Ecosystem Goods and Services from Plantation Forests

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Ecosystem goods and services – the key for sustainable plantations

Jürgen Bauhus, Benno Pokorny, Peter J. van der Meer, Peter J. Kanowski and Markku Kanninen

Improved ecosystem services from plantations of the future

Mankind has altered and transformed 40–50 per cent of the ice-free terrestrial surface of the Earth and appropriates an estimated 20 per cent of the global net primary production (Imhoff et al, 2004). The world's population is predicted to increase by 34 per cent from today to reach 9.1 billion people in 2050 (FAO, 2009). At the same time, this population will be more urbanized and have higher income levels than today. This larger and richer population will place unprecedented demands on the Earth's natural resources for the production of food and fibre (FAO, 2009). Currently humans appropriate 40–50 per cent of the available fresh water, and this is predicted to increase to 70 per cent by 2050 (Postel et al, 1996). In addition, it has been estimated that humans have doubled the nitrogen inputs from fertilizing agricultural systems and fossil fuel burning into terrestrial ecosystems (Vitousek et al, 1997), and the current atmospheric nitrogen deposition has enhanced the forest carbon sink by some 10–20 per cent (Schulze et al, 2009). These figures indicate that a large proportion of the increase in the production of food and fibre has come through intensification of agricultural and forest management systems, although extensification of agriculture and plantation forestry through land-use change, e.g. forest clearing, has also contributed to this. It is expected that 20 per cent of the required increase in food production in countries with developing economies between now and 2050 will be contributed through the extensification of agriculture. These projections demonstrate that there will be intense competition for land between different land-use options such as food production, production of timber, fibre and biofuels as well as nature conservation, and the development of urban areas and infrastructure. The growing demand for food, fibre, water, etc. is likely to lead to further deteriorations of ecosystem services as has been documented in the Millenium

Ecosystem Assessment (2005). The projections also stress that we need to be mindful about the possible consequences of replacing natural ecosystems that provide great benefits to human societies such as clean drinking water, soil protection, etc. Many of the ecosystem services they provide are irreplaceable, or the technology necessary to replace them is prohibitively expensive (Palmer et al, 2004). Thus the role of both natural and replacement, or man-made ecosystems in maintaining these services becomes increasingly important. In the past, tree plantations have had ambivalent roles with regards to ecosystem services. Their production function has served in a very efficient way to meet the growing demand for wood products. However, where tree plantations have replaced native ecosystems (forests or grasslands), many ecosystem services have deteriorated. The expansion of fast-growing industrial plantations for pulp, together with the rapid expansion of oil-palm plantations, has been a major driver of deforestation in the past, for example in Indonesia (Barr, 2002; Uryu et al, 2008). Where plantations were established on degraded or former agricultural land, many ecosystem services improved (see previous chapters and Cossalter and Pye-Smith, 2003). The future development of forest plantations, both in terms of extent as well as quality and management has to be viewed in this context.

Although there is great uncertainty about the future development of the spatial extent of the different land-use options (Lambin et al, 2001; Berndes et al, 2003; de Groot et al, in press), it is unlikely that tree plantations will occupy substantial shares of the land suitable for sustainable agriculture, unless there are political instruments such as a carbon tax, and incentives or subsidies, for example for bioenergy, that make the products and services from plantations more valuable than agricultural commodities (Johansson and Azar, 2007). Given the likely increasing competition for land and the growing need also for ecosystem services, plantations would be best established in locations where they contribute to improving ecosystem and landscape functioning and thus contribute to increasing the provisioning of ecosystem services. Due to improved industrial safeguards, certification schemes, REDD+ schemes, and needs for better corporate social responsibility, it is likely that much of the future expansion of plantations will take place in areas in need of restoration, i.e. degraded tropical lands (e.g. Otsamo, 2001). Also areas which are marginal for agriculture, or where synergies between agricultural production and tree plantations can be achieved may become more attractive for plantation expansion. This is particularly the case in those tropical countries, where the reduction of natural forest cover has produced large areas of forest and agricultural mosaics (de Jong, 2010).

Areas in which plantations can contribute positively to improving ecosystem services may comprise land degraded through unsustainable past land use (Evans and Turnbull, 2004; Metzger and Hüttermann, 2009), or marginal land, where agricultural intensification, e.g. through irrigation, is not possible. However, the term 'degraded land' is highly subjective and is not a terra nullius for afforestation projects. Livelihoods of many people, in particular in countries with developing economies, depend on the use of 'degraded' land, even if restoration through afforestation would yield higher returns in the future (Hunter et al, 1998). In the tropics and subtropics, much of the restoration of degraded land has been through afforestation with industrial monocultures involving a limited number of species from very few tree genera. Although these efforts may have been successful in terms of generating goods such as pulpwood, very few of these plantations provide the variety of goods and services to the local people that were once provided by the original forests or even the degraded systems that were replaced (Lamb et al, 2005). However, restoration approaches that diminish the provision of ecosystem goods and services that people gain from such degraded land, e.g. through grazing, will not receive lasting support (Maginnis and Jackson, 2005). Ignoring the immediate needs of local populations and replacing their use of land with tree plantations that could not maintain their livelihoods has led to the failure of many such projects in the past (see also Chapter 6). This type of situation highlights the need to design plantations and landscapes containing plantations to accommodate the needs of local people for the range of ecosystem services they depend on. In many regions, plantations have already been effectively used to restore forest ecosystems (Parrotta et al, 1997) and the economic, social or environmental services they provide (Chokkalingam et al, 2006; de Jong, 2010). There is growing evidence that plantations can effectively assume the provision of several ecosystem services, such as maintaining water and nutrient cycles, soil protection and the provision of habitat for biodiversity (see Chapters 3, 4 and 5 in this book). In addition, the focus on ecosystem services in restoration efforts does not contradict but may complement socio-economic objectives such as poverty alleviation (Lamb et al, 2005; Mansourian et al, 2005).

