Tomás Schlichter
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Forests in Development: A Vital Balance

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Preface

The objective of this book is to show some of the main advances in forestry over the 6 years spanning between the XII World Forestry Congress in Canada and the XIII WFC held in Buenos Aires. The book will cover most of the themes of the XIII WFC, from biodiversity through production, policies, environmental services, and economic perspectives, linked by sustainability. It intends to provide a comprehensive view of forestry today, conveying its different aspects through one solid piece addressed by authors whose work denotes a concept of sustainable forest management which is not so much a puzzle laboriously put together as a many-faced unity, steered to achieve ultimately a better quality of living for present and future generations.

A persistent theme throughout the chapters reflects the dynamics of changes acting upon forests and forestry and the adaptation of policies, management and objectives, if they are to continue providing support to societies. The first question addressed is what the aims of forest management will be in the face of these changes. Further on, some of the key aspects to forest management are dealt with: the drivers which regulate forest growth and its relation to the ecosystem and ecosystem services; the influence of these factors on forest management, and some of the productive uses ensued. Relevant aspects related to the future of finance in forestry are carefully considered. New institutional and political arrangements are proposed to develop such a manifold sector. Ecosystem health, taking into account a changing climate, is the object of analysis, from which derives a suggested course of actions designed to minimize or mitigate the effect of pests and invasive species. Important information for forest plantation management, wishing to boost environmental service production while minimizing possible negative impacts, is proffered. Bioenergy production, especially of biofuels, a potential contribution of forests to humanity, is expounded from different perspectives, including a comparison with those originated from agricultural products. Technical, economic and political aspects are shown in a balanced, in-depth outlook, to reflect in a synthesis the vast richness and quality which characterized the 2009 WFC and the state-of-the-art in knowledge of these subjects essential to forestry.

The Editors

Acknowledgements

This book is the final result of the XIII World Forestry Congress, edited within the framework of supportive actions of INTA-MAGyP as part of the XIII WFC Organizing Committee.

The XIII WFC may be considered a success thanks to the hard work of many people within the host country and from the forestry world. We would like to acknowledge in the first place the nearly 7,000 participants from over 25 countries worldwide, mostly Latin Americans. Such a diverse congress was possible thanks to the donors, who opened the opportunity of attendance to countries usually excluded due to the high participation costs. The Food and Agricultural Organization's intervention smoothed the way and aided in the global dissemination of the event as well as in the call to forest experts and donors through the Advisory Committee. The numerous groups which constituted the Argentine Organizing Committee were involved in over six WFC support commissions. Thanks are also due to the Argentine Provinces, Universities and NGOs, and Buenos Aires City. But overall, we would like to acknowledge the Ministry of Agriculture, Livestock and Fisheries (MAGyP), which undertook the responsibility of representing the country, covering the greater part of the cost entailed in the organization and fulfillment of the WFC without regarding expense.

We would like to thank very specially the small group of the General Secretariat, which during 4 years overcame the multiple obstacles and uncertainties of the long preparatory way, including the last world crisis before the XIII WFC. To all of them and to the authors of these chapters, our most sincere acknowledgment.

The Editors

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Chapter 1
Conundrums, Paradoxes, and Surprises: A Brave New World of Biodiversity Conservation

Ariel E. Lugo

Abstract Anthropogenic activity is altering the global disturbance regime through such processes as urbanization, deforestation, and climate change. These disturbance events alter the environmental conditions under which organisms live and adapt and trigger succession, thus setting the biota in motion in both ecological and evolutionary space. The result is the mixing of species from different biogeographic regions and formation of novel communities of plants and animals. In this essay I present the point of view that this mixing and remixing of species is a natural response to the changing condition of the biophysical environment. The assembly of novel ecological systems reflects a healthy biota changing and adapting to acute and chronic anthropogenic disturbances. These anthropogenic disturbances add uncertainty to the state of the environment by inducing directionality and unpredictability to the disturbance regime, as opposed to the cyclic and predictable patterns of historical natural disturbances. If this view is correct, the paradoxes and surprises that are being recorded in the scientific literature should not surprise us nor appear paradoxical. Rather, they reflect normal responses to the uncertainty and magnitude of change of condition generated by anthropogenic activity. The current conditions under which we must manage tropical resources confront us with conundrums that must be approached with caution. Land managers need to consider their options in terms of cost and opportunities of success when they focus attention and resources on restoring natural conditions that can no longer exist on the planet.

Keywords Novel forests • Introduced species • Species eradication • Anthropogenic disturbances

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In Shakespeare's The Tempest, when the character Miranda says *O brave new world That has such people in't!,* she is expressing her awe at the beauty and diversity of human characters in the island where she and her father had been banished. Immediately, her father Prospero cautioned her about her enthusiasm by saying: *'Tis new to thee*. We are in a similar situation in the brave new world of biodiversity conservation in that we face a diversity of new combinations of species and community assemblies new to us, but that nevertheless appear beautiful and goodly just as Miranda perceived her new world, (Behrensmeyer et al. 1992). The new angle on the issue is the predominance of human effects on the biota.

Fundamentally, humans are now so dominant on Planet Earth that they are not only changing conditions and creating new habitats at local scales, but are doing so globally and changing the climate of the Earth. The consequences of these anthropogenic changes are reflected in warnings from scientists of impending catastrophic species extinctions, rampant species invasions, homogenization of the world biota, and disruptions of ecosystem services. These warnings are based on changes of the biota that scientists document day to day throughout the world. Sodhi et al. (2007) nicely summarized these effects for tropical ecosystems. Is the world biota at the edge of impending doom or is it adapting and reacting to the new conditions imposed by human activity, in which case the observed changes reflect a healthy biotic system?

I take the view that what we are seeing is adaptation and adjustment to environmental change, and that it behooves us to read the situation correctly to facilitate compliance with our responsibility as forest and land stewards. I base my views on the writings of early ecologists such as Elton (1958), Odum (1962), and Egler (1942) who observed the changes in the biota taking place as a result of human activity but recognized the inevitability of increased human activity and observed order and patterns in the response of the biota to anthropogenic activities. For example, Elton (1958), p 145 wrote: 'Unless one merely thinks man was intended to be an all-conquering and sterilizing power in the world, there must be some general basis for understanding what is best to do. This means looking for some wise principle of co-existence between man and nature, even if it has to be a modified kind of man and a modified kind of nature. This is what I understand by conservation.'

All three authors (C.S. Elton, H.T. Odum, and F. Egler) focused on the self-organization capacity of natural systems as a key element for understanding how new combinations of species might adaptively emerge as a result of increased human activity on Earth. And they expressed no bias against introduced invasive species. For example, Elton (1958), p 155 wrote: 'I believe that conservation should mean the keeping or putting in the landscape of the greatest possible ecological variety-in the world, in every continent or island, and so far as practical in every district. And provided the native species have their place, I see no reason why the reconstruction of communities to make them rich and interesting and stable should not include a careful selection of exotics forms, especially as many of these are in any case going to arrive in due course and occupy some niche.'

This did not mean that humans had no role in managing ecosystems. Elton (1958) p 151 added: 'The world's future has to be managed, but this management would not be like a game of chess –more like steering a boat. We need to learn how to manipulate more wisely the tremendous potential forces of population growth in plants and animals, how to allow sufficient freedom for some of these forces to work amongst themselves, and how to grow environments –for example, certain kinds of cover-that will maintain a permanent balance in each community.' At the same time, Aldo Leopold was publishing similar ideas in the United States (Leopold 1953) and Odum (1962) wrote (p 68): 'Synthetic ecosystems include conditions and combinations of organisms never before in existence. When multiple species seedings are done…a functional ecosystem soon evolves with species-number distributions like those in wholly natural systems…Multiple introductions from throughout the world may permit more diverse combinations to evolve, more closely integrating the habitation of man.'

My point is that in the 1950s to the 1960s, leading ecologists laid a strong scientific rationale for dealing with the alterations of species composition of ecosystems as a consequence of human activity. They advocated conservation paradigms that were inclusive of all species in marked contrast to the ideas of eradication of introduced species that are common with government and non-government organizations today.

Have environmental conditions changed so much, as it is commonly argued, to negate the ideas of these pioneer conservationists? One way to find out is to examine how current ecosystems are reacting to present anthropogenic conditions to see if the responses appear adaptive and exhibit order as suggested by Elton, Egler, Odum, Leopold, and others. Because ecosystems are complex and many times behave counter intuitively, a review of some of the paradoxes, conundrums, and surprises described by modern ecologists should help understand the situation and lead us to alternative approaches to ecosystem management.

A major consideration to our thinking should be the realization that with climate change and anthropogenic disturbances, we are seeing environmental change that is neither cyclic nor reversible. Instead, anthropogenic-induced environmental change is directional but we don't know the direction it might take. Uncertainty is now the rule in terms of the predictability of the environmental conditions faced by organisms. These uncertain conditions act as strong selective forces with the consequence that the world's biota must respond and adjust both ecologically and evolutionarily. Organisms shift distributions as they follow the conditions best suited to their life history requirements and in the process experience new interactions with other organisms and novel environments. These new conditions and interactions are natural forces of selection that lead to evolutionary change. Paradoxes, conundrums, and surprises follow from these considerations.

1.1 Paradoxes

The literature is documenting the turmoil of the world's biota in the form of paradoxes such as the following three examples.

1.1.1 Inbreeding Paradox

This paradox addresses the issue of how small populations of introduced species invade territories, thus suffering the effects of inbreeding, and instead of becoming extinct, become successful invaders (Pérez et al. 2006). One explanation for this paradox is that the invasion is repeated many times and the repetitive nature of the process overcomes the inbreeding effect. This explanation although plausible has had exceptions, and thus is not sufficient to explain those exceptions where a single event leads to a successful invasion in spite of the inbreeding. Of relevance to the main thesis of this essay is that the invasion involves modification of the environment by the invader, i.e., novel environmental conditions, and genetic modification of the invading species, e.g., invasions may involve genetic adaptation. Examples of genetic modification would be epigenetic adaptations and adaptive mutations. Pérez et al. (2006), p 545 point out: '…evidence that genes are not immune to environmental influences has been accumulating in the findings of molecular genetics.' Similarly, Travis et al. (2010) found increased rates of hybridization in invading clones of cattail stands in the Great Lakes region of North America. These findings are extremely important for understanding how the biota responds both ecologically and evolutionarily and adapts under the influence of a rapidly changing anthropogenic environment. This allows the maintenance of homeostasis and functioning under novel environmental conditions. In short, evolution might be accelerated under the stressful new conditions of an anthropogenic world.

1.1.2 Local Adaptation Paradox

Introduced species successfully compete and replace native species already established in their local environments, i.e., loss of home-court advantage (Allendorf and Lundquist 2003). The expectation is that native species should prevail within their natural geographic boundary because they evolved under those local conditions and this should give them an edge over an invading species. However, there is already recognition that indigenous genetic material may no longer be adaptive in modified ecosystems that have experienced significant environmental change (Jones and Monaco 2009). With increased site degradation organisms encounter both biotic and abiotic thresholds (ecological thresholds) that have to be overcome if they are to remain adaptive to emerging conditions (Whisenant 2002; Jones and Monaco 2009). Thus, if the native species lacks adaptation to a changed or emerging condition they are unlikely to be successful in competition with an introduced species that is adapted to those conditions.

Ricotta et al. (2009) gave examples of the environmental conditions of urban environments that select for introduced organisms. These were: the heat island effect, which favors species whose distribution is limited by cooler temperatures; high proportion of surface runoff and hard surfaces that increase aridity; high alkalinity or urban soils, which are affected by concrete and other lime-based materials, and select for species adapted to high pH soils. It thus appears that the home-court is no longer what local species adapted to and the paradox is resolved by the disappearance of the home court advantage.

Jones and Monaco (2009) suggested the use of 'assisted evolution' as a strategy for designing native plant material for domesticated landscapes where conditions are extreme and sites have passed both biotic and abiotic thresholds. Assisted evolution requires native species to be selected, genetically manipulated, and used (planted) under the conditions they are likely to experience in anthropogenic environments. Assisted evolution is a controlled way for emulating how wild species might naturally adapt to anthropogenic environments. In fact, this is what is already happening with the natural invasion of introduced species that are pre-adapted to the new conditions created by human activity.

The relevant point to this discussion is that home court advantage applies only where the home court environment has not changed. When the environment changes, there is no reason to expect home court advantage. Thus, it might be folly to expect that only native species are suitable for restoration or that only natives have an exclusive presence in anthropogenic landscapes. Jones and Monaco (2009), p 546 said it best: '…we believe that the tacit assumption that local material will demonstrate optimal performance, adaptation, and fitness despite severe disturbance, is unwarranted.'

The phyloecology of introduced urban floras is a testament to the close relationship between novel urban conditions and dominance of introduced species in urban environments (Ricotta et al. 2009). Ricotta et al. examined 21 urban floras in Europe and eight in the United States and found that the phylogenetic diversity of introduced urban species was lower than that of native species at the city and continental scale. They also found that introduced species in cities are not random assemblages of species, but are more clumped than expected from assemblages randomly compiled from the entire flora (the same is true of aquatic organisms [Karatayev et al. 2009]). Ricotta et al. (2009) suggest that the urban environmental filters are responsible for the decline in phylogenetic diversity in urban floras. The species of urban floras are composed of phylogenetically related species that are well adapted to anthropogenic habitats.

While invading species must overcome the environmental filter of cities to be successful in their establishment as part of the urban biota, the pre-existing native species have a different challenge. Schaefer (2009) expressed the opinion that the effect of anthropogenic modification of habitats is the erasing of the ecological memory of sites. The ecological memory consists of the species of an area and the ecological processes that determine the future trajectory of the ecosystem, including disturbances and management actions. Invasions are facilitated by loss of ecological memory, as native species find it difficult to persist under the changing conditions, resulting in loss of ecological memory and the establishment of new stability domains with introduced species.

Also related to the local adaptation paradox is the common observation that a species performs at higher levels of productivity and growth when it is introduced relative to its performance in its native habitat (Rout and Callaway 2009). Rout and

Callaway (2009) attribute this boost in productivity of introduced plants to their interaction with soil microbes that increase nitrogen cycling and boost production. They also suggest that the introduced species evolve, as might their evolutionary relationship with microbes, which allow higher levels of productivity, nutrient-use, and nutrient recycling.

1.1.3 Forest Fragmentation Genetics Paradox

Contrary to theory, forest fragmentation does not appear to reduce the genetic diversity of tree populations (Kramer et al. 2008). The incorrect notion that fragmentation would reduce genetic diversity was based on four assumptions that proved wrong: (1.) That fragment edges delimit populations. (2.) That genetic declines manifest, and are detectable, quickly. (3.) That different tree species respond the same way to fragmentation. (4.) That genetic declines supersede ecological consequences. Kramer et al. (2008) conclude that neither the ecological or genetic issues affecting how trees respond to fragmentation have been addressed broadly enough with respect to each other to allow definitive conclusions about how relatively important ecological and genetic factors are.

1.2 Conundrums

Conundrums reveal the difficulty that we find ourselves in when attempting to predict future biodiversity scenarios under the assumption that past conditions will somehow repeat themselves. A classic example is our effort to restore ecosystems to historical conditions that will not be present in the future. Thus, a fundamental conundrum facing forest managers is: 'One can either preserve "a natural" condition, or one can preserve natural processes, but not both' (Botkin 2001). This is a problem because if we elect to preserve 'a natural condition' (and thus suppress natural processes) the cost might be so high as to be practically impossible to achieve, particularly at large spatial scales. Yet, many resource management policies lead us to preserve 'a natural condition' and commit to overcoming natural processes.

Species eradication is a technique commonly utilized by land managers hoping to restore a natural condition to particular ecosystems. The idea is to remove introduced or invasive species in the hope that the native species will recover and restore ecosystems to natural conditions deemed superior to existing ones. This effort to restore a natural condition through the eradication of unwanted species has consequences, both at the population and ecosystem levels that are increasingly being assessed by ecologists. Zipkin et al. (2009) assessed the issue at the population level with plant and animal population examples, and simulation of a general population model. They found that demographic structure and density-dependent processes can confound removal efforts and lead to undesirable consequences such as increases rather than decreases of target organisms or population cycling chaos. Species with high per capita fecundity, short juvenile stages, and fairly constant survivorship rates are more likely to respond undesirably to harvest.

At the level of the ecosystem, the example of the sub-Antarctic World Heritage Macquarie Island has stimulated considerable debate (Bergstrom et al. 2009a; Dowding et al. 2009). Like many such types of islands, Macquarie Island contained a compliment of introduced species deemed detrimental to its naturalness. In this case the undesirable species were rabbits and cats. A virus (Myxoma) was introduced to control the rabbits, and cats were shot to extirpation. These two actions occurred over a period of several years between 1978, when the virus was introduced, and 2000, when the last cat was shot. By 2008 the rabbit population had grown out of control in spite of the virus, and the vegetation of the island was devastated. Bergstrom et al. (2009a, b) attribute the unexpected result to a trophic cascade, caused by the extermination of cats. The effects of the conservation action were thus island-wide. Dowding et al. (2009) point out that there were positive effects as well from the eradication program. Notably, sea bird populations recovered rapidly due to the absence of cats. They also suggested that the vegetation of the island has been devastated before, and thus likely to recover when rabbits again decrease in numbers. The important lesson from the example, however, is the system-level ramifications of single species management actions, and the unpredictability of the effects. Moreover, the example illustrates the high cost and complexity of resolving the Botkin conundrum by attempting to restore 'a natural condition' against the directions of 'natural processes'.

Conversely, if we elect to allow natural processes to take over the biota without any control, we may face outcomes that are not beneficial to humans or to sustaining human activities. In these cases we may have to steer natural processes towards desired outcomes as suggested in the above quotes from Elton (1958). Clearly we need to recognize that sustaining human activity will require a balance between the two extremes of Botkin's conundrum and that we depend on science to help us identify where that balance might reside.

1.3 Surprises

Paradoxes and conundrums reflect the many surprises that biologists are observing as they study the mixing of species and assembly of new communities of organisms in novel environments. These observations are particularly surprising or appear paradoxical if they are evaluated within the norms and rules of a cyclic natural world. However, in the context of a human-dominated world many of these paradoxes and surprises are not so, or have clear explanations.

In the above example from Macquarie Island, managers were surprised by the results of their interventions with cat and rabbit populations because they failed to consider that many protected islands of the world have had similar types of introduced animal populations for centuries and their flora and fauna exists in balanced states that have led to their recognition and selection for protection. However, the managers of this island decided to return the communities to historical conditions by eradicating the introduced species and creating transitional ecological systems whose management costs are now prohibitive. The surprise should not have been so if managers had realized that the biota of the island system had self-organized to include the introduced species. Species-by-species eradication actions based on notions of pristine communities are ineffective because they ignore the overall system's self-adjustment to current conditions and also ignore basic population ecology principles (Zipkin et al. 2009). In the context of the novel system with introduced rabbits, cats, and rats, the disruption of vegetation as a consequence of the eradication of populations is not surprising.

Another set of surprises revolves around the notion of unintended consequences of species invasion, also known as the Frankenstein Effect because many of these consequences are deemed detrimental to the biota (Moyle and Light 1996). Here I draw attention to unexpected symbiotic relations as a result of mixing species in novel environments. These unintended consequences or surprises need not be judged as positive or negative to organisms, but evaluated for their adaptive value to environmental conditions. An example would be the new food web that developed in the United Kingdom as a result of the introduction of turkey oak and gail wasps (Hobbs et al. 2009). These introduced species interacted with native species of oak, gail wasps, and Blue tit birds to form a new food web that included historical as well as new trophic links, and which appears stable.

