New Forests
https://doi.org/10.1007/s11056-018-9644-6

Production, restoration, mitigation: a new generation of plantations

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Received: 5 December 2017 / Accepted: 20 April 2018

Abstract Forests provide a wide variety of ecosystem services and international conventions and national policies for climate change mitigation and biodiversity conservation recommend forest protection and restoration. However, global forest cover continues to decline, and recent evidence suggests deforestation rates are accelerating. Against this background the area of planted forests has increased globally. Recognizing the substantial potential of well-managed forest plantations, the new generation plantations (NGP) platform was launched in 2007. NGP encourages well-managed planted forests in the right places to conserve biodiversity and meet human needs. Here we describe the NGP approach and analyze data and information from NGP participants and others over 10 years. This shows that NGP participants are responsible for c.11.1 million ha of land, much of it previously degraded or abandoned; 43% is managed as timber plantations, with the remainder being wildlife reserves, restored natural forest, grassland and agriculture. NGP case studies illustrate a range of biodiversity, conservation and socio-economic achievements. These achievements, considered together with future projections of timber demand and of the land available for restoration to tree cover, demonstrate the potential of well-managed plantations to protect natural forests, provide timber, conserve biodiversity and mitigate climate change. The NGP concept works in a variety of countries and contexts; participants have shown that it is possible to produce timber while maintaining and enhancing ecosystems

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Published online: 26 April 2018

and contributing to socio-economic development. We present the case for forest production, restoration and mitigation/adaptation to limit climate and other environmental risks and to improve the resilience of landscapes.

Keywords Afforestation · Reforestation · Restoration · Conservation · Adaptation · Mitigation

Introduction

Stop forest degradation while producing more wood

In 2015 the total global area of planted forests, defined as forests established through planting and/or deliberate seeding of native or introduced species, was 277.9 million hectares (FAO 2000). They represent an increasing proportion of the global forest area, providing a significant and rising proportion of global roundwood production (Payn et al. 2015). Jurgensen et al. (2014) showed that planted forests supplied 33% of the global production of industrial round wood from all types of forests in 2012 (c. 770 billion m^3 per year out of a total global production of 1.683 billion m^3). Estimates provided by Carle and Holmgren (2008) indicate a potential of planted forests to produce up to two-thirds of the global industrial roundwood demand, rising to as much as 80% in 2030.

Increased production from planted forests is important, as demand for wood-based products will grow to unprecedented levels over the coming decades (WWF 2012). By 2050, the world's population is projected to reach 9.7 billion (UNDESA 2015). But rising numbers of people are only part of the story: at the same time, economic growth, urbanization and increasing prosperity are driving greater consumption (Kharas 2017). Meeting these growing demands will increase the already huge pressure on the world's natural resources—and wood is no exception. WWF's Living Forests Model projects that wood harvesting will more than double by 2030, and almost quadruple by 2050: from 3.4 million m^3 in 2010, to 7.6 million m^3 in 2030 and 13.1 million m^3 by mid-century (WWF 2012). However, there are limits to how much wood can be harvested from natural forests. So where is all that wood going to come from?

Following an encouraging decrease in the rates of deforestation during the last twentieth and early twenty-first century (FAO 2015), recent evidence suggests that deforestation rates are again increasing (Global Forest Watch 2017). Land degradation due to change in land use and land cover is estimated to cost about US $231 billion per year, and the annual cost of loss of tropical forests and rainforests is approximately US $43–65 billion (Climate Focus 2017).

There is some confusion around the terminology on forest restoration, reforestation and afforestation in the literature, with the terms sometimes used interchangeably (e.g. Griscom et al. 2017). However, according to FAO definitions (www.fao.org/docrep/006/ad665e/ad665e04.htm) reforestation refers to forest regeneration as part of normal forestry activity (e.g. after harvest) where the land use (forest) has not changed. In contrast, afforestation is forest established (restored) at sites where the land use has not been forest for a period. Stanturf et al. (2014) have extensively reviewed the forest restoration literature with emphasis on functional restoration i.e. restoration of forests to support societies with resources and services.