Owing to their very efficient system of wood production, tree plantations are indispensable. The role of plantations has been ambivalent in the past, and therefore there has been much controversy about plantations (Cossalter and Pye-Smith, 2003; Kanowski and Murray, 2008). To improve the role of plantations and to reduce the conflict about their use, new approaches for plantation forestry, including an orientation towards ecosystem services, are required.

Different international processes have aimed to define some principles to guide the future development and management of plantation forests to ensure that they meet not only global but also regional and local demands for all the goods and services they can offer (Chapter 7; Kanowski and Murray, 2008). One example of such principles can be seen in the Voluntary Guidelines for the Responsible Management of Planted Forests (Box 8.1).

As can be seen from Box 8.1, the maintenance or enhancement of ecosystem goods and services is central to all but the institutional principles. In addition, or more explicitly, intelligent solutions for plantations should feature ecological restoration, aim to achieve optimum productivity of multiple products and services rather than maximum productivity of one product and

Box 8.1 *FAO principles for the responsible management of planted forests*

Institutional principles

1 Good governance
2 Integrated decision-making and multi-stakeholder approaches
3 Effective organizational capacity

Economic principles

4 Recognition of the value of goods and services
5 Enabling environment for investment
6 Recognition of the role of the market

Social and cultural principles

7 Recognition of social and cultural values
8 Maintenance of social and cultural services

Environmental principles

9 Maintenance and conservation of environmental services
10 Conservation of biological diversity
11 Maintenance of forest health and productivity

Landscape approach principles

12 Management of landscapes for social, economic and environmental benefits

Source: FAO, 2007

should be characterized by closed cycles of nutrients and energy conservation. These requirements lead inevitably to knowledge-intensive systems, which is captured in the institutional principles of the FAO Voluntary Guidelines (Box 8.1). The plantations must also be economically profitable from the perspective of investors or owners, and they should also provide economic benefits to local and regional economies.

Where plantation planning and management is following the above principles, plantations can make substantial contributions to the delivery of ecosystems services, many of which are becoming more rather than less important (Kanowski and Murray, 2008).

Plantations as designer ecosystems

Forest plantations are in most situations artificial ecosystems, designed to be simple so that they can be easily and efficiently managed for the purpose of wood production. However, artificial ecosystems must not be simple or have a narrow focus. Recently, designer ecosystems have been proposed to create well-functioning communities of organisms that optimize the ecological services available from coupled natural–human ecosystems (Palmer et al, 2004). Here, the design may not just be concerned with the choice of tree species and the arrangement of trees, but with the creation of entire ecological communities and functioning landscapes to meet specific services, and the use of complex biotic interactions becomes the key technology (Shiyomi and Koizumi, 2001; Kirschenmann, 2007). Such designed plantation ecosystems are not modelled after historical references of ecosystem structure and function for a given location, as is typically the case in ecosystem restoration efforts. Instead, such systems may be designed to mitigate unfavourable conditions by means of novel mixtures of native and non-native species with particular traits that favour specific ecosystem functions (Palmer et al, 2004). They are thus not a substitute for natural systems, but in our highly modified world, they can take over functions of natural systems or ease the pressure on natural systems. In addition, these designed systems can take account of changing environmental conditions in the future, if the knowledge exists, how well the different species and communities will cope with or perform under the new conditions that may be brought about by climate change, species invasions or other forces shaping ecosystems (van der Meer at al, 2002; Seastedt et al, 2008). In more complex settings, plantations may take over the functions of completely different ecosystems such as wetlands or of technical solutions such as sewage treatment plants. For example, in an increasingly urbanized world, safe and environmentally sound ways to treat and dispose of effluent or biosolids produced by industries and urban centres may include the use of irrigated tree plantations (e.g. Hopmans et al, 1990; Myers et al, 1999; Börjesson and Berndes, 2006). In addition to being a safe and low-cost solution to the cleaning of wastewater and recycling of nutrients, these plantations can provide energy, timber and even amenity values. The combination of these functions is likely to be particularly promising in peri-urban areas of arid and semi-arid regions, where a large proportion of available water is appropriated by humans and where the increasing demand for firewood has led to the degradation and depletion of natural forest and woodland systems.