In northeastern forests of the United States, *Alliaria petiolata* (garlic mustard) is a successful introduced ground covering plant. Rodgers et al. (2008) found that the presence of this species improves nutrient availability in soils and increases their pH. The nutrient-rich plant parts of this species also stimulated fungal and microbial activity and resulted in positive feedbacks into the growth of the plant. Dassonville et al. (2008) examined the phenomena of soil nutrient enrichment by introduced species by analyzing data from 36 sites with widely divergent edaphic and biotic conditions in NW Europe. They found that all species-invaded plots had increased aboveground biomass and nutrient stocks compared to uninvaded sites. The magnitude of the effect was site-specific, but the stronger effects were measured in sites with low initial nutrient concentration in topsoil, while negative effects were generally found in the opposite conditions.

The examples given above show that adding introduced species to sites has wide ranging ecological effects both in the trophic structure as in site fertility. These changes in turn affect many organisms within the community. These new symbiotic relationships point to the biotic mechanisms of self-organization during natural succession. They lead directly to the establishment of novel communities of plants, animals, and microbes.

1.4 Novel Forests: The Natural Response to Human-Induced Environmental Change

The formation of the novel forests has its genesis in a variety of circumstances, one of the most important being the establishment of introduced species in sites altered by human activity (Hobbs et al. 2006). Here I emphasize the development of novel food webs by the presence of mixtures of animal and plant species. As the example above from the United Kingdom shows, when organisms that previously had not shared the same ecological space come in contact and interact, new trophic relationships and novel food webs develop. Another example describes how native predators capable of feeding on an abundant introduced prey have a fitness advantage over a predator that cannot (Carlsson et al. 2009). They can do so rapidly via existing phenotypic plasticity or slowly via natural selection. Carlsson et al. (2009) discuss numerous examples of native predators switching to introduced prey such as the Lake Erie water snake (*Nerodia sipedon insularum*) feeding on Eurasian round goby (*Neogobius melanostomus*). Unfortunately, long-term data are not available in sufficient quantity to establish how prevalent these mechanisms are under natural conditions.

Hobbs et al. (2009) recognized that the degree of novelty of ecological systems developing in altered conditions could vary from slight to completely novel. They used a two dimensional graphic to depict alternatives for management and conservation of these ecosystems with abiotic conditions ranging from historical to altered on the X-axis and biotic composition also ranging from historic to altered in the Y-axis (their Fig. 1). Within these axes they classified systems from historic to hybrid to novel depending on how far their respective abiotic and biotic attributes deviated from the historical condition. Novel ecological systems were located in both X and Y axes at the most distant states from historical systems. Hobbs et al. (2009) suggested the following criteria to evaluate if a particular novel ecosystem was suitable for conservation or a candidate for restoration: its capacity to mature along a stable trajectory, its resistance and resilience to disturbances, its thermodynamic efficiency, its production of goods and services, and its capacity for providing opportunities for individual or community engagement.

I have argued that novel forest ecosystems are a natural response to the novel environmental conditions created by human activity (Lugo 2009). Because human activity is so prevalent today, novel forest and other types of novel ecosystems are increasing in area and importance (Marris 2009). What distinguishes a novel ecosystem from a native or historical one is its species composition, which includes introduced species and combinations of native and introduced species not seen before (Lugo and Helmer 2004; Hobbs et al. 2006). The current debate about species eradication may become moot in the future as the pace of species mixing accelerates with climate change (Walther et al. 2009). Species viewed as undesirable today, could be acceptable tomorrow because of their capacity to cope with, and function in, new climates. As a result, novel ecosystems will be even more prevalent. There is a strong justification to understand the mechanisms that lead to novel forest assembly (e.g., Brandeis et al. 2009) and the functioning of these systems relative to human needs and sustainability of human activity.

1.5 Conclusion

There is no longer any question about the state of turmoil of the world's biota. The biota is on the move in both ecological and evolutionary space, as it normally does when subject to natural disturbances (discussed for hurricanes in Lugo 2008) or after anthropogenic disturbances (Lugo and Brandeis 2005). Today's global movement of the biota is due to the insidious changes to the global environment by anthropogenic activity. In this essay I have presented the point of view that this mixing and remixing of species is a natural response to the changing condition of the biophysical environment. The assembly of novel ecological systems reflects a healthy biota changing and adapting to acute and chronic anthropogenic disturbances. These anthropogenic disturbances add uncertainty to the state of the environment by inducing directionality to the disturbance regime, as opposed to the cyclic patterns of natural disturbances. The anthropogenic disturbance regime also adds trends and gradients to the biophysical world to which organisms adapt. If this view is correct, the paradoxes and surprises that are being recorded in the scientific literature should not surprise us nor appear paradoxical. Rather, they reflect normal responses to the uncertainty and magnitude of change of environmental conditions when driven by anthropogenic forces. Land managers need to consider their options in terms of cost and opportunities of success when they focus attention and resources on restoring natural conditions that can no longer exist on the planet.

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Chapter 2
Understanding the Role of Resource Use Efficiency in Determining the Growth of Trees and Forests

Dan Binkley

Abstract In the twentieth century, silviculturists commonly thought about the growth of trees and stands in terms of "growing space." Trees and stands grew faster when they obtained more growing space. Unfortunately, growing space is intangible and not quantifiable, limiting the opportunities for quantification and hypothesis testing. Patterns of tree and stand growth can be evaluated quantitatively with a production-ecology perspective, testing hypotheses about factors that influence growth. The growth of trees and forests depends on the acquisition of resources (light, water, nutrients), on the efficiency of using these resources for photosynthesis, and on the partitioning of photosynthate to wood growth. Trees and stands with high rates of resource use might be expected to show lower efficiency of resource use as a result of some sort of declining marginal return; however, empirical patterns show that increasing resource use is generally accompanied by sustained or increased efficiency of use. For example, in fast-growing Eucalyptus plantations, large trees may intercept twice as much light as smaller trees, and use the light twice as efficiently to provide a fourfold greater rate of stem growth than smaller trees. At the stand level, increases in water supply (across geographic gradients or from irrigation) often show 50% increases in water uptake by trees, and constant or increasing efficiency of water use leads to large increases in stem growth. These insights are valuable for forest management, including understanding why subordinate trees contribute so little to stand growth, why uniform stands grow better than stands with greater variety of tree sizes, and why some species mixtures grow better than others. The production-ecology approach offers a powerful framework for how to think about the growth of trees and forests.

Keywords Forest productivity • Light use • Water use • Production ecology equation

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2.1 Introduction

Everyone knows that some forests grow faster than other forests, and that within a single forest some trees grow faster than other trees. The history of forestry as a field of science and as a profession centers on understanding the many facets of growth of trees and forests across scales of time and space (Puettmann et al. 2008). For more than a century, patterns of growth were examined mostly through empirical relationships, including the development of growth curves, yield tables, and quantitative statistical models of forest growth (see Assmann 1970; Clutter et al. 1983). Silviculture often used the idea of "growing space" to explain differences in growth rates among trees and stands; sites were envisioned to contain a certain amount of intangible growing space, or capacity for plants to grow until a factor necessary for growth becomes limiting (Oliver and Larson 1990). The amount of growing space could not be measured directly, though it was believed to vary over both space and time.

The focus of forest growth studies broadened in the late twentieth century, as improved understanding of the ecology of plant growth was applied to forests. One tree (or stand) may grow faster than another if it experiences a greater supply of resources (light, water, nutrients) in the environment, or if it experiences the same supply but manages to acquire a greater share than the other tree (or stand). A third alternative for supporting greater growth is having the same resource supply and acquisition, but a greater efficiency of converting the resources into photosynthate. Each of these factors is quantifiable, and Monteith (1977) used this approach to connect basic photosynthesis with the ecology of plant growth by proposing a simple production ecology equation: plant production equals the supply of available resources, multiplied by the fraction of resources actually obtained, multiplied by the efficiency with which resources are converted into photosynthate.

Light is a key resource for photosynthesis and patterns in light interception began to reveal some major patterns in forest growth. For example, Waring (1983) and Linder (1985) stressed that forest growth was often proportional to the amount of light intercepted by forest canopies. Intensive forest management began to include assessment of leaf area in forests in the late 1980s (for example, Vose and Allen 1988). Monteith's production ecology equation formed the core of growth simulation models in the 1990s (reviewed by Landsberg 2003), and is now used routinely for estimating ecosystem productivity from satellites (Turner et al. 2006).

Some features of this production-ecology approach to understanding growth are straightforward; trees and forests with more leaves typically intercept more light, leading to higher rates of growth. The relationship between leaf area and light interception is typically non-linear; the first layer of leaves is exposed to full sunlight and intercepts a high quantity of photons than shaded layers of leaves deeper in the canopy.

The efficiency of converting resources into growth, however, is more complicated. Resource use efficiency patterns depend on interactions among a variety of resources (light, water, nutrients), and may also depend on tree species, genetics, age, and stand structure. The efficiency of resource use may also be considered from the perspective of gross primary production, or some fraction such as wood production. This paper presents an overview of some of the aspects of resource use efficiency at the level of stands and individual trees, illustrated with some key examples.

2.2 Some Misconceptions

Some people may expect that the efficiency of using a resource should decline as plants and forests use more of that resource. These expectations may derive from components of "Liebig's Law of the Minimum," Mitscherlich's "Law of Diminishing Marginal Returns," and confounding differences in the supply of a resource (such as massive doses of nitrogen fertilizer) with the rate of a resource actually used by plants. A general critique of misconceptions is beyond the scope of this paper, but two points may illustrate some of the general issues (for more discussion, see Hof et al. (1990), Pastor and Bridgham (1999), and Binkley et al. (2004)).

Economic analogies are sometimes called upon for insights into ideas about efficiency in ecological systems, but these are helpful only if the analogies are sound. For example, water might be considered an "input" in an economic system, which is invested to manufacture a product of carbon (through photosynthesis). As the "input" of water to the plant increases, it might seem logical to expect that the production of carbon might not increase as fast as water input. However, plants do not "invest" in water; they invest in growing roots (the actual input) in order to obtain water; water obtained by the plant should be considered a product rather than an input. A better set of analogs might include carbon (photosynthate) as both the input and the revenue; carbon is invested in roots to produce water within the plant, which is then exchanged (sold) to the atmosphere for more carbon (Hof et al. 1990). This approach that uses carbon as both the input (to obtain water) and revenue (photosynthesis) makes it easy to see that the more abundant the water supply, the lower the "cost" of obtaining water (less root investment), leading to greater net profit.

A second point about expectations for efficiency of resource use comes from an influential review paper published almost 30 years ago. Vitousek (1982) wanted to test whether the efficiency of using nitrogen or phosphorus would show a pattern among ecosystems as the rates of use of these nutrients increased. Few data were available for direct measures of nutrient use and stand growth, so he chose two surrogates. The nutrients contained in aboveground litterfall were used as measures of nutrient use, and the biomass of aboveground litterfall was used a surrogate for productivity. If these two assumptions were true, then the relationship between nutrient content of litterfall and the mass of litterfall would index actual patterns of nutrient use efficiency. These assumptions led to a pattern of strongly declining efficiency of nutrient use as forests increased the rate of nutrient cycling. Later work, however, showed the expectation of a good relationship between litterfall mass and ecosystem production was quite poor. Birk and Vitousek (1986) showed that nutrient use efficiency was almost constant with increasing nutrient use, when aboveground net primary production was used rather than litterfall mass. We now know that rates of aboveground litterfall typically do not increase very much across productivity gradients where tree growth may double or triple (Binkley et al. 2004).

2.3 How Resource Use Efficiency Is Measured

Calculating the efficiency of resource use requires a measurement of growth, and a measurement of resource use. The growth of trees and stands is measured routinely in forest inventories and research programs, but measurements of the rates of resource use are less common.

Several approaches are used for measuring the interception of light at a stand scale. In the twentieth century, silviculturists often dealt with issues of forest canopies by simply estimating "canopy cover" without any direct or indirect estimation of light interception *per se*. 20 years ago it was common to estimate light interception based on estimates of leaf area determined by destructive sampling of trees to create regression equations relating diameter of stems to canopy leaf area. Assumptions were then made about the exponential pattern of declining marginal light interception per unit of leaf area (Beer-Lambert pattern), and light interception was calculated. Currently, inexpensive light meters are available that can quickly measure light intensity under forest canopies (and in the open), providing rapid, direct values for stand-level light interception. The interception of light by individual trees is more difficult to estimate. The best available methods combine dissection of tree canopies with detailed light-interception models (such as MAESTRA). Forest water use can be estimated based on the hydrologic budget of a basin, or by micrometeorological/energy balance approaches. Water use by individual trees is commonly assessed based on the rate of dissipation of heat (from a heated electrode inserted into the stem) as water moves up a stem.

2.4 Tree-Level Views of Resource Use Efficiency

Within a single stand, larger trees typically grow faster than smaller trees, in part because of greater rates of use of light, water, and nutrients. But do larger trees use resources more efficiently, or do they achieve faster growth simply by the sheer quantity of resources they procure? The pattern within a Eucalyptus plantation in Hawaii is illustrated in Fig. 2.1 (from the experiment reported by Binkley et al. 2002 and Ryan et al. 2004). The smallest one-third of the trees in the plot contributed about one-sixth of the total plot stem mass, and at age 5 years they contributed only about 5% of total plot growth. In contrast, the largest one-third of the trees accounted

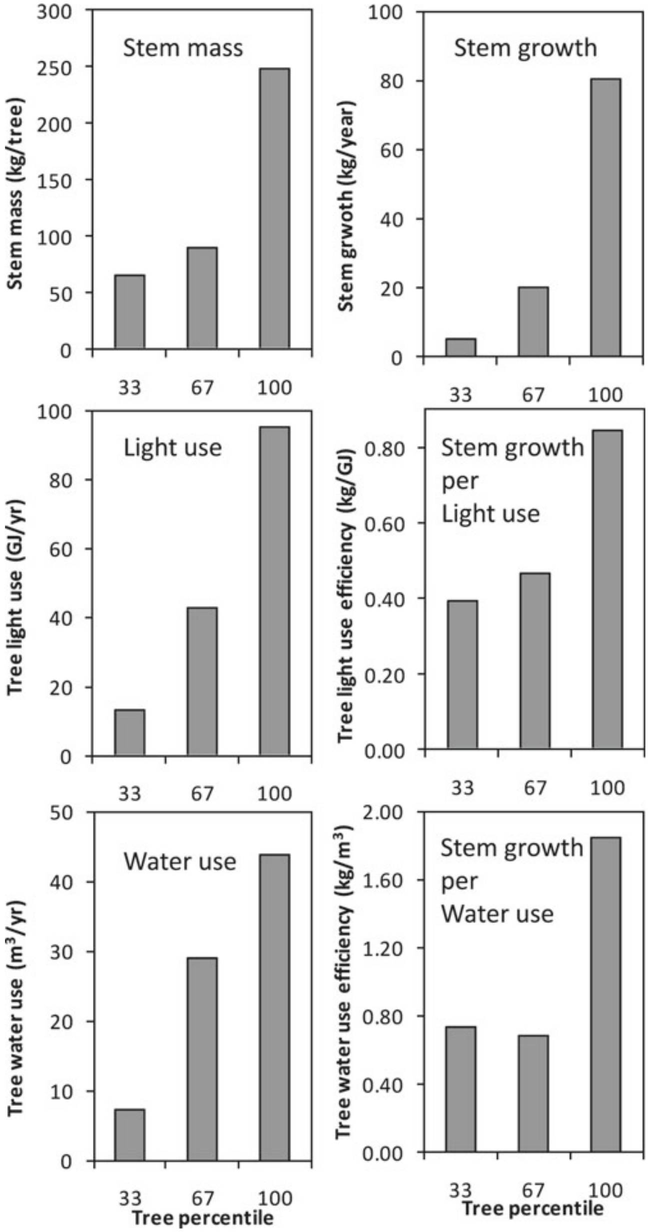

Fig. 2.1 A comparison of tree mass, growth, light use, and water use in an experimental plantation of *Eucalyptus saligna* in Hawaii (from the experiment reported by Binkley et al. 2002; Ryan et al. 2004). The largest one third of trees contributed the largest proportion of growth as a result of both greater resource use, and greater resource use efficiency

for two-third of the plot's total stem mass, and 75% of the total plot growth. Not surprisingly, the largest one-third of the trees accounted for more light use than the smaller trees, but they also produced 50% more wood per unit of light intercepted by their canopies than did the medium- and small-size trees. The same pattern applied to the use of water; dominant trees used more water, and used it more efficiently to produce wood.

Too few studies have characterized the efficiency of resource use by individual trees within a stand to allow broad conclusions. Fernandez and Gyenge (2009) examined water use and growth of individual ponderosa pine trees in Patagonia. At one site, larger trees within a stand had 40–100% greater wood growth per liter of water used, across a range of stand stocking levels. However, water use efficiency per tree was more variable at another site, and showed no significant difference between larger trees and smaller trees. Binkley et al. (2010) characterized individual-tree patterns in the efficiency of light use across a full rotation of Eucalyptus plantations, at four sites with manipulations of stand structure, genetics, and water and nutrient supplies. In all cases, dominant trees not only intercepted more light, they used the light more efficiently. About 60% of the greater growth of large Eucalyptus trees resulted from greater light capture, and 40% resulted from more efficient use of light.

2.5 Stand-Level Views of Resource Use Efficiency

The Eucalyptus plantation experiment in Hawaii from Fig. 2.1 also tested stand-level effects of intensive fertilization (Fig. 2.2). Late in the rotation, the fertilized plots were growing about 40% more wood annually than the control plots. Stand leaf area was almost 20% higher in the fertilized plots, which led to a marginal increase of about 10% in light interception. In this case, the majority of the effect of fertilization related to increases in light use efficiency rather than increases in total stand light use.

Many studies have characterized rates of resource use and growth at the stand level, and Tables 2.1 and 2.2 tally the overall patterns for light and water use. These studies span a wide range of forest types, with a variety of reasons why productivity differed among stands (including geographic gradients, fertilization, species, and aging of the forests). All of the tabulated studies showed that stands with higher growth had higher rates of light interception, with a median increase of about 40% (Table 2.1). About 95% of the studies also found that the efficiency of using light was higher in the treatments that produced higher growth rates, with a median increase in light use efficiency of about 40%. A large increase in light interception was paired with a strong increase in light use efficiency in about half the cases, whereas the majority of the growth response in other cases resulted primarily from either light interception or light use efficiency (with no clear interaction).

