Contents

PAPERS

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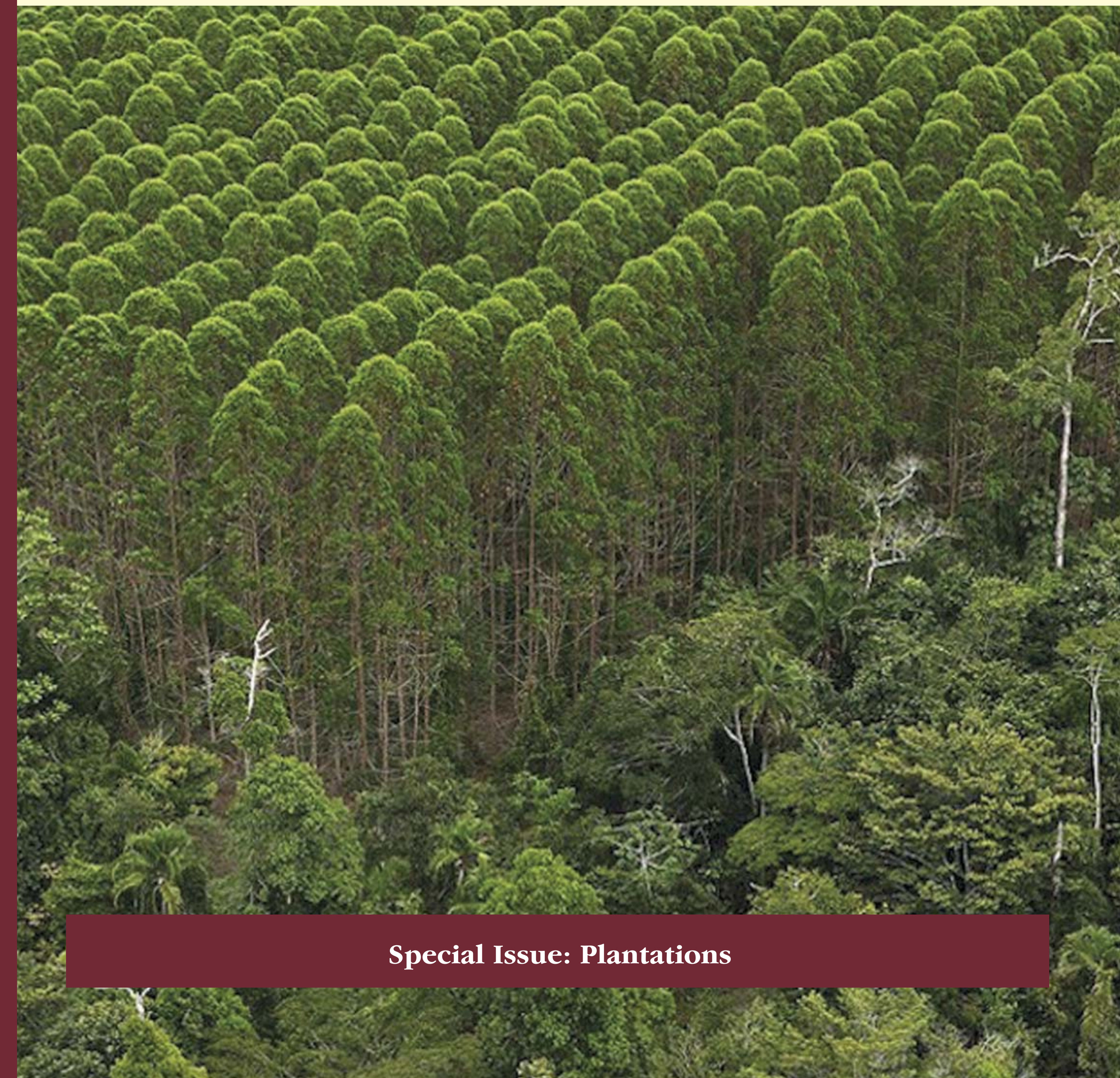

Special Issue: Plantations

EDITOR A.J. POTTINGER

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Cover photo: Eucalyptus plantation and restored rain forest on land owned by Stora Enso in Bahia, Brazil (Photo: Lasse Arvidson lasse.arvidson@tele2.se)

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Mutually beneficial company-community partnership in ensuring its long-term viability: emerging lessons from Indonesia

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  Paper or chapter in proceedings
  SMITH, W.J. 2001. Selection of tree species for arid environments. In: BLACKBURN, J.W. (ed.) *Multipurpose trees and shrubs for fuelwood and agroforestry*. CNRD Monograph No4. 366 pp.

  Book
  PHILIP, M.S. 1994. *Measuring trees and forests.* 2nd edition, CAB International, Wallingford, England. 310 pp.

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  HOLMGREN, J., JOYCE, S., NILSSON, M. and OLSSON. H. 2000. Estimating stem volume and basal area in forest compartments by combining satellite image data with field data. *Scandinavian Journal of Forest Research* 15: 103–111. Is correct.
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PAPERS

Plantation vision: potentials, challenges and policy options for global industrial forest plantation development

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SUMMARY

Expansion of global industrial forest plantations, i.e. intensively managed productive plantations is evident due to the prevailing demand and supply drivers. Forest plantations alone will not be sufficient for meeting the growing industrial roundwood demand. Natural and semi-natural forests in boreal and temperate zones will maintain their important role as the raw material source. The supply from these forests, however, is not likely to increase from the current level due to the constraints related to logistics, profitability and ownership structure. Moreover, sustainable management of tropical natural forests will not result in any increase of roundwood supply. Therefore, developing the global industrial forest plantations sustainably will be crucial to meeting increasing wood demand in the long term. Sustainable development of plantations is likely to face a number of economic, environmental and social challenges, and requires strong measures from the key stakeholders such as governments, strategic and financial investors.

Keywords: industrial forest plantations, sustainable expansion, challenges, supportive measures

Vision des plantations: potentiels, défis, et options de politiques pour le développement de la plantation industrielle globale des forêts

S.K. BARUA, P. LEHTONEN et T. PAHKASALO

La croissance des plantations industrielles globales de forêts, c.a.d. des plantations de production gerées intensivement, est évidente du fait des pressions de l'offre et de la demande. Les plantations forestières seules ne vont pas être suffisantes pour faire face à la demande industrielle croissante de bois rond. Les forêts naturelles et semi-naturelles dans les zones tempérées et boréales vont maintenir leur rôle important de source principale du matériel brut. Cependant, la production de ces forêts ne va probablement pas augmenter du fait des contraintes liées à la logistique, au profit et às la structure des propriétés. De plus, la gestion durable des forêts naturelles tropicales ne va pas résulter en un accroissement de la production de bois rond. Par conséquent, le développement durable des plantations industrielles forestières va être crucial pour pourvoir à long terme à la demande croissante de bois. Le développement durable des plantations va très probablement faire face à un nombre de défis économiques, environnementaux et sociaux, et nécessite que des mesures fermes soient prise par les principales parties prenantes tels que les gouvernements et les investisseurs financiers stratégiques.

Una visión sobre plantaciones: potencial, retos y opciones de políticas públicas para el desarrollo global de plantaciones forestales con las que abastecer la industria

S.K. BARUA, P. LEHTONEN y T. PAHKASALO

La expansión global de las plantaciones forestales para abastecer la industria, es decir, de las plantaciones productivas bajo un manejo intensivo, es evidente si atendemos a los aspectos preponderantes que impulsan la oferta y la demanda. Las plantaciones forestales no serán suficientes, por sí solas, para satisfacer la creciente demanda de madera en rollo de uso industrial. Los bosques naturales y semi-naturales de las zonas boreal y templada seguirán manteniendo una importante función como fuente de materia prima. Sin embargo, es poco probable que aumente el volumen de suministro procedente de estos bosques, debido a factores limitantes relacionados con la logística, la rentabilidad y la titularidad de la propiedad. Por otra parte, la gestión sostenible de los bosques naturales tropicales no se traducirá en un aumento de la oferta de madera en rollo. Por lo tanto, el desarrollo sostenible a escala global de plantaciones forestales para abastecer la industria será crucial para satisfacer la creciente demanda de madera a largo plazo. Es probable que el desarrollo sostenible de plantaciones afronte una serie de retos económicos, ambientales y sociales, y requiera medidas enérgicas por parte de los principales actores, como son los gobiernos o los inversores estratégicos y financieros.

INTRODUCTION

Industrial forest plantations[1] are an important raw material source for forest industries. These plantations satisfy about one-third of the world's industrial roundwood demand. According to the Indufor Plantation Databank[2] (2014), the global industrial plantations have significant growth potentials especially in terms of areas in the coming decades. The total volume of roundwood supplied from such plantations is also likely to grow. To bring these potentials into reality, a range of social, environmental and economic challenges have, however, to be overcome first. The article explores what expansion potential the global industrial forest plantations have and how much of the global industrial roundwood demand these plantations can satisfy. It also analyses the key challenges that the global plantation sector is likely to face on the way to fully materialize the expansion potential and the possible measures to ensure that the sector develops in a sustainable way.

The remainder of the article proceeds as follows. The next two sections present the expansion potential of global industrial plantations, and how much it can contribute to increasing the global industrial roundwood demand, respectively. The challenges facing and the possible measures for ensuring the sustainable global forest plantation development are analysed in the two sections before conclusions are given.

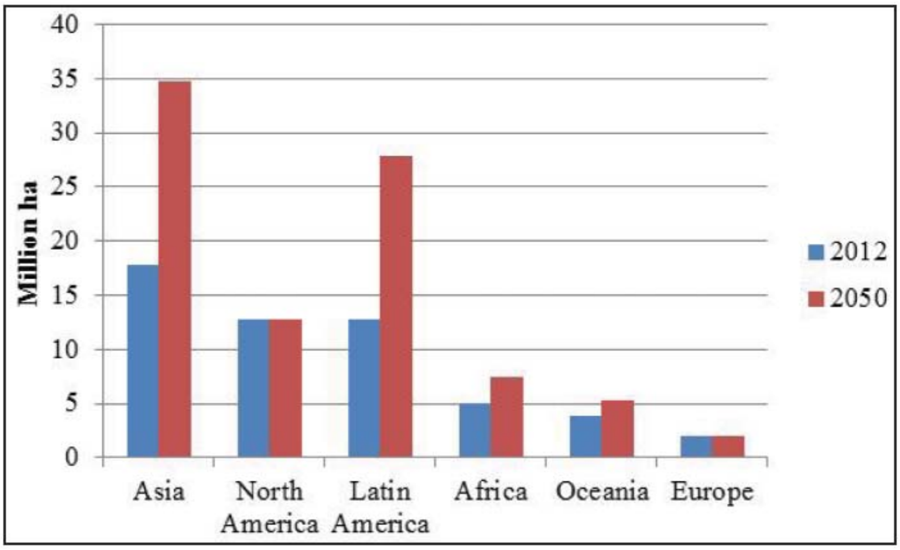
LIKELY DEVELOPMENT – EXPANSION

According to the Indufor (2012)[3], the total area of industrial forest plantations in the world was 54.3 million hectare (ha) in 2012. Asia had the largest industrial forest plantations, followed by North America and Latin America. Africa, Oceania and Europe also had considerable area of industrial forest plantations (Figure 1). The United States of America (USA) is the largest industrial forest plantation country with about 13 million ha of such plantations. China and Brazil follow the next each having about 7 million ha of industrial forest plantations. India and Indonesia are also leading industrial forest plantation growers with over 2.5 million ha of plantations each (Figure 2).

Indufor (2012) estimates that the total area of industrial forest plantations in the world may increase to 91 million ha by 2050. This corresponds to about 1.8% annual growth in plantation area from 2012. Asia and Latin America may see the biggest expansion in area of industrial forest plantations (Figure 1). The plantation area in these two regions could be doubled by 2050 corresponding to about 2.5% and 3.0% annual growth, respectively. The area of industrial forest plantations in Africa and Oceania is also predicted to expand in coming decades.

The supply of industrial roundwood from forest plantations is likely to increase from about 520 million cubic metre (m^3) at present to nearly 1.5 billion m^3 in 2050 (Figure 3). The growth in plantation area will be the key governing factor for this supply growth. Improvement in harvesting and clonal technologies, silvicultural practices and efficiency in management will enhance the growth and productivity in forest plantations and thus will contribute to securing this increasing supply. Overall, the growth in demand for roundwood, which is estimated to reach just over 6 billion m^3 (Figure 3), will be

FIGURE 1 *Global industrial forest plantation area development*



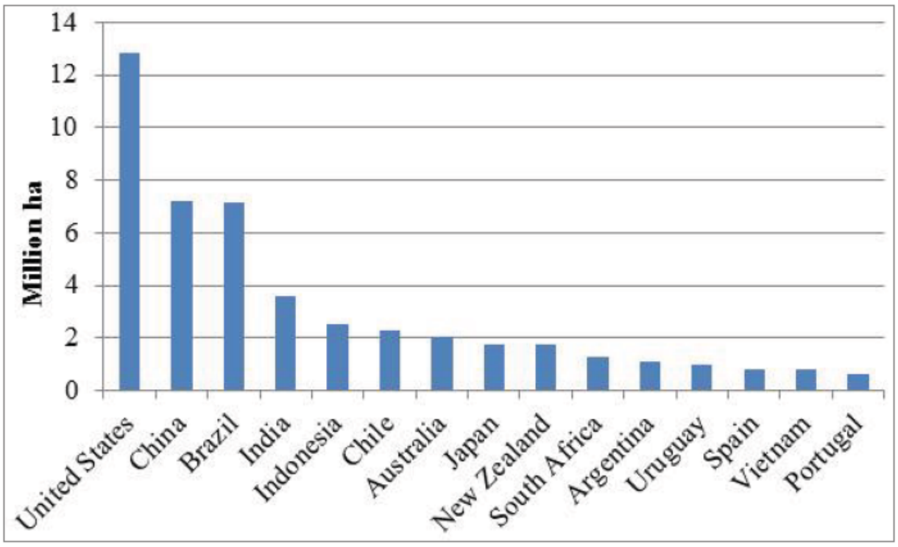
Source: Indufor Plantation Databank (2014)

[1] The industrial forest plantations refer to intensively managed productive plantations. The semi-natural planted forests, protective plantations and scattered planted woodlots are not usually considered as the industrial plantations and thus are kept outside of the scope of this article.

[2] Indufor continuously updates the databank.

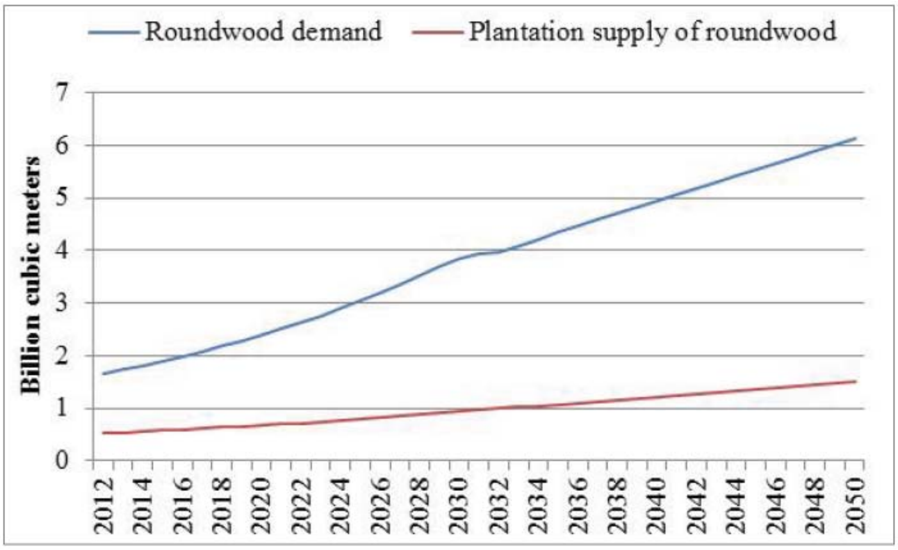
[3] Indufor did the study for the Forest Stewardship Council (FSC).

FIGURE 2 *Leading industrial forest plantation countries*



Source: Indufor Plantation Databank (2014)

FIGURE 3 *Global demand for and plantation supply of roundwood*



Source: Adapted from Indufor (2012)

the key underlying driver for the expansion of the supply of wood from plantations.

Population growth is one of the key drivers for increasing wood demand. Most of the growth in population is likely to occur in developing and emerging countries. An estimate shows that by 2050 about 90% of global population will live in these countries (United Nations 2011). Thus much of the growth in wood demand will occur in developing and emerging economy countries. Economic growth and growth in per capita consumption especially in emerging economies will increase the demand for wood in both domestic and international markets. Growing economic importance of emerging markets such as China, India and Brazil is also an important factor in this regard. Improved infrastructure and access to especially sea ports help producer countries to gain access to larger international markets and thus create incentives for plantation expansion. In addition, shift towards the green economy and consecutively the increased use of wood for energy and construction driven by climate change and energy policies, and reduced stocks of traditional energy sources, drive forest plantation expansion. Increase in demand induces the expansion of supply bases such as forest plantations and thus the growth in roundwood supply.

GLOBAL ROUNDWOOD DEMAND AND PLANTATION SUPPLY BALANCE

At present, as estimated by Indufor (2012), forest plantations satisfy about one-third of the global industrial roundwood demand. As Figure 3 demonstrates, in coming decades, the supply of roundwood from plantations could grow. But the rate of supply growth could fall behind the growth in demand, and thus gap between the global demand for and supply from industrial plantation of roundwood will widen in the coming decades (Figure 3). Therefore, the plantations will not be sufficient for meeting the increasing industrial roundwood demand entirely. This implies that the natural and semi-natural forests in boreal and temperate zones, which currently supply the majority share of global industrial roundwood, will continue to be an important source of raw material for the forest industry.

Nevertheless, it is urgently needed to increase the share of industrial plantation borne roundwood in the global supply. There are mainly two reasons for that. First, the natural forests in the tropics, which contribute to about 10% of global industrial roundwood demand, are often harvested at unsustainably high rates. Thus the sustainable management of tropical natural forests will not likely to increase the supply of wood, rather in many cases will decrease it. Moreover, the area of tropical natural forests is shrinking alarmingly due mainly to the conversion to agriculture (such as soy production, palm oil, cotton and cattle ranching)[4] and other more profitable land uses (Barua *et al.* 2012, 2013), and unsustainable uses of such forests. This further limits the availability of increasing the amount of roundwood from tropical natural forests. Secondly, while there is scope to increase the supply of roundwood from natural and semi-natural forests particularly in boreal and temperate zones, it is quite unlikely to be realized. The annual sustainable yield, i.e. annual allowable cut (AAC) of forests in the Russian Federation, for example, is estimated to be over 500 million m^3, while the average annual harvest in the past years has been about 125 million m^3 (Indufor 2012). This is mainly due to logistic limitations (for example, absence of suitable road network) and lower or even negative expected profitability of forests harvesting. There is significant wood surplus in Finland, Norway, Sweden and Canada too. However, it is not likely that this wood will be available to the markets due to the limitations related to the profitability of forest harvesting, forest ownership structure (e.g. Favada *et al.* 2009, Kuuluvainen *et al.* 1996) and increasing emphasis on enhancing the role of forests in climate change mitigation (Indufor 2013b).

The above discussion implies that for meeting industrial roundwood demand globally, the forest plantations will be of crucial importance in coming decades. Thus continued efforts are needed for the sustainable development of industrial forest plantations in both already-established and promising plantation countries in particularly Asia, Latin America and Africa. These efforts could even increase the share of plantation wood in the global wood demand in the long-term. If such development, however, is to accelerate, a number of challenges will need to be overcome.

CHALLENGES

Emergence of small- and medium-scale tree growers

In most countries with potential for significant plantation development, the number of small- and medium-scale tree growers will increase in the coming decades. In Latin America, there will be a growing number of small- and medium-scale tree farmers, even though large-scale industrial plantations are expected to remain as the dominant form of plantations in the future. Also in some Asian and African countries this type of growers are expected to play an important role in the industrial forest plantation development in the future (Indufor 2012). The out-grower schemes, company-tree farmer partnerships and producer associations are likely to play an important role in the emergence of small and medium-scale tree growers. This, in fact, has happened in Brazil, South Africa, Finland and Sweden in past.

The small and medium-scale tree growers alone are weak and cannot create the scale needed to be the part of value chain. They also usually do not have adequate information about the market and rely on the middlemen to determine volume, quality and price of their wood stock (Indufor 2013a). Providing adequate assistance to and designing efficient incentive programmes for this type of tree growers to maximize their contributions to industrial plantation development are challenging (e.g. Nawir 2013, Nugroho *et al.* 2013).

Land tenure

Securing land title for establishing plantations could prove to be a difficult task in many countries. For example, in China, even though the forest tenure reform since 2003 has devolved the use rights of collectively owned forestland and relaxed government control over private forestry operations by a great deal (e.g. Yin *et al.* 2013), land tenure transfer still is a time consuming process due to the bureaucracy. In Indonesia, lease or concession regulations are often unclear (e.g. Nugroho *et al.* 2013). Obtaining tenure right could cause social conflicts and thus induces reputational risks especially for foreign investors wanting to invest in plantations.

Land use competition

Globally, the land-use competition, being driven mainly by increasing demand for food, agricultural commodities, fibre, wood and bioenergy, is becoming more intense (Johansson and Azar 2007, Azar 2000, 2005). In Indonesia, for example, the competition for land between forest plantations, and cash-crop and other agricultural practices is intense. The expansion of oil palm plantations has made the competition even more intense as some estimates suggest that oil palm is over 10 times more profitable than forestry land uses even when

[4] In Brazil, for example, between 2000 and 2010 the area of natural forests decreased by about 55 million ha, while the area of soy, sugarcane and other agricultural crops increased by nearly 32 million ha (FAOSTAT 2014). Much of the expansion in area under agricultural crops comes at the expense of natural forests.

carbon sequestration is accounted for (Butler *et al*. 2009). The demand for arable land for food production is mainly driven by population growth and increased livestock production in developing countries as well as by populated yet developed countries such as South Korea, Qatar and United Arab Emirates suffering from shortages of agricultural land. Land-use competition will put the land prices up and shift forest plantations towards new frontiers. Moreover, due to such competition, the availability of good quality land at a reasonable price is very limited in many countries. For example, in China and India, suitable land for establishing large-scale forest plantations is already very scarce.

Environmental degradation

The type and condition of the area replaced by a forest plantation usually determine the environmental value of that plantation. In a number of countries, forest plantations have earned a bad reputation as they are expanded at the expense of native vegetation and without giving due consideration to soil and water conservation. For example, in Indonesia, much of the forest plantations were established on land which was previously natural forests (Indufor 2012). Plantations there have also been established on drained peat land causing the release of vast amount of carbon di oxide (CO_2), which would have otherwise been stored on the ground. In Lao People's Democratic Republic (Lao PDR), on the other hand, concessions, including land for forest plantation development, have been granted within certified production forest areas and inside the national parks in many cases. The concessions have often been used as a means to justify logging outside of the normal logging quota system and to gain control over the land and thus causing a range of adverse ecological and social problems.

