her ordinary work has to be completed and it restarts the next day. The time span of discretion of a regional manager of the supermarket group might count in months: this is the minimum time span we have to wait until his/her typical decisions (e.g. range of goods, reorganization of single stores) might turn out successful or not. The time span of discretion of the owner of this supermarket group might count in years or decades. Figure 10.1 sketches the conceptual bridges between L. Wirth, Jaques, and E. Wirth.

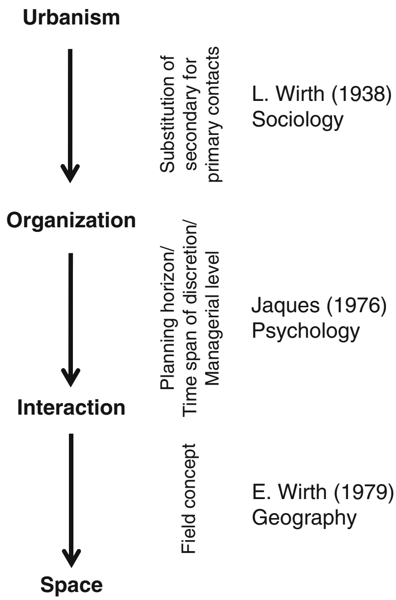

Fig. 10.1 Conceptual bridges

The resulting test hypothesis reads as follows: *The higher the managerial position, the more reduced the use of the work-related contact field.* Explanation (see also Fig. 10.2): Higher managerial levels imply more extended planning horizons with a more and more reduced resolution for a given geographical place. The reference site for the test is the location of the employing organization and its neighbourhood. We expect that managers make less use of the opportunities of the working neighbourhood as to shopping and leisure than "ordinary" employees – the reason being the higher organizational complexity managers have to manage (Jaques 1976). The resolutions of the mental maps differ, depicted as a more or less dark interaction field in Fig. 10.2. The managerial levels are assessed via the associated planning horizons (or time spans of discretion). The reason is twofold, firstly, because there is no standard definition for managerial positions used by different organizations. Secondly, the driving cognitive factor – the complexity of planning – should be emphasized.

10.4 The Planning-Horizons Study

The study was held as a part of the Research Training Group program on Urban Ecology[1] and focused on the Adlershof Science and Technology Park that is located in the South-East of Berlin and comprises several institutes of the Humboldt-

[1]The project, including data collection, has been conducted by Hadia Köhler. Data collection took place in 2007.

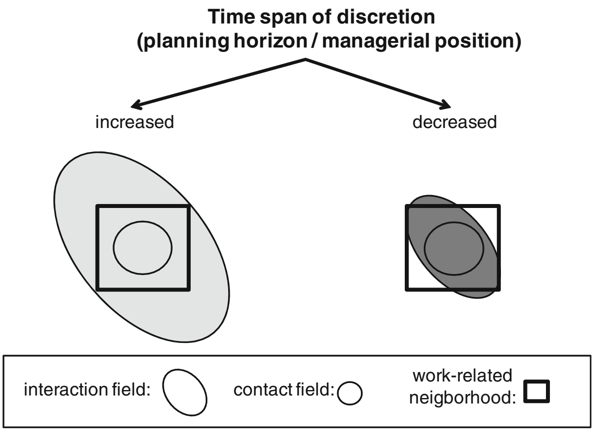

Fig. 10.2 Planning-Horizons Hypothesis

Universität. Table 10.1 presents details about the samples and variables. The time span of discretion was measured as work-related planning horizons.[2] The main dependent measure was utilization of the work-related urban environment. It was assessed in 3 categories and 20 subcategories (leisure: 7 subcategories; services: 10 subcategories; and shopping: 3 subcategories). As we see, the groups do not substantially differ in the types of utilization, except for an increased use of services by the employees of the companies of the Adlershof Science and Technology Park. What else can be seen is that among all groups, the offers in the city centre location are clearly more used than those in Adlershof.

Table 10.1 also shows more long-term management with the university than with the companies, which are in general quite young and small – the whole Adlershof Science and Technology Park being founded after 1990. How about the Planning-Horizons Hypothesis? For the employees, the result was a significantly negative correlation between long-term planning and utilization of the work

[2]The planning variable: The time span of discretion was measured as work-related planning horizons: "How much time does it usually take your direct employees to complete their work?" Five different time spans could be selected: less than 3 months; 3 months to 1 year; 1 year to 2 years; 2–5 years; more than 5 years. The definition of the time spans follows the organizational model by Jaques (1976). The students were asked how long in advance they plan their exams. In general, each time horizon was assessed by a different variable. To arrive at a single planning variable, the inter-correlations of the different time horizon variables were analyzed. This analysis revealed at least two factors: a factor of short vs. long term planning and a factor for mid-term planning (but not long or short term). For the student's sample, the planning variable has been created by identifying the short- vs. long-term factor in a principle component analysis. This would also have been the ideal method in case of the employees' samples. However, due to statistical restrictions and the many missing data that would have unduly reduced the sample, a different method was chosen: in this case, the planning variable is defined by subtracting the very short term variable (up to 3 months) from the 2–5 year long term variable. The differentiation of long-term vs. short-term planners in Figure 10.3 is based on dividing the planning variable in three thirds: the upper third comprises the top long-term planners, the lower third the top short-term planners.

Table 10.1 Results of the Planning-Horizons Study

	Established organization	*New organization*	*Control group*
	Humboldt-Universität (Berlin-Mitte and Campus Adlershof)	Companies of the Adlershof Science and Technology Park	Students (Humboldt-Universität: Berlin-Mitte and Campus Adlershof)
N	559 (employees)	144 (employees)	335 (students)
Planning horizon: content	Management (guiding employees)	Management (guiding employees)	Exams
Planning horizon: weeks (up to 3 months)	63%	76%	65%
Planning horizon: months (up to 1 year)	23%	15%	27%
Planning horizon: 1–2 years	8%	5%	7%
Planning horizon: 2–5 years	5%	3%	1%
Planning horizon: more than 5 years	1%	0%	–
Mean utilization of Berlin-Mitte (city centre)	30%	–	30%
Mean utilization of Campus Adlershof	19%	21%	19%
Mean neighbourhood utilization: leisure	35%	28%	37%
Mean neighbourhood utilization: services	12%	20%	13%
Mean neighbourhood utilization: shopping	35%	28%	37%
Planning-Horizons Hypothesis	Confirmed	Not confirmed (effect is too weak)	Not confirmed (not applicable?)

neighbourhood ($r = -0.26$; $N = 146$; $p < 0.01$). The negative correlation between planning horizon and neighbourhood utilization even increases when we check for variables connected to neighbourhood utilization, such as gender, number of children, hours of work, and campus (city centre vs. Adlershof). For the control group of students, the correlation was positive ($r = 0.29$; $N = 189$; $p < 0.01$). This, however, is not a reliable finding, as the correlation is clearly reduced when checking for campus and other variables and might even be reversed in subsamples (as seen in Fig. 10.3). Figure 10.3 depicts the results for the Adlershof campus. Here, the short-term planners always utilize the campus more than the long-term planners.

10.5 Discussion, Conclusion

The presented analysis is based on a "one-shot" study. The core Planning-Horizons Hypothesis could be confirmed; however, there are so many assumptions made (cf. Fig. 10.1) that it would be easy to construe alternative explanations. We might, for instance, refer to time geography (Hägerstrand 1953); then, restricted time budgets for long-term planners might be a general explanation for reduced local neighbourhood utilization – the Planning Horizons Study statistically controlled at least the

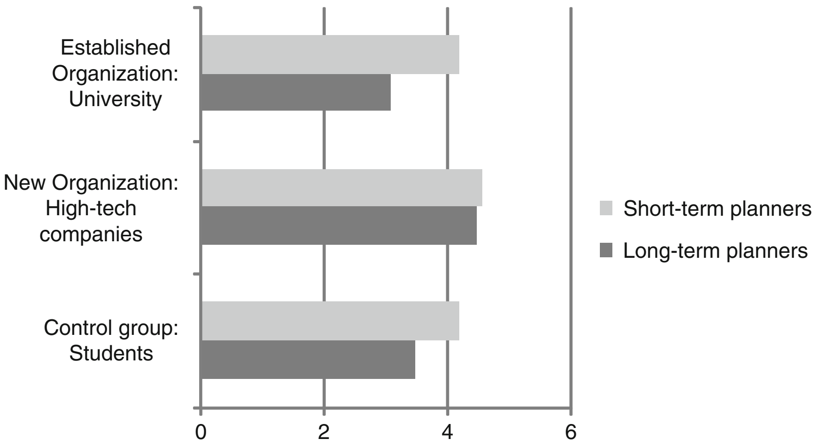

Fig. 10.3 Utilization of the Adlershof campus by the top long-term planners vs. top short-term planners (mean number out of 20 offered categories)

hours of work. Thus, there is still a long way until we know the empirical basis for the underlying assumptions. As Jaques (1976) has theorized, the division of labour in new organizations is not yet elaborated enough to allow for many operating managerial levels; the size of the company and the type of industry do also play a role. The results for the Planning Horizons Hypothesis also underline that the effects are restricted to managerial planning based on division of labour (as conceptualized by Jaques 1976) and do not hold for planning in general (as in the case of students).

The Planning-Horizons Hypothesis provides an explanation why top managers view the work-related neighbourhood of their headquarters in a more abstract, reduced manner – even when staying there as long or longer each day than their employees. This is the reality of the global cities (Sassen 2001) that are hubs in a globalized economy. The business district of global cities becomes globally standardized to keep efficient the work of global professionals and managers of multinational firms. The Planning-Horizons Hypothesis, however, refers to any elaborated organizational division of labour (Mieg 2005): this includes not only multinational companies but also large public institutions such as municipal administrations, federal offices, national professional associations, or universities. In general, these organizations are concentrated in the national capitals or big cities. Thus, the Planning-Horizons Hypothesis is a contribution to metropolitan studies, because it helps understand the determinants of urban life.

The line of argumentation of this chapter started with urban ecology as a sociological endeavour, the terminology being borrowed from biology. Since long, urban ecology has been developed as a project of natural sciences, too. The argumentation of this chapter underlines the bridging function of geography in a now truly interdisciplinary urban ecology (cf. Mieg et al. 2008). Urban ecology provides evidence for the enduring need for geographical theory. The concept of the interaction field by Eugen Wirth is such a piece of geographical theory building. In our case, it helped translate organizational theory (managerial planning horizons) into socio-spatial effects (neighbourhood utilization).

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Chapter 11
Human Perception of Urban Environment and Consequences for its Design

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11.1 Residential Satisfaction: A Theoretical Framework

In psychology, there is converging empirical evidence that it is necessary to differentiate between objective and subjective attributes of the environment and to take into account accompanying processes of perception and evaluation in examining the way humans interact with the environment. Amérigo (1990) and Amérigo and Aragonés (1997) proposed a conceptual framework to reflect residential satisfaction. We argue in favor of a much broader scope to this approach, namely studying the dynamic interaction between individuals and their residential environment, and analyzing the cognitive, affective and behavioral processes taking place in this interaction. The main tenets of this idea are illustrated in Fig. 11.1.