Plantations composed of salt-tolerant species and placed in specific locations in the landscape can assume important ecosystem functions, such as the maintenance of hydrological balance, to uphold the viability of agricultural landscapes in many dry regions of the world. Here, elevated saline groundwater tables, which may be the consequence of irrigation or of clearing deep-rooted perennial vegetation for pastures and cropping or of irrigation, threaten the continuation of agricultural land use (Johnson et al, 2009). Planting of trees to reduce the recharge of groundwater and to increase the discharge from groundwater can help to lower the water table or stop it from rising further to the surface (Chapter 4 in this book; Nambiar and Ferguson, 2005). Depending on the salt concentration of the groundwater and the height of the water table, different types of trees (or shrubs) may be most suitable for this purpose, in many cases non-native species (e.g. Mahmood et al, 2001).

These are just a few examples, where the main purpose of plantations may be on specific ecosystem services, and wood production assumes a secondary role. The conditions under which such purposefully designed plantations are established may be adverse or sub-optimal for tree growing, so that the costs for establishment and maintenance may not be recouped through the production of timber. Where the plantation owner is not also the direct beneficiary of the ecosystem service(s) provided, mechanisms such as payment for ecosystem services (PES) must be developed to reward plantation owners for providing these services. PES is often defined as voluntary, conditional transactions between the buyer and the seller for well-defined environmental services or corresponding land-use proxies (Wunder, 2005). A comparative study carried out by Wunder et al (2008) analysed 14 PES or PES-like programmes in developing and developed countries. The vast majority of the programmes studied were related to management or protection of watersheds through natural forests. Only three of the cases studied included forest and tree plantations (afforestation, reforestation, agroforestry) as eligible activity of the programme, indicating that so far plantations have not been used much within such schemes.

Payments for ecosystem services may be in the form of carbon credits and other credits for specific ecosystem services, e.g. salinity credits. However, where plantations on marginal land for tree growing are required over large areas to restore landscape or watershed functioning, the amount of financial assistance required for tree growers to break even can quickly reach very large sums. For example, Ferguson (2005) calculated for the Murray-Darling Basin in Australia that for eucalypt or pine plantations on land of lower productivity (mean annual increment of 15m/ha/yr) up to AU$2000–3000/ha respectively may be required in the form of salinity credits to achieve a net present value of zero, after accounting for revenues from timber and carbon credits.

One of the important challenges to facilitate schemes such as PES or other reward systems and to facilitate sound landscape planning is to develop ways to measure the ecological functions of plantations (Hartley, 2002; Dudley, 2005). If in future, plantation design and management should consider more fully the whole range of ecosystem goods and services, both agreed systems for valuing goods and services (see Chapter 2) and a good understanding about the compatibility, and possible trade-offs and synergies among ecosystem goods and services are required.

Synergies and trade-offs between ecosystem goods and services

To enable implementation of plantations according to the FAO principles (Box 8.1), in particular in relation to effective, transparent and integrated land-use planning, the costs and benefits and synergies and trade-offs of the many different options that may be available must be known or assessable. Therefore agreed valuation systems for ecosystem goods and services are required (see Chapter 2). Financial valuations often disregard the importance of social and cultural values, although the latter are important and should still have a place in decision-making (see principle 4 in Box 8.1). In economic terms, all goods and services can be defined as use values and non-use values. Socio-cultural values are usually lower in plantations than in natural forests and the ecological values of plantation forests depend largely upon the condition of the landscape replaced by the plantation. Although valuation systems, as discussed in Chapter 2, have a number of shortcomings, they can help to highlight the synergies, trade-offs and implications of different design and management options for plantations.

There is no form of plantation management, or any other form of natural resource management for that matter, that can provide a maximum of all ecosystems goods and services to all stakeholder groups. Some of the services conflict with each other and it would not be possible to try to maximize wood production, carbon sequestration, conservation of biodiversity, and social and cultural benefits in the same plantation stand (Figure 8.1). However, as formulated in the last of the FAO principles for responsible management of planted forests, new approaches would seek a balance of economic, environmental and social objectives at higher spatial scales. With increasing spatial scale, that is moving from one plantation stand or one property to the watershed or landscape, it becomes increasingly easier to reconcile conflicting or non-complementary objectives of management. In addition, in any landscape setting there will be a range of different interest priorities with regard to natural resource management represented by different stakeholder groups or sections of society (Brown, 2005). Satisfying these interests in different parts of the landscape may reduce conflict. Also, many of the ecosystem services depend on ecosystem processes that operate at different spatial and temporal scales, many of which exceed the scale of traditional management (Christensen et al, 1996), such as plantation stand or block and rotations. To appropriately consider these spatial and temporal dimensions, models are required that permit the analysis of spatial and temporal interactions of different types of land use on the provision of ecosystem services in the landscape. The actual planning of plantations in the landscape would be best based on a decision support framework including steps such as environmental and social impact assessments that draw on this information about cost and benefits as well as trade-offs and synergies associated with the different options. An example for such a decision support framework can be found in Kanowski and Murray (2008).

