Forests in the next 300 years

J. Blaser and H. Gregersen

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"Even if I knew that tomorrow the world would go to pieces, I would still plant my apple tree."
– Martin Luther (early sixteenth century)

The global forest estate will be much larger in 2313, and forest managers will be very important people.

Juergen Blaser is Professor for International Forestry, Bern University of Applied Sciences – School of Agricultural, Forest and Food Sciences, Switzerland.
Hans Gregersen is Professor Emeritus, Department of Forest Resources, University of Minnesota, USA.

The oak tree being planted as we write on a cold morning in 2013 at a university campus on the Swiss plateau should reach maturity sometime in the twenty-fourth century. All going well, the sipo tree (*Entandrophragma utile*) that has just established itself in a rainforest gap in northern Republic of the Congo, starting a life of fierce competition for light and nutrients, will overgrow the forest canopy to become an emergent tree sometime after 2350. The fir seedling (*Abies sibirica*) in the Northern Ural of the Russian Federation, which today is 20 cm tall, will have a stem diameter of 60 cm by 2313.

At the global scale, the question of whether individual trees such as these survive to maturity is unimportant, but the overall fate of the forests of which they are part is crucial. Forests and trees are a *renewable* resource, providing an enormous range of goods and ecosystem services. In the face of expected declines in the availability of non-renewable resources and massive environmental change, the fate of trees and forests in the next 200–300 years is

Above: The Kaybitsky Forest, Russian Federation, which houses genetic reserves of oak trees. Maintaining forest biodiversity will be crucial for a sustainable future

of fundamental importance to humanity. Forests come and go (Box 1), but in the last several hundred years there has been a dramatic decline. Nevertheless, there is potential to reverse this and to greatly increase the global forest resource. In this article, we consider the factors that will influence the fate of forests in the next 300 years, and predict a world that is more reliant than ever on its forests – and on its forest managers.

Forests come and go

Fourteen thousand years ago, at the end of the last glacial period, the world's forests were found mainly in refuges in hot and humid Southeast Asia, the central Amazon, West and Central Africa and the southeast of North America (Adams, 1997) and covered an area of less than 2 billion hectares (ha). As temperature and humidity increased, forests expanded to their largest extent of more than 9 billion ha in the mid-Holocene, 7 000–9 000 years before present. From about 3 000 years ago, the forest area declined steadily as humans developed from hunters and gatherers to farmers and herders (Figure 2). We estimate the net loss of forest area since the early 1700s at about 1 billion ha, all of it human-induced. Nevertheless, in the last two decades, 77 countries have changed from being net losers of forests to net gainers, although the forests being added are often quite different from the forests being lost (Putz, forthcoming).

THE MAIN ASSUMPTIONS

The information age[1] is giving rise to dramatic changes in the way in which societies live, think, work, buy and prioritize future investments, and the humans of today are very different – physically, mentally and spiritually – to those of 300 years ago. We assume that people will continue to change and that those who live 300 years from now will differ greatly from us in many ways that we cannot predict. We assume, however, that their fundamental values will remain the same – they will value environmental quality, economic prosperity and social equity.

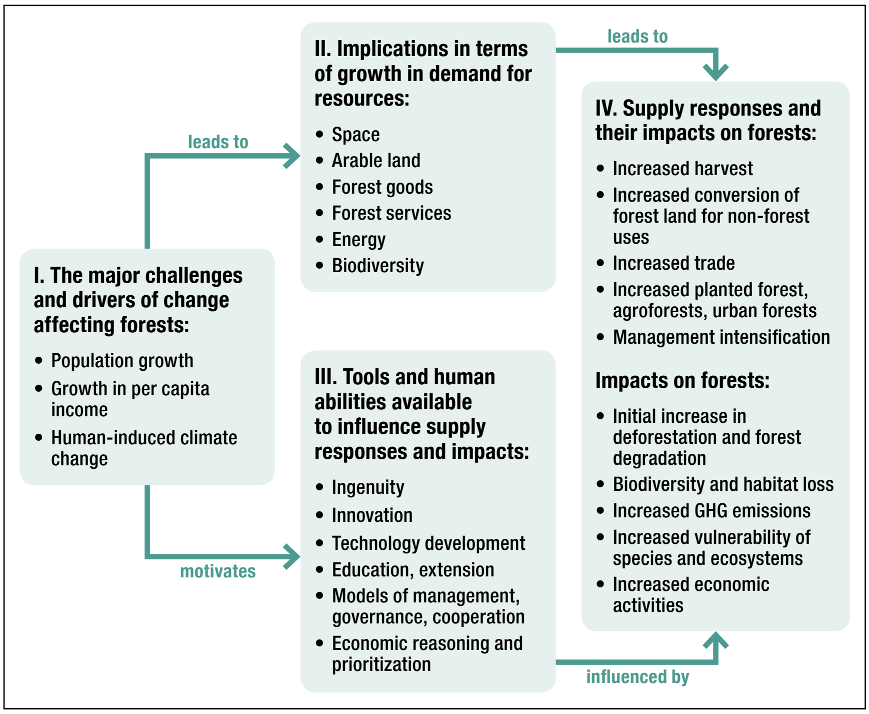
As discussed below, we assume that the overall consumption of resources will increase due to population growth and growth in per capita consumption. At the same time, we expect that climate change will have dramatic impacts on the environment, potentially inducing major movements of peoples and leading to increased conflict and civil unrest. Forest destruction could continue unabated and even increase over the next decade. In his acclaimed *A Brief History of the Future*, Attali (2011) envisioned that "forests will be rarer and rarer, devoured by the packaging and paper-making businesses and by the expansion of agriculture and cities".