The objective attributes of the residential environment, once they have been evaluated by the individual, become subjective, giving rise to a certain degree of

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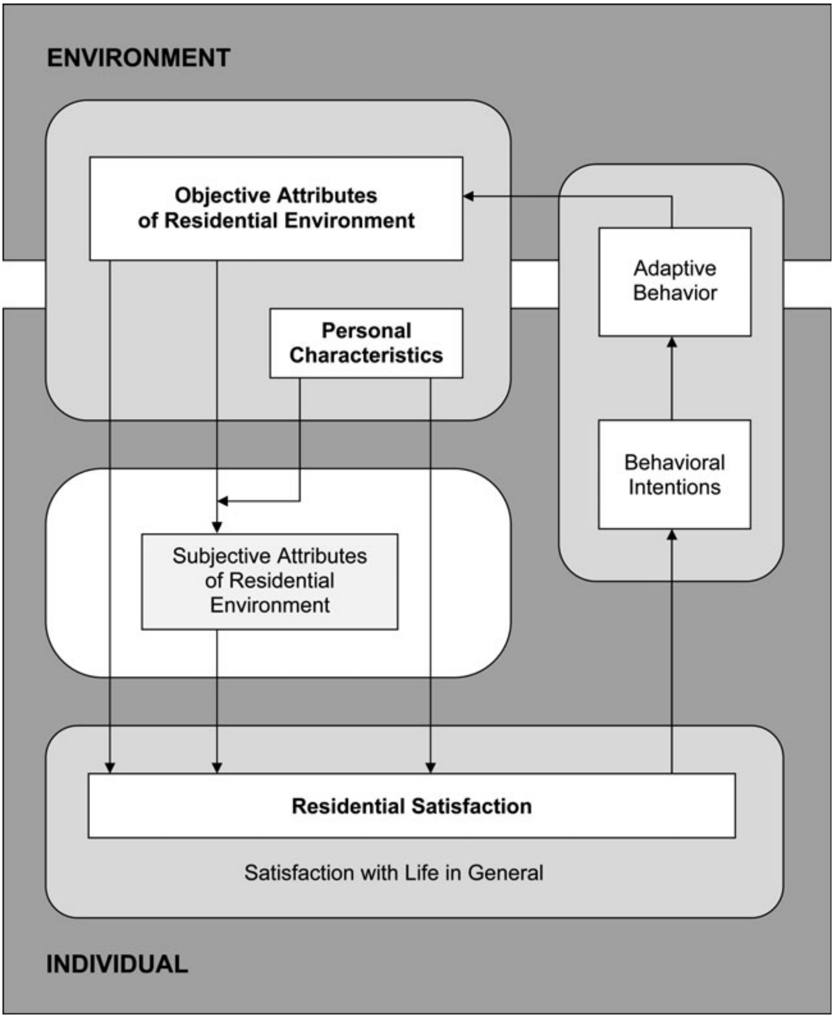

Fig. 11.1 Interactive model of residential satisfaction (Amérigo 1990; Amérigo and Aragonés 1997)

satisfaction. Thus, the subjective attributes are influenced by the individual's background, including socio-demographic and personal characteristics, as well as his or her previous knowledge of a given environment. The result of the evaluation, that is, residential satisfaction, is a more or less positive affective state regarding the environment experienced by the individual. This affective state is assumed to cause the individual to behave in certain ways intended to maintain or optimize congruence with that environment. The present article will use this model of residential satisfaction as a general theoretical framework for analyzing the perception and evaluation of different environmental attributes by applying it to recent developments in the urban environment.

In recent years city planners, developers, and policy-makers have increasingly directed their interest towards designing a more "compact city" in order to achieve an increasingly sustainable urban form. While European cities expanded rapidly during post-World War II reconstruction, ever since the 1970s, there has been a desire to slow down suburbanization and to optimize the use of inner-city spaces. As a recent vision of urban development the "model of the compact city" (e.g., Thomas and Cousins 1996) propagates higher building density along with the idea of multifunctionality, concentrated development in nodes, higher quality public spaces, and reduced traffic. This planning paradigm is regarded as providing many benefits compared to urban sprawl, which include a reduction in land and energy consumption and car dependency, while promoting a higher quality of life and the rejuvenation of existing urban areas. During the last two decades there has been a great deal of building measures aimed at increasing density including the development of empty lots, the addition of storeys, and the narrowing of streets, the last of which is linked to the master plan for inner city Berlin, "Planwerk Innenstadt". An important aim of the master plan is the reconstruction of the historic perimeter block structure, and consequently a considerable reduction of open space. As a result of this development the desirable mixture of urban functions increases, but at the same time the experience of limited spatial conditions for inhabitants of large cities is intensified. In the first experiment, we therefore investigated the perception and affective judgment of dense urban areas by human beings. We asked how specific objective attributes of the built environment (street width, building height, or greenery) correspond to an individual's specific evaluation of relevance and affective satisfaction, as well as overall residential satisfaction. At the same time, this evaluation is expected to serve as a criterion for future urban design.

To come to an important first point, take for instance the attribute "greenery", which can alleviate a pedestrian's negative affective judgments in dense urban streets. In general, urban green spaces enhance residential satisfaction (Bonaiuto et al. 1999) and contribute to physical and psychological health (Berto 2005; Mitchell and Popham 2008; Ulrich 1984). In the second experiment, we therefore investigated the perception and affective judgment of different types of greenery. We focused in particular on vegetation-covered urban wasteland areas, and asked which design measures might increase the appeal of these areas in order to supplement existing traditional green spaces.

Following Amérigo and Aragonés (1997), positively evaluated environmental attributes, residential satisfaction, satisfaction with life in general, and human health are closely interrelated. Thus, sustainable urban development should include the improvement of urban ecosystems, as well as strategies to optimize the quality of life for city dwellers (Bell et al. 2001; Evans 2003; Robin et al. 2007). In the third experiment, we therefore analysed the impact of environmental factors on residential satisfaction as an indicator of well-being in urban areas. To deepen our understanding of the dynamic interaction of environmental and individual factors we combined the conceptual framework of Amérigo and Aragonés (1997) and the cognitive-transactional stress theory of Lazarus (1991) which will be described in Sect. 11.4.1.

11.2 Perception and Affective Judgment of High-Density Metropolitan Areas

11.2.1 Density and Crowding

Crowding describes an affective and, in consequence, motivational state in which an individual experiences a certain degree of density as restrictive (Stokols 1972). In this case the term "density" refers to population density, describing the physical condition of spatial limitation, for example, the number of people per room, flat or acre (Stokols 1972; Desor 1972; Kaya and Erkip 2001). Experimental studies show that crowding is a function of various personal, situational, and cultural factors (Gillis et al. 1996; Sinha et al. 1995; Stokols et al. 1973). In the psychological model by Gifford (2002) three categories of parameters influencing the emergence of crowding are described as (1) the physical setting, (2) the social setting, and (3) personal factors. An own adaptation of his framework is illustrated in Fig. 11.2.

Within the "physical setting" category, Gifford distinguishes between quantitative and qualitative spatial factors. He furthermore points out that crowding is a psychological state yielding stress, which can lead to health problems if experienced over a long period of time. The relevant studies on crowding name physical factors as contextually important but define crowding itself as a social phenomenon. The present study focuses on a completely different aspect of crowding, namely when do people feel confined by the built environment itself, and how can environmental design alleviate these crowding phenomena? In the past, research on crowding has primarily focused on indoor long-term environments like private homes or dormitories. An important and largely ignored aspect of this phenomenon remains how crowding is perceived in public outdoor spaces like urban streets or squares. This study examines the perception and affective judgment of building density in public outdoor spaces – streets in particular – of large cities.

11.2.2 Research Questions

11.2.2.1 Crowding and Objective Measurements of Building Density

Our objective is to identify features of city streets that influence a person's perception and judgement of building density, and which can at the same time be modified in planning processes. But which parameters do city planners use to regulate building density? Architects and city planners deal with objective, purely quantitative measurements like "coverage", "floor area ratio", "building height", or "number of floors" to define the building density of an area. Coverage is defined as the ratio of the area covered by a building to the area of the site (expressed as a decimal fraction), while floor area ratio (FAR) is the ratio of the sum of the whole

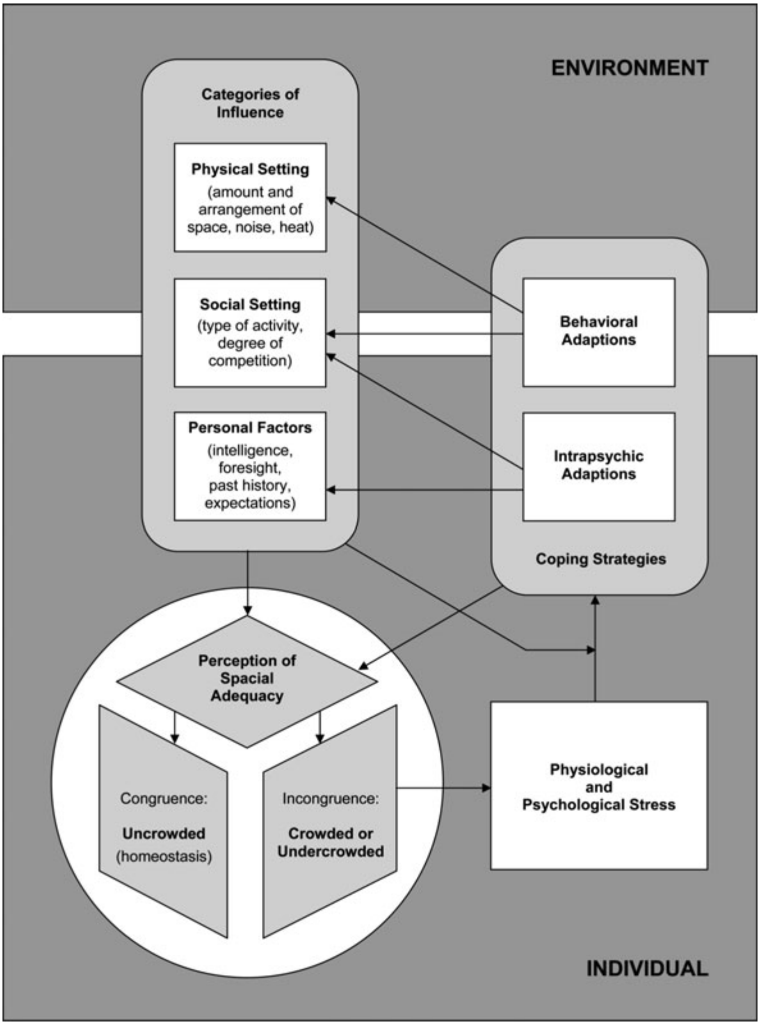

Fig. 11.2 Adaption of the crowding model by Gifford (2002)

built floor area to the area of the site. Another parameter is the specification of a minimal distance between buildings. The main purpose of all these measures is to regulate the intensity of permitted land use for a given area by providing objective criteria for the comparison of different areas. Our first research question is whether these objective measurements can predict the experience of crowding. The architectural features analysed for our study (i.e., street width, building height and storey height) are derived from the quantitative measurements used by city planners, as mentioned above.

