CHANGES IN PLANTED FORESTS AND FUTURE GLOBAL IMPLICATIONS

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ABSTRACT

Global population is projected to reach 9.6 bn by 2050 and demand for forest products is expected to grow. With concerns about halting deforestation of natural forests mounting, demand will need to be met from planted forests. We explored trends in planted forests from 1990 to 2015 and implications for the future of forest products supply in the context of a changing population and climate.

Over the period, global forest area declined from 4.13 bn hectare to 3.99 bn hectare, with percent global forest cover dropping by 1.25%. Natural forest area declined, but planted forests increased from 167.59 to 277.97 million hectares or 4.06 to 6.95% of total forest area. Increase was most rapid in the temperate zone, and regionally in East Asia, followed by Europe, North America, and South and South Eastern Asia.

Total forest net annual increment increased over the period from 4.1 m^3/ha to 5.3 m^3/ha probably related predominantly to planted forests. Roundwood production from planted forests comprised 45% of global production in 2012 and increased from 2000 to 2012.

Population is projected to reach 9.6bn by 2050. Rate of planted forest area growth is faster than population suggesting adequate future product supply. However in Europe and South and South Eastern Asia forests were increasingly being planted to provide protection or other ecosystem services and this may decrease wood product supply. Climate change is also likely to affect future forest production especially from storms, and increased risks from fire, pests and diseases, or spread of weeds. The need for increased food supply is another significant challenge with pressure for conversion of existing forests to agriculture or inability of forest investors to compete for land.

A risk analysis based on population density and rate of increase and likely climate impacts suggested that of the FAO sub regions South and South Eastern Asia, North Africa, and Central America would face the strongest challenges to their planted forests in the future and that North America, South America and Oceania (and probably Europe) would have the least challenges. Planted forests will increasingly have to compete for land for food. Projections show that the demand for new agricultural land will continue. To continue to expand forest product supply from planted forests and minimise risks, new forest investments should focus on low population density regions, and overall productivity and productive efficiency of existing forests will need to increase..

Keywords: Planted Forests, Global trends, climate, population

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INTRODUCTION

In 2013 the 3rd International Congress on Planted Forests was held to discuss the current state of knowledge on planted forests globally and regionally. Amongst a number of findings (International Congress on Planted Forests (ICPF) 2013), (Payn, Carnus et al. 2014) the congress noted that planted forest area continued to increase and that the goods and services provided by these forests were becoming increasingly diverse. The interaction of planted forests with other land uses within landscapes and their contribution to poverty alleviation and food security was identified. Risks to planted forests from climate change, socio-economic pressures and responses to these risks were seen as important. A global analysis indicated the importance of planted forests for economic environmental and social values, and also the complementary nature of planted forests to natural forests. Regional perspectives indicated that expansion of planted forests varies regionally as do issues affecting them; Africa for instance has challenges round governance, and the opportunity to expand farm forests and woodlots, Asia by contrast is constrained in its ability to further expand its commercial planted forest area and will need to increase production on existing forests.

With the availability of a new comprehensive dataset from FAO's Forest Resources Assessment 2015 project we saw the opportunity to explore some of these issues in more detail both at the global and regional scale. The FRA2015 dataset covers all forests and the period 1990 to 2015. For this paper, one of a series commissioned by FAO, we concentrated on planted forests.

Definition of planted forests

Since 1980, FAO, through its Forest Resources Assessments (FRA), has been collecting data on forest areas for two main categories of forests: natural forests and forest plantations. In 2005, the FRA introduced two additional forest categories: modified natural forests and semi-natural forests (Evans, 2009), which resulted in five major forest categories based on the degree of human intervention and the silvicultural method of forest regeneration: (1) primary forest; (2) modified natural forest; (3) semi-natural forest, comprising natural and planted regeneration (SNPF); (4) plantations comprising productive and protective plantations; and (5) trees outside forests (see Figure 1). Productive and protective plantations, together with SNPFs, constitute the subgroup 'planted forests', as defined in Forest Resources Assessment 2010[2] (Food and Agriculture Organization of the United Nations (FAO) 2010) and are used in this paper. The planted component of SNPFs includes areas where deliberate efforts are made to increase the proportion of desirable species, thus leading to changes in the structure and composition of the forest, but still with the possible presence of naturally regenerated trees from species other than those planted or seeded. The logic behind the creation of the planted forests subgroup is that the planted component of SNPF, with its often intensive management, is not always significantly different from that of forest plantations. Often, the only distinction is that SNPF are composed of native species and continue the overall character and species composition of the previous forest on the specific site. Plantations, on the other hand, often use planting stock of improved genetic characteristics, are often managed through fertilization and apply similar methods of establishment (e.g. regular spacing), tending, thinning and pruning; in addition, they have wood product outputs that are uniform in size and technical specification (Evans 2009).

[2] Planted forests are forested areas of more than 0.5 ha with trees higher than 5 metres and a canopy cover of more than 10 percent. They are predominantly (more than 50 percent of growing stock) composed of trees of native or introduced species established through planting and/or deliberate seeding. They include coppice from trees that were originally planted or seeded, as well as rubberwood plantations.

Figure 1: Scope and concept of natural and planted forests

Natural forest			Planted forest			Non-forest
Primary	**Modified natural forests**	**Semi-natural forests**		**Plantations**		**Trees outside forest (TOF)**
		Assisted natural regeneration	**Planted component**	**Productive**	**Protective**	
						
Forest of native species, where there are no clearly visible indications of human activity and ecological processes are not significantly disturbed	Forest of naturally regenerated native species, where there are clearly visible indications of human activity	Intensive silvicul-tural management, e.g. weeding, fertilizing, thinning, selective logging	Forest of native species, established through planting, seeding, coppice	Forest of primarily introduced and native species, established through planting or seeding mainly for produc-tion of wood or non-wood products	Forest of native or introduced species, established through planting or seeding mainly for provision of environmental services	Smaller than 0.5 ha; tree cover in agricultural land (e.g. agroforestry), trees in urban environments, and scattered along roads and in landscapes

Source: After (Carle and Holmgren 2008), modified and illustrated.

There have been significant studies on planted forests previously, for example : data trends and projections (Carle and Holmgren 2008), plantations, biodiversity and climate change (Pawson, Brin et al. 2013); the impact of planted forests on the global forest economy (Buongiorno and Zhu 2014); timber investment (Cubbage, Mac Donagh et al. 2014); and multi-purpose plantations (Paquette and Messier 2009).

This paper explores the latest data on planted forests from the FRA2015 dataset in the context of current and future climate and population pressures and attempts to draw some conclusions on future trends and issues for the forests globally and regionally and draws on the wealth of past work.

METHOD

The FRA2015 dataset contains a number of variables (FAO 2012) directly related to planted forests that will allow us to explore various aspects of trends in Planted forests. Other variables were derived from the core variables. Overall the data form a small subset of the full FRA database, and in a number of instances it was not possible to view planted forest attributes of a specific variable as they formed a part of the whole forest. Key variables are listed in table 1 and included for example total forest area, planted forest area, species composition, wood supply and population trends. We analysed the data at a global, FAO sub region (Table 2), and climate domain (Table 3) scale. We also sourced data and information from other sources that would allow us to put the FRA data in context. This included climate information.

Table 1. Variables used in the analysis

Variable Code (FAO 2012)	Description	Units
1.1 Forest	Forest Area	m hectares
Region	FAO sub region	
Domain	Climate Domain	
TotPop	Total Population	million
1.5 TotArea	Total land area	m hectares
Popdensity	Population density	n/ha
ForePerc	Percent of landcover in forest	%
PerCapFor	Area of forest per capita	m hectares
1.7 Deforest	Area of deforestation	m hectares
3.3 NettAnnIncr	Forest Nett Annual Increment	m3/ha/yr
2.3 Plantfor	Area of Planted Forest	m hectares
Proportion planted	Proportion of total forest categorised as planted	%
2.3.1 Introsppplant	Area of planted forest with introduced species	m hectares
4.4 WooRemov	Total Volume of wood removals	m m3

Table 2. FAO Subregions

FAO Subregion code	Sub region
SSEAsia	South and South East Asia
Europe	Europe
Carib	Caribbean
Easia	East Asia
WCAsia	Western and Central Asia
ESAfr	East and Southern Africa
Oceania	Oceania
C Amer	Central America
WCAfr	West and Central Africa
Nafr	North Africa
SAmer	South America
NAmer	North America