The pattern was similar for water use and efficiency (Table 2.2). More productive stands showed substantially greater water use (median of 25% more) in about 90%

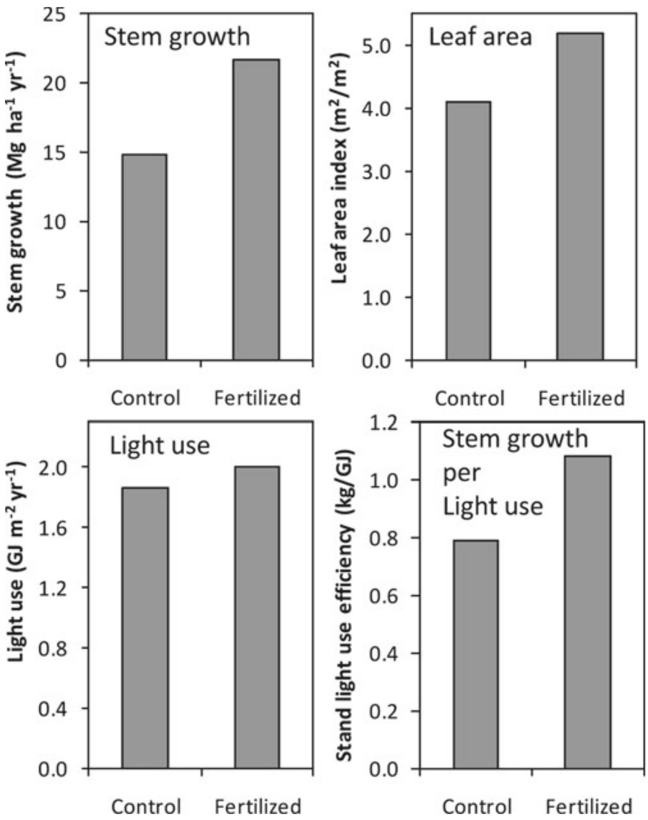

Fig. 2.2 Fertilization of an experimental plantation of *Eucalyptus saligna* in Hawaii (Ryan et al. 2004) sustained higher growth and leaf area near the end of the rotation, and the increase in growth depended primarily on greater efficiency of wood production per unit of light interception, and secondarily on greater light interception

of the cases, and greater water use efficiency (median of 70% greater) in about 90% of the cases. About two-thirds of the studies showed strong increases in both aspects of water use, whereas the growth response in other cases resulted primarily from just one factor (use or efficiency of use). Indeed, the efficiency of water use increased curvilinearly with increasing water use ($r^2=0.41$, $P=0.02$).

Future work will expand the number of case studies of stand growth, resource use, and efficiency of resource use, and the general patterns may shift as the amount of available information increases. Perhaps the most important point from Tables 2.1 and 2.2 is that none of the cases showed a strong negative relationship between resource use and efficiency of use: higher rates of use of light or water were associated with either no substantial change in efficiency, or an increase in efficiency. This general pattern may of course have some exceptions, but clearly our general expectation should *not* be that efficiency ought to decline when use increases.

Table 2.1 Higher rates of stem growth in response to genetics, geographic gradients, or silvicultural treatments, may be associated with higher rates of light interception (APAR), higher efficiency of light use (LUE), or both

Forest type	Location	Treatment	Range of difference (%) in light interception (APAR)	Range of difference (%) in Light Use Efficiency (LUE, growth/APAR)	Relationship between APAR and LUE	Reference
Eucalyptus plantation	South Africa	Intensive silviculture	15	10	Positive	du Toit (2008)
Eucalyptus plantations	Bahia, Brazil	Geographic gradient	40	300	Positive	Stape et al. (2004)
Eucalyptus plantation	São Paulo, Brazil	Geographic/soil gradient	1	93	None	O. Campoe, unpublished data
Eucalyptus plantations,	São Paulo, Brazil	Geographic gradient	8	12	Positive	Marsden et al. (2010)
Eucalyptus plantation	São Paulo, Brazil	Stand age (year 2–5)	31	65	Positive	Marsden et al. (2010)
Eucalyptus plantation	Bahia, Brazil	Irrigation	15	90	Positive	Stape et al. (2008)
Eucalyptus and N-fixing *Falcataria*	Hawaii, USA	Comparison of species	40	30	None	Binkley et al. (1992)
Loblolly pine plantation	North Carolina, USA	Intensive silviculture	100	100	Positive	Albaugh et al. (2004)
Loblolly pine plantations	Georgia, USA	Tree spacing	270	15	None	Will et al. (2005)
Loblolly and slash pine plantations	Florida, USA	Intensive silviculture	60	50	Positive	Martin and Jokela (2004)
Slash pine	Florida, USA	Intensive silviculture	50	75	Positive	Gholz et al. (1991)
Radiata pine plantation	Canberra, Australia	Irrigation + fertilization	20	40	Positive	Raison and Myers (1992)
Maritime pine plantation	Southwest France	Irrigation and fertilization	10	25	Positive	Trichet et al. (2008)
Native pine and hardwoods	Wisconsin, USA	Comparison of species, geography	100	100	None	Ahl et al. (2004)
Jack pine forests	Saskatchewan, Canada	Geographic gradient	400	25	None	Chasmer et al. (2008)

Black spruce forests	Saskatchewan, Canada	Geographic gradient	400	0	None	O'Connell et al. (2003)
Black spruce forests	Ontario, Canada	Geographic gradient	65	300	Positive	Groot and Saucier (2008)
Black spruce forests	Ontario, Canada	Tree spacing	5	40	Positive	Groot and Saucier (2008)
Old-growth spruce and fir	Colorado, USA	Geographic gradient	100	60	None	Binkley et al. (2003)
White pine versus hardwoods	North Carolina, USA	Comparison of species	100	100	None	Pangle et al. (2009)
Birch-pine succeeding to oak-beech	Northwest Germany	Ecosystem development	30	40	Positive	Leuschner and Rode (1999)
Willow biomass plantation	Scania, Sweden	Comparison of clones	10	100	None	Linderson et al. (2007)
Sycamore plantation	South Carolina, USA	Irrigation + fertilization	100	100	Positive	Allen et al. (2005)
Sweet gum plantation	South Carolina, USA	Irrigation + fertilization	100	0	None	Allen et al. (2005)
Poplar plantation	Wisconsin, USA	Genotypes	50	210	None	Green et al. (2001)
Mixed-hardwood forest	Indiana, USA	Geographic gradient	40	35	Positive	Jose and Gillespie (1996)
Metrosideros forest	Hawaii, USA	Ecosystem development	30	30	None	Herbert and Fownes (1999)

A value of 100 indicates that the rate of light interception, or efficiency of light use, was twice as high for the faster-growing treatment. In about half of the cases, LUE increased strongly with increasing APAR; in other cases, no strong interaction was apparent

Table 2.2 Higher rates of tree growth in response to genetics, geographic gradients, or silvicultural treatments, may be associated with higher rates of water use and efficiency of water use

Forest type	Location	Treatment	Range of difference (%) in water use	Range of difference (%) in Water Use Efficiency (growth/water use)	Relationship between APAR and WUE	Reference
Eucalyptus plantations	Bahia, Brazil	Geographic gradient	65	300	Positive	Stape et al. (2004)
Eucalyptus plantation	Hawaii, USA	Fertilization	30	20	Positive	Hubbard et al. (2004)
Eucalyptus plantation	Hawaii, USA	Tree age	0	40	None	Barnard and Ryan (2003)
Eucalyptus plantation	Bahia, Brazil	Irrigation	40	40	Positive	Stape et al. (2008)
Eucalyptus plantations	Eastern Brazil	Irrigation	15–30	0	None	Hubbard et al. (2010)
Eucalyptus plantations	Espirito Santo, Brazil	Annual climate differences	180	>200	Positive	Almeida et al. (2007)
Eucalyptus plantations	Victoria, Australia	Age sequence	400	200	Positive	Forrester et al. (2010)
Willow biomass plantation	Scania, Sweden	Comparison of clones	100	130	Weakly positive	Linderson et al. (2007)
Willow biomass plantation	Scania, Sweden	Drought treatment	25	40	None	Linderson et al. (2007)
Birch-pine succeeding to oak-beech	Northwest Germany	Ecosystem development	10	60	None	Leuschner and Rode (1999)
Norway spruce forests	Germany	Stand age	35	70	None	Köstner et al. (2002)
Ponderosa pine forests	Oregon, USA	Stand age	15	65	Positive	Irvine et al. (2004)
Douglas-fir versus native forest	Patagonia, Argentina	Species comparison	20	180	Positive	Gyenge et al. (2008)

A value of 100 indicates that the rate of water use, or efficiency of water use, was twice as high for the faster-growing treatment. In about two-thirds of the cases, water use efficiency increased strongly with increasing water use; in other cases, no strong interaction was apparent

2.6 Why Does Resource Use Efficiency Vary with Resource Use Rates for Trees and Stands?

This question is a major topic for future research. High efficiency for individual trees may results from higher rates of photosynthesis per unit of leaf area for trees intercepting large amounts of light. Alternatively, trees with large rates of light interception may partition less of the photosynthate to growth of roots and more to growth of stems. Available evidence for patterns at the stand level strongly supports such a shift in partitioning (see Litton et al. 2007). Other explanations may need to focus on trees as whole organisms, and consider whether maximizing growth (especially for subordinate trees) is an optimal approach for the overall, long-term fitness of the tree.

2.7 Insights for Management

The production-ecology perspective on forest growth provides some valuable insights for forest management. Most importantly, it moves silviculture from the domain of non-quantifiable ideas about "growing space" into the realm of quantifiable hypothesis testing. Smaller trees in stands have less access to "growing space," but we can't measure whether low growth rates results from limited growing space *per se*, or whether the efficiency of using growing space is low. In contrast, a production-ecology approach can show that smaller trees not only obtain lower supplies of resources, they use these resources less efficiently. The lower efficiency of resource use by smaller trees within stands reinforces the idea that these trees contribute little to overall stand growth. Removal of smaller trees might allow greater resource use by larger trees, and the higher efficiency of resource use would provide extra value in the growth of large, high-value trees.

The lower efficiency of smaller trees also highlights the value of maximizing uniformity of tree sizes within fast-growing plantations. The Brazil Eucalyptus Potential Productivity study found that lower uniformity of tree sizes in lowered whole-rotation stem growth by 10–15%, despites equivalent light interception in uniform and heterogeneous plantations (Ryan et al. 2010).

At the stand level, patterns of resource use efficiency might be particularly important in mixed-species stands. An experiment with nitrogen-fixing *Falcataria* in Hawaii showed increases in soil nitrogen availability, but low efficiency of light use by *Falcataria* limited the total productivity of monoculture stands (Binkley et al. 1992). Monocultures of *Eucalyptus* showed higher efficiency of light use, but very low availability of nitrogen in the soil limited the development of full canopies. Mixed-species plots showed greater stem growth than either monoculture, because moderately high availability allowed for high stand-level light interception, as well as high light-use efficiency. Of course these interactions of resource supply and efficiency of use vary widely among forests, so this analytical approach provides a framework for evaluating the productivity and long-term development of mixed-species forests.

Perhaps the most valuable insight from this production-ecology perspective will be in helping silviculturists and forest managers view patterns in stand growth with a process-level understanding that can be quantified and tested. Empirical patterns of growth and yield provide retrospective insights on past responses of forests to silvicultural operations, but the inclusion of process-based insights will be vital to predicting future stand growth.

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Chapter 3
Invasive Species, Climate Change and Forest Health

Jacques Régnière

Abstract Species have been invading new territories ever since life appeared on Earth, as invasion is part of the struggle for life. From the times of supercontinents Rodinia and then Pangea to the current distribution of the world's continents, species have moved within and between land masses in search of opportunities for survival and growth. Species have always taken advantage of every opportunity to move that was within their behavioral and physiological capabilities. *Homo sapiens* is arguably one of the most successful invasive species on the planet, and his activities have greatly increased the range of opportunities for movement of other species. The ancient invasions of Europe and Asia, Australia, the Americas and New Zealand, and the more recent colonization of much of the world by Europeans, have spread a large number of human-associated species: crops, ornamentals, domesticated animals, pets, pests and diseases. International commerce (globalization) has ratcheted this process to new heights. While some of the species spread by humans are beneficial, at least to man himself, many have negative impacts on the ecosystems they invade. These negative impacts can be particularly profound in widespread, long-lived ecosystems such as forests, although undisturbed ecosystems tend to be resilient to invasion. We face an increasing prevalence and impact of invasive species on forest ecosystems as a result of increasing human transportation and commerce, our influence on Earth's climate, and the increasing prevalence of disturbed ecosystems. In this paper, I discuss the issues of mitigation and adaptation in the context of land use changes and climate change. The focus is on the most fundamental aspects of biology that determine the potential range of invasive species in their new environments: development and survival during periods of extreme climatic conditions with specific examples using North American forest insects, the indigenous mountain pine beetle and the alien gypsy moth.

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> *"Know thy self, know thy enemy…**Strategy without tactics is the slowest route to victory. Tactics without strategy is the noise before defeat.**" Sun Tzu, The Art of War, China, 500 BC.*

3.1 Introduction

The issue of invasive species is intimately linked to that of climate change. Many authors have recognized and discussed this in the scientific literature (for a good recent discussion of the science involved, see Walther et al. 2009). The specific problems posed by invasive species in forestry are similarly linked to habitat disturbance and climate change (see Simberloff 2000 for a succinct overview). However, invasive species, and indeed climate change, are not new problems. In fact, invasion, resulting from the movement of species followed by intense competition for essential resources, has been going on since life began on Earth.

Many evolutionary ecologists consider allopatric speciation as one of the key processes of evolution. This process occurs when a population becomes isolated geographically from the remainder of the parent species, which results in genetic isolation (restricted gene flow). Often, such isolation occurs in climatically marginal (fringe) environments where a new subspecies adapts differentially to these marginal conditions, until further change in climate confers it an adaptive advantage in the parent species' traditional range. Invasion follows, and the new species quickly replaces the old (Gould 2006). A striking example of this process occurring in recent time is Dutch elm disease, caused by the fungus *Ophiostoma ulmi*, usually vectored by bark beetles. This disease was introduced into North America from Europe in the 1930s. Once in North America, it rapidly developed a far more aggressive mutant species, *Ophiostoma novo-ulmi*. This new species was then reintroduced, once again by man, into Europe (Brasier 2000).

Invasion is intricately linked to climate change, which is a perpetual phenomenon on Earth. Life responds to climate change through evolutionary adaptation, accompanied by changes in species distributions through movement, invasion and extinction. Climate change on Earth is due to interactions between the ever-changing configuration of land masses (Nield 2007), the chemical composition of the Earth's atmosphere (much of which is caused by life itself), solar energy inputs as determined by fluctuations of the Earth's orbital path and rotational axis, and catastrophic events such as meteoritic impacts and volcanic eruptions. Many of these climatic drivers are highly periodical and predictable (Gore 2006). The response of biological systems to these changes is not as predictable because they are contingent on the genetic material available at the moment.

3.2 Invasion and Ecosystems

While it is an interesting and even comforting concept to view nature and ecosystems as being in equilibrium with the environment and thus in some idealized stable state, ecologists have come to realize over the past few decades that this is far from reality. In fact, ecosystems are very dynamic, constantly changing in part to catch up with changes in the environment. Ecosystems are assemblages of species that vary tremendously in their requirements, plasticity, and mobility, and thus in their ability to keep track by reproducing, moving, and adapting (Botkin 1992).

For example, all species currently living in Canada, with the exception of parts of the West Coast that were never glaciated, can be viewed as invaders from farther south that arrived (and continue arriving) after the continental ice sheet melted some 12,000–15,000 years ago at the end of the Wisconsinian glaciation (Jacobson et al. 1987). This invasion is ongoing (Pielou 1992) and it includes all plants and animals. An example is earthworms. The current distribution of native earthworms in North America still reflects very closely the limits of the continental ice sheet of the last glaciation. Most earthworms currently found in Canada are actually invasive species from Europe (Addison 2009).

Thus, many of the Earth's ecosystems are constantly being re-designed by invasion, and many believe that invasion is a fundamental ecological process to which these systems are very resilient in the long term. The response of ecosystems to invasions is another major source of evolutionary change. The new invading species attempts to occupy a somewhat different niche from its native competitors, and the ecological interactions that were established between the native species and its hosts, competitors and predators need to change. Species are rearranged in terms of frequency and intensity of main ecological processes that lead to energy flow up and down the food chain. Some plants may be favored in the change, others disfavored or even eliminated. Co-evolved relationships are deeply affected by an invading species that replaces another. This is why generalist species have a strong tendency to be better at tolerating climate change and to become invaders, while specialists tend to be the ones negatively affected by both climate change and invasions (see Régnière 2009). The impact on ecosystems thus depends very much on the role played by invading species in the new food web. Perturbed ecosystems, those that have been made fragile by environmental change or by anthropogenic alteration, are thought to be both more easily invaded (less resistant) because of the availability of empty niches, and more fragile (less resilient) because of fewer or altered feedback control mechanisms.

Invasion proceeds in phases. In a large number of cases, invading species go through a period called the "sleeper" phase during which they barely survive in their new environment. Many, if not most, invader populations become extinct during that period. Extinction often results from so-called Allee effects, when numbers are so low that essential collaborative processes such as finding mates are severely hindered (Keitt et al. 2001). However, in some cases (and those are the ones we notice), opportunity presents itself either in the form of a change in environmental conditions or the decline of competition with native species that allows the invader to grow in numbers. In many instances, this becomes the notorious "first wave" of invasion during which the invader's population expands both in numbers and in geographical range and causes the most perturbation to the ecosystem or the services derived from that ecosystem. Eventually, the system of balance present in most ecosystems switches into action, with natural enemies establishing themselves on the invader or with the plant community changing sufficiently to restore some form of balance, and the invader becomes an integral part of the new ecosystem.

3.3 Man as the Ultimate Invasive Species

Homo sapiens is a very recent addition to the Earth's fauna. Man has a very well-documented invasion history, based on recent tracking of mutations in mitochondrial (maternal) and Y-chromosome (paternal) DNA (Wells 2002; Watson 2006). Over the past 150,000 years, our species has successfully invaded the entire planet, with permanent settlements everywhere except Antarctica and some smaller oceanic islands. *Homo sapiens* is now the only representative of the genus *Homo*, and evidence suggests that this situation may have been the consequence of competition, following invasion, with now-extinct species such as *H. neanderthalis* (Hublin and Seytre 2008).

The arrival of humans almost everywhere during that period (except in Africa and Eurasia, where animals co-evolved with hominids) was accompanied by rapid extinction of a large number of species, perhaps most notoriously among the vertebrate megafauna used as "game" that had not co-evolved with man. The date and method of arrival of *H. sapiens* in the Americas is somewhat controversial (Hardaker 2007), but the main invasion at the end of the last glaciation (15,000 years ago) is well documented (Fagan 2004). That invasion was followed by a very rapid demographic expansion and was accompanied by the extinction of over 50 species of the Americas' megafauna, from woolly mammoth to giant beaver. Some say this was a coincidence, and that it resulted from climate change. But given that the more recent recorded history of human invasion in areas such as New Zealand and Mauritius was accompanied by the rapid disappearance of large game (tame flightless birds like the moa and the dodo) and their predators, my opinion is that the extinction of megafauna during the Holocene was hastened if not caused by anthropogenic ecosystem modification and overhunting.

Changing climates and ecosystems were probably the main motivators forcing man into "economic" migration. In his displacements (and commerce), he has not travelled alone. He has voluntarily traveled with his domesticated animals and plants. He has also unwittingly brought along for the ride many species such as rodents, parasites and pathogens. It is believed that the human population of the pre-Columbian Americas was near 100 million, of which 18 million lived in North America. Perhaps the highest hunter-gatherer human population density on Earth lived along the northern Pacific Coast, where resources were abundant. After the first contacts with Europeans in the fifteenth century, this population was decimated (to the order of 90–95%) by diseases such as smallpox, typhus, measles, influenza, bubonic plague, cholera, malaria, tuberculosis, mumps, yellow fever, and whooping cough. This occurred before most of the indigenous population had even seen or heard of these fair-skinned, bearded invaders (Dickason 1992). By the time European men of war had undertaken conquest by steel weapons, they faced a very much reduced enemy (Diamond 1997).