11.2.2.2 Crowding and Qualitative Design Factors

In addition to quantitative spatial factors the psychological crowding model by Gifford (2002) also mentions qualitative environmental factors, that is, those aspects of the built environment which are not included in density measures. This includes, for instance, the character of a building or diversity of design. The impact of qualitative environmental aspects on crowding has not been sufficiently studied before. We asked, therefore, which design factors can alleviate a pedestrian's sense of crowding in urban streets and which might even intensify it. In our experimental study two qualitative spatial factors were analysed: the amount of parked cars as an aversive factor and the existence of trees in the street as a non-aversive one (cf., Husemann 2005).

11.2.3 Method

11.2.3.1 Participants

Ninety-five students of psychology, computer science, geography, and history took part in the first experiment. All students lived in Berlin, were native German speakers and had no specific architectural background knowledge. They received either course credit or 5 Euros as payment for their participation.

11.2.3.2 Stimuli and Materials

The study was conducted in a laboratory using computer-simulated pictures of high-density urban street scenes (see Fig. 11.3).

These pictures showed streets from a pedestrian point of view with houses lining both sides. Empirical evidence shows that participants' responses to simulations are surprisingly similar to real life settings. In one study, Bateson and Hui (1992) tested a theory of crowding and showed that using photographic slides to simulate environments evoked the same psychological and behavioral phenomena as the actual setting.

11.2.3.3 Design and Procedure

The following independent variables were used in the experiment (within subjects): street width (14 m vs. 17.5 m), building height (17 m vs. 22 m), storey height (3.10 m vs. 4.20 m), parked cars (7 vs. 14), and greenery (trees vs. no trees in the street).

The experiment took place in a quiet, averagely illuminated room. The participants received oral instructions. All pictures were presented by video projection.

Fig. 11.3 Example of computer-simulated pictures of high-density urban street scenes used in Experiment 1

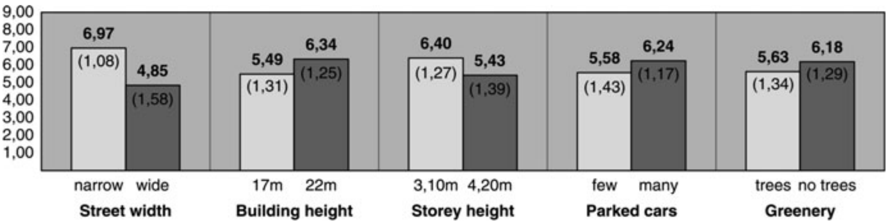

Fig. 11.4 Crowding judgments on design features. Means and standard deviations (SD, in brackets), 1 = not crowded at all, 9 = extremely crowded

The impression of a realistic scene was achieved by the projection size (7.00 m × 4.50 m) and by placing participants at an adequate distance to the projection surface. Participants were presented a sequence of 32 pictures, each shown for 10 s, followed by an interval of 10 s in which the participants rated the street scenes according to their personal experience of crowding. For this purpose a 9-point Likert-scale was used, with "1" corresponding to *not crowded at all* and "9" to *extremely crowded*. The pictures were presented randomly.

11.2.4 Previous Empirical Findings and Current Results

11.2.4.1 Impact of Architectural and Design Features on Crowding

Means and standard deviations (SD) of judgments are illustrated in Fig. 11.4.

Street Width. From the crowding definition mentioned above (Stokols 1972) we derive that spatial limitations due to the width of a street should influence a person's sense of crowding. Stokols et al. (1973) furthermore show that smaller rooms make people feel more crowded and restricted than larger rooms. The statistical analysis revealed a significant effect for street width [t(94) = 19.176, $p = 0.00$]. As predicted, participants rated narrow streets as more crowded than wide streets. The strong impact of street width on the participants' judgments is consistent with Stokols' (1972) assumption related to population density that crowding will result when "the restrictive aspects of spatial limitation are perceived by the individuals exposed to them" (p. 275). Thus, what Stokols points out for population density is also true for spatial limitation by physical features of the environment.

Building Height. Empirical studies have demonstrated that crowding depends on whether the setting provides an open view or not. In one such study, college students rated their dormitory rooms as larger and less crowded if they lived on higher floors and thus had a more open view from their windows (Schiffenbauer et al. 1977; Schiffenbauer 1979). Moreover, the importance of building height was tested in different studies. Gifford et al. (2000) identified building height as one of several important objective elements of a building exterior. The results of this study showed that building height indeed predicts arousal when lay-persons judge a building. Furthermore, Rapoport (1990) confirms that tall elements are likely to create high levels of enclosure. Therefore, we hypothesized that streets with high buildings will be judged as significantly more crowded than streets with lower buildings. This assumption could be confirmed by the results of our experimental study [t(94) = −8.951, $p = 0.00$].

Storey Height. Given a fixed building height, the number of floors within the building can vary. Apartment buildings from the end of the nineteenth century often have a storey height of 4.0 m or more, while contemporary apartment buildings have storey heights between 2.50 m and 3.00 m. Research in indoor situations has shown that men in particular perceive less crowding in rooms with higher ceilings (Savinar 1975; Walden 1981). In addition, there is a correlation between storey height and the floor area ratio measure (FAR) described above. Within a fixed building height lower storey heights are linked to a higher FAR and consequently to a higher degree of building usage. Thus, lower storey heights could be perceived as a cue for a higher degree of spatial limitation. Therefore, we hypothesized that a street will be judged as more crowded when a building has more floors within a fixed building height. The results of our study confirm this assumption [t(94) = 8.951, $p = 0.00$].

Parked Cars. Many studies have shown that people prefer downtown street scenes if there are fewer vehicles (Nasar 1987, 1988). Parked cars in a street reduce the space available to pedestrians and therefore – according to the definitions given by Stokols (1972) – influence pedestrians' perception and experience of spatial limitation. In other words, more parked cars will increase the experience of crowding. In our study a significant effect was observed for the amount of parked cars [t(94) = −8.033, $p = 0.00$]. Participants experienced streets containing numerous parked cars as more crowded compared to streets with only a few parked cars.

Greenery. As Zube (1973) proposes, trees can reduce a city's perceived scale, perhaps making it appear smaller or more comprehensible. These suggestions are not tested empirically, but various studies show that people prefer streets with trees or shrubs compared to non-vegetated urban settings (e.g., Sheets and Manzer 1991; Kuo et al. 1998). Vegetation can obviously alter people's experiences with urban places. Therefore it might also affect a person's sense of crowding. We assumed that streets without trees were experienced as more crowded compared to tree-lined streets. As predicted participants reported significantly less crowding as soon as trees were added along city streets [$t(94) = -6.187$, $p = 0.00$]. The positive influence of trees on the participants' judgments reflects the preference of natural elements in urban settings which has also been found in other studies (e.g., Kuo et al. 1998; Kaplan and Kaplan 1989).

11.2.5 Discussion: Consequences for Urban Planning

Summarizing the findings, it is evident that design factors affect the sense of crowding in street scenes. These results are interesting for several reasons. First, they support our basic assumption that architecture itself can make an individual feel crowded. Therefore, the assumption is confirmed that besides population density building density also has a substantial impact on crowding. These results can be explained by existing theories of human crowding (e.g., Gifford 2002). Our findings validate the practice of applying concepts of crowding to building density. Additionally, the findings provide further empirical support for the impact of design features on experienced crowding in an outdoor setting. It is also shown that variations in street design can alleviate crowding even if objective density is held constant. Finally, the results of the present study point to some necessary changes in city-planning in order to provide a user-friendly compact city structure. These include the suggestion that wide streets, greenery, and a fewer number of parked cars decrease the perception of crowding among residents.

In light of the results concerning the effects of street width on crowding, the contemporary urban development measures in Berlin to narrow streets must be seen critically. In addition, if streets are narrowed, measures to reduce the amount of parked cars need to be taken, for instance, by building parking garages. If storeys are added they should be set back in order to avoid a change in perceived building height from the pedestrian's point of view. Thus, from the perspective of environmental psychology, Berlin's inner city restriction of the building height to 22 m is useful.

The results concerning storey heights, however, do not answer the question of whether on one hand the variation of social cues or on the other hand structural variation of the façade influence the experience of crowding. In further studies the question of how the crowding effect of low storey heights can be compensated by an optimized façade design still has to be answered.

In conclusion, it appears that high urban densities can lead to an increased quality of life if combined with necessary changes in the design of street scenes.

11.3 Perception of Urban Green Spaces: The Example of Urban Wasteland Areas

Urban green spaces have a positive effect on residential satisfaction (Bonaiuto et al. 1999), and physical and psychological health (Berto 2005; Mitchell and Popham 2008; Ulrich 1984). They also affect urban climate – a function that will become increasingly important with the expected changes in climate (Endlicher et al. 2008). While the world is facing rapid urbanisation (United Nations 2008), urban green spaces are especially rare in cities with high growth rates. Given these circumstances, it seems economically and ecologically attractive to re-use vegetation-covered urban wasteland areas for purposes usually served by classic green spaces in ways that do not substantially interfere with flora and fauna. Thus, it is important to know how urban green space is being perceived and used by city dwellers, and how vegetation-covered urban wasteland areas may be sensitively altered to substitute for traditional green spaces where they are unavailable or rare.

11.3.1 Urban Green Space Perception and Use

In a pre-test, we aimed at identifying the visual features – or classification criteria – which are relevant to (a) the perception and (b) the preference of urban green spaces and urban wasteland areas. The participants ($n = 82$; landscape planners and city residents) sorted 24 photographs of parks and urban wilderness areas according to perceived similarity (Rosenberg and Kim 1975) and preference.

From the similarity rating, a number of classification criteria were derived including degree of canopy closure, artificiality, prospect (availability of wide views), and beauty, which have already been used in previous studies of rural nature (Im 1984; Özgüner and Kendle 2006; Real et al. 2000; Shafer et al. 1969). Additionally, the feature "physical accessibility," defined as the possibility to physically enter a site and not visual accessibility, was identified and is particularly relevant for urban wasteland areas. For residents, the degree of canopy closure was the most important classification criterion. For landscape planners, the degree of the human influence on a site was most important. These results indicate that not only simple visual features or basic shapes are important in the perception of urban green spaces and urban wasteland areas, but also higher-level characteristics like physical accessibility.

In regard to preference ratings, some differences between the two groups of participants were found. While the landscape planners preferred naturally developed areas with low accessibility and high species diversity, the residents preferred culturally shaped areas. The residents did not seem to disapprove of using urban wastelands as recreational areas per se, but a minimum level of maintenance and accessibility appeared to be necessary.

For urban wasteland areas to be redesigned as substitutes for green space, the ways in which urban green spaces are used should be considered in the redesign process. In a survey, we therefore analysed the actual use of urban green spaces ($N = 113$ city residents). The analysis revealed passive recreation (e.g., going for a walk, enjoying nature) as most important followed by extrinsically motivated activities like walking the dog, and social and sporting activities.