There are several studies dealing with tools to assess the effect of silvicultural techniques on the maintenance and provision of forest goods and services. For example, Köchli and Brang (2005) modelled the effect of different forest management scenarios on recreational suitability and water- and air-purification potential. They show how such an approach may help to explain how different goods and services are interrelated, and what the trade-offs are of the various stand types. Other studies show that the inclusion of high conservation value areas and biodiversity corridors could help to improve

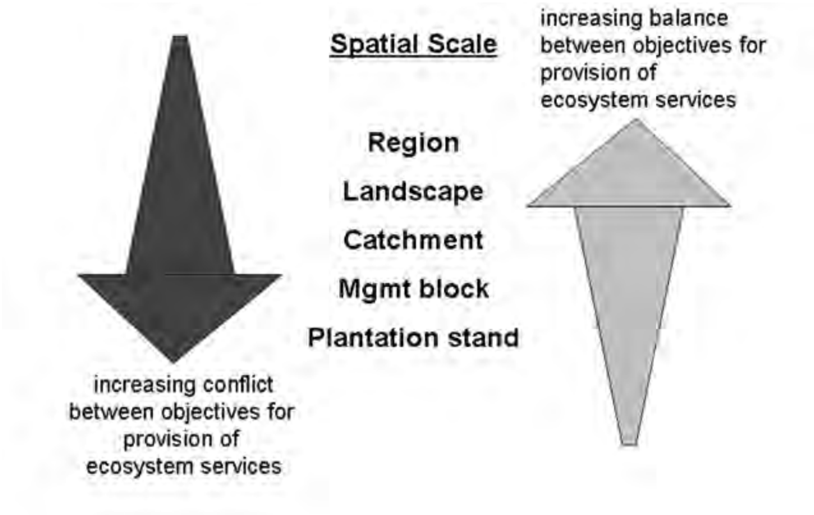

Figure 8.1 *With decreasing scale of management, the conflict between the provision of different ecosystem services or forest values increases. Sustainable solutions aiming at the balanced provision of ecosystem goods and services can only be achieved at higher spatial scales of management*

Source: adapted from Bauhus, 1999

biodiversity levels in plantation areas without affecting the production function (e.g. Barlow et al, 2007; Cyranoski, 2007).

Table 8.1 is an attempt to illustrate these trade-offs between a range of ecosystem goods and services related to the management options at the spatial scale of plantation stands and landscapes. Here, the management encompasses different silvicultural options, which have already been mentioned in Chapter 5, and landscape-level planning options. In the following, some examples from this table, which reflects the information provided in previous chapters, will be explained.

As can be seen from Table 8.1, most of the measures that benefit biodiversity, impact negatively on plantation productivity, both at the stand as well as the landscape level. However, at the landscape level, it would be important to separate between effects that impact on the production per unit of planted land or on the overall plantation estate including other forms of vegetation or land-use types. For example, maintaining corridors of native vegetation instead of converting them to plantation stands, may reduce productivity at the estate or property level, but there is no likely negative influence on the productivity of the plantation stands. Perhaps these are on average even more productive and more efficient to manage, if the native vegetation is occupying parts of the landscape that are less fertile or difficult to cultivate, such as wet soils, steep slopes or rocky outcrops. The synergies

Table 8.1 *Estimated trade-offs between the effects of certain management options on selected ecosystem goods and services including the provision of biodiversity, carbon sequestration or storage, clean water in sufficient quantity, and provision of non-wood forest products*

Management options	Plantation productivity	Biodiversity	Carbon#	Water*	Amenity values
Stand level					
Structural retention	–	+	?	+	+
Use of native species	–	+	(–)	(+)	+
Mixed-species stands	+	+	+	–	+
Long rotations	–	+	?	+	+
Thinning	0	+	–	+	(+)
Site preparation	+	–	?	?	–
Herbicides and fertilizer	+	–	?	–	–
Landscape level					
Riparian buffers (of native vegetation)	–	+	(+)	+	+
Retaining patches of native vegetation	–	+	(+)	+	+
Connectivity between plantations and native forests	0	+	0	0	+
Maintaining landscape heterogeneity (different land-use types, special places, etc.)	–	+	?	+	+

Regarding the influence of plantations to reduce atmospheric CO_2, sequestration and storage need to be separated. Sequestration, the uptake of carbon into vegetation and its partial transfer into the soil pool, removes CO_2 from the atmosphere. This process is tightly coupled with plantation productivity. Storage of C in vegetation and soils simply prevents C from being released to the atmosphere as CO_2. Forest systems such as plantations may have a high sequestration potential but little storage, whereas the opposite situation can be found in old-growth forests. For many of the management options it is difficult to ascertain the effect that they have on atmospheric CO_2 since this depends to a large extent on the fate of the material harvested (see Chapter 3). If the harvested wood is turned into long-lived products, which, at the end of their service live, are used energetically to offset fossil fuel burning, the effect can be very positive. In contrast, if the wood is turned into short-lived products (such as paper), and is not subsequently used as an energy source, the overall effect may be less than if the wood was left in the forest to decay (Profft et al, 2009). Therefore, the ultimate effect of plantations on C cycling and atmospheric CO_2 cannot be assessed within the plantation management system.

* For the purpose of this assessment, management options were considered to have a positive effect on water services, if they contribute to cleaner water and more groundwater recharge from the land (but see discussion on salinity, Chapter 4). The effect is considered negative, if planning or management options lead to water pollution and reduced groundwater recharge from the land carrying plantations.