Despite such a potentially bleak medium-term outlook, we choose to accept an equally reasonable assumption; namely, that, despite the many problems humanity will face in the next 300 years, social cohesion will generally be maintained. Societies will become increasingly democratic, research capacity will increase, and nanotechnologies and other undreamed-of innovations will flourish. Three hundred years ago, societies used forests and trees for the same basic reasons we use them today, but in totally different ways. We expect that the same will be true 300 years from now – the same benefits will be reaped from forests, but in many new ways. Below, therefore, we make a case for expanded demand for forests and trees over the next 300 years and therefore for an expanded global forest estate.

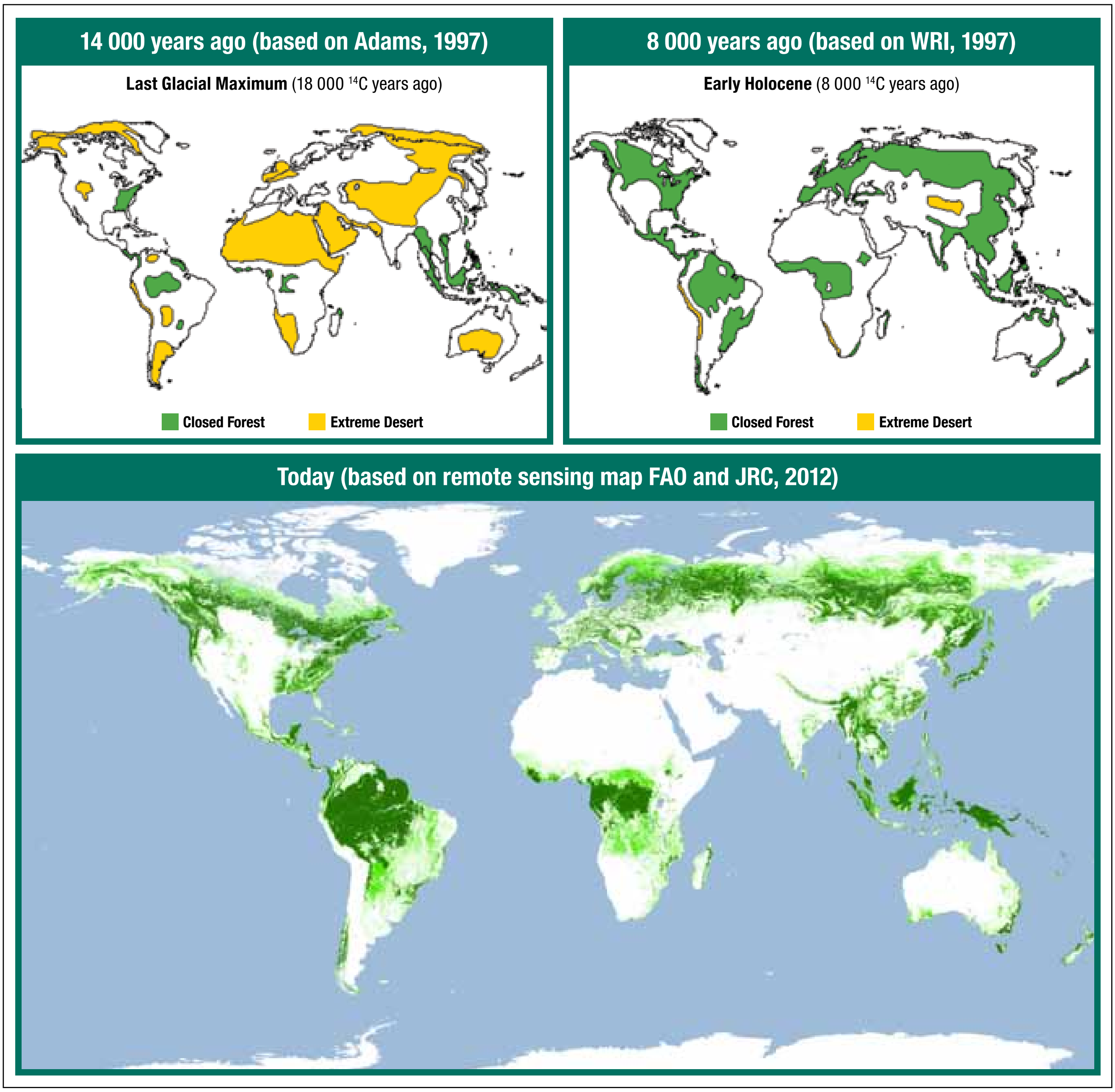
MAJOR CHALLENGES AND A PATHWAY FOR CHANGE

Figure 1 shows the major elements we considered in projecting what will happen to forests in coming centuries. Of the many challenges and drivers (Box I in Figure 1) that will influence forests of the future, we focused on what we view

1
The future of forests: challenges, responses and impacts



[1] The first two "ages" were the agricultural age and the industrial age (Toffler, 1980).



2
The world's forest area

as the three most important: population growth; growth in per capita consumption; and climate change. These give rise to many challenges (Box II), but also to many opportunities to meet the challenges by providing incentives for ingenuity and innovation to flourish and leading to the development of new technologies and ways of organizing societies (Box III). Societal priorities, abilities and tools will determine the responses to the challenges, and the responses, in turn, will determine the size and nature of the impacts (Box IV). Each of these four elements (as shown in boxes I–IV) is discussed below.