11.3.2 Increasing the Appeal of Urban Wilderness Areas

In his model of mental functioning, Grawe (2004) assumes four basic psychological needs that humans intend to meet: orientation/control, attachment, self-enhancement, pleasure/avoidance of pain. Adopting this model, urban wilderness areas are expected to be evaluated as increasingly attractive and to be used more frequently the more they match human needs. For example, if an area is designed to provide or convey safety (a key factor for the acceptance of public areas), it will more likely meet the users' need for pleasure/avoidance of pain and will consequently be used more often. Of the four psychological needs to be met, orientation and control can be regarded as one of the most important. There is empirical evidence that humans prefer a medium level of complexity (Berlyne 1970; Spehar et al. 2003). However, the visual input from urban wilderness areas is rather complex due to the high fractal dimensions of plants (Cutting and Garvin 1987; Höger 1997) and the natural, that is, unsettled state of these areas. This complexity is assumed to impair orientation and control. To increase the appeal of urban wilderness areas, we aimed at reducing its complexity by introducing visual structuring and thereby increasing the site's coherence (Kaplan and Kaplan 1989). For that reason, the following design measures were considered in the second experiment. First, mowing certain parts of a site was assumed to decrease the complexity of urban wilderness areas and, thus, to enhance the sense of orientation and control. Second, trails structure urban wilderness areas and facilitate wayfinding. Thus, they decrease the complexity of urban wilderness areas and enhance orientation and control. To test these hypotheses, a rating procedure was used in the current experiment.

A second aim of the study was to support these findings with psychophysiological data. In our study, this was the task-evoked pupillary response, which reflects an overall aggregate of mental resource allocation that is not limited to a specific part of the cognitive system (Aston-Jones and Cohen, 2005; Beatty and Lucero-Wagoner 2000; Just et al. 2003; van der Meer et al. 2010). In essence, the more difficult a task, the more the pupil dilates (Nuthmann and van der Meer 2005; Verney et al. 2004). For the current study, the following global hypothesis holds: Processing highly complex urban wilderness areas consumes more resources than processing less complex urban wilderness areas. Therefore, to test this hypothesis, peak dilation was measured in order to deduce the magnitude of the pupillary response. By measuring peak dilation during the first 3.5 s of stimulus presentation, we were able to compare the results of each participant. For highly complex urban wilderness areas, peak dilation was expected to have higher values than for less complex urban wilderness areas.

11.3.3 Methods

11.3.3.1 Participants

Sixty-eight participants took part in this experiment, 36 women and 32 men, with a mean age of 37.5 years ($SD = 12$). All of them were residents of Berlin and were native German speakers. They were paid for their participation.

11.3.3.2 Stimulus Materials, Design, Procedure

Computer-generated, photorealistic prototypes of urban wilderness areas were created. The following independent variables were varied in the experiment (within subjects): trail type – without trail, narrow unpaved trail, broad paved trail – and open spaces – annually mowed parts of a site vs. wild growth (cf. Fig. 11.5). This resulted in 6 images, three sets of which were used, yielding a total of 18 items. The images were each presented twice (block 1 and block 2). Within each block, images were presented randomly. The participants were instructed to rate each image according to their preference in the personal residential environment in block 1, and according to complexity in block 2. For this purpose 7-point Likert-scales were used with “1” corresponding to *very low preference* and “7” to *very high preference*

Fig. 11.5 Examples of the images used in Experiment 2

in block 1 and with “1” corresponding to *not complex* and “7” to *extremely complex* in block 2.

The experiment took place in a quiet, averagely illuminated room. The participants were seated comfortably in front of a 19″ computer monitor at a distance of 50 cm. Pupillometry was done with an iView system (SensoMotoric Instruments). Pupil diameter was sampled at 240 Hz and the luminance of the stimuli was controlled. In addition, we intended to control the experimental materials for the objective richness in detail. This was done by comparing the file sizes of the images using the JPEG-algorithm (International Telecommunication Union 1993). There were no significant differences.

Analyses of variance were performed to test the impact of the independent variables on the ratings of complexity and preference. Differences between conditions in peak dilation were analysed by subjecting the data to t-tests for every time frame (cf. Satterthwaite et al. 2007).

11.3.4 Results

Complexity ratings. Visually structured sites where annual mowing occurred on certain parts of the site were rated to be less complex than sites without such structuring [$F(1,396) = 5.752$, $MSE = 1.081$, $p = 0.017$]. Adding trails to a scene did not influence complexity ratings ($p = 0.593$). No interactions were observed ($p = 0.876$).

Preference ratings. Visually structured sites where annual mowing occurred on certain parts of the site were rated as more preferable than sites without such structuring [$F(1,396) = 13.907$, $MSE = 1.503$, $p = 0.001$]. Adding trails to a scene did not influence preference ratings ($p = 0.316$). No interactions were observed ($p = 0.890$).

Peak dilation. The pupillometric data showed a similar pattern. The peak dilation for sites with visual structuring was significantly lower than for sites without such structuring ($t = 120.974$, $p = 0.036$). The manipulation in trail design did not influence pupil diameter. The analysis by time frame yielded analogous results (cf. Fig. 11.6).

11.3.5 Discussion

The present experiment clearly suggests that urban wasteland areas with visual structuring – i.e., annually mowing parts of a site – are rated as being less complex. The pupillometric data points to the same results. Visually structured sites produce smaller pupil dilations indicating the presence of a less demanding visual input. Annually mowing parts of an urban wasteland area thus enhances the site’s coherence, leading to an increase in preference as predicted by Kaplan and Kaplan (1989). Similarly, Dörner and Vehrs (1975) argued that detail-rich visual input

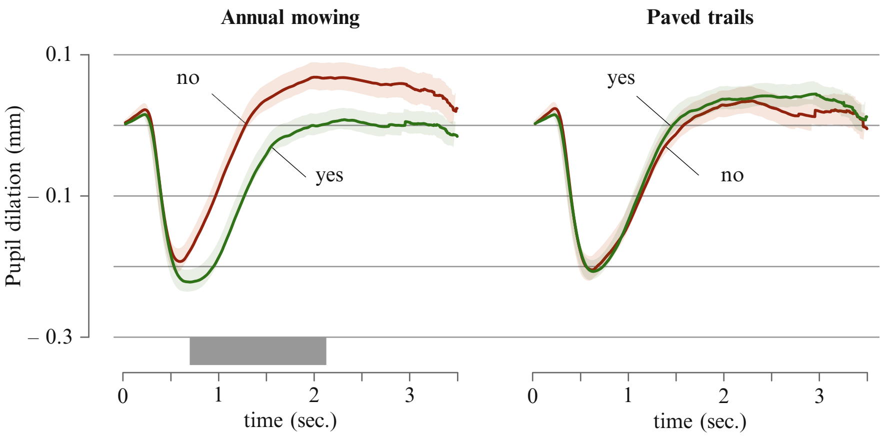

Fig. 11.6 Pupil peak dilation is lower for sites with visual structuring, that is, with annual moving (yes-condition) than for sites without visual structuring, that is, without annual moving (no-condition). This indicates the impact of specific visual structuring on the allocation of cognitive resources for processing the images of urban wasteland areas. In contrast, the manipulation of trails does not affect pupil peak dilation. The *grey* bar along the X-axis indicates significant differences between conditions, the envelopes of the lines indicate the SEM (standard error means)

is only preferred if its uncertainty can be reduced through ordering its details – i.e., structuring the site.

Our findings have a number of implications for the reutilisation of urban wasteland areas. It appears that these areas might prove a good substitute for traditional green spaces if they meet specific human needs (cf. Hofmann 2010). First, urban wasteland areas should be visually structured by, for example, annually mowing parts of the site. This design measure reduces the complexity of urban wasteland areas leading to an increase in orientation, control, and preference by residents. Second, urban wasteland areas must be recognisable as accessible to the public. Third, they should promote different possibilities of use – especially for passive recreation, the most frequent usage. Furthermore, a sense of orientation and control of urban wasteland areas also contributes to perceived safety in these areas. Perceived safety is a key factor in the acceptance of an urban wasteland area. Adding human artefacts like park benches, lanterns, waste bins, etc., or signs of human intervention – such as the annual mowing described above – to urban wasteland areas may signal the presence of helpful others enhancing perceived safety.

11.4 Environmental Stress in Urban Neighbourhoods

With regard to sustainable urban development it is of special interest to investigate if, and if yes, how abiotic and biotic environmental factors affect human health and well-being. This question has mostly been addressed within the field of epidemiology and environmental medicine rather than psychology. However, before city dwellers end up suffering from health consequences such as lung diseases caused by fine dust particles or heat strokes in urban heat islands, they may first experience stress induced by such critical factors. This applies to a much larger proportion of urban populations as severe diseases are usually caused by the concurrence of multiple and often independent risk factors rather than just one. In regard to human health, psychological effects do matter. Human health is defined as a "(. . .) state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (WHO 1946). At the end of the last century researchers began to put more emphasis on psychological processes as mediators in the relationship between objective environmental conditions and human well-being. This is partly due to the fundamental theoretical work of Richard Lazarus' research group outlined briefly in the following.

11.4.1 The Cognitive Stress Theory of Lazarus (1966, 1991)

The cognitive-transactional stress theory of Lazarus and colleagues (Lazarus 1966, 1991; Lazarus and Cohen 1978; Lazarus and Folkman 1984; Lazarus and Launier 1978) explains how stress reactions to environmental stimuli arise by cognitive processes and by a dynamic and interdependent interaction of objective attributes of the environment and personal characteristics. Thus, the theory is most suitable to explain inter-individual differences in reactions to or consequences of stressful environmental conditions. In short, stress is conceptualized as a perceived imbalance between environmental demands and resources to fulfill these demands.

According to the theory, a situation is perceived and evaluated in regard to one's own well-being (*primary or demand appraisal*). If it is perceived as potentially endangering well-being, an individual checks if there are sufficient personal and/or situational resources to cope with the situation. This *secondary* or *resource appraisal* is more strongly influenced by cognitive structures, personality traits and demographic variables like problem solving competences, optimism, self-confidence, age and education, and by the situational context, such as perceived control over the stimuli, social support or financial resources (Carp and Carp 1982; Robin et al. 2007). Only when resources are evaluated as insufficient will an acute stress reaction arise on different dimensions that are not necessarily corresponding. That is to say, stress is reflected in heightened physiological activation, changes in emotional states, at a cognitive-functional level – that is, in attention and performance – and/or in modified social behavior.

Subsequently, a strategy to cope with the actual stress is chosen. Coping strategies are cognitive, emotional or behavioral processes aimed at reducing the acute stress by adapting oneself or by changing the situation (Homburg and Stolberg 2006; Lazarus and Folkman 1984).

Finally, the success of the chosen strategy is evaluated in respect to stress reduction. We refer to this process as *reappraisal*. If stress was successfully mitigated, the same stimulus is less likely to cause a stress reaction the next time it appears. Otherwise, the stress reaction continues or follows should the stimulus reoccur. In the long run, this can result in various detrimental consequences such as mood disturbances, increased symptom reporting, elevated blood pressure, susceptibility to infectious diseases, use of psychotropic substances, or slower recovery from otherwise induced diseases (Adler and Hillhouse 1996; Cohen et al. 1986; Dougall and Baum 2001; Marsland et al. 2001).