Note: + = positive effects, – = negative effects, 0 = neutral effect, ? = unknown or uncertain effects, brackets indicate that the effect may not be so clearly positive or negative depending on other factors not captured here

and trade-offs between biodiversity and productivity at the landscape level depend largely on the forest policy context. If plantation establishment is directly related to and dependent on the area of native forests set aside for conservation, there can be strong synergistic effects (Paquette and Messier, 2010). In addition, there are also options to increase biodiversity values that have little or no additional costs (see Chapter 5).

Most measures that are suited to improving biodiversity in plantation landscapes also have positive effects on amenity values. Owing to their orderliness and their uniformity in shape, structure and composition, plantations can have a dramatic impact on amenity and recreational values (Evans, 2009). Artificial boundaries, strong contrasts and sharp edges between stands and large clear-felled areas or other land-use types and the monotony of landscapes dominated by single species are important aspects of how the public perceives planted forests, although perception may also be influenced by the designation of the forested landscape (Anderson, 1981) and the history of afforestation and forest use (Ní Dhubháin et al, 2009). However, the preservation of patches of native vegetation and the maintenance of landscape heterogeneity as well as the creation of stand structural diversity, are likely to benefit the cultural services of planted forests.

In general, there are mostly synergies between the supporting ecosystem services such as the maintenance of soil resources, water and nutrient cycles, and biodiversity. However, most of the above-listed management options that have a direct or indirect negative effect on plantation productivity, have a positive influence on water services and vice versa (e.g. Vertessy et al, 1996; Jackson et al, 2005). However, this does not apply universally to all other – including undesirable and unintended – negative effects on productivity, as for example through soil compaction or erosion. Here, the focus is on effects on the physiological activity and transpirational demand of planted forests. Where measures such as structural retention or longer rotations result in fewer young and vigorously transpiring trees on site, the water demand of plantations will also decline. Less productive native species are likely to consume less water, than more productive exotics such as eucalypts, which have been criticized for their high water demand (Calder, 2002). Long rotations are likely to reduce the average plantation productivity, if the rotations are extended substantially beyond the culmination of mean annual increment. Slower-growing, older plantations will have a lower transpirational demand (Vertessy et al, 1996) and less frequent disturbances will also lead to overall improved water quality (Croke et al, 2001). Reduced transpiration and interception following thinning will increase water yield from plantations (e.g. Breda et al, 1995), albeit only for a limited period of time (e.g. Lane and Mackay, 2001), while thinning is unlikely to have negative impacts on water quality, except through the use of forest roads and extraction tracks. In contrast, typical plantation management practices such as site preparation and the use of herbicides and fertilizer have the potential to reduce water quality through the disturbance of soil, removal of protective soil cover and addition of nutrients, which may not be taken up by the vegetation (e.g. Malmer, 1996). However, these effects can be minimized through adherence to appropriate codes of forest practice.

Options to improve water services from plantations at the landscape scale are largely related to the percentage area under plantation, the specific location of plantations and the protection of soils and waterways (see Chapter 4). Here, the services can be optimized through policy settings, certification requirements or sound landscape planning (see Chapter 7). However, stand- and landscape-level management options to improve water services of plantations are unlikely to conflict with the provision of other ecosystem goods and services besides the production function (e.g. Wang et al, 2009).

Synergies and trade-offs with other ecosystem goods and services are most difficult to identify for the carbon sequestration or storage function of plantations, because the influence of the above-considered management options depends on many other factors, such as the fate of the harvested wood. However, most options that increase productivity at the stand level, are likely to also increase the sequestration of carbon, unless these increases are at the expense of soil stored C, which may be the case for site preparation. While the effects of site preparation on C storage are likely to be negative in the short term, in particular in relation to soil C (Paul et al, 2002), increased productivity in the long term may offset these reductions. While C sequestration may be reduced through longer rotations owing to reduced productivity, it is likely that more C is stored on site.

At the landscape scale, interspersing plantations with buffer strips and reserves of native vegetation creates patches with more long-term C storage than in the plantation stands, although the C sequestration in these patches may be less than in the highly productive plantations. Table 8.1 illustrates that focusing plantation management on mitigating climate change through C sequestration and possibly replacing fossil fuels through bioenergy, may have serious implications on many other ecosystem services, in particular if perverse incentives are provided for some short-term goals (e.g. Danielsen et al, 2008).

At the stand scale, the production of wood and fibre has limited synergies with the other ecosystem services listed here, except for C sequestration. Typical measures to increase plantation productivity such as site preparation and the use of fertilizers and pesticides have no direct beneficial effects on the other ecosystems services. However, Table 8.1 provides a very general and simple perspective on trade-offs and conflicts between services, which are often specific to the site and context. The concept shows that it is necessary to identify how different ecosystem goods and services may be differently affected to optimize their provision at various scales. The table also shows that synergies are easier to achieve and trade-offs easier to avoid at the landscape scale when compared to the stand scale. However, higher provision of other ecosystem services often comes at the expense of plantation productivity. Therefore one of the important challenges is to devise mechanisms to reward landowners for these other plantation functions that may conflict with the production of conventional plantation products. However, only in very few cases have ecosystem goods and services been quantified for a particular plantation setting (e.g. Nambiar and Ferguson, 2005; Barlow et al, 2007). And few studies have aimed to explore what the optimal spatial aggregation of the various stand types should be to deliver the best mix of goods and services. To achieve this, several studies suggest a combination of forest growth models, geographic information systems (GIS) and indices of goods and services to support the development of land-use visions and forest planning policies on a regional scale (e.g. Köchli and Brang, 2005).