In addition, most of the industrial forest plantations are of monoculture nature and thus subject to biotic and abiotic damages. In some areas, the frequency of disease is higher in the next generations of forest plantations. Also in draught-prone areas, forest plantations consisting of species with high transpiration rates are blamed for reducing the availability of water for other uses (Indufor 2012).

Governance

Insufficient law enforcement is a serious problem especially in many Asian and African countries with potential for forest plantation development. Indufor's extensive experiences suggest that there is no shortage of good laws and regulations to protect forests and trees in developing countries. Inadequate implementation of the laws is, however, the problem. The key factors contributing to this situation are poor funding and limited institutional and human capacity to patrol forests and markets, detect and deter offences, prosecute cases and educate stakeholders. Political interference has also created challenges for forest management over the past few decades. In general, weak governance aided with political and economic instability induces high transaction costs affecting the entire investment cycle of forest plantations.

FIGURE 4 *Reducing the environmental impacts is one of the key challenges to sustainable plantation development (a post-harvest plantation site in Indonesia)*

Social issues

The ambiguous situation regarding statutory and customary land-use rights poses a difficult challenge for forest plantation development in parts of Africa, Asia and Latin America. Particularly in Latin America unequal landownership has been criticized by the civil society and non-government organizations (NGOs) and a key driver from rural landless movements. The pressure arising from rural landless people and civil society groups is likely to impact the land ownership structure in the future. In Indonesia and many other countries, indigenous people and other local communities often rely on customary rights, whereas plantation companies are committed to follow the statutory licensing and tenure statutes. The statutory system does not always recognize or respect customary land rights, which can mean loss of land-use rights for the local people. In some countries the state does not allow plantation developers to take local people's wishes into consideration even if the plantation companies are willing to do so. This situation creates a serious challenge for the foreign companies working in developing countries – not least since sometimes plantation companies end up as stakeholders in local conflicts that were initiated long before they entered the area (Indufor 2012).

In Lao PDR, for example, land concessions for forest plantation development have been in some cases issued to the companies without even consulting the local people and paying attention to their traditional rights over land. This puts the livelihoods and food security of the local people in danger as well as adds more fuel to already existing land conflicts problem in the country (Indufor 2012).

Investment gaps

Investment is the key to fully materialize the potential for sustainable forest plantation development. However, except for a few countries such as Brazil and South Africa, there is a major gap in terms of plantation investment in developing countries with good growing conditions for forest plantations. The insecure land tenure, political, social, environmental and reputational risks, and limited understanding of forest sector investments within the financial institutions appear to be the key factors contributing to the investment gap (Indufor 2013a).

Poorly designed incentive programmes also contribute to widening the investment gaps. For example, Indonesia has launched the smallholder timber plantation programme in 2007 with an aim to establish 5.4 million ha of forest plantations in the country. This programme includes a scheme to offer loans to smallholders. The minimum loan size of this scheme is, however, too large for an average smallholder to handle. The loan application process, involving over 20 steps and nine different organizations, and the reporting process are burdensome. Moreover, the geographical targeting of the scheme is considered improper. As a result, the awareness and interest about the programme among the smallholder have so far been far less than expected, and much of fund allocated for the loan scheme has remained unused (Nugroho *et al*. 2013), despite tree growers need financial assistance.

SUPPORTIVE MEASURES

To make the expansion of global industrial forest plantations sustainable by overcoming the challenges discussed above, the following actions should be undertaken.

Building alliances, coalitions and cooperatives

The small- and medium-scale tree growers require special support. They alone are too small and too weak to access the markets and to negotiate effectively with suppliers of inputs and buyers of their products. Forming of associations and cooperatives allows them to benefit from the economies of scale, access to information and negotiate more successfully. Such cooperation helps these tree growers to access to professional and reliable partners as well as to integrate into broader supply chains. The support to forming of associations needs to be gradual and performance based, and could come from both governments and NGOs (Indufor 2012, 2013a).

Through associations and cooperatives, small- and medium-scale tree growers can also benefit from partnerships with larger companies which can offer improved market access, better market information, technical and financial know how. Larger companies benefit from such partnerships by strengthening their supply bases, and gaining deeper and broader community involvement in their operations, thereby improving the acceptability of their operations and reducing reputational risks (Indufor 2012, 2013a). Moreover, through associations and cooperatives, small- and medium-scale tree growers can afford more mechanized operations in plantation management and harvesting which contribute towards increasing productivity and decreasing production costs.

Increasing availability of financing for responsible and sustainable investments

The availability of longer-term, reasonably priced, loan financing is a major constraint for plantation investments in many developing countries. Thus continuous efforts are needed to develop tailored loan facilities in existing national development banks or other financing institutions, particularly targeting small- and medium-scale tree growers who are unable to access loan financing from abroad (Indufor 2013a). The existing national and regional funds that are investing in private forestry and processing with good track record should be supported and provided with additional capital.

Building awareness and capacity

Many national and regional financing institutions that have not financed forest investments lack understanding of forest assets as an investment class. Often financing institutions and investors do not know how to assess risks related to forestry investments. They are also often not familiar with forestry business in general, and therefore are reluctant to deal with it. There is a general need to educate financing institutions on the basics of forest asset valuation, forestry investment and risks (Indufor 2013a).

Improving sector governance and improving transparency

Comprehensive governance reforms are needed in number of countries with potential for forest plantation expansion especially in Asia and Africa. Such reforms typically streamline and increase the transparency in the processes of issuing licenses and permits. They, therefore, reducing the risk of corruption and excessive bureaucracy accelerates the investment execution and improves the investment environment (Indufor 2013a).

Providing secure land tenure

There is a need, in many countries, for policy and legislative reforms, or to implement earlier reforms and establish clear, transparent and cost efficient procedures for land acquisition and leasing. Also social safeguards and related community consultations need to be in place to avoid land grabbing and conflicts with local communities. Cadastral system and land allocation maps are required to be strengthened in many countries (Indufor 2013a).

Introducing targeted incentives

Well-planned incentives schemes such as tax exemptions and direct or indirect subsidy programmes have proven effective in plantation development in a number of countries[5]. They have become effective especially when measures have already been undertaken to secure macro-economic, political and institutional stability, access to land, clear resource tenure arrangements, and access to good infrastructure and extension services. This implies that variable incentives must be linked to the introduction of enabling incentives that change the overall framework conditions within and outside the forest sector.

Various combinations of incentives have triggered the adequate volume of investments in forest plantations that have been necessary for attracting investments in downstream processing in a number of countries. These have mobilized further investments in plantations by providing well-paying market for the plantation-borne timber in a number of cases. This evidence suggests that the conditions should be such that plantation investments are driven by competitive and efficient markets, not by government incentives. At the same time, it is important to assess and remove the negative impacts of incentives of other sectors that act as disincentives in the forest sector, e.g. agricultural incentives that lead to extensive deforestation (Angelsen 1999, Rudel 2009).

Based on Indufor experiences in working with plantation incentive programmes around the world (e.g. Indufor 2012) and earlier literature (Bull *et al*. 2006, Barua 2011), an effective incentive programme should have the following characteristics:

- It should be performance-based focusing on high survival rates and high productivity,
- It should combine direct incentives with indirect enabling incentives. In most countries, indirect enabling incentives have usually been well justified especially with aspects like improved land tenure, infrastructure development and technical assistance,
- It should have a finite lifespan and be phased out at a certain point of time,
- It should be inclusive rather than exclusive supporting small, medium and large-scale tree growers,
- It should comply with the best environmental and social standards,
- It should have a set of clearly defined objectives for the program,
- an effective monitoring of the program to ensure that the incentives are used efficiently,
- It should have flexibility within to cope with the changes in conditions that could occur during the long planning horizon of the plantation projects,
- It should have a well-designed compliance, penalties and enforcement procedure, and
- It should be consistent with the existing forest policy and regulatory framework, and other land-based sectors.

Moreover, for designing an effective plantation incentive programme, the appropriate role of government both in the design and implementation phases should be identified. Building the institutional capacity with efficient administration especially for implementing the programme is also necessary. Furthermore, identifying all major stakeholders of and ensuring their involvement in the programme already from the design phase is also very crucial for the success of a plantation incentive programme. Last but not least, the impacts of the programme should be thoroughly assessed and one should always be prepared for any potential negative impacts (Bull *et al*. 2006).

Plantation development: the case of Brazil

Brazil is one of the world's leading plantation countries with about 7 million ha of forest plantations[6] (Figure 2). Over the

[5] Almost all countries with well-established forest industry sector have had in the past and some still have incentive schemes supporting forest plantation development. Also emerging plantation countries like Thailand, Uganda, Costa Rica and Malaysia have recently introduced appealing small-scale and well-targeted grant schemes. The key positive impacts of the past plantation incentive programs include: (i) creating a critical mass of forests that has led to the establishment of forest-based industries, (ii) catalysing socio-economic development and reducing poverty in rural areas, (iii) reducing pressure on natural forests, and (iv) strengthening land tenure, for example, in Brazil, Uruguay, Chile, South Africa and New Zealand. Poorly designed incentive programmes in some countries, such as Mexico, however, resulted in sub-optimal land use, poor quality plantations, biodiversity loss and neglect of small and medium-scale tree growers.

[6] Eucalyptus (*Eucalyptus spp*.) and pine species (*Pinus spp*.) together constitute about 93% of Brazil forest plantations. Other notable plantation species in Brazil include Seringueira (*Hevea barsiliensis*), Acaciá (*Acacia mangium* and *A. meamsii*), Paricá (*Schizolobium amazonicum*) and Teak (*Tectona grandis*) (Indufor Plantation Databank 2014).

FIGURE 5 *A pine plantation in Brazil*

past three decades the country has been able to develop significant forest industries based on systematic investments in forest plantation development. The plantation development accelerated in 1970's and 1980's thanks to the incentive schemes comprising of subsidies and tax exemptions. Along with the incentive schemes, large-scale forest and other industrial development initiatives supported by foreign investments, the development of loan and other financial instruments by the local institutions such as the Brazilian Development Bank (BNDES) have driven the forest plantation investments. Indeed, most of the plantation investments have been developed jointly with pulp and paper industries and to some extent with pig iron industries.

Public investments in, for example, major infrastructure and research and development (R&D) projects have increased productivity and competiveness of the forest sector and thus have accelerated private investments in the sector. The government has supported extension as well as R&D of plantation technologies especially through the Brazilian Company of Agricultural Research (EMBRAPA). In the course of time many private companies have developed their own R&D and extension programmes as a part of their tree farming schemes (Indufor 2012).

In the past, the incentive schemes and financial instruments were criticized for favouring large-scale tree growers and ignoring the conversion of native forests to plantations. Over time forest companies and other plantation developers, however, have become more capable in developing socially and environmentally sound models considering civil society concerns. Environmental legislation was initially taken as a constraint; however, it has forced the companies to improve their performance and has also facilitated financing from sources that demand sustainability. Today forest plantations in Brazil follow strict national environmental and social standards. In fact, much of the plantations in the country are certified under the Forest Stewardship Council (FSC) and the Brazilian Forest Certification Programme (CERFLOR)[7].

The key underlying reasons for Brazil's success with forest plantations have been (i) the availability of land areas with excellent tree growing conditions, (ii) existing infrastructure, (iii) adopting developed plantation technologies, (iv) access to markets, (v) favourable policies towards forest investments and (vi) following strict sustainability standards. The main remaining obstacles have been general weaknesses in the business environment as reflected, for example, in poor ranking with Ease-of-Doing Business of the World Bank, conflicts with civil society related to large-scale landownership and monocultures threatening biodiversity, and local social development (Indufor 2012).

[7] CERFLOR is the Brazilian national programme under the Program for the Endorsement of Forest Certification Schemes (PEFC).

Develop tested plantation models, and build research and development (R&D) capacity

The plantation models adapted and tested locally are necessary for securing high growth rates and resistance to pests and diseases. Large-scale plantation investors can afford developing and testing such models themselves. Small- and medium-scale investors do not have the capacity to do it. It would be highly beneficial if the governments carry out good quality R&D in developing such models and providing related extension services particularly for small- and medium-scale tree growers (Indufor 2012). However, one must not forget that any plantation technology should be used in a responsible manner and in compliance with high social, ethical and environmental standards.

Developing and disseminating risk mitigation tools

Biotic and abiotic threats such as pests, diseases and fire make forest plantations prone to investment failures. The risks of investment failure can be partially controlled by proper management (e.g. fire prevention measures) but such risks are difficult and expensive to remove entirely. There is a need to develop and provide risk mitigation tools, for example, in the form of insurance schemes or risk guarantee funds. Such arrangements would buffer the small- and medium-scale tree growers from financial catastrophes, and thus would lower the bar for investing in plantations (Indufor 2013a).

Other measures

There are many longer-term measures such as intra- and extra-sectorial reforms, and improving political and economic stability which are beyond the forest sector and apply to the overall business environment, but contribute to the sustainable plantation development. However, there are many critical governance and regulatory constraints that can be influenced by the decision-makers in the forest sector. Availability of trained labour is an important criterion for large scale investors when assessing investment opportunities. Therefore training and education of labour and technical experts are required to create professional and management capacity.

CONCLUSIONS

It is evident that the global industrial forest plantations, i.e. intensively managed productive plantations will expand significantly in the coming decades. The global forest plantation area could increase from just over 54 million hectare (ha) in 2012 at a rate of about 1.8% per year to reach about 91 million ha in 2050. Asia and Latin America could experience the biggest growth in plantation area. Africa and Oceania could also see significant growth. Population growth and economic development especially in emerging economy countries will be the key factors in the global plantation expansion. This

FIGURE 6 *Sustainable plantation development is possible with appropriate measures (a eucalyptus plantation in China)*

expansion coupled with improvement in plantation technologies and management will lead to the increase of industrial roundwood supply from plantations.

The supply of industrial roundwood from plantations could increase to 1.5 billion m^3 in 2050. Still the share of plantation wood in global industrial roundwood demand will not increase from the current one-third share. The rate of this supply growth is rather likely to fall behind the rate of growth in wood demand in coming decades increasing the gap between the demand and supply. Thus forest plantations alone will not be sufficient for meeting the growing industrial roundwood demand. Natural and semi-natural forests in boreal and temperate zones will maintain their important role as the raw material source. The supply from these forests, however, is not likely to increase from the current level due to the constraints related to logistics, profitability and ownership structure. Moreover, sustainable management of tropical natural forests will not result in any increase of roundwood supply. Nevertheless, sustainable development of industrial plantations particularly in many promising plantation countries of Asia, Latin America and Africa, will be necessary to maintain plantations as an important supplier of raw materials to forest industries and even to increase the share of plantation wood in the global wood demand in the long term.

Sustainable development of plantations is likely to face a number of challenges especially regarding the emergence of small- and medium-scale tree growers in emerging plantation countries, land tenure and land-use competition, environmental degradation and governance. To overcome these challenges, strong measures (e.g. policies) from the key stakeholders: governments, strategic and financial investors and NGOs are required. These measures may include helping the small- and medium-scale tree growers to form alliance, coalitions and cooperatives to enhance their market access and negotiation power, facilitating responsible and sustainable investment in plantations, improving governance, introducing targeted incentives for plantations and removing disincentives, and building R&D capacity.

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Paradigms in tropical forest plantations: a critical reflection on historical shifts in plantation approaches

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SUMMARY

This paper traces macro-level trends and changing approaches to plantation forestry, with particular emphasis on tropical and subtropical regions. Introducing the theoretical concept of a paradigm and drawing on the notions of discourse and epistemic community, it analyses the development of knowledge structures present in the history of plantation forestry. The historical context with an economic and developmental focus is provided to better understand the political economy of forest plantations in the South. A typology of plantation paradigms according to the selected criteria is put forth to illustrate both the discursive and technical changes plantation projects underwent in time. The paper concludes with a critical discussion on the parallels between the historical developments, change in economic thought and development aid and their influence on tree-planting activities as well as the strengths, weaknesses and challenges for both the plantation and general forestry epistemic community in the years to come.

Keywords: planted forests, forest plantations, paradigm change, history of plantations, development

Paradigmes des plantations forestières tropicales: une réflexion critique sur les changements historiques dans les approches aux plantations

J. SZULECKA, J. PRETZSCH et L. SECCO

Cet article retrace les tendances au macro-niveau et évolutions dans l'approche aux plantations forestières, se concentrant en particulier sur les régions tropicales et subtropicales. S'appuyant, d'un point de vue théorique, sur le concept de paradigme et mobilisant les notions de discours et de communauté épistémique, il analyse le développement des structures de savoir au sein de l'histoire de la foresterie de plantation. Le contexte historique, et en particulier ses aspects économiques et développementaux, est présenté dans un premier temps afin d'éclaircir les caractéristiques de l'économie politique de plantations forestières dans le Sud. Une typologie des différents paradigmes ayant guidés aux pratiques de plantation selon les critères spécifiques est avancé afin d'illustrer les changements tant discursifs que techniques qu'ont connu les projets de plantation. L'article conclut par une discussion critique sur les parallèles établis entre les événements historiques, les évolutions de la pensée économique et l'aide au développement, et leur influence sur les activités de plantation forestière ainsi que sur les forces, faiblesses et défis à venir pour la communauté épistémique foresterie en générale et celle des plantations en particulier.

Paradigmas en las plantaciones forestales tropicales: una reflexión crítica sobre los cambios históricos en los enfoques de las plantaciones

J. SZULECKA, J. PRETZSCH y L. SECCO

Este trabajo rastrea las tendencias a nivel macro y los enfoques cambiantes hacia las plantaciones forestales, con especial énfasis en las regiones tropicales y subtropicales. Introduciendo el concepto teórico de paradigma y basándose en las nociones de discurso y de la comunidad epistémica, se analiza el desarrollo de las estructuras del conocimiento presentes en la historia de las plantaciones forestales. Se proporciona el contexto histórico con un enfoque económico y de desarrollo para comprender mejor la economía política de las plantaciones forestales en el Sur. Se plantea una tipología de los paradigmas de las plantaciones en relación a criterios seleccionados, para ilustrar tanto los cambios discursivos como técnicos a los que fueran sometidas las plantaciones a lo largo del tiempo. El artículo concluye con una discusión crítica sobre los paralelismos entre la evolución histórica, el cambio en el pensamiento económico y la ayuda al desarrollo y su influencia en las actividades de plantación de árboles; así como las fortalezas, debilidades y retos de las plantaciones y de la comunidad epistémica forestal en general para los próximos años.

INTRODUCTION

The continuous increase in the volume of planted forest area began in the 1950s, and according to the FAO scenarios, the rising trend will prevail in the next decades (Carle and Holmgren 2008, Sedijo 1999). In 2005, plantations and planted forests constituted about 7% of the global forested area and occupied about 264–271 million hectares (depending on the sources of the data: FAO 2006 or FAO FRA 2010).[1] In the two decades between 1990 and 2010 the scale of tree-planting efforts increased the most rapidly worldwide, albeit at different rates in different regions.

The significance of forest plantations is manifold, and depends to a great extent on the perspective from which they are assessed. Although the area of forest plantations is rather limited compared to that of natural forests, according to FAO data (2006) their contribution to global industrial wood production represents about 50% of the total. For this reason forest plantations play an ever more important part in the global and regional economies to secure both industrial wood and energy sources.[2] Industrial timber plantations have formed the basis for an increasing forest-based manufacturing and export sector in many developing countries (Cubbage 2009). In addition, especially protective but also productive forest plantations are seen as providing important environmental services, which are not always recognized by the market (Kanowski 2010). What is more, smallholder and community-based plantation projects are increasingly perceived as a potentially efficient source of income and wood for local use in the developing regions, helping in poverty alleviation. Finally, in the on-going climate change mitigation debate, forest plantations are perceived as means of carbon sequestration. It is therefore clear that although a consensus seems to exist as to the need of large-scale tree planting, the *why?*, *how?*, *what?* and *where?* – basic questions in the political economy of forest plantations – are answered differently according to different visions, interpretations or *paradigms* adopted.

It is those paradigms that this paper focuses on. It looks at the history of plantation efforts and their general trends, offering a macro diagnosis by categorizing the development and change of dominant paradigms that have been driving plantation projects in the past decades (e.g. modes of thinking about, planning and governing plantations), with a special focus on the tropics. A classification of these paradigms is proposed based on qualitative research. Finally, the driving forces of previous and current policies regarding plantations, the role of the scientific community and institutional set-up are critically assessed and discussed.

THEORY: PARADIGMS, DISCOURSES AND EPISTEMIC COMMUNITIES

In studying the changes in understandings, definitions and priorities of plantation forestry, this analysis draws on the epistemology and sociology of scientific knowledge. The concept of a *paradigm* is used to describe the discrete structure of knowledge that encompasses the understandings and impacts of plantations, and directs the policy and practice of plantation forestry.

A paradigm is defined as "a set of assumptions, concepts, values, and practices that constitutes a way of viewing reality for the community that shares them, especially in an intellectual discipline" (American Heritage Dictionary 2000). In other words, paradigms are shared structures according to which (predominantly natural scientific) disciplines are organized (Kuhn 1996 [1962]). They are understood as answers to a set of questions about what is to be observed and scrutinized, what the dominant research questions are, and how they are posed and structured. Other important issues are the interpretation practices and the methodological apparatus used for the studies, as well as the social aspect of a paradigm, seen as "what members of a scientific community, and they alone, share" (Kuhn 1977). In their social and political nature, paradigms are not stable, and science experiences paradigm shifts that alter the understanding of the role of science, the perceptions of reality and the available tools for inquiry. Later, Handa (1986) introduced the concept of a *social paradigm*. He emphasized the social context which influences the dominant paradigms and causes shifts, which in turn influences the social sphere and the institutional setup. Similarly, Hall (1993) put forth the notion of a *policy paradigm*, generating longer periods of continuity in policy terms, punctuated by paradigm shifts when the system of ideas and standards are questioned and changed (pp. 279–280). Although Kuhn's (and related authors') ideas on paradigms in science as a whole have been criticized – as an error of collective judgment on the capacity of science to remain an independent, progressive force in the society (Fuller 2003) – the concept can be a useful tool in the historical analysis of the particular

[1] This includes about 140 million hectares of forest plantations and the remainder is constituted by the planted component of semi-natural forests. Due to the historical scope of this analysis and bearing in mind the changing definitions of forest plantations and planted forests in the last decades (FAO FRA 2000, FAO FRA 2005), a very inclusive definition of plantations as *forest stands raised artificially* is applied (Zhang and Owiredu 2007).

[2] More than 25 Mha of plantation forests are "intensively managed" for industrial wood production. Intensively managed planted forests (IMPF) are those of relatively high productivity, in which the owner makes a sustained investment, over the life of the forest, to optimize industrial wood production. The high productivity of IMPF is such that they contribute up to 40% of the world's industrial wood supply (Masiero 2010). Carle and Holmgren (2008) report that with an assumed average efficiency rate of 70% the potential industrial wood production from planted forests in 2005 was estimated at 1.2 billion m^3, i.e. about two-thirds of the overall wood production. However, it needs to be emphasized that such estimations refer to the production potential for plantations harvested on schedule and often, due to various obstacles (political, social, economic and environmental), the real harvest rates may be significantly lower.

domain of plantation forestry in its socio-political entanglements. It provides an approach that helps to transcend the temporarily dominating approaches and discourses.