Major challenges and drivers of change affecting forests

Population growth. The world is getting more crowded. It took about 2 000 years for the world population to grow from 60 million to 600 million people in 1700 (McEvedy and Jones, 1978) and only 300 years to grow almost twelve-fold to 7 100 million in 2012. However, the good news, based on a well-justified "medium growth" scenario, is that the world's population will grow, at a slowing rate, to around 9 billion by 2050 and then stabilize up to 2300 and beyond (UN, 2004). The growth to 2050 will occur nearly exclusively in tropical and subtropical countries, mainly in Africa and Asia, where deforestation for food production is likely to remain a challenge for the next 50 years. However, the current trend of migration from tropical areas to temperate areas, and from rural to urban areas, is also likely to continue, perhaps mitigating the direct impacts of population growth on forests. A global population of 9 billion people could live sustainably (see, for example, Tudge, 2007), except for expected growth in per capita consumption.

Consumption and income growth. OECD (2012) and The Conference Board (2012) projected that world gross domestic product would continue to grow for the next 20 years or so, with rates of growth higher in developing countries and higher than population growth rates. The consumption of goods and services differs dramatically between poorer and richer countries, both in absolute and relative quantities. According to the Worldwatch Institute (2011), "the 12% of the world's population that live in North America and Western Europe account for 60% of private consumption spending, while the third of the population that lives in South Asia and sub-Saharan Africa accounts for only 3.2%". As per capita incomes increase in developing countries it is likely that resource consumption will also rise.

Income growth will also shift the mix of goods and services demanded from forests. The demand on the world's *natural* forests is likely to increasingly shift away from uses such as fuelwood and timber towards services such as watershed protection, carbon sequestration, biodiversity conservation, recreation and other non-deforesting uses. This increased acknowledgement of the importance of forests is one reason why most developed and middle-income countries are now net adders to their forest areas. Another reason is that some major countries have "exported their deforestation" to mainly developing countries by becoming net importers of food and forest products because they are often cheaper than domestic production (Gregersen *et al.*, 2011).

Climate change. Science-based predictions of climate change generally do not go beyond 100 years from now; thus, a projection to 300 years involves many uncertainties. We have chosen an optimistic scenario of an increase in mean global temperature of 4 °C by 2313; this is optimistic because this increase is projected by most climate models by the end of the *current century*, given no serious policy changes (World Bank, 2012a). Despite being

Mid-altitude (1 500 m above sea level) fire-affected savanna in Madagascar. Under climate change there is a risk that many forested areas today will become savanna-like landscapes, with small islands of biodiversity-rich but isolated forest stands

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Savannah in the Republic at the Congo in October 2012. This could be the landscape in a large part of the Congo Basin in 2313

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optimistic, such an increase is projected to have devastating consequences, including the inundation of coastal cities; increasing risks to food production, potentially leading to higher malnutrition; increased aridity in many dry regions and increased rainfall in wet regions; unprecedented heat waves in many regions, especially the tropics; substantially exacerbated water scarcity in many regions; an increased frequency of high-intensity tropical cyclones; and the irreversible loss of biodiversity, including in coral reef systems and forests (World Bank, 2012a).

The 4 °C scenario involves an increase in the mean global temperature from the pre-industrial value of 13.5 °C in 1800 and the 14.5 °C today to about 18.5 °C in 2313. Changes in climate could happen very fast, prompting dramatic changes to forests. When trees, plants and animals are exposed to environmental conditions that differ from those to which they are adapted, the resulting physiological stress makes them more susceptible to catastrophic damage from ecological disturbances such as disease, insects and fire (Bergengren, Waliser and Yung, 2011) and increases the likelihood of local and even regional extinctions. Research to better understand vulnerability and resilience will play a major role in providing forest management options in the face of climate change.

Implications for resource demand

The three major challenges discussed above will lead to increased demand for natural resources and have major implications for the future of forests.

Deforestation and reforestation. If technological progress in food productivity per unit of land does not keep up with the growing demand for food, then there are likely to be significant reductions in forest area as agriculture expands to meet growing demand. Over the next 50 years, much forest and woodland in developing countries will likely be cleared to make room for food and possibly biofuel crops. Thus, deforestation will continue to convert forests to land suitable for agricultural crop production (Bruinsma, 2003). On the other hand, the area of land in agricultural use in the industrialized countries of Europe and North America will actually decrease to 2030, and much of it will revert to forest and other environmental uses (Wirsenius, Azar and Berndes, 2010; Gregersen *et al*., 2011). We expect a similar, if somewhat later, trend in most developing countries.

Watershed management. Freshwater scarcity is likely to become a major constraint to development in coming centuries. Water use and availability are affected by population size, technology development and income growth, and climate change is likely to have an increasing impact. There is evidence that trees can reduce

An old-growth tree in the Nkula forest, Republic of the Congo. Climax forests will dwindle in the face of climate change and will be rare by 2313

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runoff at the small catchment scale and, at a very large scale (e.g. the Amazon Basin), forests are linked to precipitation patterns and water availability (Ellison, Futter and Bishop, 2011). In drier areas, trees can reduce the amount of available water (although through sheltering effects they can also increase local water availability). In the future, such direct links between forests and water will be crucial, and managing forests specifically for water quality and the timing of water flows will be increasingly important.