In the early days of colonization (be it in North America, Australia, South Africa or New Zealand), man very systematically established invasive species into his newly acquired lands. He introduced game, livestock, pets, crops and ornamentals (often as reminders of "home" to compensate for homesickness). There are so many examples of this, from the rabbit in Australia to the deer on Anticosti Island in the Gulf of St. Lawrence and moose on the Island of Newfoundland, that it is pointless to attempt making a list.

So while invasiveness is a biological trait closely linked to evolution in the face of climate change, man has played, and is still playing, an increasing role in the rate at which invasion takes place in nature. This results from three processes. Increased international commercial activity from globalization and the industrialization of developing countries have multiplied travel opportunities for a wide array of species. Anthropogenic climate change, due to the increase in the atmospheric concentration of greenhouse gasses, is making Earth's temperate zones increasingly hospitable to species from milder climes, increasing the probability of establishment of the international travelers. Finally, perturbed habitats and ecosystems are deemed less resistant/resilient to invasion. Expanding agriculture needed to keep pace with increasing human population density has been the most important source of perturbation, but pollution and exploitation of forested ecosystems have also greatly contributed to this increasing fragility (Moore 2005).

3.4 Means of Mitigation

Several key biological traits tend to confer high invasiveness to some species. Those that are highly mobile (active dispersal) or have numerous wind- or water-borne propagules (spores, seed, free-floating larvae, winged adults) figure predominantly among the most invasive species. However, low mobility does not prevent species from becoming invasive (e.g., earthworms). Short generation times and high population growth rates (especially high fecundities) are also favorable traits. Species that have few natural enemies tend to fare better upon arrival in their new environments. Generalists, species with a wide host range, predominate over specialists that have low flexibility in selecting food sources. Of course, these are tendencies, not rules.

Another set of factors that greatly affects how much risk a species poses are those that determine its probability of emigrating. Species that are very numerous or that undergo outbreak episodes are the most likely to emigrate (Moore and Allard 2009).

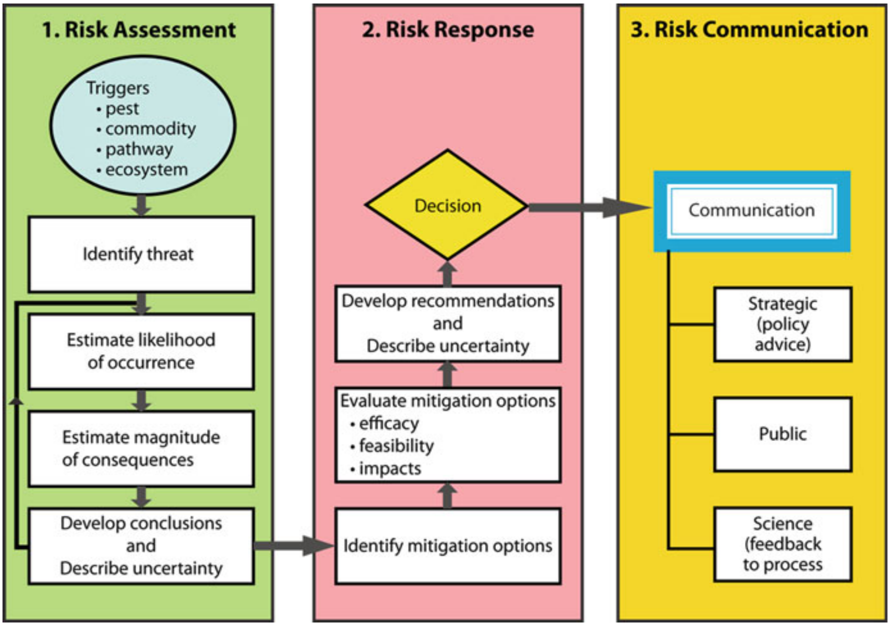

Fig. 3.1 The process of Risk Analysis, illustrating the three main steps of risk assessment, risk response, and risk communication (adapted from Information Forestry, April 2008, Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia, Canada)

Also, species most likely to be transported by humans are those that exploit or are commonly found in commodities or products of high-intensity commerce, in particular those in live plants, stored products and packaging materials. Finally, cryptic species (those that are most difficult to detect) are the ones most likely to escape vigilance at points of departure as well as arrival. This is perhaps the most obvious motivation for the development of molecular diagnostic tools (Stoekle 2003).

Finally, the probability of immigration or establishment in a new environment is determined by another set of factors. First and foremost is the environmental suitability of the destination in terms of climate and food resources (here generalists fare better than specialists). Species that have a high tolerance to harsh shipping conditions pose particularly high risks. This includes species with highly resistant resting stages such as spores or with a diapause phase.

The best opportunity to reduce the risks posed by invasive species is prevention. Perhaps foremost in prevention is the identification of high-risk species and risk analysis. Risk analysis is a formal, multifaceted, stepwise and iterative process (Fig. 3.1) in which a perceived risk is first assessed in light of available scientific information. The potential or actual invader's probable geographical range in its new environment is predicted on the basis of its climatic and host requirements. This information helps quantify the magnitude of consequences of its establishment (potential impacts). Because the risk assessment step is intended to be iterative, the need to reduce key uncertainties should trigger the gathering of new knowledge that feeds back into refining estimates of occurrence or impacts, and providing additional mitigation options. Impact estimates (with their inherent uncertainty) are the main motivation for the second step, which is the design and application of a risk response. Here, mitigation options are evaluated in terms of costs, benefits and uncertainties, and recommendations for action are made to decision makers. The third step involves communicating the intervention strategy to policy makers, the public and stakeholders. The results of a solid risk analysis can be used to determine the intensity of efforts to be devoted to monitoring at points of departure, sanitation measures for shipping materials (e.g. irradiation, heat-treatment of dunnage and wood crates), inspection at points of departure and arrival, and attempts to eradicate the usually small and confined populations that often escape the monitoring and sanitation measures. Eradication is easier said than done, and in many cases such efforts fail. At that point, once a new species is firmly established in its new environment, regulation is needed to reduce the risk of inadvertently accelerating the spread of the organism through internal commerce. Finally, control measures may be required to fight against the newly established organism to mitigate its negative impacts on the invaded ecosystems (FAO 2005).

3.5 Knowledge Issues

One of the primary knowledge issues with respect to invasive species, especially in forest ecosystems, is one of biodiversity. This is the "know thy self" part of the Sun Tzu quote at the beginning of this paper. It is necessary to know the species that compose current ecosystems in order to readily identify not only which ones are invading species, but also their impact on indigenous fauna and flora (Kenis et al. 2009). However, our knowledge of forest biodiversity, let alone of the services species render in ecosystems, is very limited. In addition, the quantification and monitoring of biodiversity require the development and maintenance of taxonomic expertise as well as the establishment and support of monitoring activities. Taxonomic expertise is in very short supply in many parts of the world, including in the most developed countries, as a result of past decisions on funding and training. This situation is an issue that requires immediate attention from political and academic organizations.

The second part of the Sun Tzu quote is "know thy enemy". Adequate knowledge of the species that pose a risk of immigrating, or that have been found in a new environment is required to predict their potential range (the area over which they are likely to spread and establish themselves), and impact. Such knowledge includes the fundamental responses of a species to the climatic conditions that constitute the environmental limits within which it can successfully complete its life cycle, reproduce and survive from year to year. Another fundamental set of knowledge concerns the food resources that are likely to be available for the species in its new habitat. As invasion often involves a lack of co-evolution, few, if any, potential food sources can be expected to have efficacious defenses against an invader. It is generally believed that indigenous control agents such as predators, parasitoids, and diseases cannot eliminate an invader, but may at best help limit its rate of population growth and range expansion. However, determining the probable role played by competitors and natural enemies is a very difficult task. In many cases, these higher-level trophic interactions start playing a major role at the end of the "invasion wave", and are most likely to become important in undisturbed ecosystems.

While risk analysis provides a solid framework to assist decision makers in the management of invading species (either preventive or palliative), its application is only as good as the knowledge that is available to develop it. In many cases, such knowledge is severely lacking, and the resources needed to obtain it are in short supply. For example, research on thermal responses must be done either in the country of origin of an invader, an activity that involves international collaboration and funding channels, or in the country of arrival. In the latter case, adequate quarantine facilities are often required where the invader can be safely confined for study. Host ranges are usually investigated in the location of arrival, and such investigations also require quarantine facilities. This is also true for the development of monitoring tools such as traps, pheromone lures, and genetic markers, as well as control methods (biological control, pesticides).

Thus, four areas of scientific activity are involved in mitigating the threat posed by invasive species: taxonomic and biodiversity knowledge, determination of basic biological requirements (bionomics) and host range, monitoring tools, and control methods. This knowledge constitutes the tactics mentioned by Sun Tzu in the last part of the quote at the beginning of this article. Their integration through the process of risk analysis constitutes what Sun Tzu referred to as the strategy. All are needed if the management of invasive species is to succeed.

3.6 Examples

There are large numbers of plants, insects, diseases and marine organisms that have already immigrated into new territories. In Australia, over 30 species of vertebrate and invertebrate invasive species have been documented to have a major impact. These are concentrated in the south eastern portion of the continent where human activity is at its highest. In Canada, there have been over 180 invaders in the aquatic ecosystem of the Great Lakes since 1840. Over 480 alien species of plants have successfully established themselves in Canada. On trees in Canada, there are over 419 alien insect species (Langor et al. 2009), and nine major diseases (Loo 2009). Most of the insects are Hemiptera (223 species, mostly aphids and scale insects), Lepidoptera (91 species, mostly defoliating caterpillars), and Coleoptera (91 species, mostly bark beetles and wood borers). The Canadian government's National Strategy of Invasive Alien Species is an $85,000,000 program over 5 years (ending in 2010) involving some 100 scientists and research professionals spread across four departments. Over $52,000,000 of these funds are used to support the acquisition of new knowledge and risk analysis. Over $33,000,000 are invested in prevention measures, including early detection. In addition to insects that we know have established populations in Canada, the Canadian Food Inspection Agency has drawn up a "white list" of 27 undesirable alien insects that present a high risk although so far they have not, to our knowledge, established themselves anywhere in Canada. Most of these are notorious pests such as bark beetles and wood borers in their potential countries of origin. The Canadian Forest Service has access to a real goldmine of historical data on Forest Invasive Alien Species through which it is possible to conduct analyses on ports of entry, spread rates, success/failure of eradication or control operations, potential distributions as well as, in some cases, the expected effects of climate change.

Régnière et al. (2009) conducted a study on the invasion of Canada by the gypsy moth, *Lymantria dispar*, which first arrived from Europe and established itself near Boston, Massachusetts (USA), at the turn of the nineteenth century. In Canada, since the mid 1900s, the gypsy moth's northern progression has been limited in large part by cool summers that prevent the successful completion of its univoltine life cycle. In their risk assessment, these authors made extensive use of the available historical monitoring data on male moths caught in pheromone-baited traps as well as additional data on the presence of other life stages (such as egg masses or larvae) that are more directly indicative of successful establishment. They also used a detailed model of the insect's developmental responses to temperature (best described in Gray 2004) linked to BioSIM, a software tool that facilitates the application of such models using weather information over wide geographical areas (Régnière 1996) to determine the probability of successful completion of the insect's life cycle over the entire country. This was also complemented with an analysis of the impact of climate change on these probabilities. The conclusions of this study led to improved strategies for the deployment of pheromone trap monitoring (a tactic) by the Canadian Food Inspection Agency, and better decisions about the application of insecticides to eradicate introductions of the insect in western Canada (another tactic).

Another major application of knowledge on the climatic responses of an insect using similar tools concers the assessment of the risk posed to eastern pine species of the Canadian boreal forest by the mountain pine beetle, *Dendroctonus ponderosae*, an insect that had up to very recently been confined to the west of the Rocky mountains by a combination of habitat (prairies to the south) and climate (to the north). The insect having crossed over the mountains from British Columbia (Canada) into the pine forests of the western boreal forest in northern Alberta, and is now considered an invasive species threatening those ecosystems all the way to the Atlantic Coast (Nealis and Peter 2008).

3.7 Conclusions

Many actions need to be undertaken to face the increasing threat posed to forest ecosystems by invasive alien species. These were well summarized by Simberloff et al. (2005) and Krcmar (2008). Research is needed to provide baseline knowledge of existing local biodiversity and ecosystem services provided by keystone species. Knowledge of the bionomics of target invasive species, be they black- or white-list members, such as host range and temperature responses, is needed to determine with some certainty their probable geographical ranges and impacts. This requires international cooperation and widespread availability of quarantine facilities and taxonomic expertise, as well as adequate funding. Research in the area of monitoring tools, including molecular markers and control tactics is also needed.

Sufficient funding must be provided to conduct knowledge-based risk assessments and, when warranted from these, risk management and risk communication activities. These invariably involve the enforcement of monitoring and sanitation measures, as well as eradication and control practices that are well-integrated into well-analyzed and well-communicated risk management strategies. These strategies, integrating adequate tactics, have a good likelihood of success (Simberloff 2009).

Finally, a word of caution. As the saying goes, "an ounce of prevention is worth a pound of cure". However, too much caution can cause severe disruption in trade and consequent loss of economic activity. Because of this potential loss, risk analysis should always be done before contemplating any specific actions against real or perceived threats posed by invasive species. In this line of thought, international collaboration and information sharing about the status of major forest pests among major commercial partners is essential. Trade barriers should not be erected as a result of such information exchange, but instead common mitigation measures should be devised. Sharing technological tools, such as software products like BioSIM or molecular markers, and expertise in their application is also an important component of such international collaboration.

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Chapter 4
The Biorefining Story: Progress in the Commercialization of Biomass-to-Ethanol

John N. Saddler, Warren E. Mabee, Ralph Simms, and Michael Taylor

Abstract Continued insecurity around oil supplies has helped to keep oil prices high, and the combination of these factors have driven a rapid expansion in global bioethanol and biodiesel production. While foods such as sugar and corn are still the dominant feedstock for biofuel production, interest in utilizing lignocellulose for the production of a 2nd generation of biofuels has grown significantly. The agricultural sector has made significant progress in developing bio-based fuels and chemicals. Technologies from the agricultural sector may be combined with recent technical improvements that have made wood-based bioconversion more feasible. The biorefinery concept has been proposed as a means to extract maximum value from lignocellulosics, of which only a portion of the chemical structure is suitable for biofuel production. Within the biorefinery, some components of the lignocellulosic feedstock may be converted into a range of material, chemical and energy, as the basis products, such as wood chips. The continued development of new conversion technologies will allow these biorefineries to utilize lignocellulosic feedstocks, enabling the production of additional value-added bioproducts and more efficient recovery of bioenergy. There are a number of complementary platforms for processing lignocellulosic feedstocks, including traditional platforms (i.e. existing pulping technologies) as well as emerging technologies that are biological-based or thermochemical-based.

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Each of these platforms can be organized to produce bioenergy, biofuel, and/or bioproducts (including both material and chemical products). The emerging biological platform uses biological agents, including enzymes and microbes, to hydrolyze and ferment components of lignocellulose to ethanol and other value-added products. The thermochemical platform utilizes pyrolysis and gasification stages to convert lignocellulosic biomass into synthesis gas, which can then be catalyzed into a variety of products. It is apparent that technical barriers remain for 2nd generation biofuel production. Production costs are uncertain but currently thought to be around USD 0.80–1.00/l of gasoline equivalent. There is no clear candidate for "best technology pathway" between the competing biochemical and thermo-chemical routes and monitoring of large-scale demonstration projects is essential to provide accurate comparative data. Even at higher oil prices, 2nd-generation biofuels will probably not become fully commercial nor enter the market for several years to come without significant government support. Considerably more investment in research, development, demonstration and deployment (RDD&D) is needed to ensure that future production of the various biomass feedstocks can be undertaken sustainably and that the preferred conversion technologies are identified and proven to be viable. Once proven, there will be a steady transition from 1st to 2nd generation biofuels (with the exception of sugarcane ethanol that will continue to be produced sustainably in several countries).

Keywords Biofuels • Bioenergy • Biorefinery • First and second generation biofuels

4.1 Introduction

It is increasingly understood that 1st generation biofuels (produced primarily from food crops such as grains, sugar beet and oil seeds) are limited in their ability to achieve targets for oil-product substitution, climate change mitigation, and economic growth. Their sustainable production is under review, as is the possibility of creating undue competition for land and water used for food and fibre production. (A possible exception that appears to meet many of the acceptable criteria is ethanol produced from sugar cane).

These concerns have increased the interest in developing 2nd generation biofuels (produced from non-food biomass, ligno-cellulosic materials such as cereal straw, forest residues, and vegetative grass crops). These biofuels could avoid many of the concerns facing 1st generation biofuels and potentially offer greater cost reduction potential in the longer term. This report looks at the technical challenges facing 2nd generation biofuels, evaluates their costs and examines related current biofuels policies. Although significant progress continues to be made to overcome the technical and economic challenges for 2nd generation biofuels, they still face major constraints to their commercial deployment.

4.2 First Generation Biofuels

4.2.1 Current Status

The production of 1st generation biofuels – such as sugarcane ethanol in Brazil, corn ethanol in US, oilseed rape biodiesel in Germany, and palm oil biodiesel in Malaysia – is characterised by mature commercial markets and well understood technologies. The global demand for liquid biofuels more than tripled between 2000 and 2007. Future targets and investment plans suggest strong growth will continue in the near future.

The main drivers behind the policies in OECD countries that have encouraged this growth are energy supply security; support for agricultural industries and rural communities; reduction of oil imports and the potential for greenhouse gas (GHG) mitigation. Several non-OECD countries have developed their own biofuel industries to produce fuels for local use, as well as for export, to aid their economic development. Many others are considering replicating this model. Driven by supportive policy actions of national governments, biofuels now account for over 1.5% of global transport fuels (around 34 Mtoe in 2007).

4.2.2 Constraints and Concerns

While most analyses continue to indicate that 1st generation biofuels show a net benefit in terms of GHG emissions reduction and energy balance, they also have several drawbacks. Current concerns are that they contribute to higher food prices due to competition with food crops; are an expensive option for energy security taking into account total production costs excluding subsidies; provide only modest GHG reduction benefits and at relatively high costs in terms of $/tonne of carbon dioxide ($/t CO_2) avoided; do not meet their claimed environmental benefits because the bioenergy feedstock may not always be produced sustainably and that they are accelerating deforestation (with other potentially indirect land use effects also to be accounted for); potentially have a negative impact on biodiversity; and compete in some regions for scarce water resources.

At least to some extent, some 1st generation biofuels have contributed to the recent increases in world prices for food and animal feeds. However, much uncertainty exists in this regard and estimates of the biofuels contribution range from virtually zero to around 75% of the total price increase. Regardless of the culpability, competition with food crops will remain an issue so long as 1st generation biofuels produced from food crops dominate total biofuel production.

Production and use of some biofuels can be an expensive option for reducing GHG emissions and improving energy security. Estimates for GHG mitigation from biodiesel in the US, EU, Australia, Canada and Switzerland vary between USD 160–1750/t CO_2 avoided, depending on the country and pathway. For corn ethanol it varies between USD 250 and 5500/t CO_2 avoided. Given the relatively limited scope for cost reductions and growing global demand for food, little improvement in these mitigation costs can be expected in the short term.

Additional uncertainty has also recently been raised about GHG savings if indirect land use change is taken into account. Certification of biofuels and their feedstocks is being examined, and could help to ensure biofuels production meets sustainability criteria, although some uncertainty over indirect land-use impacts is likely to remain. Additional concerns over the impact of biofuels on biodiversity and scarce water resources in some countries also need further evaluation.