The concept of paradigms and the idea of paradigm change or shift have already been applied to the domain of forestry, albeit often in a rather general way. Mery *et al.* define forestry paradigms as "the ways in which forests are perceived, used and conserved" (2005: 14). This rightly points to the dual nature of paradigms, encompassing both attitudes and practices towards forests, but the authors only distinguish two historical paradigms – 'rationalist' and that of 'sustainable development'. In their impressive historical study, Arts *et al.* (2010) trace the evolution of a much wider set of forestry "discourses", yet keep it separate from an analysis of actual practices. Sayer and Elliot (2005) in turn depart from the tension between conservation and service provision, coming up with a convincing overview of changing paradigms in forest *governance*. Both publications, however, do not capture the multidimensionality of paradigms and do not address the specific issues of planted forests. On the other hand, Liu *et al.* (2005) and Galloway *et al.* (2005) recognize a wide range of factors which constitute the context for forestry (such as management, governance, livelihoods and environmental services), and discuss plantation forests as a separate issue, but leave the concept of paradigm un-theorised, pointing rather to the practical impacts of 'shifts' in different issue areas.

In studying the paradigms of plantation forestry it is necessary to look at both the levels of social structures and agency (cf. Stones 2007). The first level is linked to the post-structuralist concept of *discourse* as a "manifestation of power through language" (cf. Foucault 1972); throughout the paper, the word "discourse" is used in the sense of a "mode of speaking" about a certain topic, the dominant threads and the limitations for acceptable speech acts. The second level refers to the actions of the subjects able to create paradigms and empowered to cause their shifts, well captured by the concept of *epistemic community* (Haas 1989), which sees it as "a network of knowledge-based experts or groups with an authoritative claim to policy-relevant knowledge within the domain of their expertise" (Haas 1992: 3). Furthermore, its members "hold a common set of causal beliefs and share notions of validity based on internally defined criteria for evaluation, common policy projects, and shared normative commitments" (Ibidem). The epistemic community influences the policymaking realm by providing expert knowledge, and in this way setting the agendas for negotiations and framing policy options.

Paradigms in tropical plantation forestry were influenced by the shifts in the structure of the global political economy (material) as well as the theoretical, scientific and ideological (ideational) changes. For a better understanding of plantation politics and tracing of changes between the dominant approaches, key issues and specific elements are proposed to study plantation paradigms (Table 1).

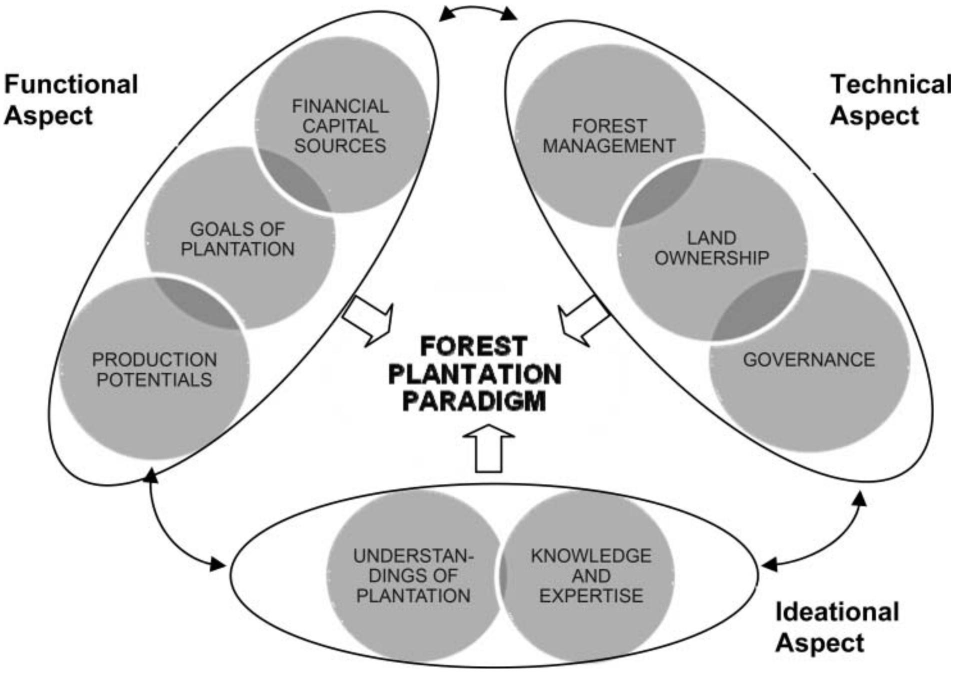
Plantation forestry underwent many shifts in the perception of its core elements, from land ownership modes, forest management, governance, goals for planting, scale, investment source, production potential and expertise centres. Planting activity, which was expected to be a rather technical skill, has always been highly subjected to changes in ideas related in turn to broader historical and economic developments (the context includes political, environmental and socio-economic background and policies for plantation investment, depends on markets, livelihood strategies, other land use types, etc.). The changes in paradigms result in what is being planted, where, on what scale, on whose land, what kind of actors are involved, what kind of incentives used, who can produce expert judgments and how it is justified.

To analyse the evolution of paradigms in tropical plantation forestry, several qualitative methods were employed. The authors began with a historical analysis of the most significant policy milestones, which significantly altered the

TABLE 1 *Elements for studying plantation paradigms and their shifts. Source: own elaboration, drawing on Pretzsch (2013)*

Aspect	Element	Explanation
Technical (HOW?)	land ownership	*How is access regulated? What is the plantation land status? (i.e. private/public, exclusive/inclusive etc.)*
	forest management	*How is the plantation managed? Who is responsible? (Centralized, community-based etc.)*
	governance	*How is the plantation governed? (top-down, bottom-up, vertical etc.)*
Ideational (WHAT?)	understandings of plantations	*What are plantations and how are they justified? (Progress, profit, equitable growth etc.)*
	knowledge and expertise	*What is the source of authority? (Local knowledge, Western scientific discourse, political framing etc.)*
Functional (WHY?)	goals of plantations	*Why are we planting? What is the long-term purpose? (wood production, environmental services, carbon sequestration etc.)*
	financial capital source	*Why the actors invest? Who provides capital and expects to benefit? (State, private, community, NGO etc.)*
	production potentials	*Differences in growth rates under different paradigms* ($m^3\ ha^{-1}\ year^{-1}$)

FIGURE 1 *Variety of Elements Constituting a Paradigm in Plantation Research*



international approach to planted forests. This was followed by a discourse and content analysis of the FAO archival documents and World Forestry Congresses' outputs as well as a content analysis of the journal "Unasylva", central to the field.[3]

POLITICS OF FOREST PLANTATIONS IN A WIDER HISTORCAL, ECONOMIC AND DEVELOPMENTAL CONTEXT

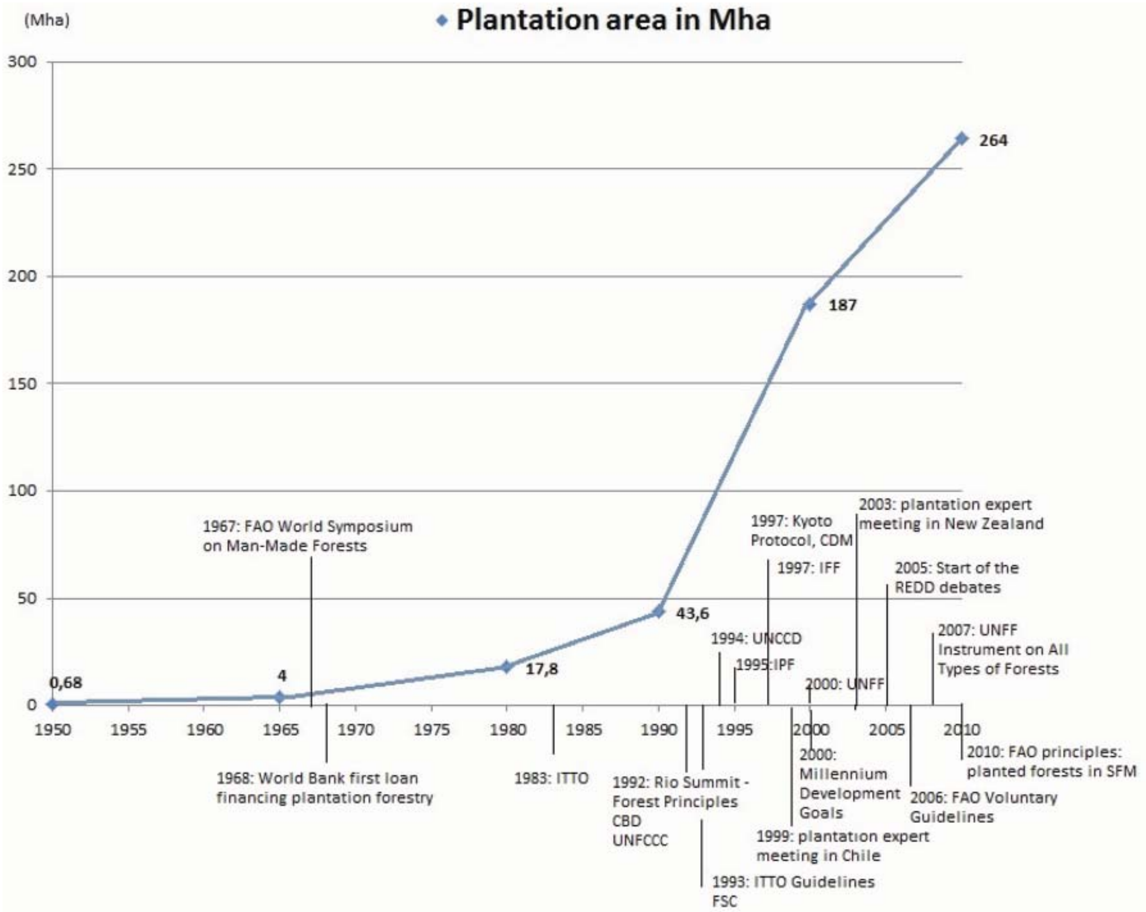
The social activity of tree planting can be placed in a broader context of human development, history and economic thought. With the migration of peoples, seeds have been spread over new areas and valuable species have been artificially propagated, i.e. myrrh trees in Egypt, frankincense in southern Arabia, olive trees in the Mediterranean or stone pines and firs brought to the British Isles (Bass 1992, Evans 2009a). As long as natural forests were widely available, tree planting was very limited and aimed particularly at cultivating valued species for aesthetic, cultural and religious purposes. This situation changed initially in Europe of the late Middle Ages, where the shortage of natural forests in the 14th century resulted in the need for large scale reforestation. As Savill and Evans (1986: 8) point out that up until the beginning of 19th century most of the planting was conducted with native species in traditional forest areas. It was in Germany and through the influence of Heinrich Cotta that "new plantation forestry", involving species conversion and large scale afforestation was first introduced and popularized. This shift signals the move from a pre-industrial to an industrial mind-set in tree planting, and the practices developed in moderate zones had a very significant influence on emerging tropical plantations.

The development of plantations in tropical areas started with the colonial influence and can be traced back to the 16th and 17th centuries (Evans and Turnbull 2009). Early activities in the colonies concentrated on small scale valuable species plantation (i.e. teak) and generally did not promote larger tree-planting projects, seeing them as expensive and insecure long-term investments (Bass 1992). At the peak of the colonial period, plantations were developed for strategic (shipbuilding) and commercial purposes, with plantation forestry being framed and encouraged as "progress". During this period, between 1905 and 1912, the first "Eucalyptus boom" took place (Santos in: Spirko 2010), particularly in South America (Brazil, Uruguay) and Africa (Ethiopia, South Africa). However, detailed data on plantation area were not available at that time. In the decolonization era, the newly independent countries continued the "forestry as progress" justification and the State-led plantation model spread worldwide. Centralized plantation activities were also better documented and reported in terms of scale.

After World War II, the dominant economic growth approach and modernization calls (with emphasis on economic growth per capita and direct technology transfer) (Kirkpatrick *et al.* 2002) affected the way plantations were organized. Large scale planting programs were promoted by donors and governments. Plantations were perceived as a strategy for

[3] Due to limited space, the details of this analysis, the broad discussion of the entire corpus of texts and some of the specific findings cannot be discussed here.

FIGURE 2 *Changing area of forest plantations worldwide with the most influential milestones of global forest plantation politics (Own elaboration, plantation area from: Evans and Turnbull, 2009; FAO 2010). List of acronyms at the end of this article*[4]



industrial growth and tree-planting gained global recognition. This was reflected on the agendas of the World Forestry Congress held for the first time in the global South in 1954 (Unasylva 1954) and the FAO World Symposium on Man-made Forests held in Australia in the next decade (Zaman 1967). In 1968 the World Bank started to finance large plantation projects (Evans and Turnbull 2009: 30). From the 1960s, softwood plantations (predominantly pine) gained importance with the growing pulp and paper industry.

The research interest in technology adaptation leading to the Green Revolution in those years left a mark on the subsequent plantation approaches, bringing back the so-called "agroforestry" model – an old concept re-invigorated to optimize the combination of both agricultural and forestry crops (Bene *et al.* 1977). The dominant emphasis in development aid, as well as that of plantation forestry, of the 1950s and 1960s began to cause widespread criticism, once the "externalities" of growth became more visible. The *per capita growth* approach, treating plantations as an element of a macro-economic, industrial design, encountered growing opposition because it was not fulfilling its promises. The late 1960s and early 1970s marked a shift in the general understanding of aid, emphasizing equitable growth (including employment, income distribution and basic human needs issues) (Jolly 2002) as well as environmental awareness (the concept of "responsible forestry"), which began the evolution towards sustainable development and the re-distributive mechanisms for poverty reduction. From the 1970s, the notion of *growth with equity* gained importance and Integrated Rural Development together with microfinance propagation dominated the agenda (Kirkpatrick *et al.* 2002). Social forestry has been applied to plantation by development agencies

[4] Specific data regarding the global amount of planted forests over time was chosen to come as much as possible from one source (Evans and Turnbull 2009) and was accompanied by the current prognosis on forest plantation area in 2010 (FAO 2010). The numbers should be considered as general suggestions of a trend showing huge increase of plantation areas over the last decades rather than exact figures. Due to problems with obtaining global data and also problems of changing definitions (Evans *et al.* 2009) about what a plantation is, they are not precise. There is now a growing agreement that plantation volume may be strongly overestimated (many countries reported areas aimed to plant, sometimes not even planted, or planted with huge losses) (cf. Shvidenko *et al.* 2005); we thus tried to base our figure on more conservative estimations.

and other actors in order to better address multiple local needs.

The focus was reversed in the next decade, when a larger, global shift, associated with the economic impacts of the post-1973 economic crisis, led to a grand re-conceptualization of the economy according to (neo-)liberal ideas and the so called "Washington Consensus", promoting privatization and market liberalization, reducing trade barriers and the role of the State (institutional restructuring). In forest plantations, this led to the ITTO Agreement in 1983, focusing on the worldwide tropical timber economy and empowering industrial international timber trade players (forest plantation owners, producers, importers). The neo-liberal ideas, based on privatization and deregulation, extend beyond the economy and emphasize "growth" in all fields (in a similar way as the notion of "progress" before), giving an important imprint to plantation forestry, which began to be understood in monetary terms. As one expert put it: "no more time must be lost to start big industrial pulpwood afforestation programmes" (Deville 1975: 3). The last decades have shown that forest plantations in the tropics can be vital financial investments.[5] These developments encouraged the second boom of Eucalyptus plantations during the 1980s due to that species' potential for biomass production and very high growth rates. Used for large scale industrial plantations, Eucalyptus became the most widely planted species in the world. But at the same time from the 1980s onwards, especially at the end of the Cold War, the voice of the civil society gained some attention and recognition, supporting social forestry and increasing the role of non-governmental organizations (NGOs) in tree-planting. At the beginning of the 1990s, a huge increase of NGOs active in the forestry sector could be observed.[6]

In the 1990s global thinking and transboundary concerns regarding deforestation, sustainability or climate change led to the global governance architecture with institutions, conventions and fora trying to establish dialogue and in some cases coordinate common efforts to address pressing global problems (Kanowski and Savill 1992). However, forestry has never been regulated in the form of a single global regime due to the stalemate in the negotiations of the UN forestry convention, firstly with the Intergovernmental Panel on Forests (IPF) and later with the Intergovernmental Forum on Forests (IFF). Despite years of negotiations, no legally binding instrument could be agreed on. Instead, the UNFF was established.

The IFF was successful in catalyzing an international expert meeting dedicated to plantations entitled "Role of Planted Forests in Sustainable Forest Management" in Chile in 1999 (IFF 1999). The UNFF maintained this promising process, bringing together plantation related experts at the meeting in New Zealand in 2003 (UNFF 2003). However, the evolving IPF/IFF/UNFF was criticized for remaining a loose forum and for remaining the main advocate of forestry within a fairly narrow, production-oriented approach, with the state sovereignty over forest resources as the unquestionable principle (Chaytor 2001, Dimitrov 2005, Werland 2009). The focus of these international institutions remains fast-growing tree plantations and ascribes to international cooperation only the coordination of global resource supply. However, especially after the Rio Earth Summit of 1992 and the Millennium Development Goals, new global discourses are redefining the role forests (Brown 2002), and thus plantations should play in the 21st century by stressing their importance in poverty alleviation, climate change mitigation (carbon sinks) and adaptation (e.g. mangrove plantations), biodiversity conservation and desertification debates (cf. Bauhus and Schmerbeck 2010, Böttcher and Lindner 2010). These new inputs and expectations create tensions with the existing global forestry regime, an issue that will be discussed at a later stage.

PARADIGM SHIFTS IN PLANTATION FORESTRY

Based on the discussed interrelation of forest plantation politics with global historical and economic development approaches, as well as the proposed operationalization of elements for analysing and describing a plantation paradigm (Table 1), a categorization of paradigms in plantation forestry (including some sub-variations) can be put forth (Table 2).

"Man-made forests" were initially planted according to what can be called a *pre-industrial* paradigm, where plantations provided particular goods (forest products) or services (aesthetic, cultural) to human communities which until the development of modern, industrial capitalism were neither privatized nor quantified in monetary terms. Also, the forest land was either a *common (patrimonium)* or a *dominium* (Pretzsch 2003). But even in the latter mode certain traditional rights for forest use were provided, thus having a *non-exclusive* land ownership character. At a general level this can be said both of Europe, or the West, as well as the non-European contexts. The other important elements are community-based forest management practices and a certain "micro" perspective on plantations, which were at the time small-scale and developed according to local needs in a bottom-up manner. Lastly, plantations were based on traditional forms of knowledge, in which the emerging natural science disciplines (botany, forestry) were not yet prioritized. At that time, the still abundant natural forests were able to fulfil the demand on timber and non-timber products and, therefore, the level of production of forest plantations was low.

This last factor rapidly changed with the outbreak of the industrial revolution. The subsequent growing demand for

[5] Especially the pulp and paper production strongly shifted to Southern tropical countries, where the climate is more suitable for fast growing trees. Moreover, land in these regions is more affordable, wages are low and there are generally few barriers for industrial expansion (Lang 2007).

[6] While during the 9th World Forestry Congress in 1985, the General Director referred to "hundreds of NGOs", six years later, at the 10th Congress in 1991, "literally thousands of NGOs" were mentioned (Unasylva 1985, Unasylva 1991).

TABLE 2 *Paradigms in Plantation Forestry*

PARADIGM (approximate period)	**Land Ownership / Forest Management**	**Understandings / Goals of Plantations**	**Governance**	**Knowledge and Expertise**	**Capital Source / Potential Growth Rate**[1]
1. PRE-INDUSTRIAL (until the 19th century)	Non-exclusive ownership Community-based	Material goods and non-material services equally important, production among many other goals	Bottom-up approach	Local	Individual and community planting, low capital requirement Low growth rate
2.a INDUSTRIAL COLONIAL (ca. 1900–1960)	Exclusive ownership Concentration of land Central control, designated authorities	Economic goals, "progress" (technocratic forestry)	Top-down (colonial State-plantations)	European/ Northern scientific forestry	Imperial enterprises, first big capital investments in plantations Low to moderate growth rate (mainly valuable hardwood)
2.b INDUSTRIAL POST-COLONIAL (NATIONAL) (1950–present)	Central control, National Forest Departments		Top-down (newly independent State-plantations)	National scientific forestry educated in Europe	State incentives Moderate growth rate (both softwood and hardwood)
3. PROTECTIVE (ca. 1960–present)	Public; State and community land (generally non-exclusive) National Forest Administration	Protective function of planting trees (regulating water, windbreaks, protecting soil against erosion etc.) Plantation's function perceived both in local and broader terms	Usually top-down, regulated by environmental legislation	National scientific; Local and national priorities	State-financed or compensated by state Low production (not a goal), similar to natural forests
4. SOCIAL (ca. 1970–present)	State and village common land, regulated community use (non-exclusive) Participatory management.	Equitable growth (responsible forestry)	Horizontal	Multiple; local knowledge, adapted technology transfer Participatory local governance	Community investment, projects financed by bilateral, multilateral organizations, NGOs, private foundations Moderate growth rate (lower productivity in agroforestry systems)
5.a NEOLIBERAL (ca. 1980–present)	Exclusive, private land accumulation Private	Profit	Top-down	International Scientific Forestry	Private sector investments, multinational capital ventures, High growth rate
5.b NEOLIBERAL MODIFIED (ca. 1990–present)	Exclusive, with partnerships agreements Outgrower schemes		Top-down with participatory elements	International Scientific Forestry, Local Knowledge	Private sector investments with farmers contribution (land) Can reach the growth rate of neo-liberal, although usually lower

[1] Precise and comparable general data on productivity (and therefore on production potential) of different types of tropical forest plantations were and are not available. The only existing data are referring to quite recent periods and specific species (e.g. Carle *et al.* 2003, Carle and Holgrem 2008) and/or genera (e.g. Tiarks *et al.* 1998). A comparison of Mean Annual Increments provided by the FAO plantation database and the FAO reports show quite high differences depending on the source of the data and species. Thus, to calculate and estimate the full production potential on the basis of productivity is problematic. It is clear, however, that different plantation types display significantly different growth rates and this factor needs to be acknowledged when plantation paradigms are discussed and compared. To illustrate the growth rate differences we used a simple tripartite scale: low, moderate and high. Exemplary growth rates and clues about production potentials of plantations can be drawn from the assessment of 16 plantation experimental plots in tropical and sub-tropical sites analyzed in the period 1995–2005 by CIFOR, where a range of annual growth rate is reported varying from 6 to 46 m3/ha/year for tropical and sub-tropical plantations (with 4 main species taken into consideration) (Nambiar and Kallio 2008).