Table 3. Climate Domains

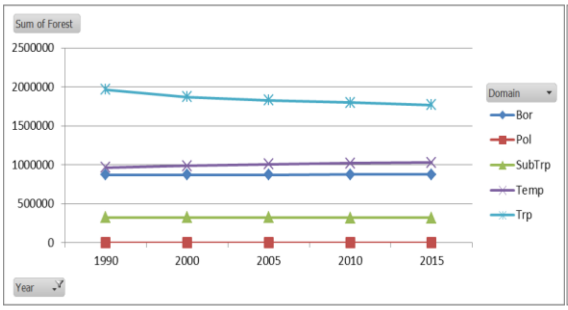
Climate Domain Codes	Climate Domain
Pol	Polar
Bor	Boreal
Temp	Temperate
SubTrp	Sub tropical
Trp	Tropical

RESULTS AND DISCUSSION

GLOBAL FOREST TRENDS (1990-2015)

Global forest area decreased between 1990 and 2015 (Figure 1) from 4.13 to 3.99 bn ha, but the pattern was not consistent across climate zones and regions. Forest area in the tropics decreased the most, while temperate forest areas increased slightly from 0.966 to 1.03 bn ha. Other zones (sub-tropical, boreal and polar) were stable. Regionally, EAsia showed the largest increase in area from 209.19m to 257.04 m ha followed by Europe with an increase from 99.42 to 101.54mha. Of the regions showing a decrease in area (SAm, ESAfr, WAfr, SSEAsia, CAm), the largest decrease was South America (93.08 to 84.20mha, followed by ESAfr (31.97 to 27.48mha). Overall forest area decreased by 129mha and global forest cover decreased from 35.53 to 34.28% from 1990 values (Figure 2). The rate of net global deforestation was not constant during that period however, it increased from 1990 to 2005 and then slowed dramatically between 2005 and 2010 through a very large decrease in South American forest loss (Figures 2 and 3), while other regions continued to increase (ESAfr, Oceania, Cam).

Fig 1: Change in Global Forest Area by FAO sub region and climate domain



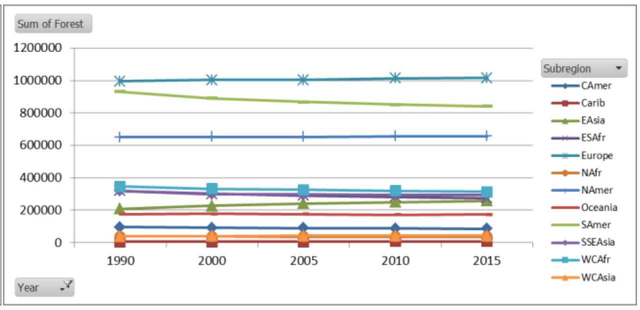


Fig 2: Percent of land area with forest cover

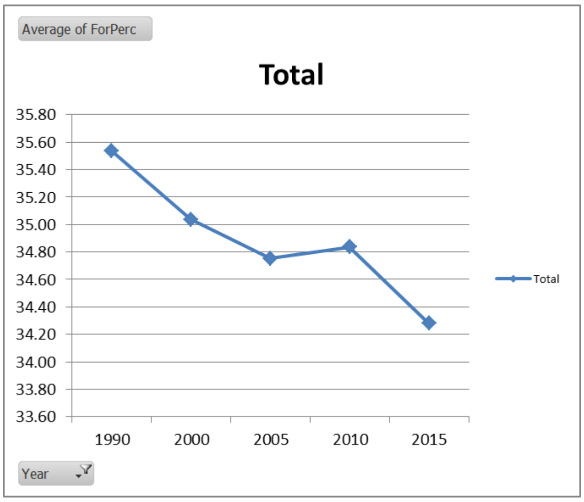
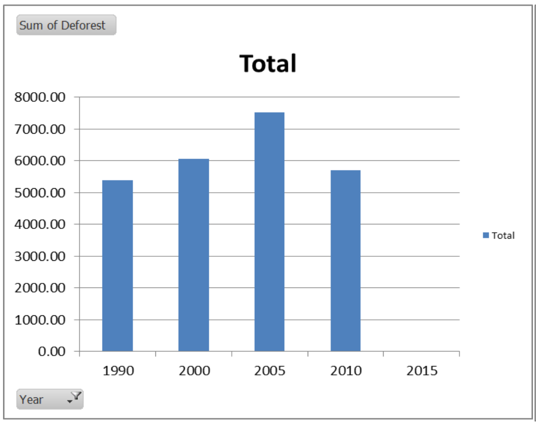
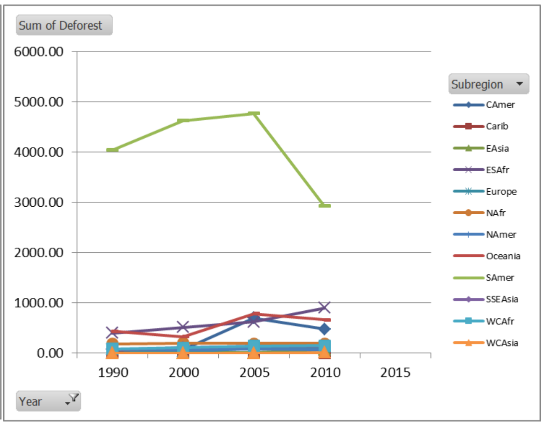


Fig 3: Total Annual Global deforestation rates *Fig 4: Annual Deforestation rate by region*





While forest area declined, forest productivity increased over the period from an average $4.10 m^3.ha^{-1}.yr^{-1}$ to $5.26 m^3.ha^{-1}.yr^{-1}$ (Figure 5) the changes varied by climate domain and region (Figure 6). Temperate zone productivity increased the most ($1.91 m^3.ha^{-1}.yr^{-1}$) with the boreal zone increasing slightly. Other domains were stable. Regionally WCAsia and the

Caribbean showed the largest increases followed by Europe with a small increase. Other regions were stable.

Fig 5: Change in average net annual increment

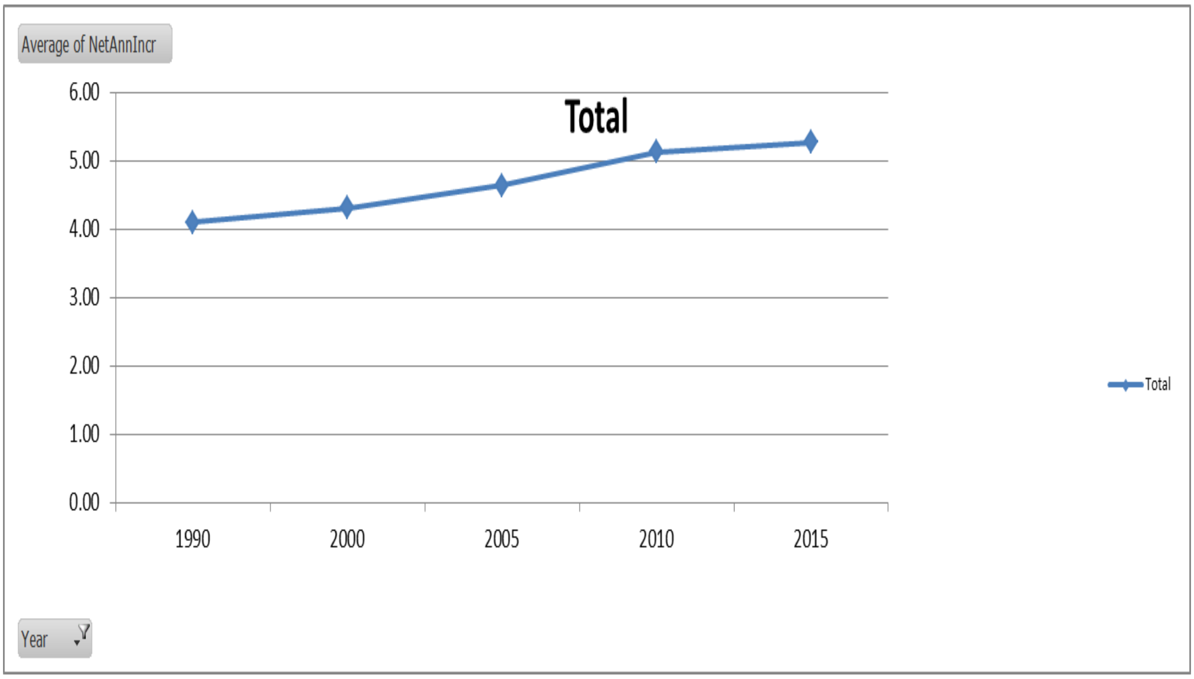
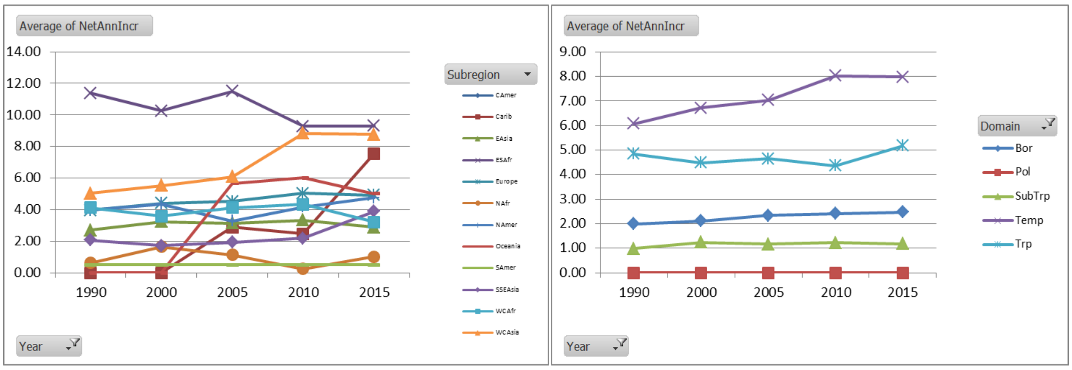