11.4.2 The Cognitive Stress Theory in Urban Research

Urban research based on the cognitive-transactional model of stress is primarily focused on emotional rather than perceptual-cognitive appraisal. Unfortunately, the reactions studied in the field of "annoyance research" are varied and not clearly distinguished. Appraisal is surveyed using terms as diverse as *annoyance, disturbance, bother*, *anger*, *displeasure*, *discomfort*, *distress*, or even *concern* (Koelega 1987; Lima 2004). Thus, it is not surprising that research on the same environmental stressors comes up with enormously different results.

Another problem in this field of study is how to determine as to when a person can be considered affected. Do they have to be highly annoyed, or only moderately annoyed? As of yet, there is no conclusive answer in the literature.

Negative environmental appraisal is not only a prerequisite to the experience of stress, it is also associated with social or political actions that support the improvement of the environment (Prester et al. 1987), and with neighbourhood dissatisfaction (Amérigo and Aragonés 1997; Kearney 2006; Marans and Spreckelmeyer 1981).

As neighbourhood satisfaction is related to residential satisfaction and satisfaction with life in general (Amérigo and Aragonés 1997; Campbell et al. 1976), we operationalized it as an indicator of well-being in the urban environment. Besides physical factors, it is influenced by other environmental conditions (Francescato 2002; Hur and Morrow-Jones 2008), and by demographic variables (Galster and Hesser 1981).

One of the limitations of the cognitive-transactional stress theory is that predictions of "objective" environmental stressors are impossible. Hence, researchers attempt to identify stimuli that cause stress with a considerable probability in specific populations. The following stressor classification according to Lazarus and Cohen (1978) simplifies this issue. Environmental stressors can be classified as (1) *cataclysmic events* that affect large numbers of people overwhelmingly like natural disasters or war; (2) *personal stressors* with a powerful and sudden impact like illness or job loss, and (3) *background stressors* that bring about less severe and more gradual changes. The latter are subdivided into *daily hassles* – distinct "events" or instances affecting individuals rather than groups of people – and *ambient stressors*. Ambient stressors are environmental conditions that are perceptible (although they may go unnoticed), chronically present, negatively valued, non-urgent and intractable, meaning they cannot be altered structurally by an individual (Campbell 1983), and are the category of interest in the third experiment.

11.4.3 Empirical Findings and Research Questions

Noise from sources like traffic, industry, crowds, or a high population or building density, air pollutants and ozone, water pollutants, odorous substances, weather conditions like heat waves and cold temperatures, and aspects of visual pollution such as litter, billboards and unaesthetic urban design have empirically been identified as potential ambient urban stressors (Bullinger 1998; Cohen et al. 1986; Craik and Zube 1976; Evans 1982, 2003; Flade 1987; Glass and Singer 1972; Husemann 2005; Robin et al. 2007; Taylor 1982; Taylor et al. 1997; Walsh Daneshmandi and MacLachlan 2000; Zimring 1982). In the third study, we investigated which of these factors are perceived critically in the metropolitan area of Berlin. Moreover, we explored another, more subtle kind of urban pollution – the urban sky glow at night, or *light pollution*. Lately, the issue has gotten into scientific and public debate because of its ecological consequences and because it hinders astronomers' work. It is often argued that light pollution also impacts human well-being. Indeed, constant light exposure has been associated with health consequences such as altered immune functioning or breast cancer (Kloog et al. 2008; Navara and Nelson 2007; Stevens 2006). However, it is unclear whether these effects are due to physiological or psychological pathways, and epidemiological reports remain inconclusive (de Molenaar 2003; Langers et al. 2005; Padgham and Saunders 1995; van Ratingen 2001).

Most published studies on environmental stress have only investigated exposure to a single stressor. However, in real life people react to combinations of multiple stimuli. As suggested by the literature (Bell et al. 2001; Cohen et al. 1986), we hypothesize that the concurrence of several critical factors predicts neighbourhood satisfaction better than a singular factor alone. As there is no indication in the literature, we explore whether multiple factors concur in an additive, an exponential or in an alleviative way.

11.4.4 Method

In order to effectively obtain a geographically wide, demographically diverse and large sample, the third experiment was conducted as an online survey. The questionnaire was developed according to internet research guidelines (see e.g., Gräf 2002; Tuten et al. 2002; Sassenberg and Kreutz 2002) which dictated the questionnaire's instructions, item wordings and sequences, screen randomization, layout, and the general procedures. Data was collected from February to April 2009.

11.4.4.1 Questionnaire

We first assessed demographic variables, information about the housing situation and neighbourhood satisfaction by asking how satisfied participants were, generally speaking, with their proximate living environment on a 7-point Likert-scale, with "1" corresponding to *extremely unsatisfied* and "7" to *extremely satisfied*. Proximate living environment was defined as the area of a maximum two-minute-walk from participants' home. The second section of the survey focused on light pollution. Two 7-point scaled items asked for the actual and desired brightness in the proximate living environment, with "1" corresponding to *extremely dark* and "7" to *extremely light* Participants were further presented with a list of various lighting sources to indicate which ones were visible from their homes and to rate how much they felt disturbed by those on a 5-point Likert-scale, with "1" corresponding to *absolutely not disturbing* and "5" to *very disturbing*. We also assessed whether the term light pollution was known at all. In the final section the perception and appraisal of various factors was measured by similar 5-point Likert-scales. Appraisal was assessed by *impacted well-being* as a comprehensive measure for widely-used terms like annoyance, nuisance or disturbance. We also requested participants to indicate which factor disturbed them the most. At the end of the survey respondents were given more detailed information about the overall research project and the purposes of the study, as well as space for remarks.

11.4.4.2 Participants and Procedure

The survey was kept as short as possible to maximize return rates (Bosnjak and Batinic 2002). It could be completed in 10–15 min and it was possible to leave items unanswered. Participation was limited to Berlin residents with sufficient German language skills and internet access. Participants were recruited by emails distributed through personal networks or student and topic-related mailing lists, by notes in newsletters and on websites of local networks, authorities and initiatives. The only content-related information given was that it was a study on the perception and appraisal of environmental conditions in the urban area of Berlin. As an incentive for participation, participants were offered a report of the results via email. In addition, we promised to forward the outcomes to local authorities.

The survey was completed by $N = 763$ residents from all 12 administrative districts of Berlin. Most submissions were obtained from the central districts Friedrichshain-Kreuzberg (22%), Mitte (13%), and Pankow (13%) while residents of the peripheral districts Reinickendorf and Spandau are underrepresented with only 1% each. Sexes were almost equally represented (54% female vs. 45% male participants with 1% not indicating sex). The age range was 9–80 with an average age of 31 years. The sample was very well educated with 48% having a school qualification for university entrance and 44% holding a university or a similar academic degree.

11.4.5 Results

Light pollution. The term light pollution was known by 51% of the respondents. The mean perceived nocturnal darkness in the proximate neighbourhoods was somewhat higher than the desired ($M = 3.97$ vs. $M = 3.22$). Commercial lighting visible from rather few people's homes like illuminated advertisements/LCD-Displays ($M = 2.66$, $SD = 1.42$, $N = 128$) and laser lights ($M = 2.33$, $SD = 1.45$, $N = 72$) were perceived as the most disturbing. More widespread, unavoidable and safety-related light sources like street lighting ($M = 1.90$, $SD = 0.95$, $N = 558$), traffic lights ($M = 2.01$, $SD = 0.99$, $N = 303$) and interior illuminations ($M = 1.59$, $SD = 0.80$, $N = 586$) were least disturbing.

Environmental perception and appraisal. To explore how the quality or intensity of environmental factors was perceived, we computed the mean appraisals as well as the summed percentage of participants choosing the most and second most negative category of the 5-point scale. The results are displayed in Table 11.1. 32% reported to live in a neighbourhood with quite or very strong traffic noise while the mean perceived traffic noise level is 3.01. In regard to odors, we did not ask participants to rate the perceived intensity and/or frequency as a measure of environmental perception. Instead participants were merely asked if they regularly perceived unpleasant odors. Among the 35% who answered yes, most specified odors from litter and excretions in the public space (31% of this subsample), neighbours (28%), and traffic exhaust emissions (17%).

Among the factors rated by all participants, traffic noise and litter and dirt are the most critical, as shown by mean appraisal ratings and the percentage of participants who chose either of the two as *the most* disturbing one. When unpleasant odors are regularly present, however, they are on average rated even more negatively. Among

Table 11.1 Descriptive results of the perception and appraisal of environmental factors, correlation between mean perception and appraisal of each factor ($r_{\text{ep-ea}}$) and between appraisal and neighbourhood satisfaction ($r_{\text{ep-ns}}$)

Environmental factor	Environmental perception			Environmental appraisal			Correlations	
	M^{a}	*SD*	*Extent*[b]	M^{c}	*SD*	*Worst*[d]	$r_{ep\text{-}ea}$	$r_{ep\text{-}ns}$
Traffic noise	3.01	1.07	32%	2.64	1.13	26%	0.72**	0.17**
Cleanliness resp. litter/dirt	3.01	0.95	28%	2.55	1.13	20%	0.68**	0.29**
Cold temperatures in winter	n.a.+	n.a.+	n.a.+	2.47	1.19	11%	–	0.12**
Air quality	3.08	0.82	20%	2.37	1.05	6%	0.61**	0.21**
Noise by crowds	3.43	0.99	15%	2.31	0.97	11%	0.67**	0.15**
Heat in summer	n.a.+	n.a.+	n.a.+	2.29	1.05	6%	–	0.11**
Artificial lighting	n.a.+	n.a.+	n.a.+	2.09	0.99	3%	–	0.12**
Residential density	2.45	0.79	51%	1.96	0.94	3%	0.33**	0.22**
Industrial noise	4.58	0.69	2%	1.36	0.74	1%	0.61**	0.09*
Subsample								
Water quality ($N = 381$)	2.69	0.93	40%	2.18	1.03	1%	0.37**	0.12*
Unpleasant odors ($N = 269$)	n.a.+	n.a.+	n.a.+	2.98	0.99	4%	–	0.20**

**$p < 0.01$; *$p < 0.05$; +not assessed

[a]High mean perceptions indicate positive ratings in regard to noise sources, air and water quality and little population density

[b]Extent is the summed percentage of participants who chose the most and 2nd most negative/intense category

[c]High mean appraisals indicate strong impacts on well-being

[d]Worst is the percentage of participants disturbed most by the corresponding factor

the 27% who indicated that there were other factors in their proximate surroundings which impacted their well-being, most referred to noise from various sources (6% of the total sample), to a lack of public green space and the absence or the cutting down of trees (5%), and to dirt and canine excrements (4%).

As the correlations in the second last column of Table 11.1 show, environmental appraisal is to a large extent determined by the perceived quality or intensity of most factors except water quality and population density. This implies that the appraisal of these two latter factors is influenced stronger by non-perceptual factors. In other words, the perception of a poor quality of open urban waters or a high population density does not necessarily imply feelings of impacted well-being.