TABLE 2 *Continued*

PARADIGM (approximate period)	Land Ownership / Forest Management	Understandings / Goals of Plantations	Governance	Knowledge and Expertise	Capital Source / Potential Growth Rate[1]
GLOBAL POLITICAL (1992–present)	Project dependent, i.e. state, private, Lease agreements. Project-defined, according to developed standards	Resources supply for the global market Global/National	UNFF	Political framing, International Experts, Negotiations, Global priorities	Private and state investors High growth rate
		Climate Change Global	UNFCC		Private and state investors Still unclear (few and recent projects, i.e. CDM)
		Biodiversity Global/Local	UNCBD		State incentives Low production (not a goal), similar to natural forests
		Desertification Global/Local	UNCCD		State and community driven Very low growth rate

wood products and other large-scale processes influenced the shift to the *industrial* paradigm. The industrial, exhaustive mode of production started to dominate the developed world, and quickly also its colonies, soon affecting forest plantations management practices. The modern industrial capitalism, with its emphasis on private, exclusive property rights, also influenced forest plantation land ownership modes. Whereas the land in Europe was most often parceled already, and thus expensive to obtain, the status of land in the colonies was less clear (Bryant 1996). Traditional land tenure of the colonized peoples was overlooked, and the European understanding of property was transplanted to non-European contexts, a conceptual move that creates unresolved conflicts until today. The scientific revolution of the Enlightenment introduced a formalized practice of science, which marginalized competing forms of knowledge (i.e. traditional/local) and constituted the expert status of European foresters as the group monopolizing the rational decision making regarding plantations (Steinlin and Pretzsch 1984).

Whereas decolonization meant a very important political shift in the developing world, in plantation forestry the change was not that significant. That is why the new mode of thinking about planted forests can be seen as an extension of the previous industrial paradigm, in a *post-colonial* (or – *national*) form. One of the changes occurred in the organization of plantation management. Various colonial authorities, either façade or real, were replaced by national forestry authorities of newly independent states, and governments became key actors (Bull *et al.* 2006, Williams 2001, Zaman 1967). This change had no structural impacts, plantations governance remained as detached from the local populations "on the ground" as that conducted under the colonial paradigm. National forestry agencies were the site of expertise and "were largely staffed by people who shared the same educational background, and they tended to develop strong internal cultures and to harbour entrenched views about how forests should be managed" (Sayer and Elliot 2005: 40). The exclusive land ownership form – either private or national – was maintained (Brown 1967), as well as their main goals as "productive plantations" (i.e. mainly to satisfy the growing demand for industrial timber) (FAO Secretariat 1967). In the state-promoted industrial plantations, the monoculture debate started, with many environmental groups starting to oppose monoculture fast-growing and often genetically modified tree species as a threat to biodiversity (Cossalter and Pye-Smith 2003).[7]

In a somewhat parallel way, even if it seems difficult to pinpoint the precise moment, also "protective plantations" developed (FAO Secretariat 1967), gradually increasing in the last 20 years.[8] Often planted on state-owned land, their governance patterns depend largely on country-specific environmental regulations. In some forms, the protective function of planted forests was perhaps known since pre-modern times. However, in their modern form, they are also linked to modern forestry science as the dominant form of knowledge. With pre-industrial plantations they share low productivity and their service orientation, which is not meant to generate profit in the immediate sense (although such suggestions were also made: Kolar 1961). Their functions can be as different as regulating water, creating windbreaks, protecting soil against erosion and preventing landslides. The scope adopted is linking local and national protection conditions.

From the 1970s, with the growing emphasis on equitable growth and environmental concerns of development, a radical shift in forest plantations to the *social paradigm* can be observed, although its development paralleled the existence of the industrial paradigm. Many previously marginalized actors and discourses were to play a role (FAO 1994, Ngamsomsuke and Saenchai 1987). An emphasis on participatory orientation in governance was coupled with a non-exclusive perspective on land ownership, which acknowledged the needs of various stakeholders and was closer to the concept of the planted forest as a *common* (FAO 1987). Plantation forestry in this paradigm was also growing more receptive to previously excluded forms of knowledge (Bacon 1967), and in its present form (especially clear in some NGO-led plantations) aims at the reinvigoration of local forestry knowledge, which is site-specific. Within this mind-set it was then acknowledged that "there are multiple ways of managing forests lands, and that what is desirable in one location at a point in time may well be different from what is wanted in another place or a different time" (Sayer and Elliot 2005: 40). In its initial form, it meant that uniform ideas of technology transfer (i.e. whatever works in the North should also eventually work in the South), were adapted to local specificities. In this sense also the paradigm has a more balanced scope, attempting (not always successfully) to couple top-down planning (development) with bottom-up signals.

With the neo-liberal ideas (based on the concept of growth, privatization, and deregulation), large industrial forest plantations for pulp production moved to the South due to land "availability", cheap labour and weak environmental regulations (Carrere and Lohmann 1996). In 1992, 70% of the total high-yield planting was in the South, while as much as 84% was on private lands (Moulton *et al.* 1993 in: Sedjo 1999). The inclusive tendencies of social forestry characterizing the previous decades were countered with a return to exclusive modes of land ownership and private property rights guaranteed by the national governments. Powerful private investors were also often able to secure government non-interference in plantation management, which can be observed as the role of

[7] The negative standpoint evolved with time, leading to the current site-specific approach to plantations adopted by many NGOs (plantations should be locally judged according to what function they play and what they replace); but in the climate change debate the carbon storage discourse is sometimes stronger than the conservationists, gaining new NGO attention even for monoculture tree-planting.

[8] According to FAO State of World's Forests (2010), about 22% of forest plantations and about 26% of all planted semi-natural forests have been explicitly assigned a protective function (Masiero and Secco 2013).

national agencies diminishes, even in the eyes of international organizations and UN agendas (Bayly 1991). In this paradigm, the goal of plantations is profit maximization, and although this is indirectly meant to create national growth, the link is not as clear as was in the case of "plantations as tools of progress". Under this paradigm, very high growth rates are being achieved, as for example the official growth rate for Eucalyptus in Brazil ranges between 45–60 m^3 ha^{-1} $year^{-1}$ but some GM tree species can even reach 90 m^3 ha^{-1} $year^{-1}$ (Evans and Turnbull 2009). This drive towards narrowly defined economic benefits was already visible in the 1960s (Wendelken 1967).

The corporate, *neo-liberal* paradigm, as perhaps no other since the *industrial colonial/national* one, creates conflicts, most importantly over land tenure and land use rights (in the face of which many societal opposition movements developed; the Mapuche in Chile or Thai movements against the large pulp and paper transnational companies may serve as examples [Pye 2005]). For those reasons, a modification of the paradigm can be observed, blending certain limited ideas about non-exclusive land use (Varmola and Carle 2002). An example is the idea of *outgrower schemes* (Race and Desmond 2001). However, this is sometimes only a means to merge private management with local property rights, but not necessarily land ownership. In some cases the dominant scientific forestry is also reinforced with local traditions, although the goal is still financial profit.

The last, still emerging paradigm can be termed *global political*. It grows outwards from a general shift towards "global thinking". The four sub-strands, or offshoots, of this paradigm, are looking at plantations through the lens of traditional wood resource supply in the market, climate change, biodiversity conservation and combating desertification. This implies that while science plays a crucial role, forestry is no longer the dominant discourse. Biology, climatology and other disciplines are the discourses which set the political agenda and from which the new definitions of plantation goals and understandings emerge. Project-based planning and management, typical for plantations of these new types, is on the one hand flexible, but on the other maintains a limited temporal scope, rather short-term. The high politicization of this process needs to be clearly underlined. The question of land ownership is not settled, often case-dependent, linked to the actors responsible for planting.[9] Forest plantation management becomes involved in the multi-polar and fluid global governance. That is why it is difficult to point to the most important authorities (although all private, national policy-making and third sector remain important) and the regulations are often contradictory (as for example between plantations seen from resource-based, climate change and biodiversity perspectives). The level of focus also varies, although global justifications of plantation efforts are a very important change. Forests, previously perceived as national resources, have with time shifted to be seen as "global commons", or a "global heritage". This is related to the acknowledgement of deforestation as a problem on a global scale – making forests (also planted) a global resource. However, the UNFF is defending the traditional view of forests as national resources under the sovereign authority of states and advocates a very soft law role of a global forestry regime as disseminating information and providing data (Brown 2002).

The *global political* paradigm and its mutually contradicting offshoots change the previous step-wise evolution of paradigms in plantations. Previously there were similar tensions in the field, as between the *industrial* vs. *protective* or *neo-liberal* vs. *social*. However, they evolved slowly and as a result of certain externalities. By contrast, the *global political* paradigm embedded in the UN institutional framework gives many new views, ideas and incentives to organize tree planting, which are not compatible with one another. The initial development of paradigms was closer to the Kuhnian paradigm revolutions (*pre-industrial to industrial*) while subsequent developments are examples of paradigm evolution (*industrial colonial* to *industrial national* or *neoliberal* to *neoliberal-modified*). Since the 1990s, more of a "policy stretching" can be observed that is enlarging the policy paradigm area and the inclusion of new concerns, actors and institutions as well as institutional layering with decreasing intellectual coherence within the original paradigm (Feindt 2009 and 2010).

CONCLUSIONS

Paradigms in History: What can we learn?

It is important to critically assess the evolution of plantation paradigms and its parallels to global developments for a diagnosis and lessons to be learned for the future. In the following, some key observations on the shifts of forest plantations paradigms are reported, including: the limited adaptive capacity of the forest plantation domain to respond to external developments; the weaknesses of inter-disciplinary exchange and inter-sectorial coalitions; the inadequate evidence of learning from failures; the opportunities and threats connected to paradigm plurality; and the need for a more transparent global forestry regime (cf. Rosendal 2001, Werland 2009).

Passive adaptation to external developments

The first critical observation is that all the shifts in paradigms are responses aimed at the adaptation to other developments 'on the outside' – in economic and development policies on the global arena rather than the result of an internal learning process. It is visible that forestry science represented in the epistemic community and its ideas on how to organize plantations are adapting to external factors rather slowly. The

[9] It is worth mentioning that about 50% of productive forest plantations are owned and managed by public entities, a percentage that is sensitively lower than the one referring to plantations that are managed for protection purposes. The remaining part is under private sector smallholder (32%) and private sector corporate ownerships (18%) (Evans 2009b).

industrial-colonial paradigm was not even questioned after the end of the colonization era but the *industrial-national* paradigm took over and remained completely detached from local inputs, bringing social conflicts, environmental degradation and false incentives. Similarly, the emergence of the *social* paradigm was caused rather by external factors: strong criticism of failures in plantations and changes in development aid. It was also late in coming, as it took time to be adapted in foresters' curricula.[10] The emergence of the *neo-liberal* paradigm was caused by an attractive cost-benefit ratio, stable demand and shortening rotation periods attracting private investors worldwide. Its modification in the form of outgrower schemes is similarly a late response to the plantation governance architecture caused by social conflicts rather than its own innovative driving force.

Lack of inter-disciplinary exchange and inter-sectorial coalitions

Traditional silviculture was for a long time missing a social scientific component and displayed insufficient problem-solving, policy-oriented capacity as well as a critical self-reflection going beyond the narrow confines of the discipline. To cope with today's complex problems and needs, it should adopt a more active, strategic role and contribute to public debates and political forums (Savenije and Dijk 2010: 70). This lagging behind is visible in the latest developments, where plantations have been subsumed under different global regimes, while the forestry epistemic community was to date not able to work out any internationally acknowledged standards for both natural forests and plantations.[11] Even with the private certification schemes combining good practices on plantations with market information (Cubbage *et al.* 2010), forestry regimes become even further fragmented and non-transparent. The forestry community seems similarly powerless in giving shape to climate change mitigation and adaptation mechanisms relevant for the sector. Due to the lack of robust inter-sectorial connections, the epistemic community of foresters faces a political marginalization in the ongoing negotiations and "frequently watches from the sidelines and feels to a certain extent excluded from decisions" (Savenije and Dijk 2010: 67). To enhance these inter-sectorial connections, forestry, also plantation forestry, should look for synergies with other scientific disciplines on the one hand and technical sectors on the other, to bring adequate responses to the current problems. Studies of the core gatherings of the epistemic community reveal, however, changes towards a more critical and open attitude. While during the first man-made forests symposium in Australia in 1967 the inputs were repeating the dominant paradigms and different voices were very marginal (as Bacon 1967), the last World Forestry Congresses had inclusive agendas and provoked important debates (WFC Bulletin 2003 and 2009). The institutional symptom of the strengthening of this trend is the emergence, in 1998, of The Forest Dialogue (TFD 2013), a catalyst of expertise-sharing between individuals representing different stakeholder categories. It is telling that planted forests, once a minor issue, are high on the agenda of this recent voluntary forum within the forestry epistemic community.

Self-reflection and learning from experience

In the light of the politically and socio-economically entangled history of plantation efforts, forest plantations need to be perceived as complex projects, which may fail (or be successful) due to very different factors ranging from silviculture and technical issues to various social, environmental, economic, managerial and organizational reasons and such records of both failures and best practices would be a valuable input into plantation research (Gerber 2010). Even the newly emerging carbon plantations already show traces of insufficient reflection on past experiences and may be repeating their mistakes. Today, once again a global enthusiasm for large-scale tree-planting in the tropics can be observed, perceived as a solution for global problems (previously wood demand, now additionally climate change mitigation). Due to high prices for validation and sophisticated carbon methodologies, carbon projects re-establish colonial dependencies, where external experts and companies organize planting activities in the developing world. Similarly, large plantations are favoured due to the mentioned validation costs. As these plantations have one main goal – to gain emission reductions for sale on the market, the carbon plantations are very strongly moving towards the *neo-liberal* top-down paradigm. By promoting exotic species in monoculture stands and the accumulation of land in foreign hands, they may repeat the failures from the 1970s and 1980s where large-scale planning in plantations resulted in negative social and environmental externalities. Learning forums play a critical role for the inter-sectorial and interdisciplinary exchange and self-reflection mentioned in the previous paragraph. In spite of the apparent grid-lock on the global political forum (UNFF), or perhaps in response to the limits of the top-down approach, signs of positive bottom-up learning initiatives are emerging within the forestry epistemic community. These include the New Generation Plantation project, which collects knowledge and good practices to promote better plantation management across the globe (NGP 2013). Certification, insistence on transparency, rising consumer awareness or engaged journalism (see: Carrere and Lohmann 1996) are means for making also regular citizens and consumers part of the process.

Paradigm plurality – opportunity and threat

As the historic analysis indicates, when one paradigm gets a hegemonic position, other views can face marginalization. It has already been noted that the attention paid to the climate

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[10] For a critique of slowly changing curricula of foresters and other limitations see: Sood and Mitchell 2009.

[11] Out of 42 standards and guidelines for sustainable/responsible management of forest and/or forest plantation, only 11 are specific for the latter, and most of them are country-specific (for example for forest certification purposes in Brazil, Chile, Indonesia and Malaysia) (Masiero and Secco 2013).

change mitigation through plantation establishment is marginalizing other discourses on the forest plantation agenda (Pontecorvo 1999, Rosendal 2001). Social forestry, a remedy developed for local participation in global timber supply, a concept which still needs scholarly attention and on the ground experience, has become neglected. Discussing the XIII World Forestry Congress gathering, Savenije and Dijk state that "the topic of forest and climate had little visibility in 2003 and hardly any role at the XII World Forestry Congress, but in 2009 it was of the greatest interest, attracting the largest audiences" (2010: 67). And they continue: "for many years, participation by local population in forest management, in the form of community forestry and social forestry, was strongly promoted as the way to sustainable forest management. Although interest in this subject has not actually disappeared, it no longer takes an important place in the discussion (Ibidem: 68)". With the waning attention for the *social* paradigm, both its positive and negative experiences could be forgotten instead of being used to guide new plantation efforts. However, both the climate mitigation perspective and the social paradigm could be compatible to assure benefits for the local populations, investors and the international community. Multi-purpose plantations are a solution, but clear guidelines and monitoring mechanisms are necessary. And even if the carbon plantations are more present at the discursive level than on the ground,[12] today's debates are often shaping the realities of the future. Therefore, it is important to build dialogue between the different paradigms at this stage already. The same is important for the *neo-liberal* paradigm, or the internally divided *global political* paradigm, to open for learning and synergies. The positive changes in that direction include the spread and formalization of multi-purpose plantations (Evans 2009b). Although in some sense all plantations were serving more than one purpose at once, the novelty in this form is that plantations are consciously maintained to serve multiple goals, without prioritizing one of them. From a governance perspective, however, this still remains a challenge and the actual know-how for such multi-purpose plantations is at early stages of development (cf. FAO 2010).

For a more transparent global regime

Lastly, the UNFF has yet to prove useful and successful in bringing the expert knowledge from the epistemic community to transnational policy-making and to shape global forestry governance and plantation politics. As numerous other studies point out, it failed to coordinate the complex institutional set-up with various actors, duplicating work and producing overlapping guidelines. Neither ITTO (1993) nor FAO (2006) guidelines on plantations nor any certification schemes are *binding* governance instruments. The plantation regime remains based on soft law clusters with a growing amount of fragmented and to some extent contradictory rules (cf. McDermott *et al*. 2010). Standards elaborated by intergovernmental organizations (FAO, ITTO), certification bodies (FSC and other, see: Masiero and Secco 2013) or UN forums and conventions (UNFF, UNFCCC, UNCBD, UNCCD) cause an institutional chaos and may provide contradictory incentives (Rosendal 2001, cf. UNFF 2003: 8). On the other hand, Glück *et al.* (2010) argue, that the challenges arising from that multiplicity can be changed into opportunities, by means of 'forest+ policies' that "acknowledge the inter-sectoral character of forest policymaking and the importance of international regimes" – beyond forestry (Ibidem: 52). A better institutional set-up could put forestry and plantation issues higher on the agenda and introduce better standards, research funds and information flows.

Concluding remarks

Plantation efforts analysed from a macro perspective show strong interlinkages between the general historical and economic developments. The changes in plantation forestry can be categorized as paradigm shifts. In the case of tropical developing countries, the impact of the *industrial colonial* paradigm was perhaps the strongest, and through the shift to *industrial national* paradigm (which kept many of the features of the former), influenced tropical plantation forestry for decades. The categorization of paradigms proposed here reflects the mutating assumptions, values and practices in the field and takes into account both social structures and agency. It shows that currently a paradigm plurality can be observed (rather than the hegemony of one concept), and internal fragmentation (especially visible in the late-in-coming *global political* paradigm).

The debate on plantations is highly important for the metaphorical "people, profit and the planet" (van Bodegom *et al.* 2008), especially in the face of demographic growth, risks coupled with climate change and world economic crises. It should call for a problem-solving attitude in the field, better synergies with other scientific disciplines and technical sectors, historical diagnosis and records on plantations' performance and externalities, establishment of learning mechanisms (forums), an internal dialogue between the different paradigms and a more transparent institutional setting on the global level.

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[12] Chokkalingam and Vanniarachchy (2011) report only 22 registered Clean Development Mechanisms (CDM) afforestation and reforestation projects worldwide from more than 3 000 CDM projects in total.

ABBREVIATIONS

CDM – Clean Development Mechanism
FAO – Food and Agriculture Organization
FRA – Forest Resources Assessment
FSC – Forest Stewardship Council
GM – Genetically Modified
IFF – Intergovernmental Forum on Forests
IMPF – Intensively-Managed Planted Forest
IPCC – Intergovernmental Panel on Climate Change
IPF – Intergovernmental Panel on Forests
ITTO – International Tropical Timber Organization
NGO – Non-governmental organization
REDD – Reducing Emissions from Deforestation and Degradation
UN – United Nations
UNCBD – United Nations Convention on Biological Diversity
UNCCD – United Nations Convention to Combat Desertification
UNFCCC – United Nations Framework Convention on Climate Change
UNFF – United Nations Forum on Forests
WFC – World Forestry Congress

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The future of plantations in Africa

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SUMMARY

The increasing demands now being placed on Africa's natural and planted forests mean that they cannot sustainably supply the wood products the continent needs. Serious shortages of wood are forecast in many countries for the near future and this has serious socio-economic implications as well as contributing negatively to global climate change. Whilst tree plantations have long been seen as a way to combat such impacts by producing wood products in a cost-effective way, the current level of tree planting in Africa is well below the level required to meet the predicted demand from the populace and industry.

Of the estimated 3.8 million hectares of commercial plantations in Africa, the most successful ventures have generally been where the private sector has been encouraged and supported to invest in commercial-scale tree planting and these point the way to the future expansion of plantations in Africa.

Keywords: forestry plantations, Africa, commercial forestry, tree planting, forestry investment

Futur des plantations en Afrique

P.A. JACOVELLI

Les demandes croissantes pesant sur les forêts naturelles et de plantations en Afrique signifient que ces dernières ne peuvent plus fournir la demande du pays d'une manière durable. Une pénurie sérieuse de bois est prévue dans de nombreux pays dans le futur proche, ayant de sérieuses implications socio-économiques et contribuant négativement au changement climatique. Alors que les plantations d'arbres ont été longtemps considérées comme à même de combattre de tels impacts en produisant des produits du bois à bon marché, le niveau actuel de plantation des arbres en Afrique est bien en deça de la prévision du niveau nécessaire pour faire face à la demande de la populace et de l'industrie. Sur les 3.8 millions d'hectares estimés de plantations commerciales en Afrique les initiatives ayant eu le plus de succès ont généralement été celles où le secteur privé a été soutenu et encouragé dans l'investissement à planter des arbres sur une échelle commerciale. Ces initiatives montrent le chemin à emprunter pour parvenir à une future expansion des plantations en Afrique.

El futuro de las plantaciones en África

P.A. JACOVELLI

La creciente demanda que están acusando los bosques naturales y las plantaciones de África supone que no van a ser capaces de proporcionar de forma sostenible los productos de madera que necesita el continente. Se ha pronosticado a corto plazo una grave escasez de madera en muchos países, lo que supone graves consecuencias socio-económicas, así como una contribución negativa al cambio climático global. A pesar de que las plantaciones forestales han sido consideradas durante mucho tiempo como una forma eficaz en función del costo de combatir estos impactos mediante la obtención de productos de madera, el nivel actual de la plantación de árboles en África está muy por debajo de las cifras necesarias para satisfacer la demanda prevista de la población y la industria.

De las aproximadamente 3,8 millones de hectáreas estimadas de plantaciones comerciales en África, las inversiones con mayor éxito han sido generalmente aquellas en las que se ha alentado y apoyado al sector privado a invertir en la plantación de árboles a escala comercial y éstas señalan el camino para la futura expansión de las plantaciones en África.

INTRODUCTION

Africa's once abundant natural forests cannot now meet the demands being placed on them by a rapidly growing population and fast-developing economies. With the widespread realisation of the importance of the remaining natural forests for mitigating climate change and for environmental protection, the timber, poles and woodfuel that traditionally came from such forests will have to increasingly come from other sources. Large scale tree planting – whether it is intensively managed, commercial plantations or widespread planting by small farmers – offers a potential solution to this problem. As pressure on land (including existing forests) increases in many African countries, the need for large scale tree planting is rapidly strengthening.