Biodiversity protection. In past millennia, human societies used hundreds of plant and animal species to ensure their food and health security. Today, however, global food security depends on only a few crop species (Salim and Ullsten, 1999) and genetically narrow high-yielding varieties, increasing the vulnerability of food production to biotic and abiotic stresses. The risk of crop failure will increase further with climate change and the increasing fragmentation of habitats. Conserving biodiversity, particularly in tropical dry and moist forests, should be a top priority for humanity because genetic diversity will be essential as a buffer against changing environmental conditions and as a pool of variation to be used in crop and forest tree improvement and breeding.

The permanence of carbon stocks. Besides oceans, sediments and fossil fuels, forests, tundra and peatlands constitute the planet's main carbon pools (about 2 000 gigatonnes). Ensuring the stability of forest carbon stocks will be a major challenge for foresters. REDD+[2] was first proposed in 2007 as a mechanism to reduce greenhouse gas emissions from forests, and there are high expectations that it will become a major tool for funding forest management. However, there is considerable work to do to put this or other similar mechanisms into effect and to ensure the permanence of forest carbon.

Wood energy. Oil, gas and coal are exhaustible resources; the first two will likely be almost exhausted in 300 years,

[2] A term that has come to mean reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries.

but coal may last longer. Addressing the energy challenge will be a priority in a hotter and more crowded world. Wood was the main source of energy before the nineteenth century and continues to be an important energy source. In 2009, about 1.7 billion m^3 of wood was consumed as fuel, amounting to 73 percent of the world's renewable energy supply in that year (IEA, 2010). Third-generation biofuels[3] will become increasingly important, but most other types of wood-based energy are likely to decline.

Wood as a raw material. The global consumption of industrial roundwood was about 1.9 billion m^3 in 2009 and is projected to grow to 3 billion m^3 by 2050 (FAO, 2010). The consumption of wood for industrial purposes and as a biofuel will increase in the next 30–50 years. Beyond that, wood fibre will play an increasingly major role as a raw material for composite products and as substitutes for petroleum-based materials, with a vast range of applications in medicine, electronics, biomaterials and energy. Wood and many other forest products are recyclable, another factor in their favour. The bottom line is that wood will likely continue to be important, and indeed will increase in importance, as we move toward 2313.

Tools and human abilities available to influence supply responses and impacts

Human societies are ingenious, inventive and creative, once the incentives present themselves. Societies can apply systematic approaches to discovery and innovation and use research, development and education to produce workable new technologies and applications. It has also proved possible to change human behaviour, at both the sociopolitical and individual levels; for example, increasing the rights of local communities and citizens to, and responsibilities for, public-domain forest resources can lead to more sustainable forest use and management. Most of the major innovations that will be needed to secure a positive forest future must occur outside the forest sector; they include advances in food production to increase productivity per unit area of land to help reduce deforestation, energy technologies that move away from inefficient fuelwood use, and the development of means to deal with the threat posed by climate change.

Advances in forest science and knowledge. There is no technical reason why the goals of sustainable forest management (SFM) cannot be achieved in all forest biomes. In the past 300 years, forest management systems have been developed in most biomes that mimic nature, and there is a good understanding of the regeneration of many forest-associated plant and animal species. Nevertheless, climate change represents a major challenge for forest scientists: climax forests are at high risk; successional forests with fast rotational cycles may take over in many areas because of extended droughts, forest fires and other extreme events; and many tree species might not reach maturity due to physiological stress and the increased frequency of disturbance. Forest science must enable a better understanding of forest vulnerabilities and stressors and develop implementable solutions to the challenges posed by climate change.

Technology development. Much effort will be needed to develop technologies based on renewable resources such as trees that are cost-efficient and environmentally friendly. Wood has huge potential as a raw material, and the genetic improvement of commonly used tree species could make it even more versatile. Genetic modification is contentious; nevertheless, as the risks become better evaluated, and as competition for land intensifies, the practice of genetic modification is likely to become more frequent for both agricultural crops and trees. Overall, continual innovation in forest products is needed to ensure the economic viability of production forests.

Governance and management. The main governance challenges in the future will be linked to access to crucial natural resources such as land, forests, water, energy and minerals. Good global governance will be required to avoid devastating conflicts and disputes over resources, particularly water in transboundary situations but also land. Human migration towards areas with the best living conditions is likely to increase in the coming century. We expect that the current governance structure will change towards a more comprehensive, resource-based approach with greater focus on resource access. The present trend to provide forest communities and indigenous groups in developing countries with statutory legal rights and responsibilities will need to continue. New institutional arrangements for making payments for and managing ecosystem services will be needed.

Intersectoral governance will also require greater attention. Multifunctional solutions that optimize the use of a given landscape will be needed to address, for example, integrated climate change mitigation and adaptation, energy generation, freshwater protection and ecosystem resilience. Securing a permanent forest estate is likely to be a significant challenge: potentially, some of the best future living areas for humanity will be where forests are growing now.

Global cooperation and policy processes. It seems obvious that existing global arrangements on forests will be insufficient, even to tackle forest-related issues over the next 20 years or so. How to address the current void is a crucial policy challenge. New international agreements dealing with issues such as international land-grabbing may be required. There is a need for stronger emphasis on compliance and enforcement in many forest-related agreements, including the multilateral environmental agreements. Strong regional and global technical and scientific institutions with clear mandates to address environmental, sociopolitical and economic challenges across national boundaries will be needed.