So far many challenges remain with incorporating and applying the ecosystem goods and services approach in actual design, planning and management at the landscape level (de Groot et al, in press). Only a few ad hoc attempts have been made to use spatial planning as a tool to improve the overall yield of ecosystem goods and services and to find the appropriate level of trade-offs and synergies at the landscape level. For instance Van Eupen et al (2007) used scenario-dependent maps, which indicate habitat suitability of landscapes for certain flagship species. When integrated with planning for the other most important provisioning, regulating, cultural and supporting goods and services, this could be used in new approaches for plantation planning, for example in the restoration of degraded forest landscapes in tropical areas to address both sustainable use of biodiversity as well as the alleviation of rural poverty (e.g. Lamb et al, 2005).

Unfortunately, cost-effective monitoring approaches have not been developed for many of the ecosystem goods and services, which would demonstrate and quantify the many benefits and impacts of plantations. Therefore, and for many other reasons, the identification, evaluation and negotiating of trade-offs is rarely done in the process of plantation planning in the landscape.

Particularly difficult is the assessment of temporal trade-offs between short-term benefits and the long-term capacity of ecosystems to provide services to future generations (Chapin, 2009). Most measures that maintain the productive capacity of plantation systems, in particular the maintenance of soil resources, should also maintain the natural capital in the long term. However, here the interactions with other systems such as fresh water or the atmosphere also have to be considered. For example, one would have to question the usefulness of sequestering more atmospheric CO_2 now by increasing plantation productivity through high use of N fertilizers which may lead to denitrification and increases in atmospheric concentrations of N_2O. The latter gas has, owing to its longevity of around 120 years, an estimated global warming potential (based on a 100-year period) that is 310 times as high as that of CO_2 (IPCC, 1996). Temporal trade-offs occur in particular for those ecosystem services that cannot be restored once they are lost. These include loss of species or fossil groundwater, which are at least as valuable in the future as they are now (Heal, 2000).

How plantations may help to solve some of the urgent global issues

The Millennium Ecosystem Assessment (2005) has demonstrated that the well-being of mankind depends on the maintenance or improvement of ecosystem services. It is increasingly recognized that plantations can make major contributions to the provisioning of ecosystem goods and services (Paquette and Messier, 2010), but they can also have negative impacts. Therefore, we ask here, which contributions plantations can make, through the ecosystem goods and services they provide, to solve some of the pressing global problems that are currently faced by mankind. Tree plantations already play a major role in the provision of timber and fibre such that around 3 per cent of the forest area, which is in productive plantations, provide approximately one-third of the industrial roundwood worldwide (Chapter 1). This is a success story and shall not be further discussed here. Below we discuss the different roles that plantations can play in solving the biodiversity and energy crisis, in mitigating climate change, and in reducing poverty.

Biodiversity

In Chapter 5 of this book, it has been shown that plantations can be managed and planned in ways that improve their habitat value over that of conventionally managed plantations. Beneficial effects of plantations can be expected, in particular, where these are used to restore degraded land or replace agricultural systems, and where they increase connectivity in the landscape. In addition, many options exist at the stand level to enhance the provision of habitat through increasing structural complexity, species mixtures, prolonged rotations and alternative methods of site preparation. However, the greatest benefit from plantations for biodiversity is likely to stem from the highly efficient wood production system they present.

The high efficiency of wood production that is possible in tree plantations may be the foundation for setting aside more areas of native forests in conservation reserves (e.g. Côté et al, 2009) or to reduce the management intensity in native or semi-natural forests. As was pointed out in Chapter 1, if all industrial wood came from effectively managed planted forests, only some 73 million ha, i.e. only less than 2 per cent of the world's forest area would be enough to satisfy the current global need for industrial wood (Seppälä, 2007). Given the current extent of plantations, these figures also indicate that a substantial proportion is not as effectively managed as possible and that rather than expanding their area, it may be more promising to invest in improvements in their management. In any case, fast-growing, industrial tree plantations may be one of the most effective approaches for the conservation or improved management of other forest areas valued for their biodiversity, beauty and other things. In return, the reservation of some or the majority of native forests from wood production will act as a driver for the establishment of further plantations, as has been the case for example in Australia (URS Forestry, 2007).

Energy

Energy from biomass traditionally plays a very important role in countries with developing economies. Recently, the global demand for bioenergy has been accelerating because of the depletion of fossil fuels and the CO_2 reduction targets of most countries. This is putting further pressure on forested areas. For instance, over the last five years there has been a rapid development of new bio-fuel plantations in Malaysia and Indonesia (mainly oil palm) and Brazil (mainly soybean, maize) (e.g. Mantel et al, 2007; Reinders and Huijbregts, 2008; Fargione et al, 2008). This has often gone at the expense of natural forest areas. But also forests themselves, either planted or natural, are increasingly being used for bioenergy. In Europe, fast-growing short-rotation willow and poplar plantations are being used for bioenergy (chips) (e.g. Börjesson and Berndes, 2006), and also in tropical countries fast-growing species such as *Acacia mangium* and *Eucalyptus* sp. are increasingly being used for bioenergy production (Berndes et al, 2003). This is likely to continue in the near future: Buerkert and Schlecht (2009) estimate that in 2050 there may be 500Mha of new fuelwood plantation established.