There are 56 countries[1] that comprise the diverse African continent and many of these have an extremely attractive environment – both climatically and economically – for growing trees. Although the first tree plantations in Africa were established over 100 years ago, investment in the sector has lagged behind many other regions in the world. Indeed, tree plantations in Africa have a rather chequered history, with some major plantation investments failing spectacularly, at least in economic terms. Other planting initiatives – both large and small scale – on the continent have performed way below their expectations, for a variety of reasons which will be discussed later. There has also been some very negative publicity surrounding tree plantations in Africa in recent years too – including claims of 'land grabs' by investors and of trees sucking up all the water and nutrients in the soil. Such criticisms have heavily influenced public opinion (and that of some policy makers) against forestry plantations: this is despite the clear benefits that well planned and managed plantations can bring to countries, especially in African countries with a heavy dependence on forest products.

It is not all doom and gloom though as there are some notable success stories with tree planting initiatives throughout the continent – including countries as diverse as Zimbabwe and Senegal. Sustainable, commercial forest industries are now contributing significantly to the economies and people's livelihoods in South Africa, Swaziland and Zimbabwe. In addition, major investments are currently being made by the private sector into commercial plantations in a number of countries, including Uganda, Tanzania, Mozambique and Ghana. There has been successful planting of various species (especially *Pinus* spp.) on a massive scale in Northern African countries such as Morocco, Tunisia, Algeria and Mali to protect against desertification. In North-Eastern Africa, huge numbers of *Acacia senegal* trees have been planted for the production of gum arabic (a water-soluble gum used in the production of adhesives, confectionery and pharmaceuticals). In West Africa, plantations of rubber *(Hevea brasiliensis)* and teak *(Tectona grandis)* have succeeded, whilst South Africa now boasts a world class, plantation-based industry of over 1.2 million hectares. Eucalypts in particular have been widely planted throughout the continent – by small farmers and commercial investors alike – for a variety of end-uses such as pulp, transmission poles, woodfuel and increasingly for sawn-timber.

For all these successful initiatives, however, the level of establishment of new plantations (and sound management of existing ones) in Africa is far below what is required to meet the predicted demand for key forest products such as timber and especially woodfuel. Many African countries are now importing wood and wood products which has contributed to deforestation beyond their borders, a good example being timber coming from the Democratic Republic of Congo to supply East Africa's timber needs (WWF 2012). The level of new planting is worryingly low though when one considers the rate of deforestation on the continent and the rising demand from a populace heavily dependent on wood. This paper discusses the key factors that have influenced plantation development to date in Africa and highlights what is currently holding back investment into plantations on the continent. The approach taken is to learn from the experiences to date that can point the way to more successful initiatives in the future. It is the author's belief that only by understanding the lessons of the past (both good and bad) can we unlock the immense potential provided by plantation development to meet not just Africa's current and projected wood requirements but also to help sustain the fast economic growth now underway in many African countries.

A BRIEF HISTORY OF PLANTATIONS IN AFRICA

It should be noted that this section does not attempt to be a definitive history of plantations: this has been comprehensively carried out elsewhere, most notably by Evans and Turnbull (2004), and Evans (2009). It does, however, provide a summary of the main plantation developments and trends in Africa. The history of forestry plantations in Africa can be summarised conveniently as falling into five phases – from the early days of tree planting, through to the state's increasing control of forests, the industrial plantation period, the rise of the private sector and finally, to the 'new wave' of investors currently involved in plantations around Africa. Each of these phases is briefly discussed below but it should be noted that there is no hard and fast division between each era and there are substantial differences in focus between various countries experiences with plantations too.

The early days

For a long period Africa's natural forests were able to provide the needs of the indigenous people – notably in terms of wood for construction, fuel and numerous non-timber products (e.g. food and medicines). As populations grew and industries

[1] As recognised by either the African Union or the United Nations or both.

evolved, however, the natural forests soon could not meet the demand, especially around the main settlements, and this triggered the planting of trees to meet specific needs. The first significant tree planting was of tree species known to people – particularly the early settlers on the continent – which included useful shade and fruit trees as well as the first introductions of species which had performed well elsewhere, notably *Eucalyptus* spp.

State control and commercial plantations

This realisation that the natural forests were finite and their exploitation needed to be regulated triggered state intervention and many forests were officially brought under State control. The State took on the main responsibility of planting trees too, often through various enrichment planting systems within natural forests. When this proved largely unsuccessful (and often very expensive in tropical areas), attention turned to more commercial-scale planting usually with fast-growing pioneer species like pines and eucalypts. These early plantations aimed at providing products such as fuelwood for the railways (e.g. eucalypts in East Africa), timber for construction (pines in South Africa) and fuelwood for people (eucalypts in Ethiopia).

The industrial plantation period

From the 1960s onwards, plantation forestry really gained momentum on the continent. This plantation expansion in the 1960s and '70s was largely undertaken by the state Forest Departments supported by international development organisations such as the World Bank and the UK's Commonwealth Development Corporation. With the 20:20 vision of hindsight, these plantation developments did not always achieve their stated objectives. There were, however, some notable success stories – such as Swaziland's Usutu forest producing pine pulp and the development of quality teak sawlogs for export in West Africa. The state Forest Departments, in addition to taking the lead for establishing industrial plantations, generally took the lead in undertaking research and education to support the growing forestry industry too. Table 1 summarizes the main industrial plantation developments in Africa.

The rise of the private sector

From the 1980s onwards there was a major shift towards bringing the private sector into the commercial forest sector, which coincided with a move towards privatisation globally. It was also brought on by a shift in policy from the donor community, who were not happy to keep funding the public sector without always seeing value for money. In many countries around the world, the State initiated the process of relinquishing control of production forests and encouraging the private sector to take over the role of establishing and managing commercial plantations. For the first time private growers were thus seriously encouraged to plant trees on a commercial scale.

This 'paradigm change' has taken place on various levels from small growers, through to community, participatory tree planting schemes as well as some large scale private investments in industrial plantations. Forest policies were reviewed and reformed in a number of African countries (e.g. Ghana, Rwanda, Uganda, Kenya and Tanzania) paving the way for the private sector to actively invest in commercial plantations, which had previously been dominated by the state. The private sector have now become a major force in tree planting in many African countries – with or without support from the State – as people have seen the potential of tree planting as a cash crop.

The 'new wave' of investors

The most significant development impacting on plantations in the last ten years or so in Africa has been the rise of private equity and venture capital funds being invested in the sector. These companies look to diversify their investment portfolios and are not averse to the long term nature of forestry. Most of these new plantation developments are 'green-field' investments (i.e. new planting), but most investors prefer having at least some standing, mature crops from which they can gain some early returns. Financing comes from various sources including development banks (e.g. European Investment Bank, African Development Bank and the International Finance Corporation), pension funds and other 'green' investment funds from both private and public sources. Many are also targeting Carbon markets too, though this avenue has proved difficult and frustrating for all except the largest investors. In nearly all cases, the plantation developments must be sustainable, which in this context is defined as reaching predetermined economic, social and environmental standards. The widespread adoption of independent certification through the Forest Stewardship Council (FSC) by the vast majority of the large-scale investors in Africa's plantations, has undoubtedly helped to raise the profile of investment in the sector, though this still has a long way to go.

There are a number of factors that are attracting investment funding into Africa's commercial forestry sector. There is a purely business motivation focussing on the widening supply-demand scenario and the high growth rates of trees possible in some African countries. Then there is a developmental aspect, whereby the world's richer countries are assisting African nations to lift themselves out of poverty. Indeed, some of the venture capital funds (notably the Global Solidarity Forest Fund) combine these objectives by specifically targeting forestry investments in Sub-Saharan Africa. The countries currently attracting investors are nearly all in Southern and East Africa, plus Ghana (see Table 2). Mozambique and Tanzania are attracting the most interest from investors as they offer larger tracts of suitable land, with Mozambique's proximity to the coast for exporting products to Asia being a major plus too.

CURRENT STATUS OF PLANTATIONS IN AFRICA

According to FAO, the area under plantations in Africa has increased by 30% in the past 30 years – up from 11.7M

TABLE 1 *The main historic plantation developments in Africa*

Country	Develop-ment	Start Date	Planted Area (ha)	Principle Funding*	Notes*	Ref.
Angola	State	n/a	148,000			Del Lungo 2009
Burundi	State	1978	80,000	Belgium, France, WB		Nduwamunya 2011a
Pointe Noire Congo (DRC)	ECO-SA, Mag Industries Ltd	1978	45,000	Shell	Eucalyptus hybrids; pulp market collapsed. Mag commissioned wood chip plant 2008.	Chamshama & Nwonwu 2004 www.magindustries.com/
Cote d'Ivoire	SODEFOR	1979	20,000	WB & CDC	Technical success; donor supported in 1960's–70's	Chamshama & Nwonwu 2004
Ethiopia	State	1970's	190,000	Church of Sweden		Bekele 2011
Ghana		n/a	160,000			Del Lungo 2009
Kenya	Govt. Reserves	n/a	90,000	DFID & WB	Poorly managed; much now over-mature	Mathu & Ng'ethe 2011
Malawi	Viphya Plantations	1950	53,000	WB	Poorly managed; planned pulp mill never materi-alised	WB 1990
Nigeria		1979	349,000	WB		Del Lungo 2009
Senegal		n/a	332,000	State	Woodfuel + environmental protection	Del Lungo 2009
South Africa	State Private	1870's	213,000 1,060,000	State Mondi; Sappi + other private	6% loss since 2001; privatisation still underway.	DAFF 2012 Godsmark 2013
(S) Sudan	Govt. land	n/a	16,000	DFID & GTZ	CDC/Actis & Finnfund	Gafaar 2011
Swaziland	Usutu Pulp Co.	1950	66,000	CDC & Courtaulds	Successful development; sold to Sappi 1990/2000; pulp mill closed 2010.	Tyler 2008
	Shiselweni Forestry	1967	12,000	CDC	Sustainable business; sold to RSA Growers Coop.	Tyler 2008
	Peak Timbers	1946	20,000	Anglo-American	Mondi sold to GEF 2007	SGS 2010
Tanzania	Kilombero Valley Teak Co.	1992	8,200	CDC/Actis	Potentially sustainable investment; sold to GEF (2011) & Finnfund	Tyler 2008 Ngaga 2011
	Sao Hill (State)	n/a	40,000	WB	Planned (large) pulp mill never materialised	WB 1992
	Tanganyika Wattle Co – Tanwat	1949	15,000	CDC	Sustainable business; sold to private sector Rai group	Tyler 2008
Uganda	State Reserves	1960's-1973	15,000	Norway (NORAD)	Poorly managed; cut & not replanted for many years.	Kabagozza 2011
Zambia	State Copperbelt	1967	55,000	WB/CDC	Poor performance; privatised 2001 (ZAFFICO)	Tyler 2008
Zimbabwe	Border Timbers Allied Timbers	1924	28,000 33,000	Private State	Started as British SA Police Co.	Chamshama & Nwonwu 2004

* WB = World Bank; CDC = Commonwealth Development Corporation (UK); DFID = Dept. For International Development (UK); NORAD = Norwegian Agency for Cooperation & Development; GEF = Global Environment Fund; GTZ = German technical aid.

TABLE 2 *The 'new wave' of investors in commercial plantations in Africa*

Country	Investors	Comments
Ghana	Africa Plantations for Sustainable Development Siricec (Holland) Miro Forestry Co. (Dubai)	
Mozambique	New Forests Co. (UK) Green Resources AS (Norway) Portucel Florestas Do Planalto SA (UPM) Chikweti Forests of Nyassa Florestas de Niassa ABP (Dutch civil service pension fund) Komatiland Ltd. (South African state)	Mostly green-field developments except Komatiland's investment in IFLOMA (with some mature crops) and some with concessions for selective logging in natural forests.
Rwanda	New Forests Company Ltd. (UK)	Mature plantations
South Africa	International Finance Corporation (USA) Global Environment Fund	Hans Merensky Holdings Ltd. – existing plantations + processing plants
South Sudan	Maris Capital	Includes mature Teak concessions
Swaziland	Global Environment Fund	Peak Timbers Ltd. – existing plantations + sawmill
Tanzania	Green Resources AS New Forests Co. Global Environment Fund	Mature plantations, sawmill + new planting Green-field development KVTC – existing plantations + sawmill
Uganda	New Forests Co. Ltd. Green Resources AS Global Woods AG (+ International Woodland Co.)	All green-field developments
Zambia	Green Forestry Development Ltd. (Ireland)	Green-field development

hectares in 1990 to 15.4M ha in 2010 (see Table 3). In terms of commercial plantations, however, these figures are misleading as the majority of what FAO classify as plantations has been planted for protective purposes (e.g. much of North Africa's trees) or for non-wood forest products (e.g. gum arabic from *Acacia senegal* in Sudan and Ethiopia). It is difficult to get accurate figures from a number of countries who do not regularly submit figures and also because the definition of 'plantation' changes too. Recent estimates are that there are probably only 3.8 million hectares of commercial plantations in Africa (Pöyry 2011). South Africa is by far the most dominant player, with a third of the continent's commercial plantations. There are probably only ten countries with more than 100,000 ha of commercial plantations. The recent 'new wave' plantation development discussed in the previous section has yet to have a major impact in Africa, given that the majority are green-field developments.

SUCCESS STORIES

Introduction

In order to learn lessons, this section analyses a number of predominantly large-scale planting initiatives in Africa. Of course the question of how to judge success or failure of forestry investments is a difficult one as the main criterion used to judge is not always the financial bottom-line. From a purely business investment viewpoint, however, the success stories are few and concentrated in southern Africa. South Africa, Swaziland and Zimbabwe stand out as examples of good investments of the past 50 years or so with Uganda, Tanzania and Mozambique illustrating more recent success stories.

Major commercial plantation developments

South Africa's first commercial tree planting was in 1876, when eucalypts were planted to provide firewood for railways locomotives. By 2010, South Africa had 1,275,000 ha of (mostly) highly productive plantations and a profitable, commercial forest industry supplying local demand and a thriving export market of predominantly pulp and chipped-wood. The commercial forest industry is of considerable importance to the national economy and to many rural people's livelihoods. It employs 170,000 people (directly and indirectly) with a further 560,000 in downstream processing dependent on plantation forestry. The vast majority (83%) of the total plantation area in South Africa is privately owned as the State began privatising their holdings in 2000 (at which time they owned 30% of the plantations). Whilst the sector is dominated by large multi-national companies Mondi and Sappi, there are

TABLE 3 *Area Estimates of Industrial Plantations in Africa (NB. only countries with >100,000 hectares; from FAO 2012 unless otherwise stated)*

Country	Area (ha)	Main Species	Notes
Sudan	6,068,000	*Acacia senegal (+ A. nilotica, Tectona grandis)*	Mostly for Gum Arabic production
South Africa	1,275,000	Pines, eucalypts & *Acacia mearnsii*	DAFF, 2012
Tunisia*	690,000	*P. halepensis;* Eucalypts	Sand-dune fixation and shelter belts
Morocco	621,000	*E. gomphocephala* & *E. camaldulensis*	FAO 1981
Mali*	530,000	*Acacia* spp.	
Ethiopia	511,000	*Euc. globulus; Cupressus lusitanica*	Mostly woodfuel and poles
Senegal*	464,000	*E. cam.; Acacia spp.; Casuarina equisitifiolia*	
Madagascar	415,000	Pines	
Algeria*	404,000	*P. halepensis; Quercus suber; E. camaldulensis*	Very slow growing species
Nigeria	382,000	*Gmelina arborea;*	
Rwanda	373,000	*E. grandis;*	Largely on-farm and small woodlots
Malawi	365,000	*P. patula;*	
Côte d'Ivoire	337,000	*Tectona grandis,* Rubber; *Terminalia spp*	
Ghana	260,000	*Tectona grandis; Gmelina; Terminalia spp.*	
Tanzania	240,000	*P. patula*; *Euc* spp.	
Libya	217,000	*Eucalyptus* spp.; *Acacia* spp.	FAO 1981
Kenya	197,000	*Cupressus lusitanica; P. patula; E. grandis*	Use of eucalypt hybrids increasing
Niger*	148,000		
Swaziland	140,000	Pines, eucalypts & *Acacia mearnsii*	
Angola	128,000	Pines spp; *E. grandis/saligna*	State plantations abandoned in war
Burkina Faso	109,000		
Zimbabwe	108,000	Pines, eucalypts & *Acacia mearnsii*	

* Plantations largely for protection purposes rather than commercial production.

an increasing number of small growers in the sector too who are benefiting from the ready market for timber products – especially from eucalypts (DAFF 2012; Dlomo and Pitcher 2005).

Swaziland also has a long history of commercial forestry plantations. Usutu Pulp, which was started in 1950 by the Colonial Development Service (now Commonwealth Development Corporation), established 66,000 ha of pine plantations and became the major employer in Swaziland, contributing 15% to the country's GDP. Until the late 2000s when the market collapsed, there was a strong demand for its unbleached, kraft pulp. The Wattle Company and Border Timbers in Zimbabwe followed a similar pattern by developing commercial plantations and processing facilities. The plantation sector employs around 16,000 people and contributes 3% to the country's GDP (Shumba 2001).

In Uganda there has been a mix of a few large overseas investors with many smaller local investors planting since around 2003. In Tanzania, the Norwegian Green Resources AS are investing substantially in new planting in the Southern Highlands: they are also adding value to trees by treating poles, sawing timber and generating power from the government's Sao Hill plantation. Other private companies are also investing in Tanzania and a major Finnish-funded, government programme started in 2013, which will promote further private sector investment in tree planting in the country. Mozambique is also attracting major investment for plantations (see Table 2), which was triggered by government offering to assist investors with acquiring large tracts of land in the mid-2000's.

Some other commercial plantation investments in Africa have been successful when considered from a wider social and developmental angle. Prime examples are in Ethiopia, Swaziland and Tanzania. In Ethiopia, the state-funded, eucalypt plantations supply much-needed woodfuel to millions of poor people. In Southern Swaziland, Shiselweni Forestry Company provides employment in a region with little other investment. Similarly the Tanganyika Wattle Company (Tanwat) and Kilombero Valley Teak Company in Tanzania provides major rural employment opportunities, even though as pure economic investments they are questionable (Tyler 2008).

Small growers schemes

Uganda offers an interesting case study as it has managed to attract many private investors into commercial plantations, a sector that had previously been almost completely dominated by the State, which had a poor track record of planting and management of plantations. In the 10-year period from 2003 to 2012, over 50,000 hectares (mostly *Pinus caribaea* var. *hondurensis*) have been established by private investors, including many small-scale, Ugandan farmers. This turnaround was largely down to two key factors: firstly, the 2003 Forest Act which paved the way for long-term tree planting permits on government land (Forest Reserves) and secondly, the Sawlog Production Grant Scheme (SPGS) – a semi-autonomous project funded by the European Union (from 2003) and the Government of Norway (from 2006).

SPGS has achieved its results through a potent combination of technical and financial support. It introduced a suite of silvicultural and management techniques into Uganda, such as careful planning and budgeting, site-species selection, using only improved seed, thorough land preparation and intensive weeding. Financial support comes in the form of a subsidy (grant) that covers around 50% of the establishment costs. Importantly, the grant is only paid retrospectively, after a site inspection to ensure that pre-agreed conditions and standards have been met. An important part of SPGS's success has been their communication strategy, which included the publication of practical guidelines, frequent field meetings with growers and the training and mentoring of young forestry graduates in modern plantation management techniques (Jacovelli 2009, Jacovelli *et al.* 2009).

In Kenya there has been an explosion of interest in tree planting by small farmers since the turn of the 21st Century. This interest has been driven by market supply shortages (a ban on harvesting from the state's plantations has been in place since 1999) as well as by excessive cutting for charcoal from forests and woodland areas countrywide. The UK-based Gatsby Charitable Foundation has been highly influential by supplying small growers with hybrid eucalypt clones. Since 1997, Gatsby (through their Tree Biotechnology Programme) have produced and distributed clones and improved seedlings throughout East Africa, including over 20 million to some 12,000 small farmers in Kenya alone. The availability of quality planting material is often a major constraint for commercial tree planting. These fast-maturing plants have provided many small farmers with valuable income as well as woodfuel and poles. In early 2014 (and prompted by the 2010 Constitution), Kenya was reviewing its Forest Policy and legislation to encourage more involvement in commercial tree planting from the private sector.

Research and education

The Southern African forest industry been well supported by professional research and training institutions. A very practical training school for foresters was opened in Cape Town as early as 1906 and this has been one of the main drivers behind the successful plantation programmes in the region. The need for research was also seen at an early stage during plantation expansion and lead to a rich history of applied research, increasingly driven by the private sector. The focus was on silviculture initially although attention soon turned to tree breeding, pests and diseases, timber properties and market research.

There are a number of key institutions worthy of mention in the South Africa context, particularly because they are role models for other countries to aspire to. The Institute of Commercial Research (ICFR) is one such organisation, being funded by companies and organisations in the private sector. ICFR focuses on applied aspects of commercial timber growing and harvesting and its research is conducted in close collaboration with the growers. The Forestry and Agricultural Biotechnology Institute (FABI), at the University of Pretoria is another good example of how to support the commercial forest sector. FABI undertakes applied research (notably in the field of tree health) in partnership with major players in the forestry sector: they promote collaboration, freely share knowledge and most importantly are building human capacity on the continent.

Growers' organisations

Two private growers' organisations in South Africa merit mention – namely, NCT Forestry Co-operative Ltd. (NCT) and Forestry South Africa (FSA). NCT was formed in 1949 and is now the largest forestry marketing organisation in southern Africa, with over 2,000 share-holding members who own 300,000 ha of plantations. NCT have bucked the trend of many co-operatives that have failed on the continent, principally by being run in very business-like and transparent manner. FSA is a private sector, non-profit organisation representing the interests of the owners of 93% of South Africa's plantation area, from large (corporate) growers to the small (emergent) timber growers. FSA promote the commercial forest industry and coordinate (and partly fund) forestry education, training and research. They also represent the industry at government level, lobbying for a more supportive investment environment, particularly in the face of restrictions on plantation expansion based on water usage.

In East Africa there are emerging growers' organisations formed in the late 2000's to look after the interests of the expanding number of private investors in tree planting. The Uganda Timber Growers Association (UTGA) and the Kenya Forest Growers Association (KEFGA) both undertake lobbying of their respective governments for better support to the sector and they are increasingly involved also in the collective marketing of their Members' produce. Other activities undertaken include collective purchasing of inputs for their Members – such as seed, tools and chemicals. Both these organisations, however, are relatively young and they will require substantial capacity building to be effective and sustainable in the long-term. Currently UTGA and KEFGA are being supported by the Norwegian government and the UK's Gatsby Charitable Foundation respectively.

Support for out-growers

All these organisations in South Africa have something else in common too: they encourage small growers to plant trees on a commercial scale. The large South African companies initiated very successful out-grower initiatives – namely, Mondi's Khulanathi ('Grow with us') (1983–2007); Sappi's Project Grow (1983–) and NCT's small growers scheme. Whilst these schemes differ slightly, they basically offer financial and technical support to small growers to establish and manage their tree crops in return for guaranteeing them a market for the final product. Demonstration field days are commonly held for these growers too, where new techniques and practical research findings are passed on. These schemes have assisted many thousands of smaller growers in South Africa, making a huge impact on rural livelihoods. The companies benefit from supply of raw material for their mills as well as gaining support for commercial plantations amongst the local communities, something which is crucial for success in commercial plantations everywhere. The large corporate investors in Uganda and Tanzania (see Table 2) are also supporting out-growers surrounding their estates, often by providing free (or subsidised) seedlings.