More wood to support sustainable development

In the Paris Agreement on climate change, almost every nation agreed a commitment to hold "the increase in the global average temperature well below 2 °C above preindustrial levels" (UNFCCC 2015). The Paris Agreement calls on parties to "take action to conserve and enhance … sinks and reservoirs of greenhouse gases … including forests" and encourages "incentives for activities relating to 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." A recent estimate suggests that natural climate solutions such as conservation, restoration and improved land management actions across global forests, wetlands, grasslands and agricultural lands can provide over a third of the cost-effective climate mitigation needed between now and 2030 to achieve the goals of the Paris Agreement (Griscom et al. 2017).

Additionally, calculations of the mitigation potential of forests and forestry often fail to include all the important elements of mitigation. Many studies, as for example Griscom et al. (2017) focus only on the mitigation effects of storing carbon in ecosystems. The considerable substitution effects of using wood or woody biomass instead of fossil fuels or instead of energy-intensive materials such as cement, steel, aluminum, cotton or plastics receive far less attention, even though this is a core issue (Oliver et al. 2014). Wood and woody biomass play a key role in the transition to a bioeconomy. The Nordic and Baltic countries are heading towards carbon neutral societies by 2050 (Nordiska Ministerrådet 2009; IEA 2013), with woody biomass supplying 50–97% of renewable energy (Rytter et al. 2016) in all countries except Norway and Iceland, which are rich in hydropower and geothermal energy, respectively. Currently there are no single or general conversion factors available to accurately describe the substitution effects of using wood-based materials or fuels in place of fossil-based counterparts. These effects depend on both the exact system and materials that are replaced, and what they are replaced with. As such the issue is similar to the intense discussions on carbon debt repayment or carbon sequestration parity (Ter-Mikaelian et al. 2015; Bentsen 2017): the issue and models are so complex that the presumptions and the selection of model used for analysis become the key factor controlling the results and thereby conclusions (Bentsen 2017). Such a complexity is not helpful for society and decision-makers wanting to make the best science-based choices; but leaving the substitution effect out of the scope is not a good solution either, and may lead to severe misunderstandings regarding the potentials for sustainable forestry and forest restoration to mitigate climate change.

An example of this is Naudts et al. (2016) who concluded that the restoration of Europe's forests did not contribute to the mitigation of climate change—a conclusion reached by ignoring the mitigation effects of substituting fossil fuels and energy-intensive materials with wood and woody biomass. However, the climate mitigation potential of highly productive planted forests that provide large quantities of wood and woody biomass is much larger than that assumed if only carbon storage in the standing biomass of the forest ecosystem is considered (Bentsen 2017; Gustavsson et al. 2017; Taeroe et al. 2017). This potential only reaches its peak once these resources are efficiently utilized.

Upcoming technologies such as biorefineries (www.Borregaard.com), bio carbon capture and storage (CCS) based on e.g. chemical-looping combustion (www.nordicenergy.org/flagship/negative-co2) and reverse photosynthesis (www.sciencealert.com/scientists-have-found-a-way-to-induce-reverse-photosynthesis) are promising technologies at various stages of maturity—and perhaps will become core technologies in a future

bio-economy. New wood processing and construction technologies (e.g. mass-timber) incorporate engineered wood products such as cross-laminated timber and laminated veneer lumber which combine smaller wood elements to form strong structural units. Such technologies, along with conventional wood use in construction, have the potential to use substantial amounts of sustainably produced wood including for uses which substitute for steel and concrete. Such uses of wood may make an important contribution to the negative emissions needed to meet global climate goals (Smith et al. 2015).

Sustainable intensification: synergies between production, protection and mitigation

The issues outlined above raise the important question of what potential there is for well-managed plantations to "take the pressure off" natural or old-growth forests in future (Aienmababazi and Angelsen. 2014; Secco and Pirand 2015). Secco and Pirand conclude that there is a reduction in degradation of natural forests with the expansion of tree plantings. They suggest that "a promising way forward may be the promotion of highly productive plantations in strategic places where agricultural rents are low, while taking action at the demand level to avoid a rebound effect whenever the price elasticity of demand for wood products is high." In addition to wood production, there is good evidence that planted forests can compensate for the loss of natural forests in terms of forest area, habitat for biodiversity and ecological function (Brockerhoff et al. 2013). Although even reduced impact forestry systems (selective logging etc.) may have some local negative effects on biodiversity, plantations can add diversity at a landscape scale and protect ecosystem services by lessening the impacts of pests and diseases (Boyd et al. 2013).