4.3 Second Generation Biofuels

Many of the problems associated with 1st generation biofuels can be addressed by the production of biofuels manufactured from agricultural and forest residues and from non-food crop feedstocks (known as 2nd generation biofuels). Where the ligno-cellulosic feedstock is to be produced from specialist energy crops grown on arable land, several land use concerns remain, although energy yields (in terms of GJ/ha) are likely to be higher and poorer quality land could possibly be utilised. These 2nd generation biofuels are immature so have a large potential for cost reductions and increased production levels as more experience is gained. They are therefore likely to be part of the solution to the challenge of shifting the transport sector towards more sustainable energy sources in the short- to medium-term.

However, 2nd-generation biofuels face major technical and economic hurdles before they can be widely deployed. To address these issues, significant investment in RD&D funding by both public and private sources is occurring. In addition, there has been significant investment in pilot and demonstration facilities, but more is likely to be required in the near future if commercial deployment is to occur.

Given the current investments being made to gain improvements in technology, expectations have arisen that these advanced biofuels will reach full commercialisation in the near future; allowing much greater production volumes at the same time as avoiding most of the drawbacks of 1st generation biofuels. More realistically, at least in the near to medium-term, the biofuel industry will grow only steadily to encompass both 1st and 2nd generation technologies that meet agreed environmental, sustainability and economic policy goals.

Sugarcane ethanol will continue to be produced, but for more costly 1st generation biofuels, the transition to 2nd generation is likely to encompass the next one to two decades, as the infrastructure and experiences gained from deploying and using 1st generation biofuels is transferred to support and guide 2nd generation biofuel development. Policies that target biofuels with lower environmental impacts if carefully managed, along with their potential for lower costs, are likely to promote the more rapid development of 2nd generation biofuels.

4.3.1 Conversion Routes

The production of biofuels from ligno-cellulosic feedstocks can be achieved through two very different processing routes. They are: *biochemical* – in which enzymes and other micro-organisms are used to convert cellulose and hemicellulose components of the feedstocks to sugars prior to their fermentation to produce ethanol; *thermo-chemical* – where pyrolysis/gasification technologies produce a synthesis gas ($CO + H_2$) from which a wide range of long carbon chain biofuels, such as synthetic diesel or aviation fuel, can be reformed.

These are not the only 2nd generation biofuels pathways, and several variations and alternatives are under evaluation in research laboratories and some pilot plants. They can produce similar biofuel products to the two main routes or several other biofuels (for example dimethyl ether, methanol, synthetic natural gas). However, at this stage they do not represent the main thrust of RD&D investment.

Following substantial government grants recently to help reduce the commercial and financial risks from unproven technology and fluctuating oil prices, both the biochemical enzyme hydrolysis process and the thermo-chemical biomass-to-liquid (BTL) process have reached the demonstration stage. Several plants in US and Europe are either operating, planned or under construction. A number of large multi-national companies and financial investors are closely involved in the various projects and considerable public and private investments have been made in recent years. As more of these demonstration plants come on-line over the next 2–3 years they will be closely monitored. Significant data on the performance of different conversion routes will then become available, allowing governments to be better informed in making strategic policy decisions for 2nd generation development and deployment.

Based on the announced plans of companies developing 2nd generation biofuel facilities, the first fully commercial-scale operations could possibly be seen as early as 2012. However, the successful demonstration of a conversion technology will be first required in order to meet this target. Given the complexity of the technical and economic challenges involved, in reality the first commercial plants are unlikely to be widely deployed before 2015 or 2020. Therefore 2nd generation biofuels are unlikely to make a large contribution to meeting global transport fuel demand before 2030.

4.3.2 Biochemical Versus Thermo-chemical

There is currently no clear commercial or technical advantage between the biochemical and thermo-chemical pathways, even after many years of RD&D and the development of near-commercial demonstrations. Both sets of technologies remain unproven at the fully commercial scale, are under continual development and evaluation, and have significant technical and environmental barriers yet to be overcome.

For the biochemical route, much remains to be done in terms of improving feedstock characteristics; reducing the costs by perfecting pre-treatment; improving the efficacy of enzymes and lowering their production costs; and improving overall process integration. The potential advantage of the biochemical route is that cost reductions have proved reasonably successful to date, so it could possibly provide cheaper biofuels than for the thermo-chemical route. Only time will tell.

As a broad generalisation, there are less technical hurdles to the thermo-chemical route since much of the technology is already proven. The problems are with securing a large enough quantity of feedstock at reasonable delivered cost to enable the greater commercial-scale required to become economic. Also perfecting the gasification of biomass reliably and at reasonable cost has yet to be achieved. An additional drawback is that there is perhaps less opportunity for cost reductions (excluding several untested novel approaches under evaluation).

One key difference between the biochemical and thermo-chemical routes is that, during enzyme hydrolysis, the lignin component is a residue and can be used for heat and power generation. In the BTL process it is converted into synthesis gas along with the cellulose and hemicellulose biomass components. Both processes can potentially convert one dry tonne of biomass (~20 GJ/t) to around 6.5 GJ/t of energy carrier in the form of biofuels. This gives an overall biomass to biofuel conversion efficiency of around 35%. Although this efficiency appears relatively low, overall efficiencies of the process can be improved when surplus heat, power and co-product generation are included in the total system. Improving efficiency is vital to the extent that it reduces the final product cost and improves environmental performance, but it should not be a goal in itself.

A second major difference is that biochemical routes produce ethanol whereas the thermo-chemical routes can produce a range of hydrocarbon chains from the synthesis gas, including biofuels better suited for aviation and marine purposes.

Although both routes have similar potential yields in energy terms, different yields, in terms of litres per tonne of feedstock, occur in practice. Major variations between the various processes under development, together with variations between biofuel yields from different feedstocks, gives a complex picture with wide ranges quoted in the literature. Typically enzyme hydrolysis could be expected to produce up to 300 l ethanol/dry tonne of biomass whereas the BTL route could yield up to 200 l of synthetic diesel per tonne. The similar overall yield in energy terms (6.5 GJ/t biofuels), is because synthetic diesel has a higher energy density by volume (34.4 MJ/l low heating value) than ethanol (21.1 MJ/l).

4.3.3 Ligno-Cellulosic Feedstocks

Low-cost crop and forest residues, wood process wastes, and the organic fraction of municipal solid wastes can all be used as ligno-cellulosic feedstocks. Where these materials are available, it should be possible to produce biofuels with virtually no additional land requirements or impacts on food and fibre crop production. However in many regions these residue and waste feedstocks may have limited supplies, so the growing of vegetative grasses or short rotation forest crops will be necessary as supplements. Where potential energy crops can be grown on marginal and degraded land, these would not compete directly with growing food and fibre crops on better quality arable land.

Relatively high annual energy yields from dedicated energy crops, in terms of GJ/ha/year, can be achieved from these crops compared with many of the traditional food crops currently grown for 1st generation biofuels. Also their yields could increase significantly over time since breeding research (including genetic modification) is at an early phase compared with breeding of food crops. New energy crop varieties may increase yields, reduce water demand, and reduce the dependency on agri-chemical inputs. In some regions where low intensity farming is practiced, improved management of existing crops grown on arable land could result in higher yields per hectare and thereby enable energy crops to also be grown, without the need for increased deforestation or reduction in food and fibre supplies.

4.3.4 Supply Chain Issues

Harvesting, treating, transporting, storing, and delivering large volumes of biomass feedstock, at a desired quality, all-year-round, to a biofuel processing plant requires careful logistics analysis prior to plant investment and construction. Supplies need to be contracted and guaranteed by the growers in advance for a prolonged period in order to reduce the project investment risks. The aims should be to minimise production, harvest and transport costs and thereby ensure the economic viability of the project. This issue is often inadequately taken into account when 2nd generation opportunities are considered. Supply logistics will become more important as development accelerates and competition for biomass feedstocks arises. Reducing feedstock delivery and storage costs should be a goal since feedstock costs are an important component of total biofuel costs.

4.3.5 Production Costs

The full biofuel production costs associated with both pathways remain uncertain and are treated with a high degree of commercial propriety. Comparisons between the biochemical and thermo-chemical routes have proven to be very contentious within the industry, with the lack of any real published cost data being a major issue.

The commercial-scale production costs of 2nd generation biofuels are estimated to be in the range of USD 0.80–1.00/l of gasoline equivalent (lge) for ethanol and at least USD 1/l of diesel equivalent for synthetic diesel. This range broadly relates to gasoline or diesel wholesale prices (when measured in USD /lge), when the crude oil price is between USD 100–130/bbl. The present widely fluctuating oil and gas prices therefore make investment in 2nd generation biofuels at current production costs a high risk venture, particularly when other alternatives to conventional oil such as heavy oil, tar sands, gas-to-liquids and coal-to-liquids can compete with oil in the range of USD 35–65/bbl. This does not take into account any future penalty imposed for higher CO_2 emissions per kilometre travelled when calculated on a life cycle basis.

The main reasons for the major discrepancies between the various published cost predictions relate to varying assumptions for feedstock costs and the future timing of the commercial availability of both the feedstock supply chain and conversion technologies. Given that 2nd generation biofuels are still at the pre-commercial stage, widespread deployment is expected to lead to the improvement of technologies, reduced costs from plant construction and operation experience, and other "learning by doing" effects. The potential for cost reductions is likely to be greater for ethanol produced via the biochemical route than for liquid fuels produced by the thermo-chemical route, because much of the technology for BTL plants (based on Fischer-Tropsch conversion) is mature and the process mainly involves linking several proven components together. So there is limited scope for further cost reductions. However if commercialisation succeeds in the 2012–2015 time frame and rapid deployment occurs world-wide beyond 2020, then costs could decline to between USD 0.55 and 0.70/lge for both ethanol and synthetic diesel by 2030. Ethanol would then be competitive at around USD 70/bbl (2008 dollars) and synthetic diesel and aviation fuel at around USD 85/bbl. By 2050, costs might be further reduced for BTL biofuels to become competitive at USD 75/bbl.

4.3.6 Successful Development – Technology and Knowledge Challenges

Success in the commercial development and deployment of 2nd generation biofuel technologies will require significant progress in a number of areas if the technological and cost barriers they currently face are to be overcome. Areas that need attention are outlined below.

Improved understanding of feedstocks, reduction in feedstock costs and development of energy crops:

- A better understanding of currently available feedstocks, their geographic distribution and costs is required. Experience in the production of various dedicated feedstocks (e.g. switchgrass, miscanthus, poplar, eucalyptus and willow) in different regions should be undertaken to understand their yields, characteristics and costs.
- The ideal characteristics of specific feedstocks to maximise their conversion efficiencies to liquid biofuels, as well as the potential for improving feedstocks over time, need to be identified. Rates of improvement could then be maximised through R&D investment.

- On a micro-scale, the implementation of energy crop production needs to be assessed to ascertain the area within a given collection radius sufficient to supply a commercial-scale plant. Although in some regions there may be enough agricultural and forest residues available to support several processing plants, it is likely that large-scale production will require dedicated energy crops either as a supplement or in some regions as the sole feedstock. The optimal size of production facility, after trading off economies of scale against using local, reliable and cost-effective feedstock supplies, should be identified for a variety of situations.

Technology improvements for the biochemical route, in terms of feedstock pre-treatment, enzymes and efficiency improvement and cost reduction:

- Feedstock pre-treatment technologies are inefficient and costly. Improvements in physical, chemical and combinations of these pre-treatment's need to be achieved to maximise the efficacy of pre-treatment in opening up the cellular structure of the feedstock for subsequent hydrolysis. Dilute and concentrated acid processes are both close to commercialisation, although steam explosion is considered as state-of-the-art.
- New and/or improved enzymes are being developed. The effective hydrolysis of the interconnected matrix of cellulose, hemicellulose and lignin requires a number of cellulases, those most commonly used being produced by wood-rot fungi such as Trichoderma, Penicillum, and Aspergillus. However, their production costs remain high. The presence of product inhibitors also needs to be minimised. Recycling of enzymes is potentially one avenue to help reduce costs. Whether separate or simultaneous saccharification and fermentation processes represent the least cost route for different feedstocks is yet to be determined.
- A key goal for the commercialisation of ligno-cellulosic ethanol is that all sugars (C5 pentoses and C6 hexoses) released during the pre-treatment and hydrolysis steps are fermented into ethanol. Currently, there are no known natural organisms that have the ability to convert both C5 and C6 sugars at high yields, although significant progress has been made in engineering micro-organisms for the co-fermentation of pentose and glucose sugars. The conversion of glucose to ethanol during fermentation of the enzymatic hydrolysate is not difficult provided there is an absence of inhibitory substances such as furfural, hydroxyl methyl furfural, or natural wood-derived inhibitors such as resin acids.
- The need to understand and manipulate process tolerance to ethanol and sugar concentrations and resistance to potential inhibitors generated in pre-saccharification treatments, remains a scientific goal. Solutions to these issues will also need to accommodate the variability within biomass feedstocks. While pentose fermentation has been achieved on ideal substrates (such as laboratory preparations of sugars designed to imitate a perfectly-pretreated feedstock), significant work remains to apply this to actual ligno-cellulosic feedstocks.
- Due to the large number of individual processes in the overall conversion of ligno-cellulosic biomass into bioethanol, there remains considerable potential for process integration. This could have benefits in terms of lower capital and operating costs, as well as ensuring the optimum production of valuable co-products.

Given that development is still at the pre-commercial stage, it may take some time to arrive at the most efficient process pathways and systems.

Technology improvements for the thermo-chemical route, in terms of feedstock pre-treatment, gasification and efficiency improvement and cost reductions:

– BTL faces the challenge of developing a gasification process for the biomass at commercial-scale to produce synthesis gas to the exacting standards required for Fischer-Tropsch (FT) synthesis. In spite of many years of research and commercial endeavours, cost effective and reliable methods of large-scale biomass gasification remain elusive. The goal should be to develop reliable technologies that have high availability and produce clean gas that does not poison the FT catalysts, or that can be cleaned up to meet these standards without significant additional cost. Given the constraints on scalability and the level of impurities in the desired syngas, pressurised, oxygen-blown, direct entrained flow gasifiers appear to be the most suitable concept for BTL.
– Improving the efficiency and lowering the costs of the FT process are important RD&D goals, although improvements are likely to be incremental given the mature nature of the technologies. Developing catalysts that are less susceptible to impurities and have longer lifetimes would help reduce costs.

Co-products and process integration:

– The production of valuable co-products during the production of 2nd generation biofuels offers the potential to increase the overall revenue from the process. Optimisation of the conversion process to maximise the value of co-products produced (heat, electricity, various chemicals, etc.) needs to be pursued for different feedstocks and conversion pathways. The flexibility to vary co-product output shares is likely to be a useful hedge against price risk for these co-products.
– Market assessments of the biofuels and co-products associated with biofuel production need to take into account all the disbenefits, costs and co-benefits, including rural development, employment, energy security, carbon sequestration etc. if a fair assessment of their deployment is to be made.

4.4 Implications for Policies

Promotion of 2nd generation biofuels can help provide solutions to multiple issues including energy security and diversification, rural economic development, and reductions in negative environmental impacts (at least relative to those from the use of other transport fuels). However, the policies designed to support the promotion of 2nd generation biofuels must be carefully developed if they are to avoid unwanted consequences and potentially delay commercialisation.

Policies to support 1st or 2nd generation biofuels should be part of a comprehensive strategy to reduce CO_2 emissions:

– A critical first step that would help produce a more level playing field for biofuels is to ensure that there is a carbon price or other CO_2 reduction incentives in place. Taking into account the environmental impacts of CO_2 emissions from liquid fuels derived from fossil fuels would mean biofuels could compete on a more equal footing. This is also important to ensure that bioenergy feedstocks are put to their highest value use, due to competition for the limited biomass resource also for heat, power, bio-material applications etc. In addition, the harmonisation of policies across sectors - including energy, transport, health, climate change, local pollution, trade etc – is necessary to avoid policies working at cross purposes.
– The levelling of the playing field for biofuels is in itself unlikely to be enough to ensure the commercialisation of 2nd generation biofuels in a timely manner. In addition to systems placing a value on CO_2 savings, an integrated package of policy measures will be needed to ensure commercialisation, including continued support for R&D; addressing the financial risks of developing demonstration plants; and providing for the deployment of 2nd generation biofuels. This integrated policy approach, while not entirely removing financial risk for developers, will provide the certainty they need to invest with confidence in an emerging sector.

Enhanced RD&D Investment in 2nd generation biofuels

– Continued investment in RD&D is essential if 2nd generation biofuels are to be brought to market in the near future. This includes evaluating sustainable biomass production, improving energy crop yields, reducing supply chain costs, as well as improving the conversion processes via further basic RD&D and demonstration. This ultimately will lead to deployment of commercial scale facilities. The goals of public and private RD&D investments related to biofuel trade, use and production should include:

  • producing cost effective 2nd generation biofuels;
  • enabling sustainability lessons learned from 1st-generation biofuels to be used for 2nd generation;
  • increasing conversion technology performance;
  • evaluating the costs and benefits of increasing soil carbon content and minimising loss of soil carbon via land use change; and
  • increasing crop productivity and improvement of ecosystem health through management techniques, improved mechanisation, water management, precision farming to avoid wasting fertilisers and agro-chemicals, and plant breeding and selection.

– A broad, collaborative approach should be taken in order to ensure complementarity of various R&D efforts in different countries; to reduce the risk to investors; and to create a positive environment for the participation of financial institutions. Continued analysis of co-benefits including energy security, GHG mitigation, potential local advantages particularly for rural communities and sustainable development, and the value of co-products, should be undertaken. The international collaboration on assessing the benefits and impacts of 2nd generation biofuels trade, use and production, and monitoring them, should be continued. Agreement on sustainability principles and criteria that include effective, mutually agreed and attainable systems via means such as certification, and that are consistent with World Trade Organization (WTO) rules, would be a significant step forward.

Accelerating the demonstration of commercial-scale 2nd generation biofuels

- Before commercial production can begin, multi-million dollar government grants are currently required to encourage the private sector to take the risk of developing a commercial scale processing plant, even with the current high oil prices making biofuels a more competitive option than a year or two ago. This risk sharing between the public and private sector will be essential to accelerate deployment of 2nd generation biofuels.
- Funding for demonstration and deployment around 2nd generation biofuels is needed from both the public and private sectors. Developing links between industry, universities, research organisations and governments, has already been shown to be a successful approach in some instances. Present support (risk sharing) for demonstration projects, with some exceptions, does not match the ambitious plans for 2nd generation biofuels of some governments. Additional support policies need to be urgently put in place. Funding to support demonstration and pre-commercial testing of 2nd generation biofuel technology should be encouraged in order to reduce the risk to investors. Support for the necessary infrastructure and demonstration plants could be delivered through mechanisms similar to the US "*Program for Construction of Demonstration Technologies*", funded by the US Department of Energy.
- Where feasible, funding for 2nd generation biofuels and/or bio-refinery demonstration should be harmonised with national and regional renewable energy programmes which incorporate biomass production and utilisation. Links with other synergistic policies should be made where feasible in order to maximise support for infrastructure development. Integration and better coordination of policy frameworks requires coordinating national and international action among key sectors involved in biofuel development and use.

Deployment policies for 2nd generation biofuels:

- Deployment policies generally fall into two categories: blending targets (which can be mandatory or voluntary) and tax credits. Mandatory targets give certainty over outcomes, but not over the potential costs, while it is the inverse for tax credits. What pathways individual countries choose will depend critically on their policy goals and the risks they perceive.
- Deployment policies are essential if rapid scale-up of the industry is required to reduce costs through learning-by-doing. Otherwise deployment and cost

reductions are likely to be slow since initial commercial deployment focuses on niche opportunities where costs and risks are low.