POOR PLANTATION INVESTMENTS

If we are to see future plantations expand in Africa and gain the support of the public and policy makers, it is vital not just to learn not just from the success stories described above but also to study why other initiatives have struggled – or even failed. Some of Africa's big plantation developments failed to realise their potential: the list includes Tanzania, Malawi, Sudan, Uganda, Kenya, Zambia and a number in West Africa.

Planning and management

The Viphya scheme in Malawi is probably the best known example of a poor investment, where it was assumed that the plantations would eventually feed a pulp and paper mill, which never materialised. The reasons given for this include the oil price escalation in the 1970s, a glut of pulp on world markets, environmental concerns over the pulp mill's location and the risk of the rail link going through Mozambique to export the product (NAO 2011). The large Sao Hill plantation in Tanzania has had a problematic history too, with government bureaucracy being blamed for funding and procurement delays which lead to managerial issues and poor protection from fires (5,000 hectares were burnt in 1983). A World Bank report stated that *"management of industrial plantations such as Sao Hill, cannot be successfully carried out under normal government bureaucracy"* (World Bank 1992). A sawmill was built in the mid 1970's in Sao Hill (funded by the Norwegian government) and a pulp and paper mill (much smaller than originally planned) was eventually commissioned in 1985. Although these large plantation developments failed to realize their investment potential, they did provide huge rural employment for a period and are now the source of livelihoods to many people as they harvest the mature trees (although often in very inefficient manner with an 'army' of mobile sawmills).

Governance

Civil wars have been responsible for many plantations being abandoned or mismanaged – these include Uganda, Sudan and a number of West African countries. In these and other countries where governance of the country's forests has been poor, these predominantly state-owned plantations were often well established (invariably by the national Forestry Departments with external donor-support) but then not well managed as they grew. Little or no thinning, pruning or protection from fires was carried out and as the crops matured, their harvesting was poorly regulated. Replanting of felled areas was often neglected and in some cases (e.g. Kenya), significant areas were excised for uses other than tree planting. Consequently, over the last 15 years or so there has been a shift away from state-owned and managed plantations towards the private sector.

Silviculture

In some of the plantation developments that have failed, there were silvicultural issues, including wrong species choice (e.g. *Terminalia superba* was dropped as a commercial timber species in Cote D'Ivoire due to its poor timber quality). Many eucalypt plantations on the continent have failed due to poor site-species matching and especially inadequate weeding. Pests and diseases have also had a negative impact, notably the cypress aphid *(Cinara cupressi sensu lato)*, which first appeared in Malawi in 1986, quickly spread and devastated Cypress *(Cupressus lusitanica)* plantations in Uganda and Kenya.

The practice of establishing plantations through taungya (also referred to as inter-cropping or the shamba system) in many African countries has had very mixed results. In the past, commercial plantations throughout the continent were often established by local farmers who were permitted to grow their food crops in between the tree crops for a year or two, provided they tended the trees until they were established. The theory is that the trees' establishment costs are thereby reduced and the local people can use the land (albeit temporarily) for growing their food crops. In the past this generally worked well, presumably because the local people obeyed the rules (such as which food crops were permitted) set down by the government foresters who supervised them. Taungya was adopted after its success in Asia, where it was used widely to establish teak plantations from late 19th Century onwards. Over the last 25 years or so, however, taungya has generally not achieved the objective of establishing tree plantations in numerous African countries.

Taungya is popular with politicians and local farmers but often over-looks the fact that if the farmer tending the land does not own the trees (or have an incentive to ensure their survival) then the trees invariably suffer. There are many thousands of hectares of failed plantation initiatives throughout the continent that prove the point. In Nigeria *"the allocation of land for taungya without tree planting is essentially a system of shifting cultivation made possible through complicit cooperation of forestry staff and farmers"* (von Hellermann 2007). Despite such failures, however, taungya keeps reappearing under different guises around Africa – for example, Kenya's PELIS (Plantation Establishment and Livelihood Improvement Scheme) and Ghana's MTS (Modified Taungya System). Taungya has a role in certain circumstances only, especially where small farmers are themselves growing trees with selected food crops. But in terms of commercial plantations, it is generally better to keep the crops separate in time and space, for example, by permitting farmers to clear the land in return for growing their crops for a season or so and then planting the trees on the same land.

CHALLENGES

If Africa is to become self-sufficient in wood and wood products from its forests, there are a number of challenges that need addressing.

Land

Land in Africa is both an opportunity and a constraint with regard to commercial tree plantations. Even with the high population growth in most African countries, in many countries there is still plentiful land for large scale tree planting, whether it is on-farm or in plantations. What is lacking often, however, is a clear land use policy that defines areas available (and suitable) for commercial forestry. It must be remembered too that for commercial forestry to be profitable, there are significant economies of scale required. Whilst a pulp mill might require over 100,000 ha of dedicated plantations, even a small, modern sawmill might require 5–10,000 ha of plantations in close proximity to be profitable. Large investors are struggling to find suitable areas to develop, often due to the insecurity of land tenure and political instability.

A hot topic at present concerns large land deals that can seriously impact on local people's livelihoods: the so-called 'land grabs' which are aimed mostly at large overseas investors in both agriculture and forestry. Some of these claims are unfair and biased (particularly by some NGOs that see no good at all in plantations) but some have a case (e.g. some of the false claims made by biofuel companies to local people). The other land issue concerns government policy regarding moving people already living in areas to be developed for plantations and also how they deal with encroachment into such areas once investors start their operations (Oxfam 2011).

Governance

Good governance is important for attracting investment and especially for the long term business of tree planting. It is important that a country has policies that recognise land rights of people and communities and also recognises commercial forestry as a legitimate and important land use. It is also important for a country to have clear and transparent policies with regard to permits, or concessions, and regulations that govern both tree planting and harvesting. In a number of countries in Africa, for example, the market price of timber and other wood products is artificially low due to a combination of poor governance (e.g. non-transparent sales of trees from publically-owned forests) or due to the fact that the resource is 'free' (e.g. illegally sourced or harvested at no cost, usually from natural forests). This means that *bona fida* investors in commercial tree planting operate on an uneven playing field. The consequence of this is to put off many potential investors in commercial tree planting.

Difficulties with privatisation

The rise of the private sector as a major player in commercial tree planting is shifting the balance between the State and private sector. Consequently, over the past 15 years or so, major reforms have taken place in the forestry sectors of Ghana, Uganda, Kenya, Tanzania and Rwanda. These have resulted in some excellent examples of forestry policies that encourage public participation in forest management and also private sector investment in plantations. However, reforming forest policies has not always had the expected outcomes and the challenge is to turn such policies into positive action on the ground.

The changing role of the State Forest Services to one of monitoring, regulation and support has proved difficult in many developed countries. Although Africa is not unique in this, it has proved particularly difficult in some African countries, where the forests (both natural and plantations) have often been a source of considerable wealth to those who control them. Similarly there has also been a reluctance to leave the business of plantation development to the private sector, even though the private sector invariably conducts business in a more cost-effective manner.

The 'new' roles of the State's forest administrators require them to effectively and transparently implement the policies designed to attract the private sector; something that has not widely occurred. Excessive bureaucracy is frequently cited as the number one constraint by investors. In some African countries the State's forestry institutions are reluctant to support the private sector as they see the private sector taking over their traditional role of creating and managing a plantation resource. Clearly though, if Africa is to attract much-needed investment in plantations, the state's forestry institutions need to adapt to the changing environment. Increasingly, emphasis needs to be put on the State's role of managing concessions to the private sector which often requires the 're-tooling' of staff and preparing them for the new world of private-sector lead, plantation investment.

It is not only the State forestry institutions that need to change but a change in attitude is also needed for all those involved in plantation development. In particular, investors in the sector must acknowledge the importance of involving local communities in plantation initiatives and this needs to be much more than just rhetoric (or retrospective action forced onto investors by NGOs). Without the support of local communities, large-scale investments will inevitably fail nowadays, especially as the pressure on land increases in many areas.

Adopting new models

The traditional model of plantations in Africa is based on a few species often planted in large single species, or clonal, blocks. This system has clear advantages for management and it can be managed in a sustainable way with careful planning: it also produces uniform products and high yields compared to most natural forests or mixed species' plantations. However, this approach has attracted much criticism in some circles for its lack of biodiversity and its impact on certain sites. To allay such fears, in specific areas the adoption of other potential models might be more appropriate – for example, agroforestry techniques. One such approach that appears very promising here is co-cropping the trees with pasture or food crops, which is possible by adjusting the spacing of the trees at planting or through subsequent thinning operations (Shield 2007, 2009a and 2009b).

Lack of technical capacity

In the past, many countries in Africa had well funded and functioning forestry research and training institutions. Today though many are not performing well, which is partly a consequence of forestry being given low priority by governments since independence and partly through poor governance and management. A lack of financial resources is often quoted as the reason for poor performance but even where substantial funds have been made available, the results have often been disappointing. As the private sector has become the main players in plantations, the gulf between public institutions and the private sector has widened in many African countries. Many of these public institutions have become increasingly out of touch with the needs of the private sector, forcing the private sector to bypass them and look after themselves. These public institutions must reassess their roles if they are to survive: there is a great opportunity for those who can change, however, as the expanding plantation sector desperately needs support in the form of trained personnel and applied research programmes that focus on the immediate (and foreseen) problems facing them.

Information dissemination

We have come a long way in our understanding of the science and management of plantation crops in tropical and subtropical forestry. So it is perhaps surprising that those interested in commercial tree planting in Africa, particularly the smaller growers, can often struggle to obtain sound, practical information on how to plan and manage plantations. Most of the information is in the scientific press, with only some available on the internet and often not in a format that is useful to many growers. This commonly results in mistakes being made during the planning phase of plantation development and in poorly performing crops. There are frequent international gatherings of scientists (notably IUFRO, the International Union of Forestry Research Organisations) that produce some excellent research results but these and other relevant publications are difficult for the average person to get hold of. Such information also needs turning into simplified, practical guidelines.

Another issue is where plantations are established they often attract negative publicity from the public and policy makers alike, despite their undoubted importance to the country. So why do commercial tree plantations attract such criticism? Partly because the commercial forest sector has made mistakes in the past (mistakes which are visible for many years) and partly because the forest industry generally does not communicate its case very well compared to the detractors of plantations. The commercial forest sector needs to raise its profile throughout Africa. If plantations are to meet the demand, the criticisms frequently levelled at plantations must be tackled head-on and responses based on facts rather than emotion. Whilst acknowledging the mistakes of the past, the industry needs to now build on the lessons learned and promote the industry as a powerful development tool for Africa. Table 4 details the issues that are frequently levelled at commercial forestry in Africa (and beyond) and offers appropriate responses to counter them.

Silviculture

Until relatively recently (and with the notable exception of a few countries – mostly in Southern Africa), there has been a slow uptake of some of the modern silvicultural practices that have been proven to be cost-effective in terms of plantations. The use of improved seed, intensive pre- and post-plant weeding and heavy, early thinning regimes have not been the norm in many African countries despite being routine in many other countries with plantations. And whilst great strides have been made in silviculture (e.g. clonal forestry, site-species interactions and our understanding of the nutrient balance) there are still some areas where further applied research is sorely needed – in particular:

- Pest and disease management
- Responding to climate change – by testing a range of species (including indigenous), tree breeding and improved site-species matching
- Small scale forestry management
- Appropriate agroforestry (co-cropping) models
- Charcoal plantations: identifying species for both growth and calorific value and their management systems
- Increased supplies of improved seed and/or clonal material of main species

The special case of eucalypts

Even in tropical Africa, plantations can take up to 20 years to mature (e.g. *Pinus* spp.) and even longer with some hardwood species (e.g. teak). For this reason, eucalypts are more

TABLE 4 *Criticisms commonly levelled at commercial plantations in Africa and appropriate responses*

ISSUE	CLAIM	RESPONSES
Questioning the need for plantations	Trees on farms, various agroforestry systems and small-scale tree planting schemes can provide Africa's wood needs.	Whilst there is major role for small-scale planting in all African countries, the needs for timber and wood products in most countries cannot be met without some more intensive, commercial planting on appropriate sites. Ideally a vibrant, commercial forest sector would have some large investors (who are more likely to invest in efficient processing and adding value) with many small-medium growers who can benefit from the markets. The woodfuel crisis will have to be tackled by increasing the supply from sustainable sources – with the bulk from dedicated plantations – in addition to other possible solutions (e.g. reducing demand and adopting improved technologies for charcoal production and woodfuel use). Agriculture has a long history of adopting intensive management methods to meet food requirements – so must forestry. Massive new planting is needed to offset rampant deforestation. Suitable land is available for commercial forestry in many African countries – especially degraded and deforested areas.
Natural forests being cleared for plantations	Plantations are replacing natural forests.	This has happened in the past but is not acceptable practice today. Land use policies should determine sufficient, suitable land to be used for commercial forestry. Plantations should only be developed on degraded forest land (or non-forested land) where the natural forests are unlikely to ever return.
Little under-standing of a plantation-based, forest industry	Commercial forestry brings few benefits to a country and local communities.	A well planned and organised commercial forest sector can bring major benefits to both the country and local peoples' livelihoods. Commercial plantations provide major rural employment opportunities for both skilled and unskilled workers. Wood is great raw material for adding value to through downstream processing: linking such industries (large and small) with the tree growers is crucial – as in the Southern African countries with sustainable, plantation-based industries – viz. South Africa, Swaziland and Zimbabwe. Rural infrastructure and local communities can benefit greatly from plantation developments.
Land grabbing by government for large (often overseas) investors	Large tracts of land are being allocated for plantations by governments to the detriment of local people.	This has happened but commercial forestry is frequently (and wrongly) lumped together with oil palm and bioenergy crops such as Jatropha. Land planning policies and better transparency from governments are needed to ensure sufficient land is allocated for forestry plantations in suitable areas. Investors increasingly are subscribing to ethical guidelines (often insisted on by their financial backers), especially FSC Certification.
Excessive water and nutrient use	That tree plantations suck the soil dry of water and nutrients and thereby degrade the land and negatively impact peoples' livelihoods.	Poor planning and lack of sound advice to growers has resulted in some trees being planted in areas that should be left unplanted (or where natural vegetation should be assisted). The widespread adoption of industry standards (e.g. FSC Certification) is now leading to better planning and controls. Where water is scarce, controls have been enforced (e.g. South Africa) but commercial forestry should be given higher priority by governments than at present compared with commercial agriculture. Site-specific use of fertilizers on marginal sites can ensure no long-term fertility losses due to plantations (as with many agricultural crops).
Loss of biodiversity	That plantations destroy biodiversity and are 'ecologi-cal deserts'.	Commercial plantations cannot replace Africa's natural forests but crucially, they can take the pressure off such forests by supplying the products needed (especially timber, poles and woodfuel). Well managed plantations can provide a much greater yield per unit area of wood products compared to most natural forests. Adopting environmental guidelines for plantations is vastly improving their attraction for biodiversity (e.g. leaving unplanted areas and encouraging natural vegetation along water courses).

TABLE 4 *Continued*

ISSUE	CLAIM	RESPONSES
Restricted species choice	Monocultures of predominantly exotic species are not acceptable.	Exotic species are generally better suited to plantation conditions than many indigenous species: much more is known about their silviculture – especially pines, eucalypts and Acacias – and improved seed/clonal material is widely available. Monocultures with these improved, exotic species in forestry (as in agriculture) are much easier to manage: their uniformity enables significant cost-efficiencies in silvicultural and harvesting operations. Monocultures are accepted in commercial agriculture but not seemingly in forestry – presumably because tree crops are much longer-lived. Efforts can be made to use more species in large plantation developments but within economic constraints. Mixed species plantations are complex (and many have failed) but more research is needed into their management.
Genetic engineering	Plantations are genetically engineered and pose a major threat to the environment	Commercial forestry is a long way behind agriculture in terms of breeding and genetic engineering is almost unheard of in forestry. Whilst many commercial plantation developments are using either seed orchard or clonal planting material, these are not genetically engineered but involve selective breeding to combine superior traits – including resistance to pests and diseases and desirable wood properties.
Non-sustainability	Plantations are not sustainable and will ultimately degrade the environment.	Scientific evidence suggests that where many tree rotations have been grown, well managed tree plantations can be sustainable (e.g. pines in Swaziland – Evans, 2001 and 2005). The importance of fast growing plantations for Carbon sequestration is highly relevant to the climate change debate.

attractive to investors because of their fast growth and wide range of useful products they can yield: typically building poles (from 2 years), transmission poles (6–10 years) and sawlogs (over 10 years). However, there are constraints on commercial eucalypt planting as they have more exacting site and climatic conditions (although the hybrids which are now widely available are extending their range in terms of commercial planting). To maximize growth, eucalypts must also be intensively managed: thorough land preparation and weeding are essential for fast growth. They must also be subject to careful processing (especially sawing and drying) – factors that have led to many failures throughout Africa in the past.

Pests and diseases

There is little doubt that pests and diseases pose a major threat to tree plantations in Africa (as elsewhere in the world) and the threats appear to be increasing, to a large extent due to increased trade and travel around the world. The risk with planting large areas with monocultures (or very few species) is well documented and can be reduced with careful management – particularly careful site-species matching, the use of healthy planting material and adopting silvicultural regimes that minimize the stresses on the crop. It is vital for any potential or existing investors in plantations in Africa to be aware of the current and potential threats (Table 5) and for both the public and private sectors to allocate resources to appropriate, applied research.

WHAT LESSONS CAN BE LEARNED?

When analysing various plantation initiatives in Africa, it would appear that the greatest chance of success comes when the private sector are encouraged to invest in the sector and where the state creates a supportive environment. The supportive environment involves a range of key policy and institutional matters – namely:

- appropriate government policies and legislation that recognise the important role of the private sector in the commercial forestry sector,
- the availability of suitable land (public or private) free from ownership disputes,
- the forward integration of the industry – namely, establishing timber processing industries (and where appropriate develop export markets),
- direct incentives – in the form of financial grants, subsidies or soft loans – can work well when properly managed,
- building capacity in forestry education, training and applied research focussed on the real needs of tree growers,
- availability of sound, practical information on tree planting and plantation management;
- availability of quality planting material.

Where one or more of these factors is missing, plantation investments have invariably struggled or completely failed.

TABLE 5 *The major current pest and disease threats to plantations in Africa*

SPECIES	COMMON NAME(S)	TARGET SPP	NOTES
Diseases			
Armillaria & *Phytophthora* spp.	Root rots	Many species	Widespread pathogens
Botryosphaeracea	Stem cankers	Many species	Includes *Diplodia pinea* – common on stressed or damaged pine trees
Fusarium circinatum	Pitch canker fungus	Many species but especially *P. patula*	Causing major losses in RSA in nurseries and young plants.
Teratosphaeria zulense	Stem canker	*Eucalyptus* spp.	Major threat to plantations
Pests			
Gonipterus spp.	Eucalypt Snout beetle	*Eucalyptus* spp.	An old enemy making a comeback in E & S Africa
Leptocybe invasa	(Blue Gum) Chalcid wasp	*Eucalyptus* spp.	Now widespread in E & S Africa
Sirex noctilio	Sirex wood wasp	*Pinus* spp.	Causing major losses in RSA – and a major threat to industry.
Termites (various spp.)	Termites	Most hardwood spp.	Widespread in hot, drier areas
Thaumastocoris peregrinus	Bronze bug	*Eucalyptus* spp.	Now widespread in E & S Africa

Ref. sources: Nyeko and Nakabonge (2008); Roux and Wingfield (2010); Roux *et al.* (2005).

The above list applies to large investors and small farmers alike, though their priorities might be different. The larger investors, for example, are more able to look after themselves in terms of training and research needs, nurseries and investing in down-stream processing to add value to their plantations. Small tree farmers have a much greater need for information to help them in planning a forestry investment and also to support them in the establishment and management of their crops: they also depend much more on nurseries supplying them with good quality plants and on markets being available for their trees when mature. These small growers can help themselves greatly by coming together under a 'growers' association' banner, in order to have a common voice and benefit from economies of scale.

The reasons for the plantation failures are many but the critical one seems to emanate from the planning phase, where it was assumed that markets for the trees will appear once there is a resource established: this is clearly a dangerous assumption to make.

The provision of incentives – either direct or indirect – appears to be crucial too. In terms of commercial forestry plantations, various incentives have been tried to attract investment into the forest sector: these have included long-term leases for planting on state land, grant and/or loan schemes and the provision of subsidised, or even free, tree seedlings. Few African countries have gone as far as creating taxation incentives which have worked well in other countries around the world, with the United Kingdom and Norway being two good examples. Other indirect incentives can be the provision (or subsidising) of practical training, applied research and making available practical guidelines for all aspects of plantation management – from planning the investment, through harvesting and finally processing the final products.

OPPORTUNITIES

Timing

Never before has the need for forestry plantations been more important – and especially so for many African countries. The combination of increasing demand for wood and woodfuel and rampant deforestation increases the focus on plantations to provide such products. We are now also in an excellent position to be able to learn from the many plantation initiatives on the continent – from both failures and the success stories. There is really no need to repeat the mistakes of the past, and it is now possible to build on the positive developments, of which there are now an encouraging number throughout Africa. Of course, this needs concerted efforts and collaboration on the part of the key players in public and private sector.

With a greater understanding of the impact of deforestation on climate change, the public perception of plantations appears to be changing. Some highly influential organisations and individuals have recently spoken out in favour of large scale tree planting. *"International co-operation could provide funding for jobs in tropical countries planting trees and thereby fighting poverty and the climate crisis simultaneously"* (Gore 2009). WWF, the World Wide Fund for Nature, launched a high profile initiative in 2009 called New Generation Plantations. This initiative recognises the important role that well managed plantations can play in providing not only wood and wood products but also crucial environmental services and many social benefits (WWF 2009). There has also been a lot of talk in recent years about the Green Economy, which in its simplest expression can be thought of as one which is low carbon, resource efficient and socially inclusive (UNEP 2011). Plantations in Africa could play a major role in moving towards a Green Economy provided they are carefully planned and sustainably managed. The adoption of independent auditors such as the Forest Stewardship Council (FSC) play an important role here too.

Investment interest

From the level of involvement by the private sector over the last decade, it is clear that there is major interest in plantation investment on the African continent – from both large and small scale operators (Gondo 2012). Since a meeting in Washington D.C. in 2003, there have been a series of forestry investment forums which have promoted investment into plantations in Africa: these were in Kenya (2005), South Africa (2006), Kenya (2011) and Ghana (2012). These have been organised by World Bank, IFC (International Finance Corporation) and PROFOR (Program on Forests), in conjunction with governments, international donor countries and other organisations (e.g. World Agroforestry Centre in 2011).

A number of other valuable studies on forestry investment have also been undertaken. A major study was commissioned by the UK government, focussing on investment in forestry worldwide. This study recommended a variety of investment strategies that could deliver REDD+ – including afforestation and reforestation, better management of existing plantations and value added processing opportunities (Forum for the Future 2009). Other independent studies (Pöyry 2012, RISI 2012) provide information aimed at potential investors in commercial forestry – the former being specifically on Africa.