[3] Third-generation biofuels are made from algae and other microorganisms dealing, among other things, with the degradation of lignocellulose, hemicellulose and lipid-rich materials.

THE SUPPLY RESPONSE: IMPACTS ON FORESTS

Overall, we expect a greatly expanded demand for forest and tree goods and ecosystem services. Table 1 indicates likely possible supply responses to this increased demand.

A crucial supply response will be to maintain natural forests for their increasingly valued ecosystem services, including biodiversity and the permanence of carbon stocks, and to reduce extractive uses of them. To meet increasing demand for wood and wood fibre, planted forests, assisted natural regeneration, the restoration of degraded forests and the rehabilitation of degraded lands will all increase in importance (Poore, 2003). Forests will become much more important as a source of fibre and for their ecosystem services, and increasingly they will become

TABLE 1. Possible management and supply responses and their impacts on forests to 2313

	Now to 2100	2100 to 2200	2200 to 2313
Deforestation due to overexploitation for wood and to provide land for other priority uses	+++ → + Continuous deforestation in the tropics, with some success in reducing it over time through REDD+ and new, holistic forest programmes	+ → -- Reduced large-scale, human-caused deforestation but increased climate change-based disturbances. Forest area increases in majority of countries	-- → --- Human-made forests managed sustainably become much more important. Most remaining natural forests are in protected reserves
Land degradation	++ → +++ Increased degradation of arable land, mainly in tropical least-developed countries. Restoration of degraded lands in developed world	+++ → ++ Continuous degradation due to climate change, but increased restoration of degraded land due to increased land value	++ → + Land degradation remains an issue, but ways of reclaiming lands are much improved. Intensive restoration programmes are in place
Biodiversity and habitat loss	++ → +++ Continued loss of biodiversity and habitats in all biomes, slowing towards the end of the period	+++ → ++ Continuing loss, mainly due to climate change and invasive species increasing in all forest biomes. Intensive conservation programmes are in place	++ → - Stabilization and partly artificial regaining of habitats and biodiversity
Vulnerability of species and ecosystems	+ → ++ Gradual increase in vulnerability in all biomes	++ → +++ Gradual increase in vulnerability in all biomes; management systems are developed to minimize threats	+++ → +++ Continued threat, particularly in marginal areas; management systems are developed to minimize threats
Harvesting and use of forest products	+ → ++ Increased use of and trade in timber, wood products and fuelwood	++ → +++ Shift of production towards higher-end uses of wood fibre and derivates; increase in trade based on comparative advantage	+++ → +++ Wood fibre and non-wood forest products of great importance for materials of all kinds; most wood supply is from planted forests
Natural forests	++ → ++ Integrated management in temperate and boreal zones, less so in the tropics	++ → +++ Shift in emphasis of natural forest management towards the provision of ecosystem services	+++ → +++ Conservation management of natural forests; sophisticated, human-induced forest protection systems
Planted forests, agroforests and urban forests	+ → ++ Landscape forestry: steady growth in all biomes; increased domestication of tree species; development of genetically modified organisms for major planted species	++ → +++ Large-scale commercial afforestation, reforestation and agroforestry are practised more widely	+++ → +++ Comprehensive approach involving improved management systems and urban forestry; the focus is on human-made forests of genetically improved trees
Watershed and soil protection	+ → ++ Integrated through REDD+ and payments for ecosystem services; landscape-level management systems are evolving	++ → ++ Landscape management is an intensive, integrated, well-accepted approach in all biomes	++ → ++ The capital-intensive management and protection of landscapes are priorities
Carbon sequestration, ensuring the permanence of carbon pools	- → ++ Weak approaches through climate-change mitigation instruments, including REDD+ and nationally appropriate mitigation approaches	++ → +++ Increased consideration of carbon as a co-benefit of SFM	+++ → +++ The permanence of carbon pools is ensured through SFM
Other non-use values, such as climate protection and spiritual and recreational values	+ → + Recognized by stakeholders, but politically undervalued	+ → ++ Recognized as highly important local and global externalities	++ → ++ Considered among the main values of forests and a primary focus of SFM

Note: + and – indicate the level of importance and change of a management or supply response at the beginning and end of a period.

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A eucalypt plantation in India in 2008. Intensive wood-fibre production will be an important element in the future

economically competitive with agriculture. Degraded lands will become more valuable, including for planted forests.

WHAT FUTURE FOR OUR FORESTS?

Extent of forests in 2313

Table 2 shows our estimate of the extent of the world's forest estate in 2313 at about 5 billion hectares. The point here is not so much the exact increase over today (1.2 billion ha), but rather the expectation that tree cover will expand and be more important in the future as a renewable resource with great versatility, and that the increase will be almost entirely due to increases in planted and assisted natural regeneration forests, agroforestry systems and urban forests. Although competition for land is a significant issue today, we expect there to be sufficient land available for such an expansion of forests. Agricultural crops will increasingly be produced using intensive production systems (often under-roof), there will be more urban agriculture, and meat will be produced much more efficiently. However, while we expect the gross area of available land to be sufficient, it will be of variable quality and much of it will require restoration.