– Continued support for 2nd generation biofuels development by governments is essential, but it should not necessarily be at the expense of reducing current programmes designed to support 1st generation developments. The two classes of biofuels should be considered in a complementary but distinct fashion, possibly requiring different policies due to the distinct levels of maturity.

Environmental performance and certification schemes:

– Continued progress needs to be made in addressing and characterising the environmental performance of biofuels. Approaches to standardisation and assessment methods need to be agreed, as well as harmonising potential sustainable biomass certification methods. These will need to cover the production of the biomass feedstock and potential impacts from land-use change. Policies designed to utilise these measures could work as a fixed arrangement between national governments and industrial producers, or could be designed to work as a market-based tool by linking to regional and international emission trading schemes such as the one in place between member states of the EU.
– It is considered that 2nd generation technologies to produce liquid transport biofuels will not become commercially competitive with oil products in the near future unless the oil price remains well over USD 100/bbl. Therefore a long-term view should be taken but without delaying the necessary investment needed to bring these biofuels closer to market. International co-operation is paramount, although the constraints of intellectual property rights for commercial investments must be recognised. Collaboration through international organisations such as the Global Bioenergy Partnership should be enhanced with both public and private organisations playing active roles to develop and sustain the 2nd generation biofuels industry for the long term.

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Chapter 5
Tree Plantation in South America and the Water Cycle: Impacts and Emergent Opportunities

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Abstract South American tree plantations expand at a rate of 5,000 km^2/year favored by increasingly globalized markets and local economic conditions. The main hydrological impacts of these plantations involve shifts in (a) the partition of precipitation inputs between vapour vs. liquid fluxes (associated to transpiration and canopy interception shifts) and (b) the partition of liquid fluxes between run-off and fast flow vs. deep drainage and base flow (associated to infiltration and surface water routing shifts). In sloped terrains global stream flow measurements in paired watersheds indicate declining water yields (40% less on average) under plantations vs. native vegetation. These effects are stronger under drier climates, where host vegetation is herbaceous, and where planted trees are eucalypts. In flat landscapes with native grassland vegetation, tree plantations switch the water balance from positive (net recharge) to negative (net discharge) triggering local salinization. Contrastingly, where native vegetation has been a woodland tree plantation can remediate the undesirable recharge and water table rise/salinization problems brought by agriculture. In degraded rolling (sub)tropical landscapes with intense rainfall inputs and high run-off, tree plantations can increase infiltration rates, reducing erosion, stabilizing flow, but cutting total water yield. As a result of these shifts, erosion can be reduced and the stability and quality of water provision improved, yet these benefits can be erased by large scale clear cutting practices. Context (climate, current vegetation and topography/geology) and design (species, densities, harvesting methods, and scale/pattern) can decide the magnitude and sign of tree plantations effects and need to be carefully considered to get the best ecological outcome of afforestation in the continent.

Keywords Afforestation • Hydrological regulation • Water provision • Landscape design • Ecosystem services

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5.1 Introduction

Land ecosystems and the transformations and management actions imposed on them are a key, yet often ignored, mediator between atmospheric water inputs and the actual water services that humans receive and value. These services include the provision of water (quantity, quality, stability) for domestic, agricultural, industrial or energetic uses as well as hydrological regulation, perceived in different ways such as flood regulation, wetland support, or erosion control. The establishment of tree plantation, particularly in areas covered by non-forested vegetation (grasslands, shrublands, crops and pastures), often leads to important shifts in the way that atmospheric water inputs get routed through the ecosystem and, as a result, generate changes on water services. Here we revise the mechanisms, impacts, and challenges of these effects on the water cycle focused on the South American continent.

Tree plantations, particularly those of fast growing species (pines and eucalypts), have expanded globally covering in the last decade almost 2 million km^2 (FAO 2001). South America is second only to Asia in its expansion rate, adding every year 5,000 km^2 of new tree plantations (FAO 2001). In many countries of the continent, plantations were initially encouraged during the seventies by national states trough different types of tax incentives and with the aim of generating forest resources for local industries that were either unavailable or had a declining supply from shrinking natural forests. In the nineties, increasingly globalized forestry markets and companies together with favorable local ecological (fast growth rates) and economic (low land and labor costs) conditions (Cubbage et al. 2007) propitiated a new wave of expansion that continues nowadays. Most South American tree plantations have established into highly aggregated clusters which (Table 5.1). We revised the current distribution of major tree plantation foci (>100 km^2) based on existing statistics and local inspection of Google Earth imagery. Further review of the literature helped us to identify dominant species (Table 5.1). Some large clusters, approaching 1,000 km^2, are found in the Llanos (Venezuela), Vale do Jari (Brazil), Telemeco-Borba (Brazil), Uruguay river (Argentina-Uruguay), and Bio-Bio (Chile). Species covering the largest area east of the Andes are *Eucalyptus grandis, E. urophylla* and related hybrids, together with *Pinus elliotti.* West of the Andes dominants are *Eucalyptus globulus* and *Pinus radiata* (Table 5.1). While the hydrological effects of tree plantations can only be subtle in large basins and rivers, given their minor share of their territory, they can be locally important in the clusters described above.

5.2 Conceptual Hydrological "Valves"

Although complex, the role of land use and vegetation controlling the water cycle, specifically in the case of fast growing tree plantations, can be simplified into three major water routing "valves". The first "valve" (a), relevant under certain climatic conditions, operates on the partition of precipitation inputs into direct canopy evaporation (i.e. interception) and water reaching the ground (effective precipitation).

Table 5.1 Distribution of major tree plantation foci of South America

Country	Biome	Ecoregions	Subregion	Area (km^2)	Clustering	Species (%)
Argentina	Subtropical grasslands and savannas	Mesopotamian savanna & Espinal	Uruguay River margins	2,440	Medium	*Eucalyptus grandis* and others (87%), *Pinus elliottii* and others (12%)
	Subtropical Moist Broadleaf Forests	Alto Paraná Atlantic forests	Northern Misiones	1,960	High	*Pinus elliottii* and others (92%), *Araucaria angustifolia* (5%)
	Wetlands	Paraná Flooded Savanna	Paraná River Delta	720	High	*Salix* spp. (70%), *Populus* spp. (30%)
	Temperate Mixed Forests	Valdivian temperate forests	Ecotone with Patagonian steppe	700	Low	*Pinus ponderosa* and others (95%), *Pseudotsuga menziesii* (3%)
	Subtropical grasslands and savannas	Córdoba montane savanna	Calamuchita valley	350	Medium	*Pinus elliottii* and others (100%)
	Subtropical Moist Broadleaf Forests	Southern Andean Yungas	Precordillera foothills	350	Low	*Eucalyptus tereticornis* and *E. camaldulensis* (67%), *Pinus taeda* and others (33%), *Toona ciliata* (3%)
	Wetlands	Coastal dunes	Temperate belt	100	Low	*Eucalyptus globulus* and others (10%), *Pinus pinaster* and others (90%)
Brazil	Subtropical-temperate moist broadleaf forests	Araucaria moist forests	Highlands of Paraná and Santa Catarina	13,160	Several of medium	*Pinus elliotti* and others (83%), *Eucalyptus grandis* (14%), *Araucaria angustifolia* (3%)
	Tropical dry broadleaf forests	Cerrado	Central-Eastern Brazil	21,920	Several of medium	*Eucalyptus* spp. (90%), *Pinus elliottii* (10%)
	Subtropical moist broadleaf forests	Alto Paraná & Atlantic coastal forests	Lowlands from Paraná to Espíritu Santo	9,540	Several of medium	*Eucalyptus* spp. (85%), *Pinus elliottii* & *P. taeda* (15%)

(continued)

Table 5.1 (continued)

Country	Biome	Ecoregions	Subregion	Area (km^2)	Clustering	Species (%)
	Subtropical savannas	Uruguayan savannas	Rio Grande do Sul state	4,210	Several of low	*Eucalyptus grandis x urophylla* (43%), *Acacia mearnsii* and *A. mangium* (30%), *Pinus taeda* (27%)
	Tropical moist broadleaf forests	Amazon basin moist forests	Vale do Jari, in Pará and Amapá	600	High	*Eucalyptus grandis x urophylla* (94%) and others
			Amazon basin	1,180	Unknown	*Hevea brasiliensis* (46%), *Schizolobium amazonicum* (31%), *Tectona grandis* (23%)
	Tropical dry broadleaf forests & xeric shrublands	Caatinga (ecotone with Cerrado)	Nordeste	2,130	Low	Unknown
Chile	Subtopical dry broadleaf forests	Chilean matorral	Regions IV to VI	2,330	Several of low	*Pinus radiata* (33%), *Eucalyptus globulus* (31%), *Atriplex* spp. (26%)
	Temperate Mixed Forests	Valdivian temperate forests and southern Chilean matorral	Regions VII to XI	19,590	Several of medium	*Pinus radiata* (70%), *Eucalyptus globulus* and others (27%)
Colombia	Tropical grasslands and savannas	Llanos	Vichada	1,000	Unknown	Unknown
	Tropical moist and dry broadleaf forests	Northern Andean montane, moist and dry forests	Antioquia, Córdoba, Cauca and Cauca Valley	1,440	Unknown	*Pinus patula* (37%), *Cupresus lusitanica* (15%)
	Tropical dry broadleaf forests and xeric shrublands	Xeric scrub and dry forests	Magdalena	150	Unknown	*Gmelina arborea* (37%), *Eucalyptus globulus, E. grandis* and *E. tereticornis* (32%)

Ecuador	Tropical moist broadleaf forests	Northwestern Andean and Eastern Cordillera real montane forests	Unknown location	1,670	Unknown	*Eucalyptus globulus* and others (49%), *Pinus radiata* and *P. patula* (?%)
Perú	Several	Several	Unknown location	6,400	Unknown	*Eucalyptus* spp. (75%)
Uruguay	Subtropical savannas	Uruguayan savanna	Uruguay River margins	4,020	Medium	*Eucalyptus grandis* and *E. globulus* (92%), *Pinus elliottii* and *P. taeda* (8%)
			Central-north	6,000	Medium	*Eucalyptus grandis* and *E. globulus* (80%), *Pinus elliotti* and *P. taeda* (20%)
			South-east	3,820	Medium	*Eucalyptus grandis* and *E. globulus* (93%). *Pinus elliottii* and *P. taeda* (7%)
Venezuela	Tropical grasslands and savannas	Llanos	Monagás and Anzoategui departaments	4,270	High	*Pinus caribaea* (78%), *Eucalyptus urophylla* (12%)
	Tropical dry broadleaf forests	Llanos, dry forests and Andes foothills	Portuguesa, Lara and Cojedes	340	Low	*Eucalyptus grandis, E. urophylla* and hybrids, *Gmelina arborea, Pinus caribea*

Note: For each country the biome, region and subregion hosting tree plantations is indicated. The area covered by tree plantations and its relative clustering (high = massive planted area with occupying >50% of the landscape, medium = distributed foci occupying 25–50% of the area, low = sparce foci occupying <25% of the landscape; several = more than two clusters of the same characteristics). Dominant plantes species are indicated. Information was obtained from national statistics, government reports, national and international publications and official internet pages of national and subnational agencies (accessed between May 1 and June 15 of 2010)

The next "valve" (b) controls the partition of effective precipitation inputs into water that flows over the surface (i.e. run-off) or penetrates the soil (i.e. infiltration), whereas the last one (c) decides what fraction of infiltrated water is released as vapor back to the atmosphere (i.e. transpiration and surface evaporation) or escapes from root capture and reaches deep soil layers and eventually groundwater (i.e. deep drainage). In the case of "valve a" (interception vs. effective precipitation), tree plantations tend to favor the partition to vapor with respect to shorter canopies thanks to their large surface roughness. This becomes hydrologically significant in sub-humid climates with frequent light rains or fog that favor higher interception rates. In the case of "valve b" (run-off vs. infiltration), tree plantations and most generally forested systems, tend to slow down surface water flow, favoring water entrance into the soil, particularly when they replace cultivated systems with degraded soils. Finally, in the case of "valve c" (evapotranspiration vs. deep drainage), tree plantations, particularly those with high productivity rates, have high transpiration rates and lower contributions to groundwater recharge. The physiological link between transpiration and carbon uptake couples "valve c" tightly to productivity creating a strong trade-off between groundwater recharge and biomass production. All "valves" acting together define the partition of precipitation into vapor and liquid, with high interception, infiltration, and transpiration + surface evaporation rates leading to lower liquid water yields. Besides that, for a given water yield, lower partitions to run-off (surface) vs. deep drainage (subsurface) favor the supply to aquifers over rivers, stabilize stream flows at multiple temporal scales, cut the intensity of flash floods, and reduce water erosion. In the next sections we synthesize current data regarding the final outcome that tree plantations tend to have on these two aspects: total water yields and the consequences of their surface vs. subsurface partition.

5.3 Vapor/Liquid Partition (Water Yield)

The establishment of tree plantation on non-forested areas (grasslands and shrublands) generates a decline of water yields, as evidenced by a large body of watershed studies (Farley et al. 2005). These hydrological studies compare stream flows in pairs of planted vs. non-planted watersheds, in most cases during several years. The synthesis of 26 watershed pairs indicated an average absolute water yield reduction of 39% (167 mm/year), which was significantly higher under eucalypts than pines (Farley et al. 2005). Notably, water yields under periods of no rainfall (base flow) suffered similar or higher cuts than mean values (Farley et al. 2005). Relative water yield, as a fraction of precipitation, was offset by −15%, drying almost completely those watersheds that originally yielded less than that percentage of their rainfall inputs, as it typically occurs in drier climates (Fig. 5.1). While at the time of this synthesis effort, no studies from South America were available, new data has been recently published. Studies from sloped grasslands in central Argentina, Ecuador, and Uruguay as well as wet temperate forests in southern Chile show

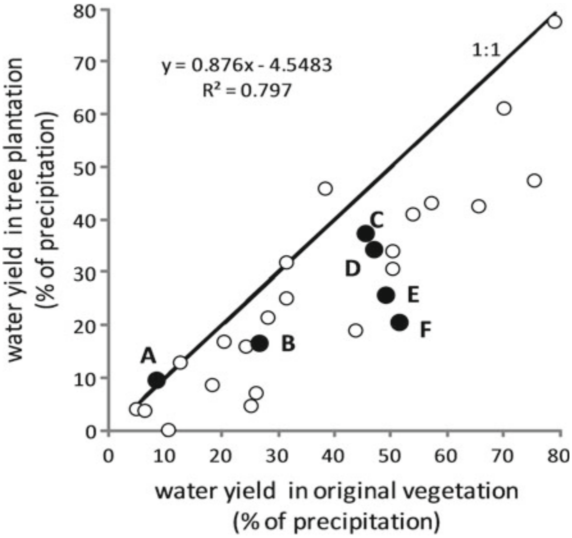

Fig. 5.1 Water yield shifts following the establishment of tree plantations. Water yield, as a percentage of mean annual precipitation, is shown for control watersheds under natural vegetation vs. afforested watersheds. All *white points* correspond to a global synthesis ($n=26$) based on paired watersheds in areas occupied by grasslands and shrublands (Farley et al. 2005). *Dark points* corresponds to different observations in South America, including (type of comparison, planted tree, original vegetation, country): *A* – Temporal analysis in pines replacing dry forests in Chile (Pizarro et al. 2006), *B* – Paired analysis in pines replacing grasslands in Argentina (Jobbágy et al. unpublished), *C* – Modeling analysis in eucalypts replacing grasslands in Uruguay (von Stackelberg et al. 2007), *D* – Temporal analysis in pines & eucalypts replacing grasslands in Uruguay (Silveira and Alonso 2008), *E* – Paired analysis in pines replacing temperate forest in Chile (Lara et al. 2009), *F* – Paired analysis in pines replacing paramo grassland in Ecuador (Buytaert et al. 2007)

substantial water yield cuts, whereas no changes are observed in dry forests of south-central Chile (Fig. 5.1). Although far from covering the diverse range of hosting ecosystems and forestry schemes found in the continent, these few studies confirm global patterns suggesting that tree plantations in non-forested systems and in some forested ones move "valve a", and more likely "valve c" towards vapor, cutting water yield rates.

While the previous cases corresponded to sloped terrain, often occupied by rocky substrates with well defined watersheds, a vast fraction of South America hosts sedimentary plains originally covered by grasslands (Pampas) and dry forests (Chaco, Espinal) (Jobbágy et al. 2008). Tree plantations can have very different effects over each of these two contexts as suggested by local and overseas evidences. In the Pampas, where the flat topography and positive water balance of grasslands/croplands sustains shallow water tables, depending on the texture and hydraulic properties of the soils, tree plantations consumed as much as 300 mm of groundwater per year – 30% more water than supplied annually by precipitation (Jobbágy and Jackson 2004). As a result, plantations achieve higher production than those in areas without access to groundwater, yet, at the cost of triggering an intense salinization of soils and phreatic aquifers (Nosetto et al. 2008). Salinization in these situations is ultimately controlled by the tolerance of tree species to salinity, which defines the maximum salt content that groundwater can achieve until groundwater consumptions ceases (Nosetto et al. 2008).

Under the drier climate and deep rooted natural woody vegetation of Chaco and Espinal, water yields are virtually nil, and in spite of the flat topography, water table levels are deep (Santoni et al. 2010). Although the hydrological consequences of the rapid agricultural expansion of that these regions are currently suffering have not been explored, experience from similar settings in Australia and the Sahel suggest that it can trigger water table level raises and intense salinization processes. In Australia one of the only effective ways to remediate this environmental problem has been the establishment of tree plantations that suppress deep drainage and consume groundwater (George et al. 1997, 1999). Sustaining larger fractions of native forest cover and adding new tree plantations to the most vulnerable areas that went into cultivation in the Chaco and Espinal will need to be considered in the near future (Jobbágy et al. 2008). In the plains, cutting water yield, as tree plantations typically do, can be a local problem, as it has been shown for the grasslands of the Pampas, or a regional solution, as the Australian experience suggest for deforested land.

5.4 Run-Off/Infiltration Partition (Regulation)

The previous section focused on total water yields. Here we turn to the role of tree plantations shaping the relative contribution of surface (run-off) vs. subsurface (deep drainage) fluxes to water yield. "Valve b" is critical in this case and the effect of tree plantations change surface water velocity and infiltration rates is the most important aspect to consider. Like in the previous case, the context in which plantations get established decides these effects. Sloped terrain, fine textured soils (even more if degraded by cultivation or overgrazing), and intense tropical rainfall inputs favor run-off. Tree plantations under these conditions have increased infiltration rates threefold, cutting run-off and in some cases increasing the base flow of streams (but cutting total water yield), as shown by a recent global synthesis (Ilstedt et al. 2007). As a result of these shifts, erosion can be reduced and the stability and quality of water provision improved. Different effects can be expected when tree plantations become established on healthy natural vegetation. In this case infiltration rates may be already high and relatively unmodified after tree planting.

A critical aspect regarding hydrological regulation in tree plantation is the application of large scale clear cutting practices (Donoso 2009). The benefits of slow surface water flow and high infiltration rates brought by tree plantations to sloped terrains can disappear and turn into an opposite situation after clearing them, particularly helped by machinery roads and traffic. The sudden shift of "valves a" and "c" to favor liquid water yield and "valve b" to favor surface water can have dramatic effects on flash floods, erosion, water quality and, in extreme cases, on base flow reduction (although total water yield is increased) (Jones and Grant 1996).