Best operating practices

Provided the best operating practices are followed, high yields are possible in many African countries. As noted earlier there is a lot of information available although not always in a readily available and practical format. The availability of information is also very important in the form of general texts (Evans and Turnbull 2004, Bredenkamp and Upfold 2012) and more practical guidelines (FSA 2002, FAO 2006, Jacovelli *et al.* 2009, Oballa *et al.* 2010, Sappi 2008).

Land availability

The economics of plantations in Africa depends largely on the scale, location and management of the enterprise. The availability of suitable land – whether government-owned or private – has been one of the main attractions for investors in Africa. In Uganda, the availability of state-owned Forest Reserves for the private sector was the key to attract investment into plantations. In Mozambique, the government facilitated land for investors to plant. To attract investors, however, the land must be free from disputes.

Bioenergy

Bioenergy has recently received a lot of publicity worldwide as alternatives to fossil fuels are sought. Between 2008 and 2011, 11.2 Mha were acquired in Africa alone for biofuel production, mostly for *Jatrophra curcas*. Such grandiose projects have to date fuelled little more than the 'land grab' accusations and added to concerns over food security. Many of these initiatives have failed and all have discovered that biodiesel production from *Jatophra* is (at least currently) not economically viable (Locke and Henley 2013, Schoneveld 2011).

Over 80% of households in Sub-Saharan Africa are dependent on woodfuel for cooking. Charcoal, which is the key driver of deforestation, is the preferred urban fuel and its demand is increasing as urbanisation increases throughout Africa. Consequently the bioenergy focus in Africa should be on the sustainable production of charcoal. Whilst a few countries have planted specifically for woodfuel (e.g. Ethiopia and Rwanda), most still rely on the natural forests or woodlands to supply their needs. Despite numerous reports highlighting the issues (e.g. AFREA 2011, Gumbo *et al.* 2013, Kambewa *et al.* 2007, Mugo and Ong 2006, UNDP 2013, World Bank 2009, Siedel 2008), there are very few serious initiatives (or investments) to either promote sustainable woodfuel production or more efficient production and utilisation of charcoal.

Dedicated woodfuel plantations could offer at least a partial solution to Africa's woodfuel problem. There have been few commercial plantation investments aimed at producing just woodfuel: the exceptions being some tea estates in East Africa who are self-sufficient in woodfuel (used for drying the tea) from well managed eucalypt plantations. The economics of charcoal production – from plantation to product – are generally not favourable to the investor as they would have to compete with the current system where the resource is free (i.e. usually from natural forests and woodlands) and taxes are frequently not collected. As demand increases and supplies are dwindling, the charcoal price is rising steeply in most African cities and thus the economics of woodfuel plantations are starting to look more attractive. It is an area which would be very suitable for subsidy by government or donors, to attract the initial investors whilst the woodfuel business is brought under better control.

CONCLUSION AND RECOMMENDATIONS

The current and predicted demands being placed on Africa's natural forests, for woodfuel, timber and other wood products, means that deforestation will continue unabated unless there is an alternative, and sustainable, supply from plantations. Forestry plantations offer the only realistic solution to meeting this widening shortfall in wood supply. However, the current level of plantation development in many African countries is woefully short of what is needed, even with the high tree growth rates possible in many parts of the continent.

The good news is that the investment and interest in plantation development in Africa is rapidly growing. From large corporate investors to small farmers, many are now investing in trees across the continent. We are also now in the position to be able to learn lessons from the many plantation initiatives in the past, some of which have been very successful and could be replicated in other areas. The history of plantations in Africa shows that the way ahead is for governments to create the right environment that attracts private sector investors into the sector. The state's role in the sector is thus rapidly changing from one of complete domination in plantations to one of regulation and support, whilst the business of commercial tree planting is carried out by to the private sector.

Provided that the plantation developments are carefully planned and sustainably managed, they would bring, and in some cases are already bringing, many other benefits to Africa, including massive rural employment, environmental protection (including reducing the pressure on the remaining natural forests) as well as major economic benefits in terms of taxes raised and imports saved. Such a vision will only come about, however, where the conditions are right to encourage the development of a vibrant forest industry that maximises the added value to the products being grown. In order for small growers to benefit, the emerging forest growers' associations in Africa need to be supported too.

This paper highlights the key areas that need addressing if plantations are to realise their potential throughout Africa. These include:

- having appropriate land policies and legislation that recognises the importance of, and supports the development of, commercial plantations,
- undertaking applied research in key areas,
- training and education in modern plantation techniques, and
- better communication to the public at large and the tree growers in particular.

The goal is a win: win situation for all stakeholders – namely governments, private investors both large and small and, crucially, the many millions of people that depend on forest products in Africa.

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Australian plantations: mixed signals ahead

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SUMMARY

Plantation development in Australia has had a history of starts and stops. In the four major softwood plantation regions, forecasts of future availability provide very little scope for expansion of softwood sawmilling. In the three major hardwood plantation regions, considerable scope exists to increase exports of woodchips or expand pulp processing. Plantation development is presently in the doldrums, pending rationalization of hardwood estates by companies that bought the recently demised Managed Investment Schemes. Following this rationalization, industrial softwood growers will need to purchase or acquire access to additional land to meet processors' desires to upscale and remain internationally competitive. Large-scale purchase is generally not economically or politically viable. However, farm forestry has public good benefits through structural adjustment, carbon and, in some localities, salinity mitigation. Government assistance to foster farm forestry could break this nexus.

Keywords: softwood availability, hardwood availability, land purchase, farm forestry

Plantations en Australie: signes mixtes à l'horizon

I. FERGUSON

Le développement des plantations en Australie a connu une histoire de départs et d'arrêts. Dans les quatres régions pricipales de plantations de bois rond, les prévisions de production futures laissent très peu d'espace à l'expansion de la coupe du bois tendre. Dans trois plantations majeures de bois dur, il existe une perspective considérable pour accroître les exploitations de copeaux de bois ou pour agrandir la manutention de la pulpe. Le développement des plantations stagne à présent, dans l'attente de la rationalisation des propriétés de bois dur par les compagnies ayant acquis les projets d'investissement gérés récemment mis de côté. A la suite de cette rationalisation, les producteurs industriels de bois tendre vont devoir acheter ou acquérir un accès à des terres additionelles pour satisfaire le désir des industriels d'accroître leur capacité et de devenir compétitifs au niveau international. Les achats à grande échelle ne sont généralement pas viables, que ce soit économiquement ou politiquement. Toutefois, la foresterie de ferme offre des bénéfices plublics positifs grâce à un réglage structurel, à la mitigation du carbone et, dans certaines localités, de la salinité. Une aide gouvernementale pour encourager la foresterie de ferme pourrait briser ce noeud gordien.

Plantaciones en Australia: un futuro enmarcado por señales contradictorias

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El desarrollo de plantaciones en Australia muestra un historial de períodos de avance y estancamiento. En las cuatro principales regiones de plantaciones de coníferas, las previsiones de existencias futuras ofrecen muy poco margen para la expansión del aserrío de madera de coníferas. En las tres principales regiones de plantaciones de frondosas existe un amplio margen para el aumento de las exportaciones de astillas de madera o la expansión del procesamiento de pulpa. El desarrollo de plantaciones está actualmente de capa caída, a la espera de una racionalización de las fincas de madera de frondosas por las empresas que compraron los Sistemas de Inversión Administrada (fondos de inversión) recientemente desaparecidos. A raíz de esta racionalización, los productores de la industria de madera de coníferas se verán en la necesidad de comprar o adquirir el derecho a tierras adicionales con las que satisfacer los deseos de expansión de la industria de transformación y de seguir siendo competitiva a nivel internacional. Generalmente, la compra a gran escala no es una opción viable, ni económica ni políticamente. Sin embargo, la agrosilvicultura ofrece beneficios calificados como bien público, a través de ajustes estructurales, carbono y, en algunos lugares, la mitigación de problemas de salinidad. La ayuda del gobierno para fomentar la agrosilvicultura podría romper este nexo.

HISTORICAL BACKGROUND

Location and species

Australia's timber and pulpwood plantations are distributed widely around the periphery of Australia, as the plantation Regions in Figure 1 show. Most are located in areas receiving at least 500 mm/year of rainfall and fall into the broad species groups of Hardwood[1] – principally *Eucalyptus globulus* [blue gum], *E. nitens* [shining gum] *and E. maculata* [spotted gum]) and Softwood (principally *Pinus radiata* [radiata pine], *P. elliottiii* [slash pine], *P. caribaea* [Caribbean pine] and hybrids of the latter two. Nichols *et al*. 2013 provide a comprehensive review of the subtropical and tropical eucalypt plantations in eastern Australia.

Early planting: 1875 to 1935

In the temperate zone, initial interest focused on trials and plantings of softwood species because hardwood timbers were in ample supply from native forests at that time.

Following trial plantings of various pines and eucalypts at Bundaleer, South Australia, in 1875, plantations of radiata pine were established by the then Forest Board of South Australia (Carron 1985). Trials and regular plantings by the infant State forest services soon spread throughout other parts of the temperate zone of Australia, including the plantings of *Pinus pinaster*) [maritime pine] on coastal sands north of Perth, Western Australia.

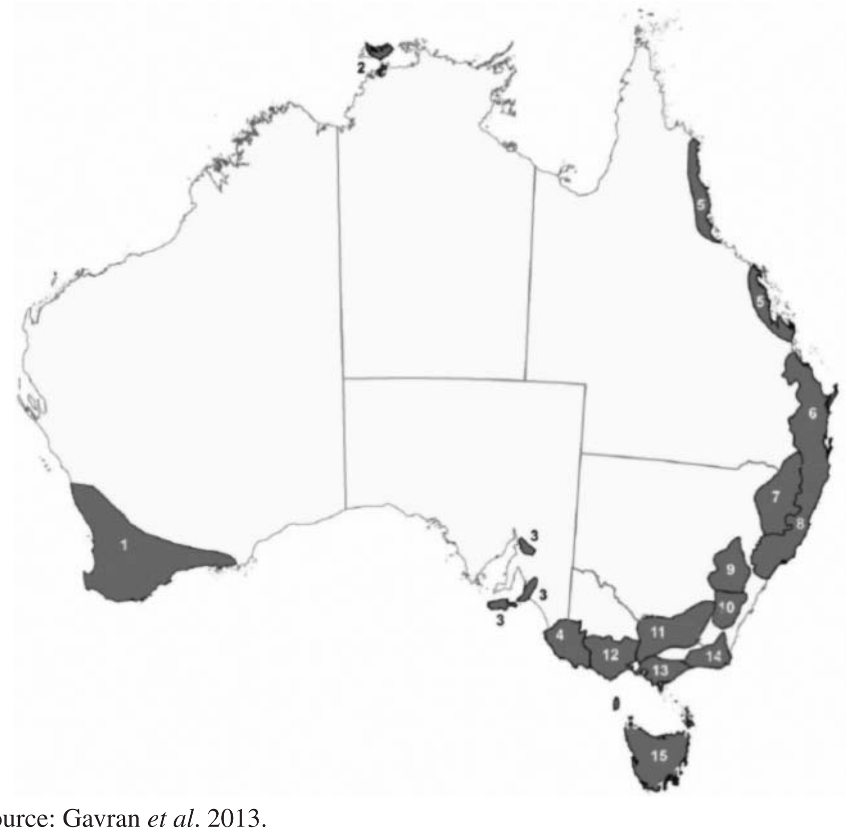
Queensland was slower to engage in planting because of access to native softwood species, notably *Araucaria cunninghamia* [hoop pine], but in 1924 commenced planting of this species and trials of *Pinus* species from the south-east of the United States and Carribeaan islands. Some of the these, eapecially *P. taeda* [loblolly pine], *P. elliottii* and *P. caribaea*, proved successful and tree breeding and silvicultural research ultimately led to the widespread use of hybrids of *P.elliottii* and *P. caribaea*.

Figure 2 shows the history of the total areas planted in Australia to softwood and hardwood commencing in 1935, when the silvicultural technologies for the major softwood species had become well established.

After World War II – 1945 to 1965

Up to 1945, most planting had been carried out by State forest services, although one private estate was established by South Australian Perpetual Forests from 1926, through prospectus

FIGURE 1 *National Planation Inventory Regions*



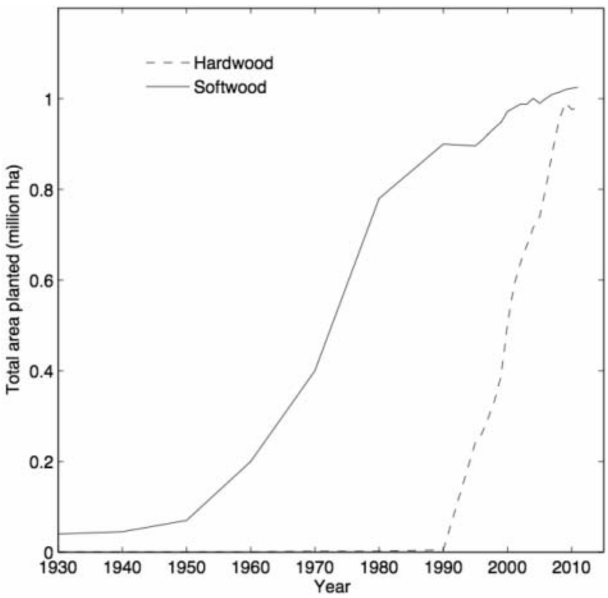
NPI Regions

1. Western Australia
2. Northern Territory
3. Mt Lofty Ranges & Kangaroo Is.
4. Green Triangle
5. Northern Queensland
6. South East Queensland
7. Northern Tablelands
8. North Coast
9. Central Tablelands
10. Southern Tablelands
11. Murray Valley
12. Central Victoria
13. Central Gippsland
14. Bombala - E. Gippsland
15. Tasmania

Source: Gavran *et al*. 2013.

[1] The internationally approved term is 'Broadleaved' but because of the long history of utilization of hardwood timber from native forests, that term is never used in common parlance in Australia.

FIGURE 2 *Total areas planted by species group and year*



Source: Gavran 2013.

subscriptions from private investors. As Figure 2 shows, the total area of plantations had only reached about 100,000 ha in 1945, almost all of it being in softwood species.

The conclusion of World War II brought a boom in house construction and economic growth and the related demand for timber and paper products. The manufacture of wood-pulp for paper products commenced in Victoria and Tasmania, eventually providing a market for harvesting residues in both native forests and plantations. However, the growth in demand for forest products at this time outstripped supply and, as a result, overseas imports of forest products rose to the point where they became a major adverse component in the national balance of payments.

Commonwealth assistance: 1965 to 1990

Under the leadership of Dr. Max Jacobs, Director-General of the Commonwealth Forest and Timber Bureau, the then Heads of Forest Services promoted the case for Commonwealth assistance to expand the plantation estate in order to counter the then acute balance of payments problem, aiming to achieve self-sufficiency in timber and paper products. The Commonwealth Government passed legislation in 1966 that provided low-interest loans to the State forest services (Carron, 1985), leading to a rapid increase in the total area of softwood plantations over the period 1966 to 1990, as shown in Figure 2.

The rate of increase of softwood planting slowed after 1990, reflecting several major influences and policy changes. Firstly, the conservation movement had gathered strength and was attacking the conversion of State native forests to exotic softwood plantations, thereby ultimately forcing the State forest services to cease this practice and to purchase land for plantation establishment instead. Secondly, in an increasingly trade-exposed economic environment, the adoption of the previous self-sufficiency argument for Australia became untenable under international trade agreements and the low-interest loans ceased. Thirdly, the State forest services, while technically capable in plantation establishment and management, were dogged by overt and covert political interference and restraints on investment and pricing, so that they failed to achieve commercial rates of return on investment (Ferguson 1985: 185) and were therefore widely seen as subsidizing the processors unfairly, relative to competitive materials supplied by the private sector.

Managed Investment Schemes: 1990 to 2010

The State forest services and the few but now significant private plantation companies noted with concern the decline in new planting of softwood and promoted an aspirational national target of achieving 3 million ha under plantations by the year 2020. In response, the Commonwealth Government introduced some new forestry-specific rules to enable tax-deductibility of establishment costs in or near the year they were incurred for forestry-based Managed Investment Schemes. This was originally intended to encourage plantation establishment, both softwood and hardwood, for the production of sawlogs – as part of a National Forest Policy (Department of Agriculture, Fisheries and Forestry 1995) to expand the plantation resource in response to the progressive reductions in supply of sawlogs from the native forest estate with the transfer of timber resources into conservation reserves.

Three further developments were to shape the introduction of the forestry Managed Investment Schemes (see Ferguson *et al*. 2010):

(1) The conservation movement had been successfully campaigning against the harvesting of native forests and the transfer of those forests into conservation reserves, thereby reducing the supply or future supply of hardwood timber and pulpwood.
(2) The use of *E. globulus* for pulping in Europe showed that it had superior qualities for the manufacture of writing papers and therefore commanded a somewhat higher price than that for pulpwood from Australian native forests.
(3) The Managed Investment Scheme companies, noting these shifts in the overseas markets for pulpwood, realized that blue gum and shining gum (*E. nitens*) plantations could be grown solely for pulpwood using short rotations of 10 to 12 years. These rotations lengths were much more attractive to prospectus investors seeking a final crop return in a relatively short period, as well as tax-deducibility of costs.

Consequently, few Managed Investment Scheme companies offered schemes for the long (25 to 30 year) rotations required for softwood or hardwood sawlogs. This resulted in the very rapid increase in the areas planted to hardwood plantations shown in Figure 2, most of which were undertaken with a view to exporting hardwood woodchips initially but were also seen as a future resource for the expansion of domestic pulp and paper manufacture.

Almost all of the Managed Investment Schemes had collapsed by 2005 (see Ferguson 2013), either as a result of the global financial crisis, erratic shifts in Commonwealth government policy pertaining to the taxation provisions, or a Ponzi-like dependence of the company on new prospectuses due to delays in the cash-flows from export sales, pending the development of woodchip processing and port facilities.

Private ownership: 1999–2013

In 1999, a profound change commenced. Plantations that had hitherto predominantly been in ownership of individual States and under the management of a State forest service concerned started to be privatized. By 2013, Victoria, Queensland and South Australia had all sold the long-term forestry rights pertaining to the growing and sale of plantation timber on former State-owned plantations to companies in which North American Timber Management Organizations held the controlling interest. The sale of plantations owned by the State of New South Wales is widely expected to follow and, in any event, that State service has been corporatized to operate on a commercial basis. Significant areas remain under the ownership of the Forest Products Commission in Western Australia. Early privatization is unlikely because long-term supply agreements to industry were initiated in recent years.

CURRENT PLANTATION RESOURCE AND AVAILABILITY

The plantation resource: 2011

By 2011, the plantation resource still fell well short of the 2020 goal of 3 million ha. More importantly, however, the increase since 1990 was predominantly intended for hardwood pulpwood production, not sawlog production.

The distinction between softwood and hardwood plantations and markets is further highlighted by the management intentions of the owners. At least 85 percent of hardwood plantation owners expect to grow pulpwood exclusively, not sawlogs, while at least 99 per cent of softwood plantation owners expect to grow sawlogs, albeit with pulpwood as a complementary product (Gavran 2012).

Availability: 2011 to 2054

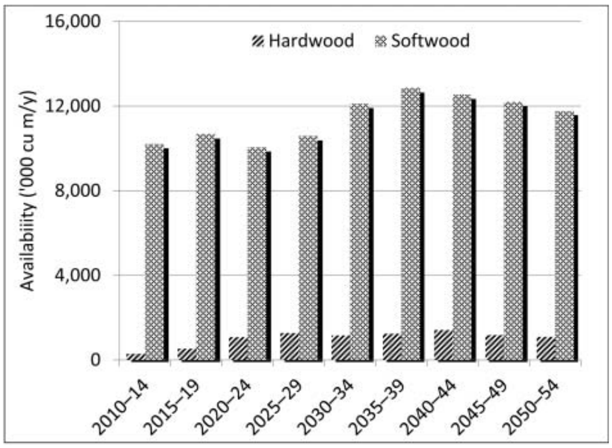
The term ‘availability’ is used here in preference to ‘log supply’ or ‘wood flows’ used in recent official forecasts (Parsons *et al*. 2006; Gavran *et al*. 2012). Supply is conditional on price, future technologies, resource location and many other factors. In any event, supply in itself does not provide a forecast of consumption – that requires the interaction of both supply and demand. Demand is also subject to change as incomes, tastes and other demand influences change. Availability is therefore only a very rough proxy for future consumption (and production) and assumes that the present setting of real prices, costs, and most other characteristics of demand and supply will change little, if at all, in the future. The major influence on future availability is therefore the amount of plantation wood at any future point in time that meets current market specifications and practices. Furthermore, ‘availability’ assumes harvesting will take place at that prescribed future point in time and that replanting will follow automatically. These are definitional matters that underpin any use of the forecasts for policy or other purposes.

The most recent national forecasts of availability (Gavran *et al*. 2012) are shown in Figures 3 and 4. They assume that there will be replanting of areas as they are harvested in the future.

In summary, the forecasts in Figures 3 and 4 show:

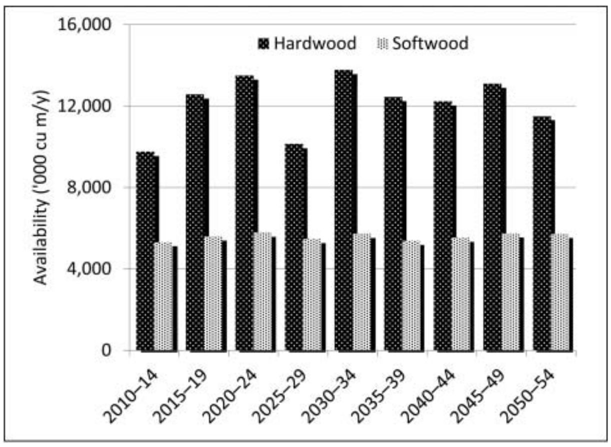
(1) The dominance of softwood over hardwood sawlog availability to 2054.
(2) The very small increase in softwood sawlog availability over the next 20 years.

FIGURE 3 *National sawlog availability*



Source: Gavran *et al*. 2012.

FIGURE 4 *National pulpwood availability*



Source: Gavran *et al*. 2012.

(3) The relatively static availability of softwood pulpwood to 2054.
(4) The very large increase in hardwood pulpwood availability over the next ten years, noting that the 2010 harvest (plantation and native forest) was 4.3 million m^3.

These statistics are slightly optimistic due to the collapse of some Managed Investment Schemes and a sequence of natural disasters over the period 2005–2012.

For example, blue gum plantations at Esperance, Western Australia, have suffered low growth rates due to drought and higher than expected prospective port and harvesting costs, such that they are unlikely to be replanted if and when harvesting proves viable. Hardwood plantations in North Queensland (see Vize *et al*. 2005 for an earlier review) suffered losses of 20,000 ha in the Cardwell area alone, due to cyclone damage. Diseases have resulted in the writing off of 25,000 ha of Managed Investment Scheme hardwood plantations in Central Queensland in 2010. Some of these changes could not be fully reflected in the data collected for the 2011 national forecasts. Nevertheless, the national forecasts for most other regions of Australia are believed to be reasonably robust, provided one accepts the assumption that future areas harvested will be replanted (Ferguson 2013)

Apart from the obvious impacts on competitive pricing, this shift has also changed the orientation of policy and industry development from a State-based focus to a regional focus. The regional boundaries are shown in Figure 1 and represent natural timber supply catchments for major processors.