Energy is widely recognized as a crucial factor for health, education, and economic development. Renewable forms of energy provide countries with developing economies with the opportunity to reduce their dependency on costly fossil fuels, and they are often the most cost-efficient way of improving energy services for rural areas, which are often not connected to the electrical grid (Shukla et al, 2004). Therefore, biomass burning is by far the most widely used form of energy in many African countries, and will remain so for the foreseeable future (Karekezi and Kithyoma, 2002). Biomass is the only form of energy of relevance to most households, especially the poor. The present pattern of consumption of wood, however, is clearly not sustainable, and will soon result in irrecoverable damage to life-sustaining ecosystems. Here, decentralized and community-based small-scale electrification schemes based on biomass from plantations can deliver affordable and sustainable power in rural areas, without which development beyond a certain level is impossible. Obviously, the fitting type of plantation required for this purpose would also be community-based, even though they may require larger areas.

New developments in bioenergy production are opening opportunities for forest plantations as a sustainable source of biomass, but they are also posing several challenges. Under the increased demand for energy crops, prices can be expected to rise and this will enable good management practices including sound ecological, economic and social production (Rootzén et al, 2010). When wood from short-rotation plantations is used for energy purposes (replacing fossil fuels) these plantations also have a high climate change mitigation potential (Rootzén et al, 2010; Chapter 3). These fast-growing plantations also have the potential to combine a range of services (see Table 8.1); however, the interactions between fuelwood plantations and other land uses such as agriculture and nature conservation, and with functions such as carbon sequestration have been insufficiently analysed (e.g. Berndes et al, 2003).

Climate change mitigation

Owing to their capacity to sequester atmospheric CO_2, there has recently been much interest in using plantations in climate change mitigation strategies. In Chapter 3, five strategies for the contribution of the forestry sector have been identified: (1) increasing the forest area through afforestation; (2) increasing the carbon stored in existing forests; (3) protecting existing carbon stocks from release into the atmosphere; (4) increasing the carbon stored in products (yielding also indirect greenhouse gas mitigation through material substitution); and (5) substituting fossil fuels with bioenergy derived from forest biomass and wood (see above).

The greatest realistic potential for plantations appears to be in the first and in the fifth options. However, carbon sequestration in the forest-based sector is largely a non-permanent strategy. The sequestration phase is finite. In plantations it may last only for some decades and then the gained carbon stocks would need to be protected to keep carbon withdrawn from the atmosphere. While this is not possible within a single plantation stand, it may well possible over larger temporal and spatial scales, if plantations are maintained and not converted back into agricultural land use. Sequestration therefore always needs to be protected by safeguarding measures to make mitigation strategies effective.

Extending the length of rotations in existing forests is currently unlikely to receive the financial reward required to compensate for not harvesting trees at their economical maturity. Increasing the proportion of wood supply from fast-growing and sustainably managed plantations to permit a reduction of harvesting and the setting aside of native forests for conservation purposes, as we have discussed above in the context of biodiversity values, may also be a substantial contribution of plantations to the protection of carbon stocks in these forests, which may be old-growth forests with high C density. Increasing the use of long-lasting wood products and improving recycling rates has the potential to reduce the pressure on forest resources; however, this is a broader issue that is not exclusive to plantation products.

Plantations, however, may not only play a role in mitigation strategies to climate change. They may also be strongly affected by climate change with ramifications for the goods and services provided by them. Adapting plantations to climate change is another challenge. Compared to native or semi-natural forest with slow-growing, long-lived trees, this task may be much easier in fast-growing plantations, where changes of species, provenances or clones to adapt to climate-induced changes in site conditions can be accommodated frequently between rotations. However, the introduction of new species may also require the adaptation of silvicultural practices and the processing chain, which may be rather difficult and costly.

Poverty reduction and the social effects of plantations

The immense productivity of plantations and attractive markets for plantation products have fuelled expectations in governments and experts of positive economic effects at regional and national level, in particular in the context of non- or under-developed rural regions in the tropics and subtropics (UN, 2002). Beyond the demand on plantation products, these expectations are one of the reasons, respectively justifications, for the still significant subsidies and numerous plantation programmes financed by governments and international organizations (Cossalter and Pye-Smith, 2003). However, with the expansion of plantation forestry and rising criticism, mostly about negative environmental effects, the public has also become more and more sensitive to the social dimensions of plantations (Chapter 6; Carrere, 1998). While some studies highlight the positive effects of plantations on employment and income generation, in particular in outgrower schemes (e.g. Mayers and Vermeulen, 2002), as well as the indirect environmental benefits from reforestation programmes, other studies have drawn a more critical picture in light of land conflicts, limited employment opportunities and environmental damage caused by plantations (Hoch et al, 2009). The social conflicts have been particularly apparent, where intensively managed forest plantations have been implemented (Kanowski and Murray, 2008). Whilst the social balance in landscapes influenced by plantations depends on the specific context and design, it seems possible to attribute the social performance to a larger degree to the functioning of interactions between actor groups (see Chapter 6).