There is, then, considerable potential for increasing productivity in planted forests and in restored forest landscapes to meet the expected and sharply increasing need for wood and woody biomass (WWF 2012) as well as for climate mitigation. However, sustainable development requires production to be balanced with the need for multiple other forest ecosystem services; intensively managed plantations covering all of the restored areas will not achieve this. To promote a more sustainable model, in 2007 WWF launched the new generation plantations (NGP) platform, with the participation of a number of companies and government forest departments that manage plantations (see www.newgenerationplantations.org). The idea was to identify and promote better practices for plantation design and management, learning and sharing experiences from around the world. Although they approach the issue from different perspectives and contexts, participants share a belief that as tree plantations grow over the coming decades they can—and must—bring real benefits to people and nature.

Productive forest land and the wood and woody biomass produced are crucial resources to support the sustainable development of society. We give particular attention here to wood production due to its importance to the economic pillar of sustainability and to its potential for mitigating climate change. However, it is a prerequisite that production is balanced with other forest functions and ecosystem services, such as protecting water resources, amenity values and habitats for biodiversity. Productive forestry is commonly viewed as a threat to these other forest functions, and thereby seen as part of the problem. We argue that productive forestry, usually in planted forests, can be part of the solution.

NGP is based on the premise that well-managed planted forests in the right places can help conserve biodiversity and meet human needs, while contributing to sustainable economic growth and local livelihoods according to four overarching principles:

- Maintain ecosystem integrity.
- Protect and enhance high conservation values.
- Develop through effective stakeholder involvement processes.
- Contribute to economic growth and employment.

The platform recognizes the need to expand planted forests as a solution to meeting the world's growing demand for forest resources while combating the loss and degradation of natural forests and other areas of high conservation value. NGP acts as a forum to take the management of planted forests forwards. Over the last 2 years topics have included:

- The role of forests in combating climate change;
- Social values, building a sense of ownership, and co-operative models;
- Recreating native woodland;
- Sustainable intensification.

Analysis

Replacing deforestation with forest restoration

Ending deforestation and degradation in forests by 2030—as envisaged in the Sustainable Development Goals (SDG15.2) and the New York Declaration on Forests—will require expansion of a range of plantation types (WWF 2012). Thus it is important that the NGP approach and the analysis presented here are rooted in forest landscape restoration—FLR; that is restoring multifunctional landscapes to improve human wellbeing rather than ecological restoration with an objective of restoring to a valued reference system. WWF's Living Forests Report projects that around 250 million additional hectares of new planted forests—including plantations—need to be established between 2010 and 2050. Figure 1 shows this requirement mapped by continent. These planted forests would take many forms and produce a wide range of timber and woody biomass products depending on site conditions—from pure conifer to mixed broadleaves and conifers of native as well as non-native species including coppiced willow and poplar in cooler northern and temperate regions. Closer to the equator, mixed planted forests of native species for high-quality timber products, or "fast-wood" acacia and eucalyptus plantations are some of the relevant silvicultural systems—but all assume no loss of natural forests. Intensively managed commercial plantations in tropical regions can produce wood fibre particularly efficiently: For example in Scandinavia 720,000 ha of semi-natural coniferous forestry or managed forest plantations are required to produce a million tonnes of pulp in a year, while managed eucalyptus plantations in Brazil can produce the same amount on just 140,000 ha (IBA 2015). However in Scandinavia, North America and other boreal and temperate regions sustainable timber production is nevertheless critically important to the mix of economic and social objectives.