Another setting in which tree plantations can have positive effects on water cycling through their influence on infiltration are sodic soils with highly degraded porosity. In the lowlands of Hungarian grasslands, the fertility of many naturally alkaline-sodic soils could not be enhanced by regional drainage practices that lowered the water tables (decoupling soil from the source of alkaline salts) because the low infiltration rates prevented them from getting leached. The establishment of oak plantation on these systems increased infiltration 15-fold and allowed salts to get leached down to the artificially lowered water table (Nosetto et al. 2007). Although the same salt concentration process described for the Pampas took place below 3 m of depth under the tree plantations, surface soil increased it fertility and escaped the alkaline-sodic condition (Nosetto et al. 2007). Similar findings have been reported in India (Mishra et al. 2004).

5.5 Optimizing Context and Design for Water Services

All possible hydrological effects of tree plantations can be locally important (positive or negative) or irrelevant depending on their context and design. In the case of context, climate, current vegetation and topography/geology can decide the magnitude and sign of tree plantations effects. Effects associated to water yield cuts gain importance in (a) subhumid to semiarid climates, in which even relative small changes in evapotranspiration can result in large changes of water yield (Jobbágy et al. 2008), and (b) when replacing herbaceous plant covers which tend to have lowest evapotranspiration rates compared to tree-dominated systems, and, in the case of forest, when replacing those in and old growth stage. It is important to highlight that water yield cuts can be negative in areas that are valued for their water provision service (e.g. mountain grasslands under semiarid climates), but positive in areas that experience land-use induced increase in groundwater recharge and flooding (e.g. sedimentary plains under semiarid to subhumid climates in which cultivation expanded rapidly). The plantations foci (Table 5.1) of Calamuchita Valley in Argentina, of the Paramos in Ecuador and to a lower extent those in hilly areas of central Uruguay can create negative water yield shortages (Farley et al. 2008). On the other hand a prospective expansion of tree plantations on areas that are currently cultivated with annual crops in the Chaco and Espinal could help restore the natural low recharge rates of these regions, preventing flooding and salinization, as seen in similar places in Australia and the Sahel. In the Pampas, the high water consumption of tree plantations could help balance high recharge rates of expanding annual crops, at the cost of local salinization. It is important to highlight that under humid climates the relative impact of the evapotranspiration raises triggered by tree plantations on water yields (naturally high) declines and the regulation aspects, more associated with infiltration and run-off partition gain importance.

Run-off/infiltration partition and its influence on the stability of water provision and/or flash flood events can be the dominant effect of tree plantations under certain contexts. Tree plantations under (a) humid climates, particularly those that have highly seasonal and intense precipitation regimes, (b) high slopes and rocky and/or clayly soils, and (c) degraded vegetation covers, are very likely to favor infiltration producing not only lower erosion and flash flood risks, but in cases of extreme degradation increasing water yield in dry periods thanks to slower water release by the watershed. Most of the plantation foci occupying previously deforested areas (but not those currently under natural forests) in the Amazonic, Yungas, or Valdivian range can benefit from this effect. In addition, flat degraded areas or those naturally affected by alkalinity can improve their vertical water transport following tree establishment. These areas however are not likely to represent prime location for high production forestry.

Together with context, the final hydrological outcome of tree plantations will also respond to design, including the choice of species, planting densities, harvesting methods, and selection of planting areas within the landscape. When water yield cuts are tried to be minimized, planting deciduous species at low densities can be the best choice. For this particular problem the scale of tree plantations is critical, since plantation foci that never exceed on fourth of the basin of interest (large river for energy generation, small stream for local drinking water) will be unlikely to create significant provision cuts. When water yield is tried to be taken back to zero to stop water table level raises and salinization, as in the case of Australian semiarid agricultural lands, evergreen species with deep roots and high salt tolerance should be the choice, and the selection of landscape positions that allow groundwater access but avoid long-term salt build up (i.e. not low, neither high, but medium landscape positions) is often the best decision. When run-off needs to be halted, harvesting methods become critical since a wrong choice (i.e. large scale clearcutting) they can counterbalance the positive effects of a whole rotation shift in just one rainy season.

As societies increasingly recognize their reliance on multiple ecosystem functions they are demanding from tree plantations (like from other land use options) not only optimum yields or economical benefits but also water provision and regulation services. Under the fast and often unplanned/uncontrolled land use changes of South America, tree plantations can emerge as an intelligent option capable of optimizing production and water services. For this to happen, Science and Policy need to merge into adaptative working schemes in which we learn from existing plantations in order to improve their design and place them in the best possible contexts.

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Chapter 6
Forest Sector Investments in a Changing Climate

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Abstract Forestry sector is at the highest priority of the climate change policy discussion, now focusing on REDD+. The developed countries pledged large funding flows for actions to mitigate climate change in the forests of the developing world during the COP-15, and confirmed them in COP-16. Their total amount is set to gradually reach $100 billion per year by 2020, outmatching other forms of public funding and foreign direct investments in forestry and industry by a huge margin. The international investors hold an estimated portfolio of $60–70 billion in forestry worldwide, which is far from the potential capitalization of the available forests. Considering its compounded future value in the future supply of wood fibre, biomass, environmental services and non-wood forest products, the forestry sector is under-invested and sub-optimally productive. Many forest corporations have relinquished forest ownership from their core industrial business to remain more profitable. Private and local control over forests outside the industry is on the increase.

Investing in forestry is at best offering counter-cyclical, predictable long-term rates of return, and serves for hedging against turbulence on other investment segments. Political mandates to sequester and stock more carbon in forests and substitute fossil fuels for bio-energy have attracted a keen interest in the forest sector. Forest industry, on the other hand, has been a low return business for most developed countries, while fast-emerging economies have established a highly competitive industry. Restructuring needs have led e.g. to the re-invention of the bio-refinery concept, which seems a promising solution for integrating multiple-product flows (solid wood products, pulp and paper, green chemicals and materials, solid and liquid bio-fuels) into the existing forestry and industry system.

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Large institutional investors may become the game changers for low-carbon economy through forest sector. Foresters must convince them on the multiple environmental benefits, and on forest industry's sustainable products and materials opening up important pathways to low-carbon production and consumption.

Keywords Forest investments • Forestry in climate change • REDD+ • Forest ownership • Forest industry

6.1 Forest Investments: Production First or Climate First?

In the aftermath of the 15th Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC) in Copenhagen, December 2009, a tidal wave of forestry funding was pledged to fight climate change in developing countries. Even though COP-15 was a failure in reaching a comprehensive climate deal, tangible success was reached on integrating forests more firmly into the toolbox for mitigating the adverse impacts of climate change. Agreement on the extended version of the Reduced Emissions from Deforestation and Forest Degradation (REDD+) mechanism and the progressive financial support to developing countries for its implementation were confirmed in Cancún 1 year later (Dec. 2010). Initially, $3.5 billion were committed to spur REDD + by a group of countries comprising Australia, France, Japan, the UK, Norway and the USA. The funding will grow to $30 billion per year by 2010–2012, and reach $100 billion/year by 2020. A new structure called Copenhagen Green Climate Fund was established to administer these funds (UNECE/FAO 2010).

If one puts these sums into a forest sector perspective, they will rather soon exceed the regular financing flows going into sustainable forest management business. Pension funds and other institutional investors (banks, insurance companies, timber funds) are investing in forestry and wood processing to hedge against inflation and diversify their portfolios. Dutch pension funds, for example, are already investing more than three billion USD in forestry in different parts of the world. More recently some institutional investors in the wealthier developing countries are beginning to open up to the opportunities presented by forestry assets. Altogether, the international investor community holds an estimated portfolio of $60–70 billion in forestry all over the world. Timber Investment Management Organizations (TIMOs) have approximately $40 billion worth of investments, of which 80% are in North America. International Finance Corporation (IFC) has since 1980 invested $3 billion in the forestry sector. These sources make up much of the private expenditure in forestry investments worldwide.

On the public funding side, there was not more than $1.9 billion of Official Development Assistance (ODA) coming into the forestry sector in 2005–2007. Foreign Direct Investments (FDI) that went to the forest industries were just $0.5 billion in the same period. These sums are unsatisfactory by a large margin. In the national forest financing strategies ODA is a catalytic element because the main focus is on revenue generation from the sector and on enabling conditions for private investments (Simula 2008).

The potential among private investors is much larger because the biggest pension funds for instance hold assets worth more than $11 trillion, and only a small fraction is today invested in forestry sector. These giant funds can become the game changers if they are convinced that forestry with its multiple environmental benefits, and forest industry with sustainable products and materials, can open important pathways to low-carbon production and consumption.

Forestry investments are in general perceived attractive because of the competitive long term rates of returns, positive impacts on portfolio returns and predictable tree growth and associated capital appreciation. The fourth fundamental is the favorable demand outlook for forest products and roundwood.

The main barriers to investments in productive forestry sector in developing economies lie in the perceived high risks caused by insecure land tenure, political instability, weak institutions and murky regulatory frameworks. Also social issues and limited capacity to absorb investments through sub-standard financial infrastructure, unstable local partners and varied skills play an undermining role for the sector. The costs for bank financing in developing economies are very high, as often commercial bank lending rates are in the range of 17%–29%, or above the achievable rates of return (Clenaghan 2009).

One must keep in mind that all the forests in developing countries will not be conserved, nor will the local populations and the world's consumers stop using forest products. Investing in production forests and processing industry remains therefore utmost important to keep the balance between conservation and sustainable utilization in check. To pin down the matter on human terms, some 1.8 billion people make part of their subsistence out of forests and trees, around 500 million people directly depend on forest resources for their livelihoods, and 50 million people live literally within forests. These people should hold a decent prospect for gradually improving livelihoods in the future and also with REDD+ implemented. Forest carbon is therefore a compatible opportunity if alternative timber, fuelwood and charcoal supplies can be generated and jobs held whilst natural forests are increasingly placed under conservation. Reforestation and planted forests for sustainable harvest is being seen by many REDD+ developers as a key method of addressing leakage, i.e. avoiding that deforestation simply moves elsewhere.

There is a need for a careful consideration on where the investments should go when donors begin to fulfill their climate change funding pledges to support the developing countries in reversing their deforestation and forest degradation. Avoided deforestation and forest conservation are the likely champions in siphoning most of the money flowing into the sector through REDD+ mechanism, but also sustainable management of forests for productive purposes will be credited for. The current forest financing debate is somewhat single-minded in its concentration on the carbon issue, instead of looking beyond REDD+ into sustainable forest utilization. Deforestation goes far beyond the carbon issue and the forest carbon market does not function widely enough yet. Therefore, the climate change funding through REDD+ and other international investment flows into the forest sector must be inclusive to sustainable production and consumption in order to bring up lasting solutions for the global good, and matching the variable societal needs on forests.

6.2 New Actors and New Instruments in Forest Investments

There have been changes among the types of investors entering into forestry in the southern hemisphere. The common pattern is that strategic investors, development banks, TIMOs and affluent individuals are investing in fast-growing timber plantations. A lot fewer investors have ventured into natural forests. More recently, also institutional investors and family enterprises have entered into deals on plantations, and in some cases hedge funds on natural forests. For example, relatively large forest blocks in the Brazilian Amazonas are owned by absentee owners who live in the cities. These are sometimes called owners with sophistication and financial resources (S/FR Owners) – meaning that they are capable of developing the mandatory sustainable forest management plans and obtaining harvesting licenses (Waack 2009).

Future trend is likely to see increased investments by institutions, development banks and private equity in natural forests, where higher combined rates of return are anticipated from multiple-use biomass, environmental services, and non-wood forest products. Institutional investors with their relatively long investment horizons and high standards on Socially Responsible Investments (SRI) are well placed to invest in the natural forests. Their traditional comfort zone has been in the temperate forest regions, but their engagement with the tropical natural forest is on the rise in certain countries.

Regardless if the biomass is produced for conventional forest industry products, bio-energy, carbon credits, bio-chemicals or whatever purpose, it has to be legally verified and certified. Supporting independent certification and adhering to internationally accepted standards on legality, carbon, social and environmental credit - all this comes with a cost. The private sector is regularly demanded to implement these standards in their investment projects. While there are large amounts of funding available for forestry and carbon activities, very little of this money benefits private companies directly. Some estimates are that private companies receive less than 2% of the public funding available for forestation, carbon and REDD activities. So although REDD+ projects with their wider scope of activities already attract some private sector participation, investment flows are insignificant compared to those required to effect the lasting economic transformations necessary to halt deforestation. As an illustration, Uganda estimates that it needs investments in establishing 500,000 ha of sustainable planted forests to meet its future demand for timber alone. At a (low) planting cost of $1,000/ha this implies an investment requirement of $500 million. Currently the annual planting rates are less than 5,000–10,000 ha in that country (Clenaghan 2009).

6.3 Forest Ownership Is Evolving

Rationale for owning forests may differ between slow-growth natural forests and planted forests to a certain extent. If industrial company owns forest it is normally aiming for high total self-sufficiency (high portion of the total wood from owned forests); or regional self-sufficiency (industry owns forest in strategic locations).

In the North industry has been commonly supplied by a number of wood sources: non-industrial private forests, state and other public forests, company forests and imported wood. In such a timber market the main reason for owning forests has been to secure wood supply in all conditions, and provide "buffer" against price shocks to the mills. In times of short-term supply problems from one or several sources, company-owned forests allow to scale down roundwood procurement from the open markets where prices are escalating. Owned forests allow the company to maintain accurate knowledge of costs and operations related to the forestry operations.

In the plantation forests, intensive management with tailor-made tending, pruning, thinning and fertilizing regimes provide customized roundwood supply for the processing units. Management of forest products value chain starts from company's own forest. This brings planning and operational challenges, to which planted forests respond better than natural forests. Plywood and sawnwood production can capitalize on higher quality logs and convert them into higher value final products. Pulp and paper companies have realized greater opportunities to develop customized fibre into their processes. Integrated management for integrated pulpwood and sawlog and peeler log growing is made possible through advanced management of planted forest.

It follows from the above that industry's self-sufficiency varies between regions: some of the highest rates are found among the South American pulp companies (60–85%). Targeting higher self-sufficiency is most relevant in regions with underdeveloped roundwood markets. Secondly, the opportunity is the highest where little or no forest exists today but where growing conditions and wood demand is supportive to establishing high-yield forests.

Industry forest ownership has been partly transferred to non-industrial private forest owners in North America. These are typically of two types:

1. Real Estate Investment Trusts (REITs), which are publicly traded companies, owning "income producing real estate" such as a forest. In the USA significant tax benefits are accrued from this form of corporate structure. Plum Creek and Rayonier Inc. are the most prominent REITs.
2. Timberland Investment Management Organizations (TIMOs), which are not publicly traded companies. They manage forest assets for institutional owners like pension funds with an aim to provide a high total yield on investments.

Even though these organizations have been typically developed in the USA, they have today substantial holdings in other progressive timber-growing countries, i.e. in Canada, Brazil, Chile, Argentina, Uruguay, Australia, the UK, Ireland and New Zealand.

Some companies have however opted to keep their forest holdings. The world's largest forest owner is Weyerhaeuser in the USA, which owns or manages a combined area of 21 million acres of timberland and has offices or operations in ten countries. In Europe UPM still holds two million hectares of forests in Finland and in Uruguay. Stora Enso has parked its Finnish and Swedish forest holdings into separate companies, and develops plantation forests in China, Uruguay and Brazil. Sappi Forest Products (South Africa), Arauco (Chile), Fibria (Brazil) and Carter Holt Harvey (New Zealand) are some of the largest owners of fast-growing plantations elsewhere in the world.

Critical observers note that there is increasingly a discrepancy between the strategies of institutional investors served by TIMOs and the practical needs of industrial users of roundwood. Planted forest investments are physically locked onto the land they occupy. Investment funds are on the other hand mobile, seeking quick countercyclical returns from multiple regions at a time. TIMOs and timber funds often buy planted forests and managed native forests with a right reserved to exit any time after the initial 2–5 years when stumpage sales have begun (Clasby, 2009, E-forum preceding the investment and financing forum at the XIII World Forestry Congress, "personal communication"). It is common that these forest assets change hands within a decade. Many TIMOs are set to have about a 10-year life span only. Even endowment funds may buy and sell on very short time frames.

Such a strategy has yielded beautiful profits to the early investors in the past two decades, secured by forest industry growth and complemented by a large share of the value creation coming from the increasing speculated value of land. But the current timberland owners may have to wait longer with the same, but now illiquid assets in their hands. Their income streams have dried up during the financial and economic crisis and land prices have fallen in many hot-spots of the past forest investments. It may be that the surge in TIMO investment in forestry has come to a low end. It remains to be seen if it will subside or settle to become just another alternative strategy among many business models.

Current financial crisis has proven again very concretely that no matter who manages timberlands for productive use, he lives under the cyclical realities of building industry, printing and publishing, packaging, etc. – and not from speculative wisdom. Future prospects in some of the end-use segments have turned into a structural decline in some of the large markets. Payments for environmental services fail to fill the gaps in earnings anywhere soon. On a more promising note, the strong policy mandated market development for bio-fuels draws renewed attention to forest as a strategic asset. Growing biomass has never been as attractive as today.

6.4 Restructuring for the Future

During the XIII World Forestry Congress in Buenos Aires, a special event "Investment and Financing Forum" elaborated on the future of forest industries. A strong consensus appeared among the participants from about 30 countries that there is a need for transformation of the forest industry and the forestry sector.

To achieve successful transformations, a cultural shift is needed in the industry which concerns both the existing business models and the current management thinking. New types of incentives have to be implemented, rewarding for innovations and for renewal of products rather than for quarterly profits. The industry has to change the current concept of bulk production into a business model of multiple products and value added maximization. The multi-production concept will utilize wood fibre and other biomass in an integrated and flexible processing system. Novel products like bio-energy, bio-chemicals, components for advanced technological applications and high performance fibers will be produced back-to-back with bulky pulp and paper. Carbon income will become an additional revenue stream for forest industries in all the countries where greenhouse gas markets operate.

One part of the transformation is restructuring through mergers and acquisitions. This will lead into regionally consolidated industry rather than truly global groups. For instance China will need to increase the average pulp and paper company size further to reduce risks connected to investments and competition for raw material. Integration with pulp is being planned by many Chinese paper companies, which may boost this tendency. Chinese companies are active in the surrounding countries such as in Vietnam (Lee & Man, Nine Dragons) and Laos (Sun Paper). The overseas Chinese business community owns a large portion of Indonesian and Thai P&B capacities, which may result in a deeper collaboration over time, cultural differences and national sovereignty issues allowing. Both Chinese and Indian companies are emerging as investors in Asia and in Africa, and as acquisition targets for foreign companies wishing to enter their huge domestic markets.

Latin American forest industries are executing a strong restructuring drive within the region. Chilean giants Arauco and CPMP are looking for opportunities in Brazil and Uruguay due to the lack of domestic roundwood for expansions. Plantations have been bought and sold already on several occasions. The European Stora Enso and UPM have set up production facilities in Latin America, and plan additional expansion projects in 2–5 years time frame. Brazilian companies are seeking for mergers and further investments in the region. Aracruz and Votorantim merged already their activities forming Fibria, and further amalgamations are expected.