Christophersen (2010) suggested that there are more than 1 billion hectares of clear-cut or degraded forest land worldwide. Forests could be re-grown on most of that land if demand for forests and trees increases and the economics of restoration become more favourable. Looking at the requirements for effective large-scale restoration, Menz, Dixon and Hobbs (2013) proposed a four-point plan to ensure that restoration sustains and enhances ecological values: identify focal regions with high restoration demands; identify knowledge gaps and prioritize research needs to focus resources on building capacity; create restoration knowledge hubs to aggregate and disseminate knowledge at the science–practice interface; and ensure political viability by ensuring recognition of the economic and social values of functioning restored ecosystems. These points are interrelated and may occur in parallel. In nearly all cases, replanting would not replicate the former forest in either carbon density or biodiversity but would provide a wide range of benefits.

We do not foresee a linear expansion of forest cover over the coming 300 years. Large-scale forest destruction, focused in the tropics, may well continue to 2050. Then, or fairly soon thereafter, a turning point will be reached at which policy efforts to stop deforestation on natural forest lands start to bite. Recovery will happen fast, but unevenly worldwide.[4] Below, the main forest biomes are discussed.

[4] A good example of what is possible is the rapid greening of the Republic of Korea in the period 1960–1980 through a large-scale replanting and community forestry programme made possible when thousands of villages were given secure rights to the outputs of their planting efforts (Gregersen, 1982, 1988; Lee, 2012).

TABLE 2. Forest distribution, by broad type, 2013 and 2313

Forest cover, 2013					**Total**
Primary forests, economically inaccessible or geographically too remote for intensive use (mainly boreal and tropical forests; also forest protected areas)	**Forest/landscape mosaic**, accessible forests including degraded forests and secondary/ successional forests (mainly in the tropics), used primarily for fuelwood and timber	**Well-managed (semi) natural forest**, including natural and semi-natural secondary forests (mainly boreal and temperate forests)	**Planted forests** (afforestation and reforestation) for production and/or protection purposes (all regions)	**Agroforestry and trees in landscapes**, including urban forests and scattered parks in urban areas (all regions)	
< 800 million ha	**> 1 900 million ha**	**> 700 million ha**	**< 300 million ha**	**< 100 million ha**	**3.8 billion ha** (29% of total land area)
Expected forest cover, 2313					**Total**
Natural forests, close-to-pristine but considerably affected by climate change; predominantly successional rather than climax forests. Almost entirely with protected status	**Forest/landscape mosaic**, with naturally grown forests in patches in dry landscapes (e.g. along rivers); managed predominantly for carbon and biodiversity, often by smallholders	**Intensively managed and controlled assisted natural regeneration forests and planted forests**, including high-yielding clonal forests, combined with semi-natural forests for fibre for various uses such as construction, furniture, bioplastics, paper, clothing and nanotechnology applications and for energy		**Urban forests and trees, and agroforestry**, for local climate, air-quality, water and recreational values, and occasional use of wood fibre	
< 500 million ha	**> 1 000 million ha**	**> 3 000 million ha**		**> 500 million ha**	**5.0 billion ha** (38% of the total current land area)

Source: Data for 2012 based on FAO and JRC, 2012; Blaser *et al*., 2011; Forest Europe, UNECE and FAO, 2011. Note that FAO (2010) estimated the global area of primary forest in 2010 at 1.36 billion ha.

In the **tropical moist biome**, population and income growth will influence land and forest use, particularly in Africa and Southeast Asia, to 2100. It can be expected that considerable parts of the tropical moist forests in the Congo Basin, which are relatively accessible, will be converted to agricultural land (World Bank, 2012b). The Amazon Basin, the Mekong and some of the major islands of Indonesia will also experience considerable forest loss in the coming 50–100 years to make way for commercial crops to meet worldwide demand for food, fodder and bioenergy. Climate change will become a major issue in these regions, not only for forests but also for agricultural production. Biodiversity and habitat loss will accelerate, and there is a risk of complete land degradation, particularly in the Congo Basin, where a savannah/forest mosaic could become the major landscape feature, and in lowland Southeast Asia. Beyond 2100, on the other hand, most of the predicted reforestation will take place in the tropics, where fast-growing tree species can rapidly sequester carbon and produce fibre.

Tropical dry biomes are likely to have different pathways: some regions will receive more precipitation and humidity (e.g. the Sahel), and some will be more at risk of extended drought due to changing atmospheric circulation (e.g. the monsoon areas of eastern Africa and India). Semi-arid and semi-humid tropical forests, including on the Indian subcontinent and in parts of Central America and southern South America, will be among the most vulnerable forest ecosystems, due to extreme events. Overall, tropical dry biomes will expand in area but tree cover is likely to reduce.

Temperate biomes will host natural forests with the best chance of adapting to major climatic changes and with most hope of ensuring the permanence of carbon stocks. In some regions, forests in temperate biomes will expand into the boreal zone. In Europe, for example, dominant tree species such as beech (*Fagus silvatica*) and various temperate-zone species of oak (*Quercus* spp.) and pine, among others, will expand from the Mediterranean area to southern Sweden and from the extreme west to the Ural in Russia. This will allow interchanging ecotypes under projected climate change as planned adaptation measures.

What today is the core area of the **boreal forests** will become vulnerable due to the increased frequency of summer drought and mild winters (Barnett, Adams and Lettenmaier, 2005) and more frequent and intense fires. In the transitional area in the south, however, deciduous tree species might take up niches left by dying conifer forests. In the transitional areas towards the north (tundra), conifer forests will expand northward, although only slowly and without any major increase in global biomass, carbon or wood supply. There will be new successional forests in Siberia, Alaska and Greenland, although these slow-growing forests will have had relatively little effect on solving global problems by 2313.