In many regions there is potential to regain lost forest cover and assist the recovery of forest landscapes through afforestation or restoration (Stanturf 2015; Stanturf and Madsen 2002), including by using mosaics of new plantations, restored natural forests and responsible farming. There is a general lack of appreciation that plantations can add benefit as part of restored landscape mosaics (see for example discussion and citations in Secco and Pirand 2015 and Stanturf et al. 2014) and NGP has an important role in sharing best

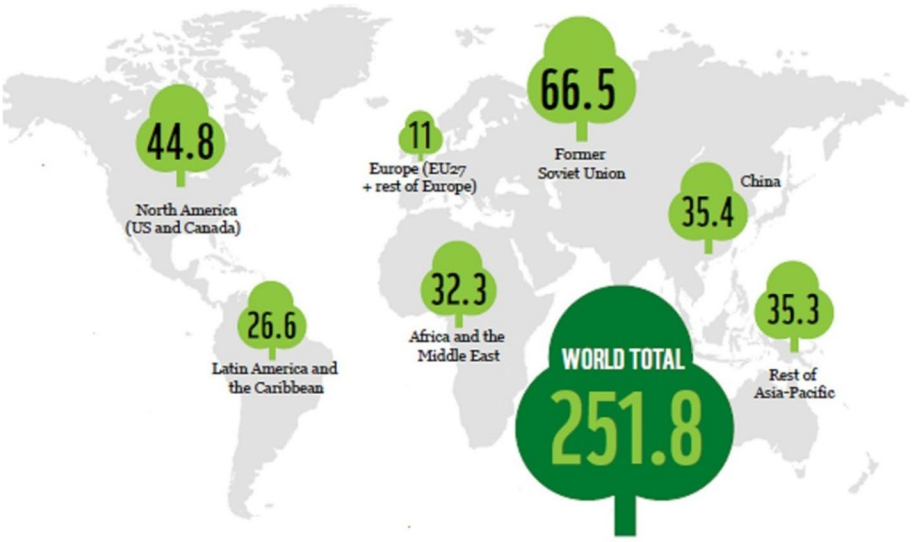

Fig. 1 Projected expansion of tree plantations (in million ha) under WWF's living forest model. *Source*: IIASA/WWF 2012. Living forests report

practice examples of this. The Bonn Challenge, launched in 2012, aims to begin the restoration of 150 million hectares of deforested and degraded lands by 2020, and 350 million hectares by 2030. Many countries have included large-scale forest restoration pledges as part of their national climate change plans, and various multi-country initiatives have been launched. Sustainable land-use mosaics and restoration of forest cover are critical components of strategies to enhance ecological integrity and conserve biodiversity in many regions. Figure 2 shows the areas of land globally where there is potential for restoration

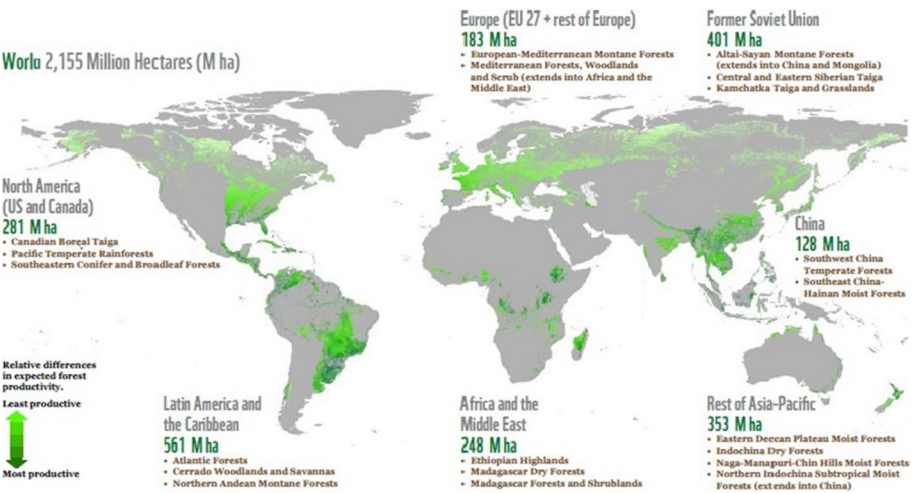

Fig. 2 Areas of land suitable for restoration of forest cover. *Source*: WWF. 2012. Living forests report

of forest cover. Since 2012 extensive forest fires and insect damage has changed the data in Fig. 2 for North America. Future analyses will describe the restoration of these areas and the extent to which resilience has been improved. The figure also indicates the potential forest productivity based on mean annual increment (MAI) of above-ground carbon.