Neighbourhood satisfaction. The correlations of environmental appraisals and neighbourhood satisfaction are displayed in the last column of Table 11.1. While the majority of the sample (68%) indicated to be at least quite satisfied, 14% of the participants were extremely, very or quite unsatisfied with their proximate neighbourhoods, with another 17% neutral and 1% missing.

Concurrence of several potential stressors. Regression analyses were used to test if neighbourhood satisfaction can be better predicted by several concurring factors than by a singular factor alone (see Cohen et al. 2003). At first we examined the influence of several control variables including age, gender, education, parenthood, duration of residence, housing type, and time spent at home on average weekdays. Only gender was found to be significantly associated, with women less satisfied with their neighbourhoods ($M = 4.76$, $SE = 1.36$) than men ($M = 5.08$, $SE = 1.20$), $t(745) = -3.39$, $p < 0.01$. To reduce the amount of variables for hypothesis testing a multiple forced entry regression was performed with all eleven appraisal variables. We set $\beta = 0.15$ as the minimally required strength of influence. Accordingly, we ran a hierarchical regression with the appraisal of litter and dirt, and industrial noise. In the first step the two variables were entered simultaneously. In the second step the multiplicative term of the two variables was added to test for an interaction effect. The predictors were z-transformed to counterbalance different standard deviations and to reduce multicollinearity (Jonas and Ziegler 1999). We found a small main effect only for the appraisal of litter and dirt ($\beta = -0.29, p < 0.001; R^2 = 0.09$). It cannot be traced back to gender differences because the respective correlations do not differ significantly between the two groups ($Z = 0.465$). The interaction term was not significant, and therefore the main hypothesis of this study could not be confirmed.

11.4.6 Discussion

Traffic noise, litter and dirt, unpleasant odors, cold temperatures in winter and air pollution were rated the most critical ambient stressors in the urban area of Berlin. Moreover, insufficient public green space and near-by vegetation also seem to influence well-being in neighbourhoods. That is, the survey may have primed subjects to think of stressful conditions when they were asked for other negative factors. As we did not present urban greenery as a factor to be rated, we cannot compare it to ambient stressors at this time, but the indication in an open question should be weighed more than when respondents only react to presented factors.

Better educated people tend to evaluate the environment more critically (Marans 1976; Robin et al. 2007) and our respondents might have a rather high degree of awareness of pollution as voluntary participation attracts people with interest in a specific topic. However, we suppose that the extent of negative appraisals is rather underestimated here for several reasons: First, the variance in objective environmental loads in our participants' neighbourhoods may be reduced. The high education degrees in our sample suggest that our participants have a rather high socioeconomic status. However, as discussed in the environmental justice literature (cf., Bolte and Mielck 2004), it is the lower and middle class groups which usually live in areas with higher degrees of pollution. Second, individuals generally do not like to express negative feelings (Boucher and Osgood 1969). They might also correct their evaluations unintentionally to reduce cognitive dissonance (Festinger 1957). For instance, if it is easier for city dwellers to change their attitudes instead of their actions, they might correct their environmental appraisal rather than move away. Similarly, correction of the evaluation may occur when respondents cognitively habituate – that is they become accustomed to – stressful environmental conditions. Habituation – to be distinguished from physiological adaptation – is a mechanism that occurs when no suitable coping strategies are available for constant stress-inducing stimuli. It can also be interpreted as a cognitive reappraisal that the stimulus deserves less attention (Bell et al. 2001). Habituation may avoid breakdowns due to stressful stimuli, however it is problematic as it can deplete resources and result in stress disorders in the long run (e.g., Cohen et al. 1986; Craik and Zube 1976). The more predictable and the more regular stressful stimuli are, the easier it is to habituate to them (Glass and Singer 1972). This could be a reason for the highly negative appraisals of unpleasant odors and litter and dirt in comparison to, for example, constant air pollution.

For the same reasons, individuals usually indicate moderate or total satisfaction with their homes, relatively independent of the environment (Marans 1976). Hence, our finding that one third of the sample is not satisfied might be a conservative estimation, which is an undesirable outcome for Berlin: Neighbourhood satisfaction is not only a desirable state for individuals but also a societal issue. Unsatisfied residents behave less responsibly and are less likely to maintain semi-private areas, display less neighbourly behavior and are more likely to move away (see Flade 1987; Gärling and Friman 2002). This can contribute to the impoverishment of residential areas as the people with higher mobility are the ones with a higher income.

We could not confirm that the concurrence of more potential stressors predicts neighbourhood satisfaction better than one dominant factor. At this point we can only speculate why. Koelega (1987) supposed that coping with one stressor may increase vulnerability to other stressors. We intend to test his assumption with more direct stress and health indicators in further studies. As constant environmental loads may cause over-activation and thus enhance vulnerability on a physiological level, we will additionally apply a physiological stress measure and contrast the findings with more subjective stress indices.

11.4.6.1 Implications for Sustainable Urban Development

Neighbourhood satisfaction could be partly predicted by the appraisal of cleanliness of the proximate surroundings, which was also rated the most critical factor besides the well-known problem of traffic noise. Thus, litter and dirt in the public space is not only an aesthetic problem. We suggest that despite the economic problems Berlin is currently facing, the city should allocate more resources to this issue. Besides more frequent cleaning, more and bigger trash bins, or public campaigns and information, more research is needed to understand why people litter and how their behavior can be changed other than by implementing fines. At present, we are going to examine these aspects in more detail.

11.5 General Discussion

Adopting the conceptual frameworks proposed by Amérigo (1990), Amérigo and Aragonés (1997), and Lazarus (1991) we have reported three studies that investigated the relationship between objective attributes of residential environments and their subjective representations, including cognitive and affective judgements, and task-evoked pupillary responses as an indicator of cognitive resource allocation. The overarching goal of this work was to better understand the dynamic interaction between individuals and their residential environment by analysing the different processes – cognitive, affective and behavioral – which take place in this interaction. In addition we aimed at examining measures to design the urban environment according to the needs and preferences of residents. These design measures are expected to enhance residential satisfaction and satisfaction with life in general just as human health. Our study focused on Berlin as an example and prototype of a high-density residential environment.

The studies yielded the following main findings. First, besides population density building density also has a substantial impact on crowding. This was shown by manipulating specific attributes of the built environment, namely street width, building height, storey height, the number of parked cars, and greenery. Second, besides urban green spaces, vegetation-covered urban wasteland areas may have a positive impact on residential satisfaction. Third, and most importantly, specific variations in environmental attributes can reduce crowding of street scences or enhance preference of wilderness areas even if objective density or richness in detail is being held constant. The effective design measures are: reducing the amount of parked cars, adding greenery to street scenes, and visually structuring urban wasteland areas. Fourth, the following abiotic and biotic attributes of residential environment, namely traffic noise, litter and dirt, unpleasant odors, cold temperatures in winter, air pollution, insufficient public green space and near-by vegetation proved to be the most critical ambient stressors in the high-density metropolitan area of Berlin. Light pollution, in contrast, had a comparatively small impact on human well-being.

What do the results of our study tell us about needed changes in city-planning in order to provide a user-friendly city structure? From the perspective of environmental psychology, well-founded changes in the urban design or in current city planning like, for example, keeping wide streets and the inner city's restriction of the building height, providing a variety of greenery including nearby vegetation and structured urban wasteland areas, and building parking garages can lead to increased quality of life (cf., Wentz 2000; Thomas and Cousins 1996). Given these changes, living in a compact city could be conceived of as an attractive alternative to single-family housing in residential suburbs. Thus, the question of urban design is crucial in order to reduce rapid suburban expansion and its negative ecological and economical consequences. It is also crucial in enhancing residential satisfaction and human health.

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Chapter 12
The Social Construction of City Nature: Exploring Temporary Uses of Open Green Space in Berlin

Julia Lossau and Katharina Winter

12.1 Introduction

For several years, Berlin has been celebrating the so-called Day of City Nature (*Langer Tag der Stadtnatur*). Organised by the Berlin Conservation Foundation, the annual event aims at providing opportunities to experience the diversity of fauna and flora to be found in the German capital. The success of the Day of City Nature indicates that there is considerable interest for nature in the city and for its protection. As in previous years, thousands of Berliners participated in the 2010 Day of City Nature, exploring "real nature" on their way "through the metropolitan jungle" (www.langertagderstadtnatur.de; transl. JL). The relationship between the human inhabitants of Berlin and "their" nature, however, is not always as harmonious as the Day of City Nature suggests. In particular, some residential areas on the Western fringe of the city are notorious for conflicts between the social and natural worlds. Many residents of Grunewald whose gardens are ransacked by feral pigs suffer from what they regard as a menace. After a series of dangerous hog attacks, angry Berliners insistently required the animals to be shot. As a consequence, the Senate Department for Urban Development has issued a website with guidelines for encounters between humans and feral pigs (www.stadtentwicklung.berlin.de/forsten/wildtiere/de/wildschwein.shtml).

Different from the Berlin-wide Day of City Nature, the example of the wild boar of Grunewald demonstrates that nature does not necessarily represent a subject of harmony – but one of conflict – and that each conservation strategy, therefore, faces a fundamental problem: It is simply impossible to protect nature *as such* (in the sense of all nature and all of nature). What can be protected are only specific and concrete elements of the natural world (Hard 2001). Gerhard Hard describes the problematic nature of this dilemma:

> Wherever nature is protected, it is never nature (all nature and all of nature) (. . .) that is protected. (. . .) In this respect, all conservation strategies and all pro-nature politics always

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> and by necessity imply the destruction of nature. Orchids yes, nettles no, and if nettles, then not where orchids are to be protected – and no knotgrass under any circumstances. (. . .) In one case, hedges with trees are planted to provide shelter to specific animals; in other cases, hedges with trees are destroyed to prevent specific beasts from finding lair (Hard 2001; transl. JL).

At closer inspection, therefore, the seemingly harmonious and holistic field of (all) nature decomposes into a series of different, pluralistic, and antagonistic natures. While some of these natures are said to deserve our protection, others are represented as a menace and consequently have to be defeated. The decisive question of which part of nature is to be protected and which to be defeated, however, is never answered by nature itself, but is a question of social evaluation and political judgment.

To some extent, such a perspective runs counter to our common sense. By saying nature in everyday language, we usually refer to a somehow organic domain, which is located outside of society and therefore not negotiable. In contrast to this everyday account, it is suggested in the following that there are many different perspectives on what nature is and on what parts of nature are to be conserved or, conversely, to be disposed of. From the point of view of this chapter, nature is not given *as such* but is regarded, imagined, or constructed differently in different times and places. By taking up such a viewpoint, the authors follow a cultural-historical perspective, which is related to a constructionist epistemology in a broader sense. While such an epistemology has had considerable impact on the mainstream of Anglo-American cultural geography in the past two decades (for the debate on nature-society relations see, e.g. Castree and Braun 1998; Demeritt 2002; Whatmore 2005), constructionist arguments are hardly made productive in the field of German-speaking urban ecology.