Sometimes overseas ventures are bound to fail, what shows the difficulty of reaching fully global company structures in forest industry. Large European firms Stora Enso and UPM have to a large extent left the North American market due to unfruitful encounters with the local labor rules, continuous losses and poor prospects for the future. Many companies are in difficulties: Smurfit Stone as well as Abitibi Bowater have gone through court-supervised restructuring. International Paper gave up the coated and magazine papers area and is concentrating on business and packing grades with expansions in Latin America, Russia, and most recently in India. Japan restructured the P&B industry already from the 1990s onwards, and now investments in China have become attractive to firms like Oji Paper. The largest Indonesian pulp and paper companies (APP and APRIL) have made major investments in China.

These examples show that in general, many companies had under-estimated the cultural and social challenges in investing abroad in the emerging countries. Several land use conflicts have been reported on the way of international forest companies entering into foreign operations and new locations. Local partnerships are essential for lowering the hurdles and mitigating the conflicts.

Pulp and paper business is changing towards a more regional approach, sourcing roundwood and pulp from lowest-cost fiber baskets. The factor guiding to that direction is the paper and board demand shooting up in Asia's heavily populated areas. The international competition for wood fiber-growing focuses, for the time being, mostly in Latin America where the local wood plantations assure high productivity, low costs and enabling conditions for transport and other infrastructure. South-East Asia, South-East Africa and Oceania compete for the same forest investments, all having their own strengths and weaknesses.

6.5 Transformation into Low-Carbon Economy

Most of the traditional forest industry products are not expected to earn the cost of capital invested in a normalized environment in the North American and European economies. Yet, the majority of production is still made up in the North, which means that the world market prices are determined against their cost structures. Competitive advantages possessed by producers in the Southern hemisphere enable them to reap profits by a large margin over their Northern competitors. It is not surprising that the global investments in pulp industry concentrate in Latin America and South-East Asia to capitalize their resource endowments and low-cost production factors. Political stability and regulatory easements help selecting where the investments will go in the future. Direct subsidies and investment incentives play an important role in attracting global firms into emerging markets.

The firms in the Northern hemisphere are fighting back by remodeling their industrial concept to ride on the low-carbon mandates set by their governments. Essentially this means that they integrate different forms of bio-energy and green chemicals and materials into so-called "bio-refinery" production systems. One should realize that this is not a new invention. During the World War II, as oil supplies were curtailed in Europe, as many as 34 Swedish pulp mills produced a combined output of 27 million gallons of ethanol a year. Tall oil, soap and turpentine were the common by-products, which were also in high demand. In the 1950s and 1960s this development came to an end as cheap oil provided raw material for refining industrial chemicals.

Now we see the reinvent of that piece of industrial history. In October, 2009, the Swedish Energy Research and Development Board decided to provide an investment grant for an industrial scale demonstration of the CHEMREC technology for the production of renewable motor fuels BioDME (dimethyl ether) and Biomethanol. The new plant is under construction at the Domsjö Fabriker pulp mill in Örnsköldsvik. The production is split between specialty cellulose, lignosulfonate and ethanol. A total of 100,000 tons per year of DME and ethanol will be made ready for deployment in the local heavy traffic fleets (buses and trucks trafficking in the area). Total investment cost is 300 million Euros. Funding comes from the

American, British and Swedish venture capitalists, supported by the investment grant (Löwnertz 2010).

Cost reductions are significant when this type of clustered approach is applied on existing pulp and paper (brownfield) sites, instead of new greenfield installations. The multi-product integrated concept should build on and utilize the current industrial structure for conventional forest industries in order to harvest the fullest synergies. This means that the existing mill sites should be integrated with new activities and production schemes. Understandably, this is not a simple task. Many of the new technological features can be engineered around the re-build of old recovery lines and boilers. Supporting functions are also important: downstream refining technology, process and ICT infrastructure, logistics chemicals and consumables, not forgetting marketing, sales and distribution – all these are steps into a renewal of the business model. Roundwood and biomass procurement system also needs to be enlarged, and pre-processing facilities created (Chambost et al. 2008).

To achieve a new industrial setup like an integrated bio-refinery is costly for forest industries whose balance sheets are weak. The leading forest industries have therefore signed strategic alliances and partnerships with partners outside their own business territory. However, the driver for this development will be the energy sector and not the forest sector. The energy sector overpowers the financial strength of forest industry. Bio-energy will not be, in itself, the final solution to the structural problems of the forest industry. It is expected to be an important component in forming the new industry and new business models. The least complicated energy products are made of solid wood: for instance torrefied pellets offer attractive returns where the strategic location, favorable public policies and fair exchange rates make up a business case. Bio-energy and carbon trade will also have strong downstream impacts in the supply chain.

6.6 Not Only Big Industry Matters

An increasing share of forestlands in the world will be under the control of local communities, and this is the tendency especially in the tropical forests. Communities have three major ways to improve their lives through the use of their forests. In an increasing degree of complexity and sophistication, they can act as resources owners; forest related workers; and as entrepreneurs operating forest-based enterprises. It is quite common that communities and their technical and political supporters set a goal in trying to become entrepreneurs without having the capacity to do so. The operational complexity, requirements for special skills, and institutional sophistication demanded by this approach frequently result in disappointment and frustration.

In order to improve the investment conditions in tropical forest countries, the *investment gap* has to be alleviated. A shared attempt to build trust and connections between forestry, businesses and financial institutions is needed. Good local partners and reduced bureaucracy would limit the friction in local investments. The Multilateral Development Banks' roles have to be enhanced in order to bridge the *risk gap* for investments (Clenaghan 2009). Offering long-term loans, insuring against for political and land tenure risks, and facilitating access to trade financing are useful tools in this respect. Also the *knowledge gap* has to be bridged by means of enhanced investor relations, improved price transparency, and promotion of country or sector investment plans. The final stumbling block is in *market gap*. This requires essentially correction of market failures, establishment of fully functioning carbon markets and long-term carbon framework agreements. Reduction of transaction costs, strengthening of price signals for sustainable products, capacity building of local banks and support for innovations are equally important to unlock increased investments in locally controlled forests.

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Chapter 7
Towards a New Model of Forest Development

José C. Carvalho

Abstract This article highlights the importance and interdependence of forests with soils, water, biodiversity and their relevance as carbon dioxide sinks, transforming them into a frontline for facing global warming. It underlines as well the cultural importance of forests for indigenous and traditional communities; and above all, the changes occurring lately in forestry policies, substituting the productivity concept and incorporating an integrated vision between economic and environmental issues in the search of sustainable development. In many cases new paradigms are ignored and postponed due to difficulties faced by governments as a consequence of the lack of sensitivity of economic agents, the indifference of the market and an incapacity of political movement of the leaders in the sector, without consideration for society's perception of the role played by forests. The scenario for the forestry sector is a politically weakened one. Development strategies sketched by countries, with rare exceptions, confirm the abyss between the importance of forests for nations and their real importance in the sphere of national and international public policies. It is urgent to adopt the construction of Forestry Development Integrated Programmes within the new institutional format, with complete rejection of the monolithic and one-sided way of thinking which oriented the programming concept on the subject in the past. This will demand a multi-sector planning that establishes active interfaces with the different areas of government. The time has come to abandon the elaboration of documents of the type "we call upon", "we recommend", "we underline", "we stimulate", "we except", "we emphasize" and others of similar tenor. We must extort national, international and supra national governments to agree, away from struggles for hegemony and institutional spaces, in the definition of a direction to congregate the efforts of all Nations in the construction of a new model of sustainable forest development contemporary of the future.

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Before specifically approaching the topic of forest development organization it is necessary to set the context of the central theme which will be addressed, translating forest development as a vital balance for forests of all the world and for humanity, with the purpose of configuring the concept that bases not only the institutionality of forest policy in the plane of the Nations, but also the international tendencies which orient the implementation and systemization of forestry policy in its most varied forms.

It is important to consider the interdependent relationship of forests with soil, water and biodiversity, as well as the more recent importance conferred upon them in the fight against global warming, as one of the most important sinks of carbon dioxide. On the cultural side, the importance of forests for indigenous communities and other traditional peoples must not be forgotten.

This conceptualization seeks to demonstrate that forest policy, as presently conceived, cannot be considered a monothematic policy, by reason of its reach and multiple ends. This is why the policies for this sector are undergoing deep changes, leaving the simple productivity concept behind to include the environmental and social dimensions, within a new perspective of sustainable development, consolidated in Rio 1992.

It is from the standpoint of these new paradigms that the subject must be addressed, in the sense of how forest development must be organized must be understood by incorporating economic, social and environmental aspects which belong to it by right, without hampering its profitability and ensuring investment returns.

Under these circumstances it is important to note that the forest, independently of the biome or ecosystem in which it is located, produces simultaneously economic and environmental services, resulting of this assessment the importance of an integrated policy founded on systemic bases, taking into account the wide group of actions which constitute the basis of its systematization and implementation.

In many cases, in practice, these new paradigms are being ignored and postponed due to the difficulties faced by governments with the lack of sensitivity of economic agents, with the indifference of the market and the incapacity of political movement of the sector's leadership and, above all, with policies divorced from society's new perception of the role played by forests.

This scenario which, with few exceptions, politically weakens the forestry sector and hinders its insertion in the development strategies drawn up by countries, ends up confirming the failure to accomplish a meeting between the importance of forests for people and the assimilation of their relevance in the sphere of national policies and international agreements.

This reality which currently constitutes an enormous challenge to the organization of forest development partly explains the slowness with which dialogue and international processes treating the subject occur, reflecting on national and regional policies which, day by day, have more difficulties in making a strategic choice between the growing demand and the preservation of the remaining natural forests. The difficulty increases due to the central role and pressure of urban societies and the economic use of forest resources, by nature almost wholly located in rural areas.

With the exception of some Countries and States of Federal Republics which learned how to maintain the centrality of their forestry policies, the management of this sector is spread out in various spheres of government. That increases the complexity of its institutionality, hindering its development organization.

However, this new reality must not be viewed as an insurmountable obstacle, but as a requirement which imposes a new and necessarily systemic, inter-institutional and multidisciplinary forestry development model.

This leads us to meditate that the forestry sector needs a different institutionality from the present one, capable of hosting the new paradigms which point the way of the sector's transformations, preventing its lack of articulation and coordination.

In this new institutional format, the implementation of Integrated Forestry Development Programmes that completely discard the monolithic and one-sided way of thinking which used to orient the programmatic concept of this subject in the past is crucial. This means searching for a multi-sector focus which establishes active interfaces with the different government areas. Thus, we are not simply talking about one area, but about the whole system, aggregating different vectors towards sustainable development to the benefit of the whole society.

In the era of instant communication, the structure of National Status is rapidly being transformed as the pace of the pressure and counter-pressure of public opinion leads to a rapid process of adaptation of the government organization, as it has occurred with the forestry sector during the last years.

With the already mentioned exceptions, today there is no area which covers all the actions related to Forestry Policy, including one of its main components, which is Forest Development. These actions are distributed in various spheres of the State: Environment, Agriculture, Industry and Commerce, Science and Technology, among others.

An institutional process is underway, although it has not been consolidated yet. However, it is rapidly taking a multi-sector shape which is tantamount to systemic.

From the previous considerations, it is highlighted the importance of the creation of Forestry Development Programmes, capable of promoting dialogue between the different government spheres, of articulating actions centralized in the past and dispersed in the present and, especially, of integrating institutions, coordinating different legal attributions, decentralizing in a way which covers the lowest levels, as well as capable of not only motivating society's participation in the necessary actions but also of recruiting citizens for this cause to the benefit of the survival of the planet.

In this sense, the main point is to set up the community, as a passive beneficiary of the Forestry Development Programmes, and as a main character of the actions, turning the citizen into an active subject as well as into a participant in the creation of policies of which he is a stakeholder, moreover, occupying a space in the land.

If we agree that forest management deserves a wider view, it is essential to meditate upon the way and the content which forest development must include in the planning of the different spheres of Power.

At this point we verify that we have been badly mistreated, because, with the usual exceptions, this important topic is not placed in a strategic level of national and regional planning as it should be, mainly due to the fact that in several countries the attributions of the sector were divided.

It is the duty of the planning instruments, at the very moment of the creation of policies, to establish a programme structure consistent with the systemic character of forest activities, with the objective of building integrated programmes of forest development with the features of the new institutional model which must arise from the changes underway.

Another issue to be discussed is related to the dominance of the State measures of command and control over the economic instruments which should stimulate a sustainably based forest development, but which are rarely inserted into the planning which determines government priorities and programmes.

This process is unfortunately fed by the persistent predatory use of forest resources which result in the occupation of forest lands due to the expansion of the agricultural frontier, to the residual and empiric use of wood extracted from deforestation and from the predatory exploitation of the forest which is still the rule in many countries, notwithstanding the reaction of society every day more attentive to the environmental importance of forests.

In the twenty-first century, this is an insufferable way of production which must be severely rejected by the Forestry Community.

Despite the fact that this may be obvious, forestry administration has not been assimilated yet, due to the lack of interest from the players of the sector and of those who exercise their leadership. Moreover, command, control and inspection measures and, although systematic and intermittent, are important but not enough to promote forest development.

The inspection punishes predatory use, but does not stimulate sustainable use of forest resources, the development of which depends on economic instruments of fiscal, credit and tax nature, with a time frame compatible to the maturing deadlines of forestry activities.

It is the duty of the leaders of the forestry sector to take the initiative of commanding the transformation process towards the new paradigms of forest development, together with governmental authorities, leaders from other productive sectors and civil society, creating the necessary political environment for conceiving a Forestry Development Programmes which attend the requirements of a systemic, integrated and decentralized management.

I would like to insist that forest development, as an irreplaceable instrument for a vital balance of all types of forests, that is capable of stopping deforestation, of creating revenue and jobs through the use of the forest and not through its destruction, will have to make use of modern regulations, efficient economic instruments, judicial stability, as well as of investments in research, extension and education applied to the sustainable management of native forests and to silviculture with multiple ends: economic, social and environmental.

Historically, forest development has always been based upon two pillars: management of native forests and silviculture, at present practised in the four corners of the Earth. The knowledge of management techniques of temperate forests, with low dendrologic density, has been the driver of forest development in several countries, as it still is today, due to the ease of managing a small group of species at a lower cost.

These same features are not replicated in the tropical regions where the largest remnants of forests in the world are located, with very high floristic diversity, composing complex ecosystems, rich in the most varied timber species and favourable to multiple different uses.

This evident complexity requires sophisticated management techniques which elevate costs and prevent, in most cases, the achievement of rates from returning which compensates the invested capital, making large-scale timber harvesting almost impossible, if sustainable environmental and social requirements are to be considered.

This picture is worsened by the offer of wood obtained through illegal or clandestine deforestation, as these are not burdened with the costs of sustainable management and decisively contribute to lower the prices excessively and deform the market, even because tropical forest management, due to the exuberance of their biodiversity, ceases to be forest management to become the management of the ecosystems constituted around them.

This picture will remain unchanged while public policies, the market and the rules of international trade do not recognize the economic value of the environmental services provided by forests. This reality is difficult to change, as long as lands covered with forests have less market value than those deforested to be destined to other land uses.

Because of this, apart from discouraging deforestation to avoid the offer of timber of which the price does not compensate forest management costs, it is essential to value the environmental services, regulate land property and encourage production and consumption of timber and derivatives obtained from sustainable management based on certification.

Under the mode of sustainable management, the comparative advantage of temperate countries disappear when faced with the extraordinary competitive advantage of tropical countries with regard to silviculture, mainly with fast growing tree species such as eucalypts, pine, teak and others.

As forest repopulation has become the main basis for forest development in a great number of tropical and subtropical countries, it is important to discuss the policies, plans and promotion plans which are redirecting and furthering forest economy, the participation of the forestry sector in the Gross Domestic Product (GDP) and the creation of employment, mainly in relation to silviculture linked to plantation based industry.

However, forestry promotion, like management activities and forest policies in general, as it is already happening, should include the social and environmental dimension in a proactive way, not only in order to fulfil the growing demands of regulations but also to harmonize with a transforming market, every day more selective where timber is concerned, due to the high number of aware consumers who alter, slowly but definitely, the behaviour of importers.

Under these circumstances, forestry promotion activities must consolidate the tendencies already underway, in the sense of integrating timber consumption with the potential of rural forestry plantation producers, searching to discourage large forest estates and incorporating small and medium farmers into timber production activities, non timber resources, besides forest linked environmental services.

These new alternatives have the merit of generating additional income for farmers, improving land use through the integration of agriculture, livestock farming and man-made forest, eliminating illegal logging of native forests for domestic and local use and protecting native species in the more ecologically sensitive rural areas which must be preserved, in the context of the lower level watershed within which the property is located.

Besides the promotion with economic ends which must cover already deforested, underutilized or abandoned lands, forestry promotion of environmental nature gains momentum, with the aim of restoring degraded areas and forest ecosystems affected by human activities.

In the past, the forest could be a synonym of timber. Nowadays, forest development must extend far beyond this bound. Timber will continue to be an important and indispensable raw material for humanity, but forest activities should consider the concepts here presented and the aspirations of society in all planes, as long as management and promotion become truly effective instruments to ensure sustainable use of forest resources with an ecosystemic vision.

The multiplicity of forests' functions and values is at once our challenge and our opportunity.

In the beginning the issue was timber, later on it was replaced by non timber products and finally, the discussion of environmental services became part of the agenda, including carbon capture and storage. The forest is all of these. All those factors are essential to organize forest development.

We must affirm here, without mistrust or mistake, that apart from protected areas and areas inaccessible to human activities, only sustainable forest management will be capable of protecting forests.

This is the moment to solemnly declare that sustainable management and silviculture undertaken in an environmentally sound manner are, indeed, the only instruments which can ensure the conservation of forest resources.

In the opposite sense, predatory exploitation of timber added to land conversion into agricultural areas and other alternative uses are contributing to the destruction of forests.

Because of this, forest economy and the market must not support that and, what is worse, stimulate it , as it happens in many cases, such as illegal and predatory logging of forest resources. On this subject it is necessary to mention that the international debate related to the illegal exploitation and consumption of timber is already far from reality, because it is not enough that forestry simply becomes legal: it is essential that it becomes sustainable.

Legality is not necessarily associated to sustainability. When law makes legal what is not sustainable or when it is lenient with devastation, it does not contribute to the final aim which must be the fixed star of every forestry policy: the sustainable use of resources.

It is necessary that we prepare for other economic alternatives which arise, besides the traditional timber market, such as the carbon market, which today is a reality, as well as the environmental services market, which is getting closer, creating new opportunities for forestry development.

The forestry issue continues to be treated with immoderate sluggishness in the international sphere.

Enough of neverending and inconclusive dialogues which, as from the 1992 Rio Conference, 17 years ago, have yet been unable to provide us with a global and contemporary framework.

Enough of exhortative documents of the type "we call", "we recommend", "we underline", "we stimulate", "we expect", "we emphasize" and others of the same tenor, which end up taking us nowhere.

The time for inexact words is over. We are living moments of courage and decision.

With forests being one of the most important sources of the planet's biodiversity, it is necessary that we have a participation equal to our importance. Why don't we play the main role in the International Convention which is addressed to this subject?

National and international organisms must finally reach an agreement, away from contests for hegemony and institutional spaces, in the definition of a directive which adds the efforts of all nations in the construction of a model of sustainable forest management which is contemporary with the future.

We will leave behind the old concepts, let us abandon the vices of predatory timber exploitation and let us reject deforestation. These are essential attitudes to organize forest development on sustainable bases. This is indispensable to give credibility to the sector and achieve the agreement, approval and support of public opinion.

"Where there is a will, there is a way".

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