Forest quality

While human-induced forest degradation is an issue today and will be for the next 50 years, climate change will have the biggest effect on forest quality in the longer term. In a world with an average temperature of 18 °C, biomass-rich climax forest types in all forest biomes will be replaced by successional forests characterized by lower biomass and lower carbon stocks and often also by lower biodiversity. Nevertheless, those forests will have to fulfil the same functions as forests today; thus, there will be a need for more forest, at least to secure permanent carbon stocks. A challenge will be to address forest vulnerability, including to wildfire and pests and diseases, and to restore degraded forest ecosystems. Another will be to ensure that forest cover is a competitive land use – otherwise it will not expand as we predict. New forest management approaches may be required (see below), and all the ecosystem services provided by forests will need to be monetized.

Development of planted forests, agroforests and urban forests

There are many legitimate concerns about the potential harmful ecological, social and economic impacts of planted forests, but sufficient experiences have accumulated to avoid such negative impacts in the future (Evans, 2009). In our prediction for 2313, there will be 3 billion ha of intensively managed planted and assisted natural regeneration forests, of which about 2 billion hectares will be planted forests for the production of wood and non-wood goods and services, including watershed and soil protection, recreation and carbon sequestration. In the future, large areas of degraded land will be afforested and reforested through community, private and government efforts. There is huge potential for the domestication of a wide range of light-demanding species, particularly in tropical areas, in genera such as *Ochroma*, *Schizolobium*, *Terminalia*, *Trema* and many others, and genetic improvement of already widely planted genera such as *Acacia*, *Eucalyptus*, *Cunninghamia*, *Picea*, *Pinus*, *Populus* and *Tectona*. Wood yields and ecological resilience can be greatly increased by genetic improvement, site–species matching and silviculture. Ways will be needed to increase the diversity and biomass of other associated plants and fauna. Urban forestry will become increasingly important for improving the liveability of city environments and performing a wide range of ecosystem and social services.

*Coppice forest management system of beech (*Fagus silvatica*) in the Republic of Macedonia, 2012. This kind of resilience-based management for wood-fibre production will be widespread in 2313*

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What kind of management will be in demand for sustaining forests?

As natural forests become more vulnerable and fragile due to the fast pace of change, especially climate change, maintaining the production of forest goods and ecosystem services will likely depend increasingly on human interventions and ingenuity. Science and governance reform will have important roles to play. Specialized forestry and forest products professionals will be required in disciplines such as biology, silviculture, physiology, genetics, soil science, entomology, biochemistry, nanotechnology, urban forestry, landscape management and resource economics. While there will be a need for highly skilled forestry professionals, there will also be much more locally based management that makes full use of local and traditional knowledge and interdisciplinary research and interactions. Forest managers will also need exemplary social skills, including in conflict management.

Forest governance, management and policy development will face many serious challenges in the future. Optimizing a variety of objectives in management, including new issues such as the resilience of tree species, securing carbon pools and optimizing materials production based on wood, will demand new approaches to forest management. Some "new" forms of forest management could be derived from the past. In Central Europe, for example, *hochwald* (high forest) systems might need to be converted from even-aged stands to uneven-aged stands or to coppice systems as a way of reducing vulnerability to environmental change and changing economic objectives. In tropical forests, managing young secondary forests in combination with enrichment plantings might lead to new forms of short-rotation forestry, where a maximum of biodiversity can be conserved and an optimal level of biomass can be maintained. Above all, forest managers will need to be versatile and adaptable as they develop and implement new forest management approaches that respond best to changing conditions.

CONCLUSION

With their huge protective and productive functions, forests will play a crucial global role in the next 300 years and beyond. Knowledge of the art and practice of sustainably managing forests will be in high demand. As one of the main renewable natural resources available to humanity, forests will be expected to help mitigate climate change, protect soil and water, provide clean air, conserve biodiversity, help maintain the mental health of humans, and produce wood fibre and other products. Thus, in 2313 we expect that:

- Natural forests will still exist but, to a great extent, climax forest types, such as primary rainforests, will have disappeared, due mainly to shorter forest cycles caused by increased (climate-related) disturbance. We expect that natural forests will cover about 0.5 billion ha, mainly in boreal and temperate areas in Europe, Siberia and North America, and in the tropics (mainly the Amazon Basin and the mountainous areas of Borneo and New Guinea). They will mostly be in protected areas, with minimal timber harvesting, and will provide important ecosystem services. Legal reforms will ensure that indigenous communities maintain their cultural associations with such forests.
- Planted and semi-natural forests, as readily renewable natural resources, will be providing huge quantities of wood and wood-based fibre. Urban forests will be providing recreational and spiritual benefits and serving as climate buffers.
- Overall, the forest area will have increased to about 5 billion ha, although those forests will have less biomass per unit area than natural forests today. The life cycles of forests and tree species will become shorter and they will be subjected to a constant dynamic of climatic and biotic disturbances.
- Forest governance, at the regional and global levels, will still be a key issue. The redistribution of ownership and better defined rights and responsibilities will increase efforts to protect, invest in and use forest resources wisely.

The scenario described in this article is an optimistic one (although some elements, such as the loss of primary forests, are depressing), but it is not an impossible or even an improbable one. It is likely that the oak tree on the Swiss plateau, the sipo tree in northern Congo and the fir tree in western Siberia will not see the beginning of the 24th century, but forests – albeit different to today's – will have spread. Humanity's future will depend in large measure on how it deals with its forests. There is still time and the ability to implement SFM. Today's and tomorrow's foresters have much work to do.