New generation plantations: status after 10 years

The NGP platform aims to share and promote high standards of plantation management around the world. The participants manage over 11 million ha of land worldwide. Managed and facilitated by WWF International, NGP is a worldwide collaboration and knowledge exchange platform between forestry companies, governments and civil society. It has close links with organizations such as the Forest Stewardship Council (FSC) forest certification scheme and the International Union of Forest Research Organisations (IUFRO), particularly the Task Forces on Sustainable Planted Forests for a Greener Future and on Forest Adaptation under Global Change, both of which have a worldwide membership (see www.iufro.org/science/task-forces). Participants in NGP publicly disclose data on the areas of land for which they have responsibility, on the proportion of this area which is managed as sustainable plantations in line with NGP principles, on the FSC certified area, and additional information on previous land use, current objectives etc. (see www.newgenerationplantations.org/en/participants). These data are supplemented by participant reports, case studies and information provided when hosting NGP study tours and workshops (see participant documents at www.newgenerations.org/en/library). Together these data submissions and reports support the analysis that follows. In addition, data provided by the FAO Global Forest Resource Assessment (FAO 2015) and published analyses of the FAO data (e.g. Payn et al. 2015) has been used. These analyses show what NGP has achieved in the last 10 years. The progress that has been made in reporting and linking the work of NGP with the wider international agenda and consideration is given to the implications of the forestry and climate change challenges outlined above. Lastly we consider the potential for NGP to further develop the themes of production, restoration and mitigation.

Table 1 shows the areas of land managed by NGP participants by country in 2017. The area of forest plantation within the NGP managed areas, the percentage certified by FSC and the land-use histories are also shown. Because of NGP commitments to ecosystem integrity, conservation and stakeholder involvement (www.newgenerationplantations.org/en/participants), relatively small proportions of NGP land is in plantation forestry (c. 43% overall) with the remaining areas being wildlife reserves, restored natural forests, grassland or agricultural land. (In the case of some greenfield developments, notably in Mozambique, only a small area has been planted to date due to ongoing consultation with communities and other stakeholders). Often plantations are within a mosaic of these non-forestry land uses, and this type of landscape-scale diversity has been demonstrated to enhance the provision of ecosystem services and social benefits (see Tables 1, 2). In many countries FSC certification is considerable, whereas in others it has not been adopted for a range of reasons. Land-use history varies and can have a significant impact on how plantation forestry has changed the provision of ecosystem services.

Plantations can bring degraded land back into productive use (Table 1), alongside restoring natural ecosystems and the services they provide. The NGP overarching principles and FSC certification ensure sustainable forest management, including the avoidance of wall-to-wall planting for timber production. Productive areas are treated as part of a larger forest management unit, incorporating ecosystem functions, natural habitats and socio-cultural components. In Rwanda, Uganda, Tanzania and the UK 100% of the land area managed

Table 1 The area of land managed by new generation plantation participants shown by country. The areas managed as plantations for timber production and percentage of this certified by FSC are shown along with a short description of land-use history. The original data are from NGP disclosures and are used for the analysis presented in Table 2

Country	NGP participants' land area	NGP participants' plantations area	% of plantations FSC certified	Land-use history
Argentina	358,867	197,754	66	Primarily cattle ranching and farming, to lesser extent forestry
Brazil	2,953,595	1,491,686	80	Cattle ranching and farming
Chile	1,827,767	1,221,996	97	Cattle farming and agriculture
China	166,200	87,900	98	Mostly previous plantations, some barren land
Ghana	32,000	7000	0	Degraded forest land due to intensive logging
Laos	3900	2300	0	Degraded land due to shifting cultivation and war
Mozambique	356,000	9368	0	Degraded land due to intensive logging, shifting cultivation and charcoal production
Portugal	119,009	99,285	100	Eroded, abandoned, low productive lands
Rwanda	9992	9992	0	Planted forests (buffer zone area)
South Africa	263,486	173,015	100	Grasslands or agricultural areas
Tanzania	8221	8221	31	Unused land, some of it agricultural
Uganda	21,967	21,967	100	Planted forests and sugar plantation
UK	873,000	870,000	100	Mostly agricultural land
Uruguay	805,333	538,072	97	Cattle grazing
Others[a]	3,319,400[a]	0	n/a	Largely natural and semi-natural forest
Total	11,118,737	4,738,556	90	