Against this background, the aim of this paper is to answer three questions: What is meant by the "social constitution of nature"? What do we see when we look at city nature from a constructionist point of view? What are the challenges posed by a constructionist viewpoint for urban ecology? In order to answer these questions, we will proceed in three steps. First, we will briefly outline the theoretical background of the constructionist perspective. In the second step, we aim to empirically show that there is not only *one* city nature. Presenting preliminary results from an ongoing research project on temporary uses of open green space in the city of Berlin, we will identify a number of everyday representations of nature which surface in the arguments and conflicts about the question of how urban space should be used. Finally, we discuss the challenges of a constructionist perspective for the field of urban ecology.

12.2 Nature from a Constructionist Perspective

In an early paper on "constructed natures", geographer Michael Flitner writes

> All [theoretical] perspectives which draw upon the construction of nature share the opinion that the access to the dominion of what is commonly regarded as nature (in contrast to culture or society) is problematic or precarious. Every perception, thought, expression, or

> action in relation to nature (. . .) is said to be mediated, is said to be based on a construction. Formulated pointedly in the words of [Donna] Haraway (1992: 296): "Nature cannot exist prior to its construction" (Flitner 1998; transl. JL).

In the course of his paper, Flitner distinguishes four approaches which act on the assumption that nature is constructed (ibid.). We will not elaborate on these approaches in detail, but we will rather work out, by means of a simplification to heuristic ends, the basic theoretical assumptions of constructionist social theory.

Generally speaking, social constructionism claims that "for society, the world exists only in so far as it has been ascribed a specific meaning by society on the basis of the latter's symbolic orders (. . .)" (Reckwitz 2000). Put differently, reality is not regarded as pre-given, i.e. given independently from social structures or agency, but as constituted by signifying practices, which in turn are based on socially and culturally specific symbolic orders. What is experienced as reality is thus inevitably shaped by the way it is constituted in processes of sense making by social actors and interpreted by them according to their worldviews.

Having said that, constructionist arguments do not apply solely to the individual or subjective level in the sense of everybody constructing their own worlds. On the contrary, they are especially valid for the inter-subjective level of social life, i.e. for socially shared meanings and for culturally specific patterns of interpreting and experiencing reality that we have learned in the course of our lives and that we usually do not put in question but rather take for granted. In light of the above discussion, the aim of a constructionist analysis is to challenge taken-for-granted assumptions and to excavate the symbolic orders, interpretive schemes, semantics, and cultural models by which reality is constituted by social groups and individuals (e.g. Reckwitz 2000; Eickelpasch 1997).

Coming back to the social construction of nature more specifically, it can be argued that, like reality, nature is not simply given, but is powerfully shaped by the human imagination. It has to be made sense of, and "is unavoidably filtered through the categories, technologies, and conventions of human *representation* (. . .)" (Whatmore 2005). Our representations of nature do not mirror an objective or universally valid knowledge about the role, function, or "essence" of nature but are, on the contrary, dependent on culture-specific knowledge systems. These knowledge systems are changing over time because they are subject to a certain form of zeitgeist. They also vary, however, at a given time since "there are many incompatible ways of seeing the same natural phenomenon, event, or environment" (Whatmore 2005).

From the perspective of social constructivism, nature "is (. . .) therefore best treated as a part of culture" (ibid.). What we know from the Alps, for example, are first and foremost our cultural representations of the Alps as they have been produced in the filtering process of our imagination. This filtering process has been described as a "way of seeing" the natural world that is culturally specific and contingent, but never neutral (Cosgrove and Daniels 1988; Berger 1972). We see in the Alps what we have learned to see. While this applies to all people, not all people see the same: Mountain farmers will have very different representations of the pastures they cultivate as the tourists who perceive the pastures as "sunny

Fig. 12.1 Photographic representation of the Alps (photography: Katharina Winter). In line with the visual character of tourist experiences, the tourist sector has institutionalised a certain 'way of seeing' the Alps as a natural environment. While there are many different ways of picturing mountain sceneries, both marketing institutions (like travel agencies or tour companies) and tourists themselves often represent the Alps as a fresh and healthy space by conveying imaginations of unspoiled remoteness ready for outdoor activities

meadows" they recognize from Luis-Trenker movies, Heidi books, or travel guides (Schlottmann 2006; see Fig. 12.1).

According to the Canadian landscape architect Alex Wilson, our representations of the natural world are instrumental in constituting our sense of what nature is like:

> Our experience of the natural world – whether touring the Canadian Rockies, watching an animal show on TV, or working in our gardens – is always mediated. It is always shaped by rhetorical constructs like photography, industry, advertising, and aesthetics, as well as by institutions like religion, tourism, and education (Wilson 1992).

Once the knowledge from these various sources has been transformed into stable patterns of representation, we usually assume that our conventional habit to see a specific segment of reality (say a sunny meadow) as nature is objectively correct and "true to life". We forget that we operate within a highly contingent, culturally specific system of knowledge, constantly objectifying our representations. The aim of the constructionist perspective is to render visible this forgetfulness. Its mission is to reconstruct the hidden cultural filters that serve to produce or construct certain representations of nature and thus to unravel the cultural and social contents of the natural world.

12.3 Representations of City Nature in Temporary Uses of Open Green Space

The following section aims at exploring everyday representations of city nature as they play a role in temporary uses of urban open green space. In our research, the term "open green space" is not used in a definite but in a qualifying sense. The first adjective (*open*) conveys two different notions of openness. On the one hand, we are interested in urban areas which are free from buildings or massive material infrastructure; on the other hand, the areas included in our research are open in the sense that they provide possibility spaces for the development of temporary uses. The term of temporary (or interim) uses refers to specific forms of non-permanent uses of urban land. In the literature on temporary use, the users are often characterized by a high degree of initiative and a low degree of financial capital, which leads to specific social and political constellations (SenStadt 2007; Schlegelmilch 2009; Oswalt 2002). There are various reasons why urban spaces are temporarily used (e.g. Arlt 2006; SenStadt 2007). Unresolved questions of ownership often pave the way for a relatively unproblematic appropriation of land. Sometimes it is also the lack of more lucrative investment alternatives which allows for uses that have otherwise fewer opportunities to exist in urban areas. Typical forms of temporary uses involve creative projects, social initiatives, catering services, or community gardens.

Forms of urban *green* spaces range from English lawns, French gardens, allotment gardens, green buffers, to the fallow vegetation of brown fields (for a more elaborate systematic of urban green, see Kowarik 1992). In all of these green spaces, however, the everyday assessment of nature by different interest groups is as diverse as it is riddled with conflict. In the case of temporary uses, stakeholders include users, urban decision-makers, landowners, and adjacent residents. The resources of the stakeholders vary greatly both in economic terms and in their power in the decision-making process. It is by illuminating the reasoning of the stakeholders in the negotiation of a given use of available land and on the importance of nature in particular that we intend to identify different understandings of nature.

Our research examines temporary uses of three open green spaces in Berlin which differ in the stage of their development. The first example, the intercultural community garden *Garten der Poesie* (Garden of Poetry), is still in the making. Community gardens in cities are jointly and voluntarily operated by a group of people. In general, public access is provided which makes community gardens very different from urban allotments (Haidle and Rosol 2005; Müller 2009). Our second example, the *Tentstation*, is an urban campsite on the premises of a former outdoor swimming pool. Initiated more than five years ago, this popular form of use is currently threatened by the development of a spa. The third example is the *Wagendorf Lohmühle* (trailer village Lohmühle), a year-round inhabited "village" of 19 caravans and converted trucks which was founded almost 20 years ago at an open green space on the former "death strip" of the Berlin Wall. The inhabitants of the trailer village have a temporarily limited use agreement with the city of Berlin, who owns the space.

In order to unravel the representations of nature embedded in the development of the case studies, qualitative methods were used. Apart from participant observation, we conducted semi-structured narrative interviews with all relevant stakeholders like initiators, users, urban decision-makers, investors, and residents. Following an initial classification, the ways of reasoning identified in the interviews can be assigned to three different representations of nature: useful nature, beautiful nature, and sensitive nature.

12.3.1 Useful Nature

Nature in urban areas is often evaluated according to the benefits it provides. Not intrinsic values, but questions about concrete benefits for the urban society are put forward as arguments for the existence and maintenance of nature. In our interviews, differing understandings of a reasonable use of nature have been articulated. With regard to the future community garden, for example, the use of land as an orchard with the concomitant possibility of harvesting is assessed as appropriate and beautiful by the initiators, while use as dog run is not. In this respect, one of the initiators dislikes the idea that the apples of the orchard are "misused" by dog owners:

> But, the apples are sometimes used by the dog owners to train their dogs. They throw them... so it's not, speaking of nature, how nature is used appropriately and in the end makes people happy (interview *Garten der Poesie* I; transl. KW).

The interpretation of nature as useful nature thus leads to contrasting ideas of how to use nature in an appropriate manner. For the community gardeners and their supporters, it is important that the garden is beneficial and recreational for as many people as possible and that it produces food. Regarding food production in urban community gardens, Marit Rosol and Ella Haidle speak of the "countryside in the city" (Haidle and Rosol 2005; transl. KW). This expression can be interpreted, on the one hand, to allude to the idea of a gradual dissolution of the urban-rural dichotomy, in which the urban and the rural are combined in the community garden. On the other hand, speaking of the countryside in the city reinforces the dichotomy of city and countryside, and city and nature. This ambivalent relationship can also be found in the arguments of the initiators of the campsite:

> It is nice this work outside. (...) We are all from small towns, you know? This way you get some sort of small-town feeling – nature in the city – and memories of childhood come to your mind (interview *Tentstation* I; transl. KW).

By speaking of "nature" and calling it "to be outside", the initiators of the campsite invest the area with memories of their childhood, connecting it to ideas of small-town living.

A representation of nature as useful is also found in arguments to increase the attractiveness of certain parts of the city by means of nature. Such an idea is articulated, for instance, in the case of the community garden, which has been considered in most of the related interviews as upgrading a neglected, rundown area. On the one hand, gardening interventions can be regarded as measures to qualitatively improve an area, leading to greater benefit for the population. On the other hand, gardening activities and their material outcome – flower beds, herb gardens, vegetable patches, etc. – replace what is regarded by the gardeners and other stakeholders as improper use (i.e. use as a dog run or as an area vandalized by young people) or no use at all. In this sense, the material practices of community gardening can be said to produce a certain degree of social control.

In their study on community gardens, Haidle and Rosol (2005) concluded that the evaluation of existing green as of poor quality or the criticism of unused land are two of the reasons why community gardens are implemented. Such gardens are "useful" in economic terms, not only for the urban institutions in charge of the plots but also for the property management of the adjacent residential buildings. By means of community gardening, the areas are improved by the voluntary commitment of the users, but mostly without monetary investment by the urban institutions or the owners.

Another dimension of useful nature comes to the fore in the case of the *Tentstation*. The success of this urban campground is based, amongst other things, on the atmosphere of the site. It has been argued that nature is an important part of that atmosphere (e.g. Plarre 2008; Heid 2009). According to the interim users, the atmosphere of the reused site resonates with a form of nature, which is preferably left unaltered. Nature is regarded here as functional, self-acting, and therefore practically useful for the campground:

> At the same time, nature is really practical somehow. It grows on its own. And, it would be more of a hassle to remove the bushes here (interview *Tentstation* I; transl. KW).
>
> We as temporary users, we don't maintain the area too much. Because we think: after us the demolition. (. . .) Because of working with lots of broken or rarely painted stuff, then somehow nature makes it beautiful. But, it was never a conscious decision. It was kind of a convenient decision to speak out for nature (interview *Tentstation* I; transl. KW).