Fig 6: changes in net annual increment by FAO sub region and climate domain



PLANTED FOREST TRENDS

Planted forest trends differ from the global trends for all forests. Global planted forest area increased from 1990 to 2015 from 167.59 mha to 277.97mha (Figure 7) and the increase varied by region and climate domain (Figure 9). Of the 277.97mha of planted forests in 2015 55% are in the temperate zone, 20% tropical, 15% boreal, 10% subtropical and 0% polar (Figure 10). The largest increase in area between 1990 and 2015 was in the temperate zone (93.44 to 154.49mha) followed by tropical, boreal, and subtropical. Regionally, East Asia and Europe had the greatest areas in 1990, and generally the regional rankings of area has stayed constant. However the rate of growth of planted forest area has varied. Four regions EAsia>NAmer>Europe>SSEAsia have the greatest growth followed by South America. Other regions have much smaller increases.

Figure 10. Percentage of total Planted forest area in 2015 by climate domain

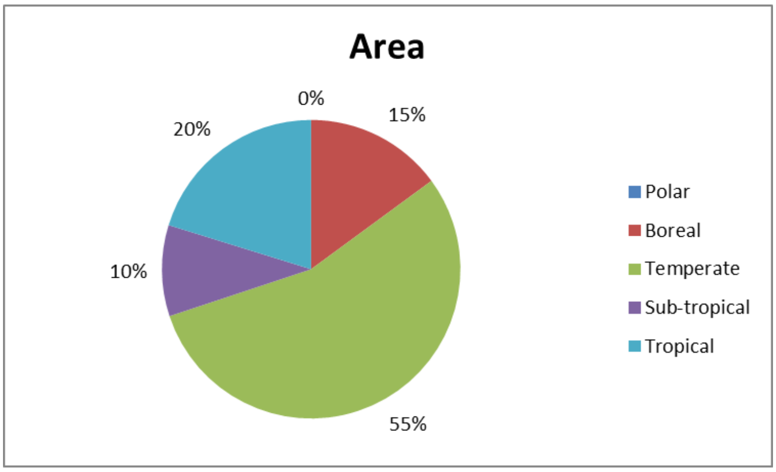


Fig 7: Change in planted forest area

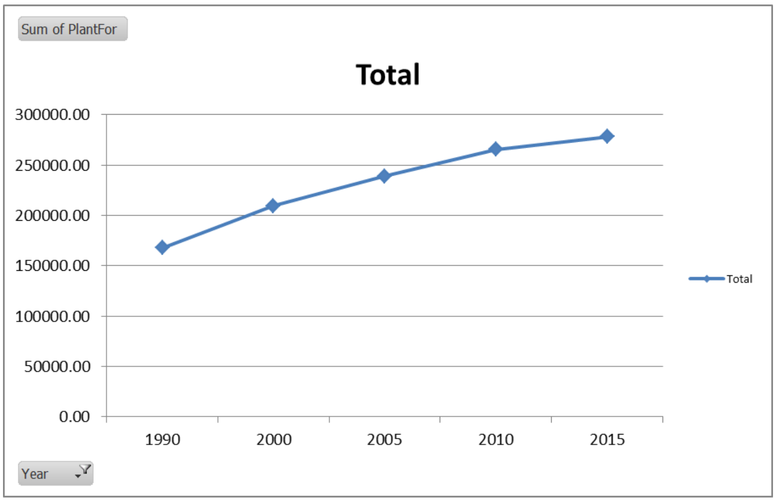
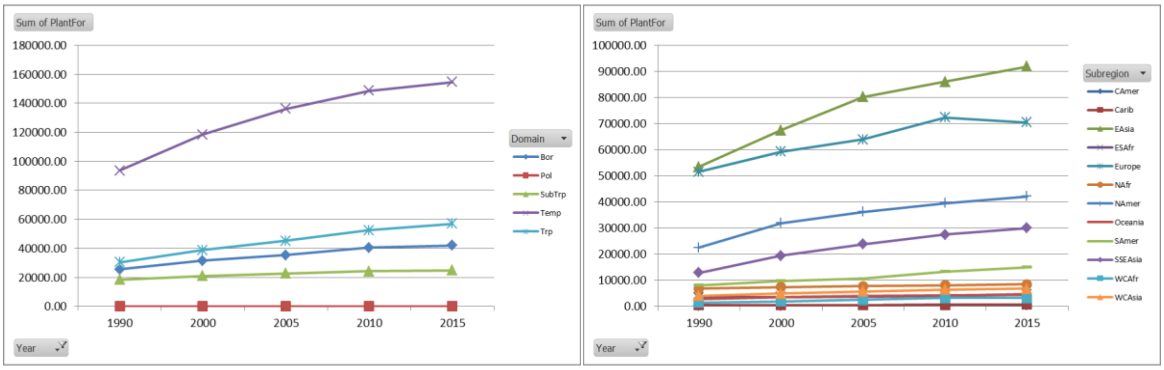


Fig8: Trends in planted forest area by FAO sub region and climate domain



Species composition

Planted forests often make use of fast growing exotic species such as Eucalypts and pines, and these are planted globally, especially in ‘productive’ forest categories. SNPF forests on the other hand may have a stronger focus on native species in keeping with semi natural ecosystem approach in these forest types and with stakeholder perceptions of naturalness. It is therefore interesting to analyse species composition trends. The total area of introduced species increased over the period from 30624 to 54484ha, with regional and climate domain variation (Figure 9). In terms of area, temperate forests had and maintained the highest area from 1990 to 2015, and also had the greatest increase in area. There was a rapid acceleration of planting of introduced species in South America and in SSEAsia from 2005 to 2010 followed by a smaller increase from 2010 to 2015. Interestingly, Europe's area plateaued between 2000 and 2010 and decreased slightly between 2010 and 2015. Over the period the total area of introduced species increased at a slower rate than the change in total area of planted forests (Figure 10). So the proportion of introduced species is actually decreasing globally with time.

Fig 9: Area of planted introduced species by FAO sub region and climate domain

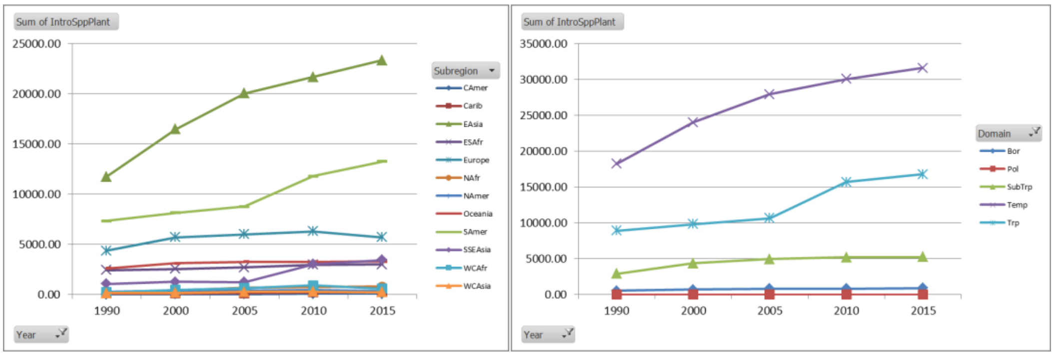
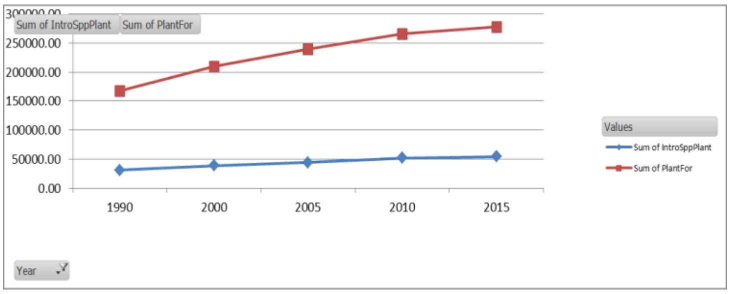