[a]Some NGP participants also manage for production areas of natural/semi-natural forest which are not classified as plantations

Table 2 An analysis of the ecosystem services provided by the sustainable plantations managed by NGP participants. These evaluations are based on the data and information presented in Table 1 shows the ecosystem services provided by NGP managed and mainly FSC certified forests in relation to the previous land uses. The approach and categorization of ecosystem services follows that of Barala et al. (2016)

	Degraded and abandoned	Cattle ranching, grassland and low intensity grazing	Plantation forestry and intensive logging	Shifting cultivation (agri.)		Degraded and abandoned	Cattle ranching, grassland and low intensity grazing	Plantation forestry and intensive logging	Shifting cultivation (agri.)
Provisioning services					*Regulating services*				
Food production	↑	↓	↑	↓	Fresh air regulation	↑	↑	≈	↑
Timber production	↑	↑	↓	↑	Carbon sequestration and storage	↑	↑	≈	↑
Medicines	↑	↑	≈	↑	Natural hazard regulation	↑	≈	≈	↑
Freshwater	↑	≈	↑	↑	Water purification	↑	↑	↑	↑
					Disease regulation	≈	≈	↑	≈
					Pollution	↑	≈	↓	↓
					Erosion prevention and soil protection	↑	↑	↑	↑
Habitat and species services					Cultural services				
Habitat for species	↑	≈	↑	↑	Spiritual and religious value	↑	↑	↑	↑
Maintenance of genetic diversity	≈	≈	↑	↑	Aesthetic value	↑	↑	↑	↑

Table 2 (continued)

	Degraded and abandoned	Cattle ranching, grassland and low intensity grazing	Plantation forestry and intensive logging	Shifting cultivation (agri.)		Degraded and abandoned	Cattle ranching, grassland and low intensity grazing	Plantation forestry and intensive logging	Shifting cultivation (agri.)
					Recreation and ecotourism	↑	≈	↑	↑

by NGP participants is classified as plantations and these plantations are often mixtures of both native and introduced species in landscape mosaics.

NGP management aims at benefiting the people living alongside them by providing jobs and income as well as funding local infrastructure, often in remote areas where economic opportunities are few. Likewise, plantations that follow FSC principles and criteria help to clarify land rights, uphold the rights of indigenous peoples, and maintain or enhance the social and economic well-being of forest workers and local communities. When companies that manage NGP-plantations engage with local communities the aim is that they become channels for inclusive green development (e.g. Mondi Zimele in South Africa—http://www.mondizimele.co.za).

NGP examples

Evidence collected by NGP over the years shows how many models for sustainable land use offer opportunities for innovative financing combined with new opportunities for economic development, especially in rural areas where jobs, innovation, and investments are much needed. It has been shown that economic development can be combined with conservation, including restoration and climate adaptation, at the same time a number of NGP participants have demonstrated sustainable models for bringing degraded land back into productive use. Full details of the case studies being run by NGP participants are available at www.newgenerationplantations.org/en/casestudies. However some indication of their achievements in summarized here:

- In Portugal NGP participant Navigator manage eucalyptus plantations which now account for around a fifth of the country's total forest cover. These areas include plantation landscapes of high conservation value. Navigator has built biodiversity conservation into its forest management framework and their management aims to maintain and enhance conservation value.
- In the UK the Forestry Commission has successfully worked with partners to bring osprey (*Pandion haliaetus*) back to the Lake District.
- In Chile Forest Mininco maintains areas of natural habitat to protect endemic trees such as *Araucaria* sp. and endangered mammals such as the southern river otter (*Lontra provocax*) and birds including the red-headed magellanic woodpecker (*Campephilus magellanicus*).
- In Brazil for NGP participants (Fibria, Suzano, Veracel, Kimberly-Clark) manage more than 2 million hectares of land in the Atlantic forest biome. Around half of this is planted with eucalyptus, almost all of it on former grazing land that had become heavily degraded. On the other half, native forest is naturally regenerating or being actively restored—with a particular focus on establishing corridors between remaining fragments of forest, and conserving native vegetation in riparian zones and on steep slopes. Fibria has also set up community tree nurseries to help improve employment opportunities and incomes for local people where job-opportunities are limited. Fibria has particularly targeted women and disadvantaged groups, who have seen a significant increase in their household incomes. So far the community nurseries supply only around 10% of Fibria's seedlings, so there is significant scope for them to expand.
- In Uruguay UPM Forestal Oriental owns around 200,000 hectares of former agriculture land where it is enabling yatay palms to recover. UPM has worked with local experts to build a palm conservation strategy into its plantation design, which includes protecting or relocating young and mature trees and connecting isolated palm groves. The palm

trees add structural diversity and provide a source of food for numerous animal, bird and insect species. The palm fruits and seedlings also provide a potential source of income for local people.