To better understand the social dimensions of plantations, it is useful to distinguish between the scale and owners of plantations: (a) large companies and governments that own or manage plantation resources from tens of thousands to hundreds of thousands of hectares; (b) independent private landowners who typically manage between hundreds to thousands of hectares; and (c) smallholders with resources typically in the range of a few hectares or even less; see also Kanowski and Murray (2008).

Owing to their capacities regarding capital and know-how, companies, governments and other actors with sufficient capital are predestined to initiate large-scale forestry plantations. The economic benefit of these types of plantations is often expressed as the return to investors, which has been in the range of 3–11 per cent internal rate of return for short-rotation pulpwood and 1–7 per cent for longer-rotation solid-wood plantations (RISI, 2007). The most important social benefit of these types of plantations at a local level is through employment. However, in consideration of the immense demand on land, the employment opportunities generated by the tree growing in plantations are rather limited, if compared to other more labour-intensive land uses such as family agriculture (Cossalter and Pye-Smith, 2003; Schirmer and Tonts, 2003). Against this background, the social balance of these type of plantations depends mainly on the attractiveness of alternative land-use options given by contextual parameters such as population density, land-use history and, related to this, soil fertility. Generally, the social impacts of large-scale industrial plantations, due to their immense requirement for land, tend to be more negative in highly populated areas with fertile soils. Most of the economic benefits of plantations are actually associated with the processing industries reliant on the plantation products (Kanowski, 2005) and hence the employment opportunities. These processing industries have often not been established in the same areas as the plantations. However, in some cases even the local commercialization of by-products such as quality timber, fuelwood or charcoal may provide significant local benefits. In addition, large-scale industrial plantation initiatives may catalyse and provide the basis for the participation of the other two types of plantation owners – (b) and (c) from above – in the business of tree growing.

For example in outgrower schemes, farmers and smallholders are actively engaged in the production process and may directly benefit from attractive income opportunities. However, despite some outstanding positive experiences (e. g. Mayers and Vermeulen, 2002), the competitive disadvantages of locals in negotiating with companies bears the risk of unfair contracts (Desmond and Race, 2000).

Many national and international development organizations have also been promoting plantations owned and managed by smallholders to generate income and to achieve environmental goals. While there have been some very positive local experiences, the success of such initiatives has been rather modest (Chapter 6; Hoch et al, 2009). The success and problems of this approach have been discussed in detail in Chapter 6. The problems typically associated with this approach are:

- the establishment of plantations on degraded soil resulting in poor tree growth;
- the technologies, capital and security of tenure required are often not compatible with smallholders' realities;
- the dependence on continuous external support not only for the establishment but also for the maintenance and, most important, the commercialization of plantation products.

As has been shown in Chapter 6, it is often overlooked by development practitioners that smallholders also grow trees on their own initiative, often as single trees within agricultural crops or in homegardens and in small plantations. Often these plantings focus on the production of NTFPs and other ecosystem services, which provide more immediate and regular benefits than wood and timber.

Given these different situations and contexts, the role of plantations in poverty reduction has been ambivalent. The conditions and prerequisites for the positive social effects of plantations at different scales have been outlined in Chapter 6 and other recent publications (e.g. Kanowski and Murray, 2008). Positive effects will only be realized if all the costs and benefits of the development of plantation landscapes are being assessed and where the legitimate interests of all actors are respected. Where this is not the case, plantations will not only fail to contribute to poverty reduction, they are also unlikely to provide ecosystem goods and services to those who are most strongly dependent on them.

Conclusions

The increasing competition for land in an increasingly crowded world may result in a shift in management focus of existing and future plantations, from single or few goals such as efficient wood production, to a range of goals. In the past, the dominant interests in societies often accorded little formal value to the non-timber ecosystem goods and services of plantation forests. Changing societal values, more progressive thinking about the potential roles of plantations, and the emergence of new forms of environmental governance regimes have created policy environments which are much more enabling of the provision of ecosystem goods and services from plantation forests.

In the different chapters of this book it has been documented that there is now a large body of knowledge and experience showing that appropriately planned, designed and managed plantation forests can deliver a range of ecosystem goods and services, at both landscape and stand scales. This book has also shown that the benefits and impacts of plantations and their trade-offs are highly context specific. Therefore, the range of impacts and benefits associated with plantation forests, which typically differ from those of other landscape components, need to be assessed, agreed and managed in a landscape context. This body of knowledge about the impacts of plantations and their contributions to ecosystem goods and services provides the foundation for developing governance regimes that are consistent with the principles of sustainable forest management. In accordance with these widely agreed principles, societies have the right to expect that plantation forests will deliver more benefits than costs. However, how the different ecosystems goods and services are traded off and to what extent different interest groups share the benefits will remain, ultimately, a value judgement. It is clear, however, that enhancing the provision of ecosystem goods and services from plantation forests is an important element of realizing the benefits of this increasingly important form of forestry.

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