Fig 10: Total area of planted forest and area of planted introduced species

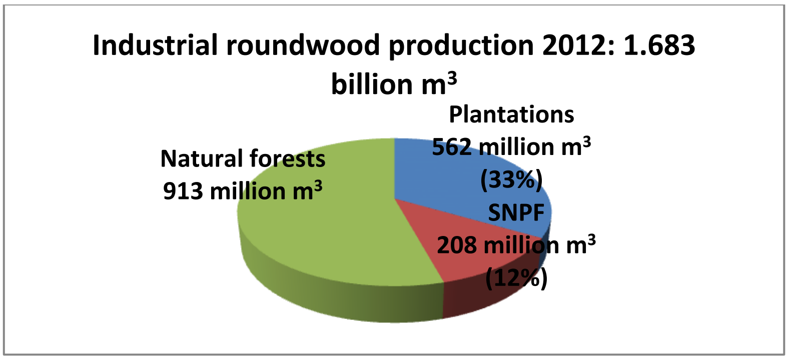


Forest Timber production [Roundwood supply]

To investigate timber production from planted forests we utilised data gathered in 2012 as part of an FAO study (Jürgensen, Kollert et al. 2014) which allowed us to investigate levels of production and trends. The FAO analysis focussed on industrial roundwood production from forest plantations in 78 countries and information on roundwood production from SNPF from only 17 countries as many countries could not provide separate information on roundwood production in their planted forests.

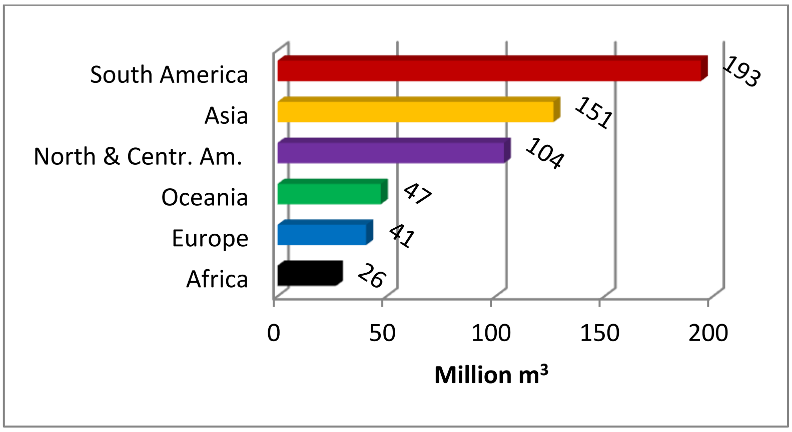
Globally industrial roundwood production from planted forests comprising plantations and SNPF is estimated at 770 million m^3 for 2012, which is equivalent to 45 percent, or almost half, of the total industrial roundwood production from all types of forests, including natural forests and trees outside forests (1.683 billion m^3, according to FAOSTAT). Plantations supplied 562 million m^3 (33 percent), while SNPFs are estimated to have produced 208 million m^3 (12 percent) in 2012. The industrial roundwood production in natural forests was calculated by subtracting the production in planted forests from the total production according to FAOSTAT. It amounts to 913 million m^3, equivalent to 54 percent of the global production for that year (see Figure 11). These estimates include all major industrial roundwood-producing countries in the world. However, for some countries, incomplete datasets had to be complemented by assumptions and model calculations, in particular when estimating the industrial roundwood production in SNPFs. Consequently, these data should only be used with the appropriate caution.

Figure 11: Assessment of the origin of the global industrial roundwood production in the year 2012



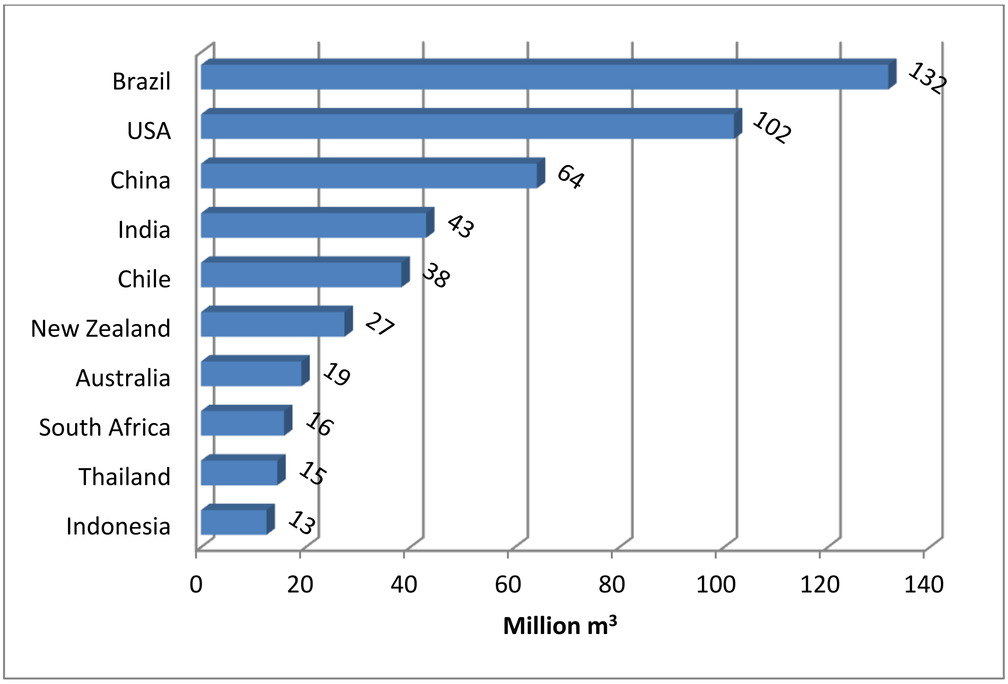
An analysis of the country data by region indicates that the production of industrial roundwood in plantations in 2012 was close to 200 million m^3 in South America (193 million m^3), followed by Asia (151 million m^3) and North and Central America (104 million m^3). Oceania, Europe and Africa produced considerably less industrial roundwood in plantations, ranging from 26 million to 47 million m^3 (see Figure 12).

Figure 12: Production of industrial roundwood in plantations by regions in 2012



The top 10 producers of industrial roundwood from plantations are displayed in a bar-chart in Figure 13. In 2012, these 10 countries together produced 83 percent of the global industrial roundwood production from plantations, totalling about 469 million m^3.

Figure 13: The world's top 10 producers of industrial roundwood from plantations in 2012



The FRA2015 dataset showed an increase in roundwood production from 1990 to 2015. However as noted previously there was much missing data so we referred again to FAO's 2012 study. Time-series data on the industrial roundwood production from plantations could only be estimated for 17 countries for which reported data were available for a period of several years. This data indicated that for many countries in Latin America and Asia (Chile, Brazil, China, Indonesia, Malaysia, Myanmar, Thailand, Uruguay and Vietnam), the industrial roundwood production from plantations had increased considerably since 2000. In Argentina, Australia, New Zealand and the United States of America, the industrial roundwood production in plantations had been increasing as well, although at a considerably slower pace. In European countries (Portugal, Spain, and Turkey) and in South Africa, the trend in industrial roundwood production had basically been stagnant since 2000, with some noticeable ups and downs during this period.

GLOBAL TRENDS AND PLANTED FORESTS

In summary the FRA data shows us that natural forests are continuing to decrease in area, while planted forest area is increasing, and overall forest productivity and round wood supply is also increasing. This suggests that in terms of timber and wood product supply the trends are in the right direction given expected increasing demand from a growing population. However it is worthwhile exploring the future in a little more detail in terms of global trends such as climate and population and how these may affect planted forests and their projected use. These trends are likely to vary across the globe and this will have a bearing on any current or future development of planted forests.

Uses of planted forests

Planted forests are established and managed for a wide range of objectives not solely for intensive wood production. Historically trees and woodlands have been planted for landscape, protection (against snow avalanche, landslip and soil erosion), hunting and other socio economic objectives. The FRA 1990-2015 data, particularly the trends for planted forests reflect this diversity of objectives, showing increases in planted forest area which are greater for those regions and climate zones where the wider benefits of planted forests are recognised. In the East Asian region the protection which planted forests provide against soil erosion and flooding have been important drivers of woodland creation. In China alone, the Natural Forest Protection Program (NFPP) and the Conversion of Cropland to Forest Program (CCPF), triggered mainly by the flooding disaster of 1998, have generated afforestation area of more than 32.5 million hectare with dominant species such as Chinese fir (*Cunninghamia lanceolata* (Lambert). Hooker), poplars (*Populus* spp.), eucalyptus (*Eucalyptus robusta* Smith), larch (*Larix gmelinii* Rupr.) and Masson's pine (*Pinus massoniana* Lamb.) (SFA, 2013, 2014). Some degree of State intervention and national programmes are often required to achieve afforestation and woodland management for which objectives such as protection from flooding, conservation of wildlife and carbon storage are enjoyed by the wider population who may even be remote from the immediate area being planted.