- In South Africa SiyaQhubeka Forests (SQF), a partnership between Mondi and local community organizations, worked with the government, environmental NGOs and the park authority to develop a scientific method to determine which areas of iSimangaliso Wetland Park (a World Heritage site) were suitable for commercial plantations and which should be returned to their natural state. Subsequent work has extending the habitat for wildlife such as elephants and rhinos and providing a buffer around core habitat areas. The wetland delineation method has since been adopted across all Mondi's properties and by the rest of the forestry industry in South Africa.
- In Minqin China the desert continues to encroach on agricultural land at a rate of 3–4 m every year. Desert expansion, land infertility and lack of water have brought continuous decline in living standards for local communities. The Chinese government supports tree planting to combat desertification, but previous projects have met with limited success however in new by FuturaGene, a subsidiary of Suzano, is running a field trial to test which species grow best in desert conditions and to develop suitable management practices, enabling farmers to maximize the social, economic and environmental benefits of tree plantations. FuturaGene aims to identify suitable species/clones for different uses and develop a set of best management practices for each.

NGP: providing ecosystem services and attracting investors?

According to the Progress Report on the New York Declaration on Forests (2017), investments in the transition toward sustainable land use offer financial returns while meeting demand. Sustainable land use is not only essential for mitigating climate change, it also offers financial benefits in the form of increased yields and higher quality commodity supplies. Despite the current huge pressure on land resources, large areas of land are in a degraded state—global estimates vary from almost 1 billion hectares to more than 6 billion hectares (Gibbs and Salmon 2015).

Table 2 shows an analysis of the ecosystem services provided by the plantations managed by NGP participants. The approach and categorization follows that of Barala et al. (2016) with the current ecosystem services of managed forests indicated in relation to those of the previous landuse. These evaluations are based on the data and information presented in Table 1 and provided annually in NGP disclosures (http://newgenerationplantations.org/en/participants/), as part of participant openness and transparency policy. NGP participants lead by example in disclosing information about their plantation practices and are nearly 100% FSC certified and with 70% allocation of GRI (www.globalreporting.org). The analysis presented in Table 2 illustrates the importance of taking a more holistic approach to addressing big challenges like food, water and energy security, biodiversity conservation, poverty alleviation and climate change adaptation—and that this is best achieved at a landscape scale. The case studies summarized above show how NGP participants have sought to balance competing demands within a given area: optimizing productive land uses such as agriculture and forestry, while maintaining vital ecological functions and providing for the needs of people.

Successful landscape approaches recognize that ecosystems and human society are interdependent. They seek to build resilience on both sides, enabling both social and ecological systems to adapt to and recover from shocks like fires, floods and droughts.

Discussion

It is time for the implementation of holistic solutions

Improved forest management offers large and cost-effective mitigation opportunities, many of which could be implemented rapidly without changes in land use or tenure. In principle some restoration activities may not need to reduce yield, but in practice most foresters find that activities like reduced impact logging can increase short term operational costs while others, like extending harvesting cycles, result in reduced near-term yields. This shortfall can be met by implementing what Griscom et al. (2017) call the reforestation pathway, which includes new commercial plantations and has the largest low-cost mitigation potential. In addition, the improved plantations pathway seeks to increase wood yields by mainly extending rotation lengths from the optimum for economic profits to the optimum for wood yield (Griscom et al. 2017). However problems can arise if harvesting machinery and sawmills are set up for the average sizes from conventional rotation lengths and if conventional rotation times were a factor in projected returns on investment.