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References

Adams, J. 1997. *Global land environment since the last interglacial*. USA, Oak Ridge National Laboratory (available at www.esd.ornl.gov/ern/qen/nerc.html).

Attali, J. 2011. *A brief history of the future: a brave and controversial look at the twenty-first century*. (Translated by J. Leggatt). New York, USA, New Arcade Publishing.

Barnett, T.P., Adam, K.C. & Lettenmaier, D.P. 2005. Potential impacts of a warming climate on water availability in snow-dominated regions. *Nature*, 438: 303–309.

Bergengren, J.C., Waliser, D.E. & Yung, Y.L. 2011. Ecological sensitivity: a biospheric view of climate change. *Climatic Change*, 107: 433–457.

Blaser, J., Sarre, A., Poore, D. & Johnson, S. 2011. *Status of tropical forest management 2011*. ITTO Technical Series No. 38. Yokohama, Japan, International Tropical Timber Organization.

Bruinsma, J. ed. 2003. *World agriculture: towards 2015/2030: an FAO perspective*. Rome, FAO and London, Earthscan Publications.

Christophersen, T. 2010. Addressing degradation as an opportunity: perspectives from the Global Partnership on Forest Landscape Restoration. Presentation at the CIFOR–FAO side-event at Bonn Climate Change Conference. 1 June 2010.

Ellison D., Futter, M.N. & Bishop, K. 2011. On the forest cover–water yield debate: from demand- to supply-side thinking. *Global Change Biology*, 18(3): 806–820. DOI: 10.1111/j.1365-2486.2011.02589.x.

Evans, J. ed. 2009. *Planted forests: uses, impacts and sustainability*. Rome, FAO and London, CABI.

FAO. 2010. *Global forest resources assessment 2010: full report*. FAO Forestry Paper No. 163. Rome.

FAO & JRC. 2012. *Global forest land-use change 1990–2005*, by E.J.Lindquist, R. D'Annunzio, A. Gerrand, K. MacDicken, F. Achard, R. Beuchle, A. Brink, H.D. Eva, P. Mayaux, J. San-Miguel-Ayanz & H-J. Stibig. FAO Forestry Paper No. 169. Rome, FAO and European Commission Joint Research Centre.

Forest Europe, UNECE & FAO. 2011. *State of Europe's forests 2011: status and trends of sustainable forest management in Europe*. Oslo, Ministerial Conference on the Protection of Forests in Europe.

Gregersen, H. 1982. *Village forestry development in the Republic of Korea*. Document GCP/INT/347/SWE. Rome, FAO.

Gregersen, H. 1988. Village forestry development in the Republic of Korea: a case study. *In* L. Fortmann & J. Bruce, ed. *Proprietary dimensions of forestry*, pp. 225–233. Boulder, USA, Westview Press.

Gregersen, H., El Lakany, H., Bailey, L. & White, A. 2011. *The greener side of REDD+: lessons for REDD+ from countries where forest area is increasing*. Washington, DC, Rights and Resources Initiative.

IEA. 2010. *Renewable energy information 2010*. International Energy Agency (available at: www.iea.org/stats/index.asp). DOI: 10.1787/renew-2010-en.

Lee, D.K. 2012. The forest sector's contribution to a "low carbon, green growth" vision in the Republic of Korea. *Unasylva*, 63(239): 9–16.

McEvedy, C. & Jones, R. 1978. *Atlas of world population history*. Penguin (data reproduced at: www.worldhistorysite.com/population.html).

Menz, M., Dixon, K. & Hobbs, R. 2013. Hurdles and opportunities for landscape-scale restoration. *Science*, 339(6119): 526–527.

OECD. 2012. Medium and long-term scenarios for global growth. *OECD Economic Outlook*, 2012/1. Paris, Organisation for Economic Cooperation and Development.

Poore, D. 2003. *Changing landscapes: the development of the International Tropical Timber Organization and its influence on tropical forest management*. London, Earthscan Publications.

Putz, F.E. forthcoming. Futures of forestry and forests in the tropics. *Biotropica*.

Salim, E. & Ullsten, O. 1999. *Our forests, our future: report of the World Commission on Forests and Sustainable Development*. Cambridge, UK, Cambridge University Press.

The Conference Board. 2012. *The global economic outlook 2013* (www.conference-board.org/data/globaloutlook.cfm).

Toffler, A. 1980. *The third wave*. Bantam Books.

Tudge, C. 2007. *Feeding people is easy*. Pari.

UN. 2004. *World population to 2300*. New York, UN Department of Economic and Social Affairs, Population Division.

Wirsenius, S., Azar, C. & Berndes, G. 2010. How much land is needed for global food production under scenarios of dietary changes and livestock productivity increases in 2030? *Agricultural Systems*, 103(9): 621–638.

Worldwatch Institute. 2011. *State of the world 2011: innovations that nourish the planet*. Washington, DC.

World Bank. 2012a. T*urn down the heat: why a 4°C warmer world must be avoided*. A report for the World Bank by the Potsdam Institute for Climate Impact Research and Climate Analytics. Washington, DC.

World Bank. 2012b. *Deforestation trends in the Congo Basin: reconciling economic growth and forest protection* (also available at www.forestcarbonpartnership.org/fcp/sites/forestcarbonpartnership.org/files/Documents/PDF/Nov2012). Washington, DC.

WRI. 1997. *The last frontier forests: ecosystems and economies on the edge*. Washington, DC, World Resources Institute. ◆