In Europe and North America the increasing areas of planted forests which is shown by the FAO data are likely to have even broader explanations. The Millennium Ecosystem Assessment and subsequent research and policy initiatives have been informed by the ecosystem services concept. This categorises the benefits/services of ecosystems as: **Supporting Services** such as primary production, soil formation, nutrient and water cycling which provide the basic infrastructure of life; **provisioning services** which are the goods such as food, fuel and fibre, **regulating services** such as climate and hazard regulation (prevention of erosion, carbon storage, water regulation, avalanche protection, etc) and **cultural services** such as recreational use, benefits to health and spiritual well-being. The important policy development has been the recognition that as population increases there is a need to manage rural and urban landscapes so as to benefit from the full range of services which woodland and trees can provide. Relative to other land-uses, and particularly when compared to food production, the benefits from planted forests especially their protection functions are often uncosted and may be enjoyed by stakeholders other than those who own the land (Boyd, Freer-Smith et al. 2013). It has become recognised that land-use policies focussed solely on say agriculture or wood production, give lower overall benefits relative to policies which consider the full range of ecosystem services (Bateman, Harwood et al. 2013). To achieve the trend in planted forest areas shown in Figure # has required intervention as for example with voluntary carbon offset accreditation schemes or on a wider scale through the FCCC REDD+ scheme.

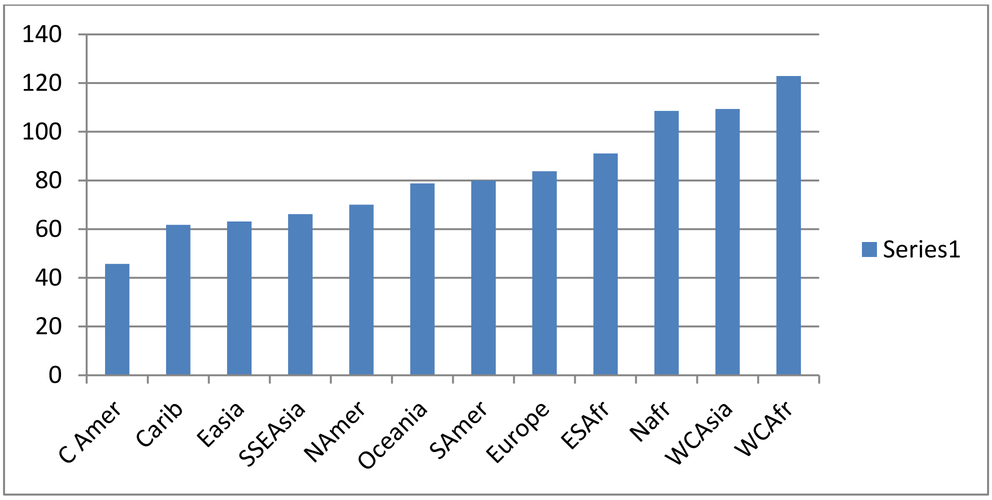
The distinction between different types of planted forests is important. Definitions can be found in FAO Forestry Paper 140 (FAO 2001). Planted forests can be established by planting of small trees or seed, are of introduced or indigenous species and there is a range from short rotation industrial plantations through to ‘close-to-nature’ forests. Well managed planted forests usually have higher yields of wood than natural, unmanaged forests, with commercial plantations in the tropics having annual growth rates of 10 to 30 m^3 ha^{-1} compared to 1 to 5 m^3 ha^{-1} for natural forests (Evans and Turnbull 2004). The use of woody biomass for renewable energy generation has placed new emphasis on high productivity and may in part explain the increased use of introduced species in temperate forests as shown in Figure 9. In Europe it has also been recognised that introduced species have a role to play in widening the resilience of forests against both climate change (i.e. in adaptation measures) and against pests and pathogens. It is interesting that Figure 10 shows the area of introduced species in planted forests increasing at a slower rate than the total area of planted forests. This indicates that although the use on non-native species, particularly fast growing pines, eucalyptus and poplar for ‘energy forestry’ may be continuing, the use of planted forests for wider objectives such as soil protection or other ecosystem services is an ongoing trend.

The FAO data suggest that in planted forests a new timber resource is continuing to be created and that it will contribute significantly not only to future wood and energy supplies but can also meet a range of wider social and environmental benefits (ecosystem services). Planted forests are likely to continue to supply an increasing proportion of the world’s wood requirements; the trend is sustained in this new dataset. The ability of planted forests to increase supply will depend on global and country policies, the sustainable forest management and trade requirements, the development of supply chains and markets (Freer-Smith and Carnus 2008). The potential of planted forests to perform protection functions at the landscape scale, to act as sinks to mitigate carbon dioxide concentrations in the atmosphere and to provide renewable low carbon energy have become major drivers, and policies to develop those benefits without loss of other ecosystem services are being developed.

Climate Impacts

The FRA database does not address climate risk itself, rather impacts that may be attributed to or affected by climate, such as fire, wind, and pests and diseases. We looked for examples of global data sources that would give an indication of risk levels globally. The Germanwatch climate risk index (CRI) is one such dataset addressing the direct impact of extreme weather events (Kreft, Eckstein et al. 2014). Adding the data on mean scores for countries from 1993-2013 to the FRA dataset allowed us to rank sub regions and climate domains by risk index. The index (smaller value indicates higher risk) is best viewed by individual country but does give a ranking of risk by FAO subregion (Figure 14). Central America, the Caribbean, EAsia and SSEAsia are the regions with highest risk, Africa generally has the lowest risk. In terms of planted forest regions this suggests that EASia and SSEAsia with large and increasing areas of planted forests are most at risk. This analysis gives a retrospective view and future risk distributions may change.

Figure 14. Climate Risk Index by FAO sub-region derived from (Kreft, Eckstein et al. 2014).



IPCC AR5 projections (IPCC 2014) for climate change suggest increased risks and impacts globally, both from direct climatic events such as storms, but also indirect from increased risks from fire, pests and diseases, or spread of invasive species. As most terrestrial ecosystems, planted forests are vulnerable to climate change projected even under low to medium-range warming scenarios (RCP[3]2.6 to RCP6.0) as defined in IPCC AR5; in the second half of XXIst century, climate change is projected to be a powerful stressor specially under high-warming scenarios such as RCP6.0 and RCP8.5 (Settele, Scholes et al. 2014). Increases in the frequency or intensity of disturbances such as droughts, wind storms, fires and pest outbreaks have been detected in many parts of the world where planted forests are located and in some cases are attributed to climate change (medium confidence in IPCC AR5). Also, the establishment, spread and survival of populations of invasive species have increased (IPCCAR5), mainly due to increased dispersal opportunities or to increased disturbances rather than climate change.

The consequences for the provision of timber and other wood products are projected to be highly variable between regions and products, but might induce an increased demand on wood supply from planted forests. Decreased production from planted forests is expected in already dry forest regions where increasing water deficit is projected such as the south-western part of Europe, USA or Africa. Extreme drought conditions will also decrease yields in areas not water limited. Under all future climate projections, a range of climate change–related factors (extreme events and disturbances, changes in precipitation, increased temperatures and CO_2) will continue to exacerbate the establishment and spread of pests, vectors and pathogens, and negatively impact production systems such as planted forests (Robinet and Roques 2010). Globally, biomass and soil carbon stocks in forest ecosystems are currently increasing but are vulnerable to loss to the atmosphere as a result of rising temperatures, droughts, and fires projected in the 21st century. Measurements of increased tree growth over the last several decades, a large sink for carbon, are consistent with this (Settele, Scholes et al. 2014), but confounding factors such as N deposition, increasing area of productive planted forests, and forest management practices make attribution of these trends to climate change difficult.

Population:

Over the period 1990 to 2015 global population increased from just over 5bn to just over 7bn and is projected to reach 9.6bn by 2050 (United Nations Department of Economic and Social

[3] RCPs (Representative Concentration Pathways) are identified with the radiative forcing by 2100; four main RCPs scenarios have been used in AR5 (8.5, 6.0, 4.5, and 2.6 W m^{-2})

Affairs Population Division 2013). Trends from the GFRA2015 database are summarised in Figure 15. Highest current populations are in SSEAsia and EAsia, Rate of population increase also varies regionally with SSEAsia, WCAfr and EAsia showing the biggest increases. Relative population increase across climate domains showed Tropical > subtropical > temperate with stable populations in boreal and polar domains.