Planted forests may seem of low value in terms of the habitats they support for biodiversity compared with what old-growth or primeval forests hold. However, this is rarely a relevant comparison. Forest degradation and conversion has taken place over centuries and even millennia; the more relevant reference for biodiversity and ecosystem services is the currently degraded land where afforestation takes place, rather than the old-growth forests that were historically lost. It could be argued that for the production services the relevant comparisons are the production systems of the alternative construction materials such as concrete and steel.

What history has taught?

Equally relevant is to consider the timeframe for restoration of ecosystem services. Case studies of forest restoration in temperate zones particularly describe some very long-lasting processes (Stanturf 2016; IUFRO SPDC 2017; WRI 2017). In severely degraded landscapes in the temperature zone, restoration may initially be rather slow. The suitable tree species may be restricted to pioneer species, which can tolerate the harsh site conditions, which may include unfavorable soil, microclimate or moisture conditions. Biotic factors such as grazing or browsing ungulates may also pose a threat to the young trees. In some cases, site conditions may initially be so unsuitable for young native trees that non-native species may be the only ones that establish and grow: they may serve as the main species in at least the first generation, or as nurse species if the initial site conditions are somewhat better (Madsen et al. 2017). Later, as site conditions improve, a wider range of species may be planted either under the shelter of the nurse crop or of the first generation when that has reached maturity. This process may take place over several rotations and adaptation to future climate needs to be considered by the choice of species planted, sown and naturally regenerated during the following generations.

In Europe, practically all forest land has been cleared at some point and only very little remains of what is considered old growth (Spiecker 2002), and in Brazil, only 7–8% of the original Atlantic Rainforest has been left (Ribeiro 2009). Much of the forest land has been cleared and land use changed for a period, so much of what we now think of as forest is the result of afforestation or forest landscape restoration. Today, these forests are capable of producing many more ecosystem services than our predecessors probably

imagined, and more wood. The mean productivity of Brazilian eucalyptus plantations reached 39 m^3/ha year in 2014, having evolved from less then 15 m^3/ha year in 1970, as result of investments in research and development, primarily seeking to improve the genetics of the plantations and forest management techniques (IBA 2015). Throughout the twentieth century the general picture on a hectare-basis is increasing standing volume, harvest and increment (Spiecker 2002) and there is potential to further increase productivity. Rytter et al. (2016) provides a good example reviewing the potentials for the Nordic and Baltic forests to contribute to the political goals of developing carbon neutral societies by 2050. They concluded that there is large and unredeemed potential to increase forest productivity (50–100%) at the stand scale even further and within the next tree generation (50–100 years) than has been achieved historically.

The concept works in practice

Over the last 10 years, NGP has demonstrated a concept that works. Planted forests make up only around 7% of forest cover worldwide, but supply a third of the total global production of industrial roundwood (Jurgensen et al. 2014). The data on changes of ecosystem services (Table 2) indicate that over and above roundwood production, plantations which are managed in line with the NGP approach can be part of the solution to the global challenges of climate mitigation, conservation of biodiversity and natural capital, and poverty alleviation. In a variety of countries and contexts, participants have shown that it's possible to produce timber efficiently and profitably while maintaining ecosystems and contributing to socio-economic development. And that doing so can open up new opportunities to create shared value for communities, restore degraded and deforested land, and contribute to climate change mitigation and adaptation.

In an increasingly complex world of limited resources and volatility, fundamental changes are required in production models, business paradigms and governance, where a new generation plantations can provide the ecological infrastructure to build a green future. A future where well placed and managed plantations provide opportunities and value for people living alongside them, opportunities to restore degraded ecosystems and build resilience, opportunities to increase the supply of renewable raw material while sparing natural forests. Success will depend on how intelligently and sensitively we integrate a mosaic world of different cultures and values, where areas for agriculture, industry, forestry, infrastructure and cities coexist with nature.

Acknowledgements We thank the new generation plantations platform Participants: China Green Carbon Foundation, Forestry Commission of Great Britain, Governo Estadual do Acre (Brazil), African Plantations for Sustainable Development, Arauco, CMPC, Fibria, Kimberly-Clark, New Forests Company, Mondi, The Navigator Company, Stora Enso, Suzano, UPM, Veracel and Barney Jeffries for his work on the typescript of this paper.

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