A more pragmatic but still beneficial representation of nature surfaces in arguments of the people living in the trailer village. According to one of the inhabitants, existing nature has been shaped by the people who live there. The plants are watered only if there is time to water them, and the vegetation is influenced by the inhabitants who brought certain plants and not others:

> And this is the first tree that stood here, that one over there. And it is only there because a bird dropped a seed there and the guy who lived where the little tree grew always put his coffee brewing on it, quasi as a kind of speed-composter. (. . .) And that is why it could grow (interview *Lohmühle* I; transl. KW).

12.3.2 Beautiful Nature

Some arguments already mentioned entail a further representation of nature. According to one of the interim users of the community garden, "it is somehow beautiful, such an orchard in the city" (interview *Garten der Poesie* I; transl. KW). Likewise, the arguments of the temporary users of the *Tentstation* convey a representation of a beautiful nature when the wild growing bushes are said to be appreciated by the users and when the derelict site of the *Tentstation* is "somehow made more beautiful" by nature (interview *Tentstation* I; transl. KW). What is put forward here is the idea of a beautiful nature in the sense of an aesthetic or pleasant nature. In a study on the aesthetic perception of urban open spaces, Wulf Tessin (2008) argues that the terms "beautiful" and "green" are the two most frequently used concepts in relation to open spaces. In the arguments brought up in our interviews, at least two understandings of beautiful nature can be differentiated. On the one hand, there is the idea of a "wild" nature; on the other hand, there is an understanding of gardeners' green as beautiful nature.

The appreciation of "wild" nature as beautiful figures, for instance, in the statement of one of the initiators of the *Tentstation*:

> But, we even think it's beautiful (. . .) especially these bushes here between the steps, which break up the concrete slabs, and all the time, we have to renew these steps with cement. Or right here at the rim of the pool, we always let the plants grow. Now you can see that the entire rim of the pool is falling off (interview *Tentstation* I; transl. KW).

Apart from the pragmatic view of nature already discussed, an understanding of self-acting nature as beautiful can be identified. This relates to a nature that has an autonomous character and grows by itself, without human intervention (for the notion of wilderness, see Kirchhoff and Trepl 2009; Trepl 1998; Rink 2005). This "wild" nature is also present in the following passage, where one of the initiators of the *Tentstation* describes her first impression of the site:

> It was something like love at first sight. And nature has played a major role. So just this enchanted place, that one can imagine being in Sleeping Beauty, which is like in a hundred years of slumber. And it's just the thing that you just find it a nice site. (. . .) and that is that green here. . . (interview *Tentstation* I; transl. KW).

The idea of uncontrolled growth, however, is not always appreciated as "beautiful" or desirable. The extent to which wilderness in urban areas is assessed as good and acceptable differs from context to context. A site that is largely left to itself, for instance, can either be described as "beautiful" or as "neglected" (Tessin 2008; Hannig 2006). In the case of the campsite, such unaltered nature is welcomed by the temporary users. Regarding the area of the future community garden, in contrast, the lack of gardening and maintenance is interpreted as a symbol of neglect. Therefore, its nature is not regarded as "beautiful", but "shabby":

> The former beautiful park that was created here in connection with this housing estate is simply run-down, as you can see. It is no longer used by the neighbours. They pretty miss it. And it is shabby. The dogs, they dig here, they poo here. Last year, there wasn't any grass in the whole area. There have been branches pulled down, you see. There are dead trees; I mean the trees are not maintained anymore and therefore they die or break apart (interview *Garten der Poesie* I; transl. KW).

One of the most fundamental arguments for the establishment of the community garden is to improve a neglected area by means of gardening. In so doing, reference is made to the former "beautiful" park that the community garden is meant to replace.

The arguments of a gardened nature as "beautiful" nature convey a specific idea of the relationship between cities and nature. This understanding is in line with a conception of nature which regards the gardeners' green as mastery of the "wild" nature (Tessin 2008). The reasoning with the "domesticated elements of nature" (Chilla 2004) is based on a dichotomous view of the city-nature relationship. The undomesticated nature is regarded as external to the city. Nature within the urban area is considered as desirable only when it is subject to gardening or horticultural activities.

12.3.3 Sensitive Nature

Arguments concerning the use of open green space comprise a further representation of nature – a representation that regards the city nature as sensitive. As in the case of beautiful nature, two understandings can be differentiated. On the one hand, urban nature is imagined as needy; on the other hand, urban nature is imagined as a resource that needs protection. In the representation of a needy and therefore sensitive city nature, the evaluation of the gardeners' green as aesthetic can be interpreted in the light of a dichotomous understanding of city and nature. This nature in the city is regarded merely as a substitute (Tessin 2008), since according to the dichotomous understanding, "true" nature can only be found outside the city. Nature is seen as threatened by the urbane. The urban gardeners' green is thus assigned a symbolic, restorative function.

The idea of city nature as a means of restoration can be found in one of the interviews about the *Garten der Poesie*, where one of the initiators speaks about the "awakening moment" which led to the idea of implementing the community garden:

> It was really like a kind of awakening moment. I have seen this pond there behind the bushes and it was terribly run-down. There was no water in it and all sorts of rubbish. So I honestly said to the pond: I will help you. I felt so sorry for it. Like disgraced beauty, which indeed plays an important role in the city. That when something is already destroyed people still kick it and destroy it even more and throw garbage and stuff on it. (. . .) So it was like my vow. I said I'll help you. And then I thought of a way to help it (interview *Garten der Poesie* III; transl. KW).

Also on a later date, when there were first activities on the site (documented on the website of the *Garten der Poesie* www.rixdorfgarten.de), the depiction of a 'proper' handling of the fruit trees reveals a conservationist idea: "The 'children of the garden' have adopted the devastated fruit trees. We have created protective covers from dead wood, 'help to self-help' – so the children cannot climb up to take off unripe fruit and throw it" (www.rixdorfgarten.de; transl. KW).

In the section on useful nature, it has already been mentioned that the present shape of nature in the trailer village is interpreted as resulting from interventions (or non-interventions) of the residents. In the basic decision to treat soil and vegetation ecologically as documented in the philosophy of the trailer village (www.lohmuehle.de), one can also recognize a sensitive understanding of nature: "Every stone, every insect, every plant, every animal, and every person is equal and has its task" (ibid.; transl. KW). Moreover, the way of life of the inhabitants of the trailer village speaks of a resource-sparing handling of nature. Resource awareness is expressed, for instance, in their decision to live "off the grid", i.e. without connection to water and electricity networks. The consequences of this decision are described by one of the residents as follows:

> Everything I need I have to bring in here. And I also have to carry it away again. (. . .) We collect our own energy. I have to pay attention in wintertime (. . .) do I have enough energy, how is the weather going to be the next three days (interview *Lohmühle* I; transl. KW)?

According to a nearby resident, it was the visibility of this resource-conscious way of life that led to a greater acceptance of the trailer village by the neighbourhood, which had been rather sceptical of the project in the beginning (interview *Lohmühle* IV).

For the initiators of the urban campsite, it is ". . . somehow self-evident that we keep it all like that and that we want to keep the fox here. This is somehow logical, because it was here before us and why should we chase it away" (interview *Tentstation* I; transl. KW). The idea of resource conservation can also be found in their sustainability-oriented concept of interim use. Not only is the temporality of the project put forward by the users of the *Tentstation* as a reason for low financial input into the maintenance of the green and the essential construction work; the resource-efficient use of building materials is also connected to the creation of the special atmosphere of the site. In the case of the *Tentstation*, environmental resources are linked to monetary resources:

> Since we have a used site here, it just fits to work with things that already have a history. The windowpanes, for example, are from *Sparkasse Ulm* [a savings bank in a city in the South of Germany]. And all the boards, we got them from somewhere. And those boards down in the pool, they are from the former grandstand. Those were the old benches. Of course, it is all right with us to save resources, for the environment, but also for monetary resources. And then, of course, the style fits (interview *Tentstation* I; transl. KW).

Another aspect of a sensitive, resource-oriented argument is reflected in the awareness of the urban climate function of green areas. As mentioned above, green space can be appraised in many different ways. The inhabitants of the trailer village define their place as green space, considered to be significant for the urban climate:

> What I always experience when I come home at night (. . .) is that the temperature here is three degrees lower than in those parts of the city that are covered with buildings. And that's very important for the urban climate and these green spaces do have a very significant influence on it (interview *Lohmühle* I; transl. KW).

In the justifications of a view of nature as sensitive, Annemarie Nagel and Ulrich Eisel have identified two different modes of reasoning, which they describe as anthropocentric and biocentric (Nagel and Eisel 2003). Anthropocentric lines of argumentation are based on human demands and interests, such as the protection of resources for economic reasons, as in the case of *Tentstation*, or of urban climate in order to increase human wellbeing, as in the case of the *Lohmühle* project. Biocentric arguments, in contrast, are based on intrinsic values of nature. They can be found, for example, in the ecological way of life and in the ecological values of the inhabitants of the trailer village.

12.4 Conclusion

Our research on different representations of city nature follows the constructionist argument that nature, in the context of temporary use of open green space, does not exist per se but is imagined differently in different contexts. In our case studies, three different conceptualizations of urban nature have come to the fore. Concepts of a *useful nature* revolve around the issue of practical benefits of certain open green spaces for the city and its inhabitants. Concepts of a *beautiful nature* oscillate between a gardened and a wild, untamed urban nature. Concepts of a *sensitive nature* are located between a needy, protection-worthy nature on the one hand and the imagination of urban nature as a natural resource on the other hand. Although these representations often go unnoticed, they play a crucial role in the decisions about how city space is used. This is due to the fact that the way city nature is treated largely depends on how it is perceived and assessed (Hard 2003). As Ludwig Trepl (1992) has argued, people behave differently in an environment that they regard as a vulnerable organic system than in an environment they consider as staunch scenery of everyday action which is green only by accident.

What does our analysis of different representations of nature imply for the field of urban ecology? In what ways is urban ecology challenged by the perspective of socially constructed nature? A review of the literature reveals that urban ecologists tend to refer to the importance of preserving city nature by "ecological" or "sustainable" strategies of urban development, calling for an "environmentally sound urban development" or for "more nature in the city" (see, e.g. Breuste 1999). This tendency can be explained by the ambivalent character of urban ecology which represents both a scholarly science and an engaged practice of preservation (Sukopp and Wittig 1998). From a constructionist perspective, however, calls to preserve nature provoke a number of questions. If nature is not given as such, it cannot be protected as a whole but only in parts. Which parts are protected – and which are not – is decided in accordance with underlying valuations and preferences. The challenge that follows from a constructionist perspective for urban ecology is to make explicit these premises and to take seriously the representations of nature that inform scientific research. What is constructed as nature from a scholarly point of view? What is included in academic representations of nature and what is excluded? What is to be protected and what is to be defeated? Last but not the least, what are the conflicts that arise from the fact that some representations of nature are more powerful than others?

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