Fig 15: Population changes by FAO sub region and climate domain

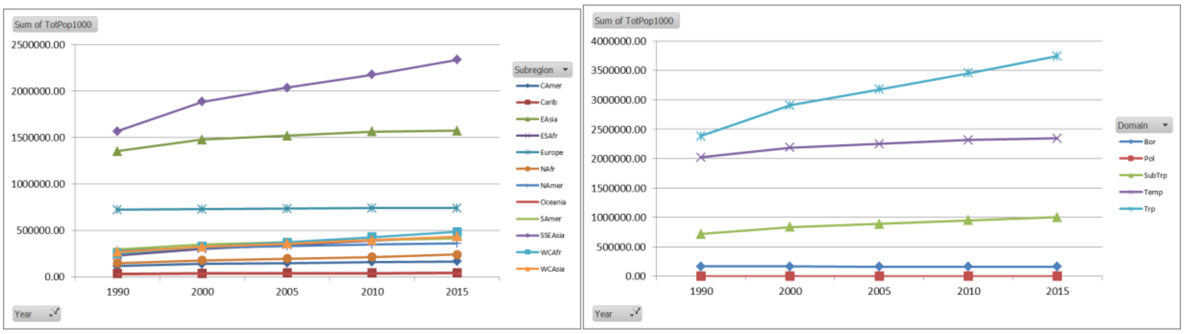
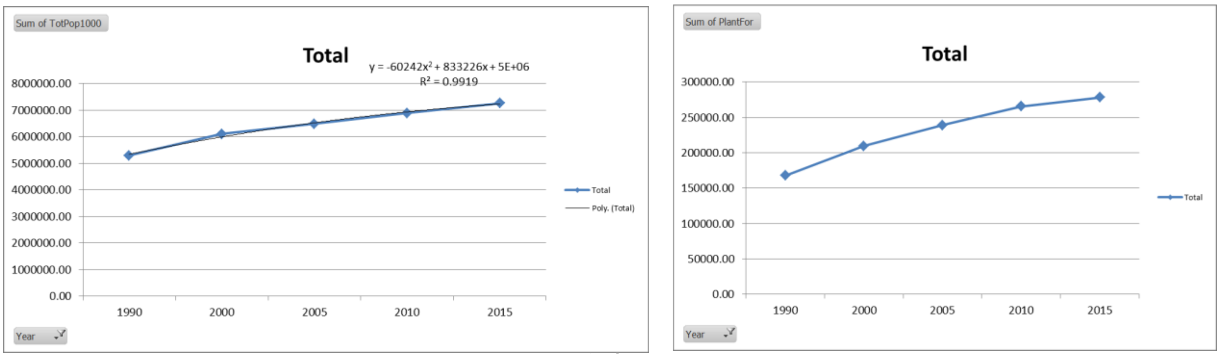


Fig 16: Comparative rates of change in Global population and planted forest area



The FRA dataset calculates area of forest per capita which can be seen as a proxy for both timber supply per person or a proxy for population pressure on the forests. This decreases overall, with some areas showing larger decreases where population growth has been particularly rapid suggesting increasing population pressure on the forests for supply of products. We compared the rate of global population growth with the rate of growth in area of planted forestThe curve for planted forest area growth shows a steeper trajectory to that for population growth, suggesting that globally the establishment of new forest area will enable increased supply of forest products per capita potentially exceeding increases in demand for resources. However some regions where population growth was particularly rapid (SSEAsia, WCAsia, NAfr) showed a showed a steeper trajectory of the population curve than the planted forest area suggesting demand may be greater than supply in the future.

The role of planted forests

The FRA dataset indicates continued deforestation and anticipates increasing reliance on high-yield plantations for timber, pulpwood, and biomass for energy. If deforestation is to be slowed, and land competition for food production minimised, a new generation of plantations would need to be established following better management practices, strong policies, and legal controls, basing sound management around carbon storage and maintenance of water, biodiversity and soils. To realize the productivity benefits of plantations with positive rather than negative social and environmental impacts, further expansion of tree plantations should be focused on degraded land, while maintaining or restoring natural ecosystems in the surrounding landscape, safeguarding the rights and livelihoods of indigenous peoples and local communities, and promoting greater benefit-sharing.

Challenges and opportunities for future planted forests

There are a variety of challenges facing the development of new planted forests.

Easier to continue to exploit natural forests

Efforts to protect forests or increase forest production might have the unintended side effect of shifting the impacts of development into other biomes containing important biodiversity. Efforts to halt deforestation could lead to other ecosystem losses unless we can find ways to increase agricultural productivity sustainably, with effective environmental safeguards. Such trade-offs may also take place within forests: efforts for emissions reductions start in the highest-carbon forests could push development into relatively low-carbon forests; or to supply more wood, from natural forests, which can either be logged more heavily or logged lightly over a larger area, or tree plantations. This makes it difficult to draw blanket conclusions about the respective merits of expanding forest production in natural forests or planted forests as a means of increasing the global supply of wood. The options will be defined by restrictions under local laws or voluntary sustainability standards, and by what is economically viable (WWF 2012).

Community involvement

The FRA dataset shows us an increase in Planted forest areas in Temperate zone and SSEAsia, NAmer, East Asia, and Europe (Figure 8), which are the worlds industrialised regions with intensively altered landscapes. This requires optimising production and conservation of forests through paradigm changes, assuming robust land-use planning, where maximising yields in production areas through precision silviculture and rezoned degraded production forests no longer commercially viable for restoration and regeneration would be the new normal. A decision to restore or establish new tree cover in a specific place, for whatever purpose, must involve local stakeholders and respect the aspirations of local communities. Recognising the right of indigenous peoples to give or withhold their free, prior and informed consent to allocation of land and water between crops, pastures, forests or tree plantations that will affect their rights to their lands, territories and food production, must ultimately depend on participatory multi-stakeholder decision-making processes. Design of these new forests is also aided through taking a landscape approach which provides a tool for planning and managing different land uses and balancing social, environmental and economic objectives. It involves thinking, planning and actions that go beyond individual sites and interests into the broader context, where people share (both risk and value) and shape the socio-economic, governance and ecological components of their setting.

Pressure on land for food supply

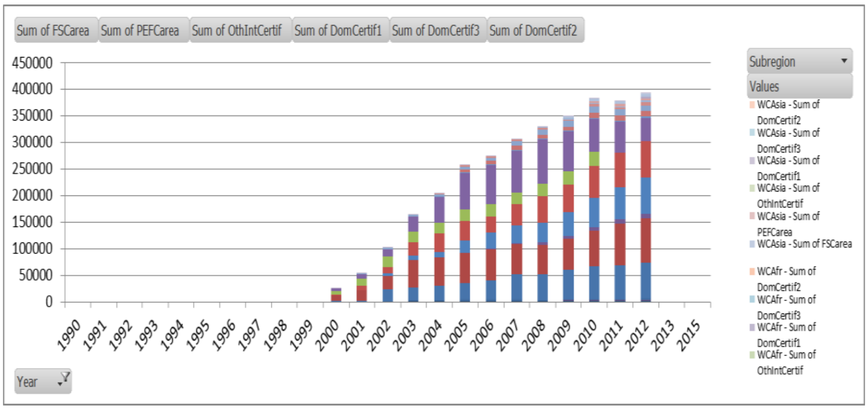
Global population is increasing and putting pressure on the land to supply a wide range of services including food, fibre and natural services. Areas of the globe with the highest population density coupled with faster growth rates will face even higher pressure to use land for food production and other uses. This will lead to competition for forest land both natural and planted and requires forestry and farming practices that produce more with less land and water. This will not be easy, addressing competing pressures over Land Use in a 9bn people environment is quite a challenge with the UN projecting that an increase in food production of 60% will be required by 2050 (UN 2013). However a more recent study (Ray et al 2013) suggests it will not be possible to meet this target by boosting crop yields on exsiting land therefore maintaining expansion pressure on forested land. The role of planted forests in producing more wood and services, without destroying or degrading natural forests or adversely affecting food production is therefore a very important topic to address. The WWF Living Forests Report (WWF 2011) suggests that between now and 2030, around 55 per cent of deforestation can be classified as unnecessary, i.e., deforestation resulting from failing to optimize land use in ways that are technically possible.

While demand grows land and water resources are becoming ever more scarce and degraded. Over the coming decades, farmers need to increase production significantly, mostly on land already in production. The large gaps between actual and potential yields for major crops and plantations show that there is significant scope for increased production through productivity growth on family farms. This can be achieved by developing new technologies and practices or through overcoming barriers and constraints to the adaptation and adoption of existing technologies and practices. So the question is where should planted forests be and what characteristics do they need to meet the future needs of a growing population and to avoid clashes with other land uses?

Acceptability of planted forests

In the past there was serious concern about conversion of natural forest systems to plantations and thus a strong negative perception of planted forests. However with the development of independent third party audit certification schemes such as FSC and PEFC in the 2000's which disallow conversion of natural forests to plantations this perception is changing. Total certified forest area has grown rapidly since 2000 (Figure 17) though still only making up ~4% of global forest area. Of this certified area possibly around 38% is planted forest though it is not possible to obtain comprehensive data on this[4]. Acceptability does appear to be increasing with a more positive view from bodies such as FSC (Maunder 2014). This will make it easier to develop new forests in the future. A major challenge to forest certification remains reaching the more than 500 million family farms and small forest owners globally with cost of certification and compliance being a major barrier.

Fig 17: Area of forest certified by FSC PEFC and other schemes



Opportunities to Increase production through Sustainable Intensification

Planted forests make an important contribution to sustainability because they provide an opportunity to restore degraded landscapes while increasing productivity. Forest cover and related environmental services could expand through mosaics of new plantations, natural forest restoration and responsible farming (New Generation Plantations (NGP) 2014) or integrated crop-livestock-forestry systems (Davi Jose Bungenstab, Roberto G. Almeida et al. 2010). Foresters, farmers and academics are increasingly required to develop innovative technologies to produce more from less land and water, and although desirable, it is important to acknowledge often it is not possible to optimise all ecological, social and economic values, because of incompatibility of interests. Given the expected pressure for food production it will be necessary to not just look at expanding the area of planted forests

[4] FSC indicates that in 2014 9.14% of the forest area certified was plantation and 29.15% semi natural and mixed plantation forest and natural forest

to meet expected demand but also to increase per hectare productivity; and it will be necessary to do this in a sustainable manner that is acceptable to society. There are a number of new approaches and technologies that can help.

The New Generation Plantations concept

New Generation Plantations (New Generation Plantations (NGP) 2014) defends the premise that well-managed plantations in the right places can help conserve biodiversity and meet human needs, while contributing to sustainable economic growth and local livelihoods, by:

- Maintaining ecosystem integrity and protecting high conservation values, making sure plantations don't disrupt natural cycles – for water, nutrients, carbon and biodiversity - and increasingly look beyond the own operations toward maintaining and restoring ecosystems on a larger landscape scale;
- Recognising social forestry as an increasingly important issue for plantations. Engaging with stakeholders means far more than simply carrying out consultations and obtaining the consent of communities affected by plantations. It's about really getting to know, talking and listening to them, and empowering them to meet their needs and achieve their aspirations;
- Accepting Plantations should be profitable businesses. They create jobs, often in poor rural areas. But can do far more than this. Plantations should be a mean to support inclusive green growth and share benefits with local communities.
- Continuing to develop sustainable management practises. Environmental issues of plantation forestry are largely known, and there are well-developed tools to address them. Precision forestry includes, accurate monitoring for fertilisers, herbicides or irrigation waste less, measures to prevent the spread of invasive alien plant species, avoid planting in freshwater ecosystems such as wetlands and riparian zones, and protect and enhance areas of high conservation value. With the tools available for assessing, avoiding, mitigating and offsetting environmental impacts of plantations, plantation forestry is a force of good for ecosystems restoration.

Biotechnology

Over the course of hundreds of millions of years, all life on Earth has evolved through random genetic modifications. Humans have accelerated this natural process by selectively breeding plants and animals that exhibit particular characteristics and taking advantage of unexpected variations. In recent decades, breeders have further accelerated the process by creating random genetic modifications. Most forest plantations now use trees that have been selectively bred within companies' nurseries and research units, allowing intensification of production and increase productivity, such as the case of Eucalyptus in Brazil, where productivity has more than doubled in 40 years. Brazilian grains and fibre production grew 312%, while the harvested area only grew 47% in the same period. Farmers efficiency increased yields in 179%, allowing the country to have 61% of its biomes preserved, appropriating 28% of its territory for agriculture (Embrapa, 2014).

Genetic Modification technology can complement and enhance conventional breeding programmes, for example, GM eucalyptus trials in Brazil produces around 20 per cent more wood per hectare than conventional trees. Recent work (Price and Howitt 2014) has demonstrated the possibility of incorporation of rubisco from a cyanobacteria into plants, making progress towards potentially increasing plant photosynthetic rates by 15-25% (Holmes 2011). Increased yields could be one response to the need to produce more with less. But the development of GM crops in agriculture over the last two decades has met fierce opposition in many areas, and Forestry is an equally contentious arena, with many environmental and social NGOs calling for a complete ban on GM trees. It remains to be seen to what extent different governments will proceed with commercial approval of GM trees, how companies will pursue them and how the public will accept them.

Dialogue approaches

Dialogue, is a basis for process-based technological advance, exploring and reconciling stakeholder perspectives and priorities, through multi-stakeholders processes. Initiatives such as The Forests Dialogue (The Forests Dialogue 2015), convenes exchanges between forestry companies and civil society organisations, provide an ongoing, multi-stakeholder dialogue focused on developing mutual trust, a shared understanding, and collaborative solutions to sustainable forest management. The goal of TFD is to reduce conflict among stakeholders over the use and protection of vital forest resources, addressing Initiatives such as, “Intensively Managed Planted Forests (IMPF)”, “Food, Fuel, Fiber and Forests (4F’s)”, “Forest Certification”, “Genetic Modified Trees (GMT)” and “Free, Prior, and informed Consent (FPIC)” among others.

Information technologies

Mobile technologies are breaking new ground, such as unifying satellite technology, open data, and crowdsourcing to guarantee access to timely and reliable information about forests is creating dynamic online forest monitoring and alert systems that empowers people everywhere to better manage forests. Global Forest Watch (Global Forest Watch 2014) is an example of a free and open data approach disclosing decision-relevant information into the public.

The farm: forest interface

Crop-livestock-forestry integration has many of the elements necessary for innovation on marginal areas for agriculture and environmentally fragile regions. The introduction of a forest component into the integrated crop-livestock systems improves carbon stocks, can diversify revenues and reduce risks. Such systems are important options for marginalised low income farmers regions (Davi Jose Bungenstab, Roberto G. Almeida et al. 2010). Agroforestry systems, while falling outside the definition of planted forests and the scope of this paper, will play a significant role in future forest and non-timber forest product supply.

DISCUSSION

Climate and population pressure will have a significant impact on the future outlook for planted forests. Key information has been summarised in Table 4 that allows us to get an overview of the pressure points. For each of the categories we ranked each of the 12 sub regions low medium or high based on the data. We then colour coded each category which allowed us to assign an overall relative ranking of low medium or high. Additionally based on the table we developed an overall outlook for each sub region based on relative expected future challenges to planted forests. For climate related impacts most regions were likely to suffer from all or most IPCC key risks. We ranked storm and flood damage, drought, and pest and diseases as the three top risks. From this exercise the three regions with the highest level of challenge are South and South Eastern Asia, North Africa, and Central America, and the three with the lowest level of challenges, North America, Oceania and South America (and probably Europe). All other regions were characterised as having moderate challenges. This perspective is qualitative and relative but will provide a foundation for future development of responses to these pressures. This will be the focus of further studies.

Table 4. Summary of forest, population trends, and climate impacts and risks by FAO sub-region

Subregion	Natural Forest Area 2015 ('000ha)	Planted Forest Area 2015 ('000ha)	Population 2015	Population density 2015 (n/'000ha)	% change since 1990 Natural Forest	% change since 1990 Planted Forest	% change since 1990 Population	IPCC key risks	IPCC climate related drivers	Climate Risk Index (Germanwatch)	Planted Forest Challenge	Outlook
SSEAsia	262878	29924	2335744	6.852	-14	132	49	Drought, decreased crop productivity, storm and flood damage, drought	Warming trend, drying trend, extreme temperatures, extreme precipitation, cyclones	66.18		Large challenges, high population density, large natural forest loss, but large PF expansion
Europe	945076	70406	740899	6.289	0	37	2	Storm and flood damage, decreased crop production, wildfires,	Warming trend, drying trend, extreme temperatures, extreme precipitation	83.76		Moderate challenges, high density but stable population, moderate PF expansion, but mainly for protection/FES
Carib	6460	735	43072	3.003	40	79	25	Storm and flood damage, decreased crop production	Warming trend, drying trend, extreme temperatures, extreme	61.78		Moderate challenges, high population density, only small area of PF, storm risk
Easia	165223	91823	1573017	2.352	6	72	16	Drought, decreased crop productivity, storm and flood damage, drought	Warming trend, drying trend, extreme temperatures, extreme precipitation, cyclones	63.12		Moderate challenges, high population density, moderate on growth of both NF and PF
WCAsia	36713	6797	433657	1.992	4	70	63	Drought, decreased crop productivity, storm and flood damage, drought	Warming trend, drying trend, extreme temperatures, extreme precipitation, cyclones	109.34		Moderate opportunity, moderate population density, high growth, but high growth of PF
ESAfr	270272	4613	429090	1.422	-15	35	35	Drought, decreased crop productivity, flood damage, increased pest and disease impacts	Warming trend, drying trend, extreme temperatures, extreme precipitation	91.1		Moderate challenge, moderate pop density and growth, high loss of NF, moderate growth of PF
Oceania	161143	4380	39310	1.264	-3	58	46	Storm and flood damage	Warming trend, cyclones, extreme precipitation	78.77		Moderate challenges. Moderate population density and growth, moderate increase of PF
C Amer	85853	436	166517	0.999	-11	17	45	Storm and flood damage, decreased crop production	Warming trend, drying trend, extreme temperatures, extreme	45.73		Large Challenges. Moderate loss of NF, low PF growth, moderate pop growth, storm challenges
WCAfr	309738	3260	485376	0.933	-10	122	94	Drought, decreased crop productivity, flood damage, increased pest and disease impacts	Warming trend, drying trend, extreme temperatures, extreme precipitation	122.94		Moderate challenges. Low pop density and moderate NF loss, but large expansion of PF. High drought risk
Nafr	27792	8425	240940	0.331	-15	24	63	Drought, decreased crop productivity, flood damage, increased pest and disease impacts	Warming trend, drying trend, extreme temperatures, extreme precipitation	108.57		Large challenges. Low population density but large loss of NF and high rate of population growth and only moderate PF growth but with climate challenges from drought
SAmer	826988	15021	412638	0.201	-10	87	39	Storm and flood damage, decreased crop production	Warming trend, drying trend, extreme temperatures, extreme precipitation	80.01		Low challenges, low population density, moderate loss of NF but large expansion of PF, moderate population growth and moderate climate risks
NAmer	615018	42148	359417	0.156	-2	87	27	Wildfires, storm and flood damage	Warming trend, drying trend, extreme temperatures, extreme precipitation, cyclones	70.08		Low challenges. Low population density, good expansion of PF, low pop growth but climate challenges

In conclusion, while only making up ~7% 0f all forests, planted forests play a significant role in reducing pressure on natural forests, and contributing to the global economy. A recent paper (Buongiorno and Zhu 2014) noted that planted forests reduced harvesting from natural forests globally by 26% and had significant ecological benefits .Planted forest area is increasing at a faster rate than population suggesting that fibre supply should be able to meet on-going human needs. However there is a caveat to that in that area may not be a good reflection of fibre supply as forests may be developed for other uses such as landscape restoration or biodiversity conservation. The challenges facing planted forests will come from population growth and also climate impacts, but also other issues such as Governance (Cubbage, Mac Donagh et al. 2014) which can affect forest investment and management. To further explore our projected regional outlook more work to understand forest productivity is warranted to better understand future supply of forest products, both timber and non-timber across regions, the expected uses of the planted forests, and other risks such as the specific impacts of pests and diseases on planted forests. Too respond to increasing demands It is likely that future focus will be on both increasing the productivity within existing planted forests and on identifying areas where new forests can be developed that do not clash with other land uses.

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Bibliography

Bateman, I. J., A. R. Harwood, G. M. Mace, R. T. Watson, D. J. Abson, B. Andrews, A. Binner, A. Crowe, B. H. Day, S. Dugdale, C. Fezzi, J. Foden, D. Hadley, R. Haines-Young, M. Hulme, A. Kontoleon, A. A. Lovett, P. Munday, U. Pascual, J. Paterson, G. Perino, A. Sen, G. Siriwardena, D. Van Soest and M. Termansen (2013). "Bringing ecosystem services into economic decision-making: Land use in the United Kingdom." Science **341**(6141): 45-50.

Boyd, I. L., P. H. Freer-Smith, C. A. Gilligan and H. C. J. Godfray (2013). "The consequence of tree pests and diseases for ecosystem services." Science **342**(6160).

Buongiorno, J. and S. Zhu (2014). " Assessing the impact of planted forests on the global forest economy. ." New Zealand Journal of Forestry Science **44(Suppl 1)S2.**

Carle, J. and P. Holmgren (2008) "Wood from planted forests: A global outlook 2005-2030." Forest Products Journal **58**, 6-18.

Cubbage, F., P. Mac Donagh, G. Balmelli, V. Morales Olmos, A. Bussoni, R. Rubilar, R. De La Torre, R. Lord, J. Huang, V. Afonso Hoeflich, M. Murara, B. Kanieski, P. Hall, R. Yao, P. Adams, H. Kotze, E. Monges, C. Hernandez Perez, J. Wikle, R. Abt, R. Gonzalez and O. Carrero (2014). "Global timber investments and trends, 2005-2011." New Zealand Journal of Forestry Science **44**(Suppl 1): S7.

Davi Jose Bungenstab, Roberto G. Almeida and H. J. Schwartz: (2010). Integrated Crop-Livestock-Forestry Systems: A Brazilian Experience for Sustainable Farming. http://www.tropentag.de/2014/abstracts/posters/705.pdf.

Evans, J. (2009). "Planted forests: Uses, impacts and sustainability." Planted Forests: Uses, Impacts and Sustainability, from http://www.fao.org/forestry/24489-0e54aef5c0bee7238cf5ebd97931a4bb7.pdf.

Evans, J. and J. W. Turnbull (2004). Plantation Forestry in the Tropics: The role, silviculture and use of planted forests for industrial, social, environmental and agroforestry purposes, OUP Oxford.

FAO (2012). FRA 2015 Terms and Definitions. Forest Resources Assessment Working Paper 180**:** 31.

Food and Agriculture Organization of the United Nations (FAO). (2010). "Global forest resources assessment 2010." from http://www.fao.org/docrep/013/i1757e/i1757e.pdf.

Freer-Smith, P. and J. M. Carnus (2008). "The sustainable management and protection of forests: Analysis of the current position globally." Ambio **37**(4): 254-262.

Global Forest Watch. (2014). "Global forest watch: Index." 2015, from http://www.globalforestwatch.org/.

Holmes, B. (2011). Billion-year upgrade. New Scientist**:** 43-45.

International Congress on Planted Forests (ICPF). (2013). "Planted forests are a vital resource for future green economies. Summary report of the 3rd International Congress on Planted Forests." from http://www.fao.org/forestry/37902-083cc16479b4b28d8d4873338b79bef41.pdf.

IPCC (2014). Summary for Policy Makers. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and sectoral aspects. Contribution of Working Group II to the Fifth Assessent Report of the Intergovernmental Panel on Climate Change.**:** 32.

Jürgensen, C., W. Kollert and A. Lebedys. (2014). "Assessment of industrial roundwood production from planted forests." from http://www.fao.org/3/a-i3384e.pdf.

Kreft, S., D. Eckstein, L. Junghans, C. Kerestan and U. Hagen (2014). Global Climate Risk Index 2015.

Maunder, C. (2014).

New Generation Plantations (NGP). (2014). "New generation plantations: Review 2014." from http://newgenerationplantations.org/multimedia/file/12b486cb-ea24-11e3-9f9e-005056986313.

Paquette, A. and C. Messier (2009). "The role of plantations in managing the world's forests in the Anthropocene." Frontiers in Ecology and the Environment **8**(1): 27-34.

Pawson, S. M., A. Brin, E. G. Brockerhoff, D. Lamb, T. W. Payn, A. Paquette and J. A. Parrotta (2013). "Plantation forests, climate change and biodiversity." Biodiversity and Conservation **22**(5): 1203-1227.

Payn, T., J. Carnus, P. Freer-Smith, C. Orazio and G.-J. Nabuurs (2014). "Third International Congress on Planted Forests: Planted Forests on the Globe - Renewable Resources for the Future." New Zealand Journal of Forestry Science **44**(Suppl 1): S1.

Price, G. D. and S. M. Howitt (2014). "Plant science: Towards turbocharged photosynthesis." Nature **513**(7519): 497-498.

Robinet, C. and A. Roques (2010). "Direct impacts of recent climate warming on insect populations. ." Integrat Zool **5**: 132-142.

Settele, J., R. Scholes, R. Betts, S. E. Bunn, P. Leadley, D. Nepstad, J. T. Overpeck and M. A. Taboada (2014). Terrestrial and inland water systems. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change. C. B. Field, V. R. Barros, D. J. Dokken et al. Cambridge, United Kingdom and New York, NY, USA, Cambridge University Press**:** 271-359.

The Forests Dialogue. (2015). "The forests dialogue: Overview." 2015, from http://theforestsdialogue.org/about.

United Nations Department of Economic and Social Affairs Population Division (2013). World Population Prospects: The 2012 Revision, Key Findings and Advance Tables. **Working Paper No. ESA/P/WP.227.**

WWF (2011). WWF Living Forests Report: Chapter 1 Forests For A Living Planet.

WWF (2012). Living Planet Report 2012: Biodiversity, biocapacity and better choices**:** 164.