With the possible exception of Tasmania and Western Australia, State boundaries are no longer a barrier to timber supply or demand, although even in those States back-loading, overseas imports and other arrangements have removed much of their previous shield of isolation. Regional forecasts of availability and the associated proximity to major metropolitan markets and export ports are therefore far more relevant to assessing future development than are Commonwealth or State forecasts.

Regional availability forecasts: 2011–2054

Softwoods

Figure 5 shows the official forecasts of availabilities for plantation softwood sawlogs in the four regions with the largest softwood sawlog production- Green Triangle, Murray Valley, South-east Queensland and Central Tablelands.

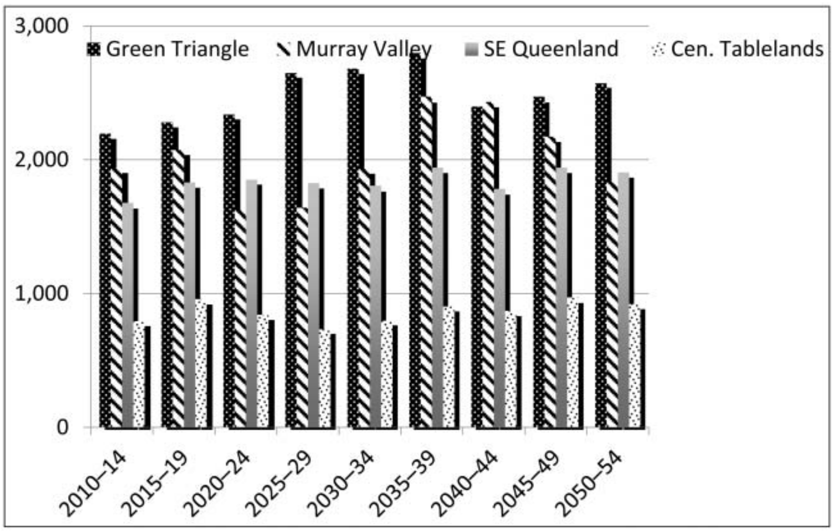
Given that the rotation for softwood sawlogs is about 26 years, Figure 5 indicates that the Green triangle has some scope for expansion after 2015 but tempered by some reductions thereafter. The other three regions have very little scope for expansion except for a limited increase in Murray Valley from 2035 to 2044. Any new planting in the immediate future would become available after 2035. Thus, assuming that replanting of harvested areas continues, scope for major expansion beyond 2035 will hinge on the rate of new planting undertaken in the immediate future.

Hardwoods

The South-west of Western Australia, the Green Triangle and the Tasmanian Regions are the major regions producing hardwood pulpwood and Figure 6 shows the forecasts of availability for them.

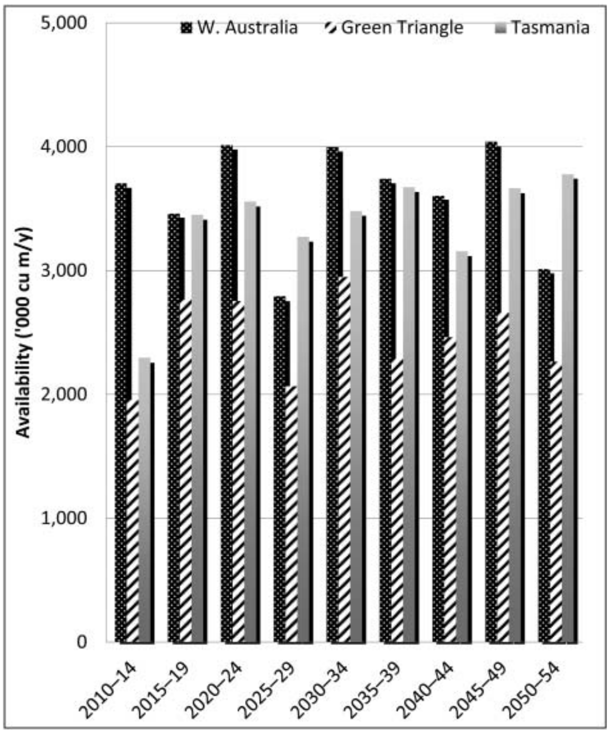
In the case of the South-west of Western Australia and the Green Triangle, large increases in the volumes available relative to the 2012 harvest levels (about 1.5 million m^3/yr and over 1 million m^3/yr respectively) are forecast. No significant new planting is likely in the next 5 to 10 years. However, a shift to radiata pine is likely in replanting some areas of blue gum on better sites, as is discussed later.

FIGURE 5 *Regional softwood sawlog availability*



Source: Gavran *et al*. 2012.

FIGURE 6 *Regional hardwood pulpwood availability*



Source: Gavran *et al*. 2012.

For Tasmania, some new planting and maintenance of replanting will result from the accord reached under the Tasmanian Forest Intergovernmental Agreement which will largely be directed to sawlog production, though with significant complementary impacts on pulpwood supply.

Figure 7 shows the forecasts of availability for hardwood sawlogs in the two principal Regions involved – South-east Queensland and Tasmania.

In 2000, the Queensland Government committed additional funds to new planting of hardwood sawlog plantations in the South-east Queensland but pest and disease issues have seriously undermined future availability from these (see Ferguson, 2013). In addition, as noted earlier, cyclone damage has greatly reduced future availability in other regions of Queensland. Future prospects hinge on success in species selection and breeding to overcome the pest and disease issues.

Tasmania has had a long-standing program of growing long-rotation hardwood plantations for sawlogs and the forecast trends reflect this history. While the inter-governmental commitments to new planting referred to earlier will expand the estate, there are still partially unresolved issues of log quality to service a viable hardwood sawn timber industry.

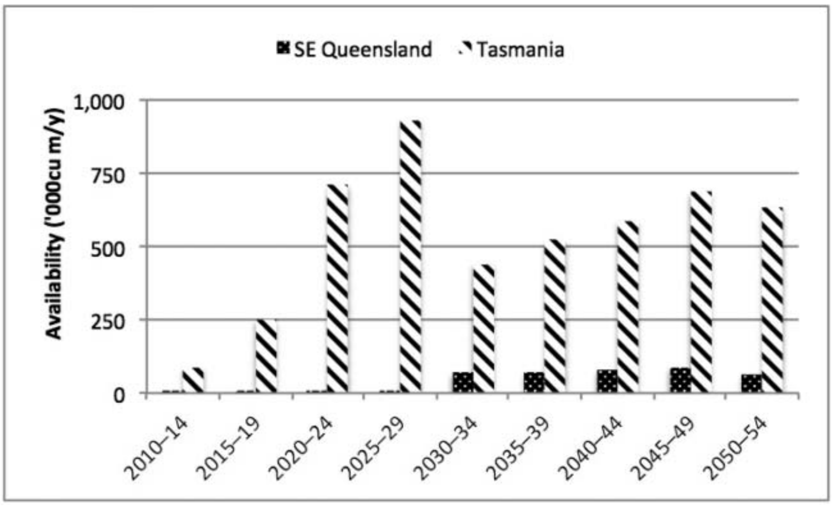
Current economic conditions

The expansion of the Australian softwood and hardwood sawlog supply is still predicated on meeting the expected modest but significant growth in demand for sawn timber (Gupta *et al*. 2013), together with further replacement of the supply of native timbers arising from marginal increases in conservation reserves. However, since 2005, macro-economic conditions have changed and have weakened that argument.

Exchange rates

A recent mining boom, principally based in Western Australia and Queensland, resulted in a marked increase in the exchange rates for the Australian dollar relative to the currencies of most of its major trading partners in 2010. This, in turn changed the economics for overseas imports of sawn timber and Stora Enso, in particular, suddenly entered the market as a major importer, increasing annual imports by about 25 per cent. Total imports of sawn timber were about 20 per cent of the national annual consumption in 2011–12, with significant flow-on effects on domestic processing of sawn timber and, to some degree, plantation stumpage prices.

FIGURE 7 *Regional hardwood sawlog availability*



Source: Gavran *et al*. 2012.

The softwood nexus

Reference has already been made to the availability of hardwood resource for processing and the shyness of investors to invest in new domestic pulp mills. The real rates of return after tax of hardwood plantation estates are also unclear, because of the changes of plantation ownership and management and early stage of developing export sales. However, the present availability trends are such that there is little incentive for investment in new planting for hardwood pulpwood in the next 10 years.

The real rates of return after tax for softwood estates are reasonably well established over a significant period and generally lie in the region of 5 to 8 per cent (e.g. Ferguson *et al*. 2010), despite the risks posed by fires, other natural disasters, and cyclical economic variables. While these may be comforting values to some, they are not the levels that encourage institutional investors to engage in funding of large-scale (so-called greenfield) new planting. That said, however, industrial forestry entities will continue to expand marginally by purchase (or leasing) of adjacent land (and trees, if relevant) that can make a profitable addition to the entity's overall rate of return.

Notwithstanding some slow expansion of the industrial plantation estates, the softwood processing industry is generally greatly constrained in its ambitions to expand the scale of processing to achieve internationally cost-competitive levels (de Fegeley *et al*. 2011). This chicken and egg situation is unlikely to be resolved without some form of government assistance to the plantation growers to break the nexus. The form and extent of that assistance are the issues.

FUTURE POLICY ISSUES

Land prices

Significant public disputes between agricultural and plantation interests regarding water use by plantations in some regions have also led to present or proposed planning provisions at a local government or State level that are arguably inequitable to plantation owners relative to other landowners. They have or will have a significant effect on the capacity of plantation interest to compete for land. Those imperfections aside, the future purchase or leasing of agricultural land for plantation development will hinge on trends in land prices.

Expansion of the plantation estate (i.e new planting) currently rests on the purchase on privately-owned land by a planation industry that is almost entirely privately or corporately owned and managed. One would therefore expect land prices to be largely determined by competitive influences. These influences include the impact of yearly rainfall and other weather conditions on annual crops and livestock, the continuing upscaling of most forms of agriculture, the age structure of agricultural owners, the market for 'hobby' farms sought by wealthier city-dwellers, and the expansion of urban development.

Relevant data on changes in land prices are not easy to obtain because the defined areas are often too aggregated to make meaningful comparisons with the principal regions where timber plantations are grown. Some include hobby farms with other rural property, others exclude sales below 250 ha, and some are valuation estimates, some transactions data. Nevertheless, Table 1 provides some indication of the trends in New South Wales and Queensland

Table 1 shows rates of increase in land prices generally well in excess of inflation, which has increased at slightly less than 3 per cent over that period. With the exception of South-east Queensland and after accounting for inflation, real land prices have been rising at moderate to high rates over the last 15 years and this is probably true of other plantation regions. Part of the increase was due to the competition for land engendered by the Managed Investment Schemes, where bidding for land immediately prior to the end of the financial year sometimes became cut-throat under the peculiarities of the tax treatment. However, other factors were at work, especially in areas around major rural towns where competition

TABLE 1 *Rates of increase of rural land prices*

Region	Area/Activity	Period	Increase (% pa)	Source
North Queensland	Coast. grazing	2000–2011	14.3	1
Central Queensland	Coast. grazing	2000–2011	11.7	1
South-east Queensland	Coast. grazing	2000–2011	2.6	1
North Coast, N.S.W.	Lismore	1996–2012	9.5	2
Central Tablelands N.S.W.	Bathurst	1996–2012	6.9	2
Central Tablelands N.S.W.	Oberon	1996–2012	3.9	2
Murray Valley, N.S.W.	Tumbarumba	1996–2012	5.8	2
Murray Valley, N.S.W.	Tumut	1996–2012	9.6	2
Wellington, Vic.	Mix. grazing	2007–2012	5.2	3
Latrobe, Vic	Mix. grazing	2007–2012	9.9	3
Strathbogie, Vic	Mix. grazing	2007–2012	2.4	3

Source: 1. Urbis, 2011 2. Land & Property Information, NSW 2012 3. Valuer-General, Victoria, 2013.

for 'hobby farms' became pronounced, as evident in the data for Lismore and Tumut.

The increase appears to have peaked in 2011 and real prices are currently dropping somewhat as a result of prolonged drought in some regions and unfavorable trends in agricultural markets. However, the earlier increases dampened the appetite of industrial plantation companies for land purchase especially since several newly formed companies had purchased forestry rights relating to former Managed Investment Scheme companies and, in some cases, the underlying land as well. It seems likely that real land prices will continue to fall slowly. Because location relative to major markets and ports is all important, some low rate of increase in new planting is still likely as companies lease or purchase land which is well located relative to their markets and improves their their internal rate of return.

Government assistance

Neither the forestry nor the agricultural sectors receive significant assistance from the Commonwealth Government through tariff barriers or direct subsidies. Commonwealth assistance given to research and development to both is on a similar basis, involving an effective taxation concession of 45 per cent. However, assistance to agriculture by all State Governments for research and extension is significantly greater than that for forestry.

Because of opposition from the conservation movement, the Commonwealth government has not recognized carbon sequestration by plantations established for commercial timber production. This opposition probably stems more from concerns about timber production in native forest, where harvesting is strongly opposed by sections of the conservation movement. However, recent changes to introduce carbon pricing on the basis of international trading in 2015 have probably eroded interest in reversing this omission, given the low international prices prevailing. In any event, the Opposition intends to abolish the carbon tax if successful in the forthcoming Commonwealth election. Such changes highlight the sovereign risk attached to legislation or regulations – a matter taken up later under Regulatory Controls.

Hampton (2013), the CEO of the Australian Forest Products Association representing Australian forest growers and industry recently published a powerful argument for government assistance in which some of the preceding points are repeated. He eschewed 'tariff barriers or other simplistic devices – which kill off innovation' but left specific mechanisms unstated other than by reference to those used elsewhere; such as innovation co-investment (Canada) a feed-in tariff program for renewable energy (Japan), a wood-first for government buildings (Norway), and zero taxation on timber sales (United Kingdom). Recently, however, the Association (AFPA 2013) has put forward a proposal for a National Institute for Forest Products Innovation with an ambitious program for a centralized hub for innovative research and development.

Henry *et al*. (2010) reported on a major review of Commonwealth taxation that canvassed the dilemma concerning subsidies faced by governments. Subsidies may be more effective in achieving a particular target, but often involve higher transactions costs and risk of default. General or sector-specific taxation concessions are more difficult to target specifically but are otherwise self-policing because of the penalty provisions applying to taxation. Subject to specific analysis of proposals, the review nevertheless favored subsidies. More recent studies of government assistance to the agriculture and forestry sectors (PwC 2013) suggest that a major review of these will ensue in the next few years.

Some of the measures suggested by Hampton (2012) may have merit and warrant further investigation of the specific nature of the potential social net benefit in Australia, the implications for competitive materials, and the transaction costs involved. However, in relation to increasing the area of plantations, there are other forms of assistance that also warrant consideration, especially relating to regulatory controls and farm forestry.

Regulatory controls

Regulatory controls are in some ways the counterpoint to government assistance and play an important role in setting the economic environment for investment. Recent major changes in those controls, such a those relating to the Managed Investment Scheme taxation provisions, carbon pricing, and the Tasmanian intergovernmental agreement, have highlighted the issue of 'sovereign risk' associated with possible changes of regulatory controls by governments at all levels, given the long periods involved in growing plantations. While controls are needed, governments need to be mindful of the perverse effects that rapid and recurring changes can bring to investment in plantations.

Reference has already been made to the need for changes on controls affecting land use to be equitable across the sectors involved. This tends to be more acute a problem concerning local government, where new zoning overlays need more research and consultation to avoid perverse outcomes. Most States have recognized these issues and are starting to address them (e.g State Management Co-ordinating Committee 2004) but there are a number of cases where the inequities are discouraging investment in plantations,

Farm forestry

In contrast to the industrial plantation ownership described in the preceding sections, farm forestry entails plantation (or forest) ownership on a smaller scale (Herbohn and Harrison 2004), generally on hundreds, or at most in the low thousands, of hectares.

Farm forestry in the form of plantation establishment has had a varied history in Australia. Very little was carried out prior to World War II, possibly because the prevailing attitude of farmers was, to quote an oft-repeated phrase characterizing farmer attitudes in that era– 'if it moves shoot it; if it doesn't, cut it down'.

Individual States and the Commonwealth (State Management Catchment Co-ordinating Committee 2004) have sponsored various programs to encourage farm forestry investment. Some involved outright grants for all or part of the establishment costs and some involved loans for that work. Given the relatively small amount of capital involved in the loans, transactions costs proved onerous and cost more than the average loan itself (Ferguson 1985), so none currently exist. Some private plantation companies provided assistance in cash and/or kind to, or entered into joint ventures with, landowners willing to plant designated species on prescribed minimum areas. A national Farm Forestry Action Statement (Department of Agriculture, Fisheries and Forestry 2005) promoted a wide range of socio-economic and environmental advantages through strong extension support until recently {Race 1999; Schirmer *et al*. 2000). A 2008 review (URS Forestry 2008) estimated that the national plantation estate included 155,000 ha of farm forestry[2] plantations. However, most of these were Managed Investment Scheme plantations established on leased land. Only 33,000 of other farm forestry plantations had been established since 2001 (URS Forestry 2008).

Surveys undertaken in 1999 (Alexander *et al*. 2000) showed a strong bias for environmental and amenity services and a minimal interest in production forestry. While this history is not encouraging, farmer and small landowner attitudes have changed over the last decade or so as environmental education and concerns have become more widespread. In any event, the rapid uptake of the forestry Managed Investment Schemes clearly demonstrated that there was a substantial interest in the leasing or joint venturing of land for production forestry, presumably motivated by the income flows derived and the need to diversify income.

While the collapse of most Schemes may have eroded that interest for a time, there is nevertheless a strong latent interest among farmers because of the secular trends proceeding in agriculture. Three inter-related trends are relevant:

(1) The first concerns the age structure of the farmers and the associated family succession in which many children are averse to taking over the farming operation when parents retire (Barr *et al*. 2005; Wilkinson 2009). When children are averse to taking over the farm, aging farmers who wish to maintain their lifestyle may look to options to reduce their workload by leasing land for plantations.
(2) The second is the structural adjustment problem in which asset-rich but cash-poor farmers eventually need to realize on their assets in order to support moving off the farm and into retirement (Mackarness and Malcolm 2006).
(3) The third is the trend to increase farm size, mechanization and the use technological improvements to improve profitability. In the 15 years from 1990, Eves and Painter (2012) report that the overall number of farms in Australia reduced by 20 percent and farm size increased by 30 per cent. Agglomeration of farm properties, however, may make diversification of income sources through leasing of some land more attractive.

These are complex issues involving lifestyle, family succession, income and risk. Research (Schirmer *et al*. 2000; Schirmer 2009) and experience (Stewart *et al*. 2011) suggest that extension and assistance needs to focus on offering choices to farmers, not single focus programs, and that community concerns also need to be addressed in any such process.

Scale and risks

Processing

The review to date has largely focused on plantation ownerships that were, or are planned to be, of substantial aggregate scale, supplying industrial scale processing plants. The scale of processing is a continuing concern in the battle to maintain a dispersed processing industry that is internationally cost-competitive, yet services a widely separated set of a few major population centres.

Despite the availability of a sufficient or near-sufficient plantation resource in three regions, investment in a new world-scale kraft pulp plant has not been forthcoming largely because it would have to export a significant proportion (at least one third) of its output overseas. Nor, indeed, has investment been forthcoming in any greenfield pulp plant in Australia since 2001. The risk of that increase coming on stream at a time when the global trade in pulp is in a trough, or imports are available at a low price, is a substantial deterrent to investment– all the more so when the exchange rate of the Australian dollar has been so high.

While achieving a world scale sawmilling operation is not quite so constrained, it nevertheless is affected by global trade, exchange rates and trans-Tasman industry ownership. In the latter case, one company (Carter Holt Harvey Ltd) dominates the sawmilling industry in both Australia and New Zealand and that trans-Tasman spread of ownership probably softens the aspirations of its New Zealand arm in exporting to Australia. In addition, future availability in the major softwood regions is limited and implies competitive pressures on stumpage prices to secure new resource in order to upscale.

Plantations

In contrast to the trends in processing, the scale of the individual plantation operations such as planting and harvesting has seen some major changes since 1990. Prior to the commencement of forestry Managed Investment Scheme operations, it was widely believed that the economies of scale of these operations precluded extensive small-scale operations that typify farm forestry. According to confidential data on several large companies, the average area planted on any

[2] In this case, defined as less than 1,000 ha of plantation in individual ownership.

title was between 150 and 300 ha but about one third of the plantings were less than 80 ha and 15 per cent less than 40 ha (Ferguson 2013).

Some will doubtless argue that the seemingly low scale of a significant proportion of these plantings was facilitated by the very high prices that forestry Managed Investment Scheme companies charged investors for establishment. While published evidence is not available, my own experience is that the actual contract operations were conducted at prices reasonably close to those of large-scale establishment by industrial-scale companies, reflecting the increase in supply and greater mobility of independent contractors (often diversifying from agricultural activities) and consequent competition. The very high prices charged investors were more a product of high management and marketing costs of the Managed Investment Scheme companies. Direct commissions averaged 10 per cent but 'soft dollar' incentives (Parliamentary Joint Committee on Corporations and Financial Services 2009) and multiple sources of commissions increased the markup greatly. Marketing costs were also substantial. Collectively, these costs were alleged to be excessive, involving 'overspending on some forestry expenses and administration and marketing expenses' (Parliamentary Joint Committee on Corporations and Financial Services 2009: 26).

Harvesting might be argued to be more sensitive to scale than planting but observation of current blue gum harvesting suggests that this is not markedly so, given the mobility of modern harvesting equipment. Haulage distance is the more critical factor to the economics than is scale of planting or harvesting.

Contrary to earlier beliefs then, if farmer attitudes can be encouraged and the commercial risks reduced, Government assistance to farm forestry by way of a revival of extension services, together with small taxation or cash grant incentives to assist structural adjustment, could assist the expansion of the resource in the key regions needing to upscale, as well as providing benefits of environmental public goods such as carbon mitigation and salinity mitigation, where relevant (Nambiar and Ferguson 2000).

Some see the lack of catastrophic fire insurance as a major risk. Experience suggests this concern in overstated. Once plantations reach merchantable size, sale and utilization can generally be effected, albeit subject to some reduction in price. For industrial growers, the problem is more the cash-flow burden imposed in replanting but insurance to cover those costs can be obtained.

The principal risk in farm forestry relates to the prices of thinnings and final crop and is significant because most large industrial forestry estates sell to large processors on a take or pay basis. This means that farm forestry growers have found it difficult to sell logs when the timber industry is in a cyclical trough. However, if farm forestry can be developed to become a material portion of the resource availability, a market segment of short–term or spot sales could develop that mitigates the problem. Changing attitudes and encouraging the development of secondary markets highlights the need for a greater emphasis on extension services, currently reduced to a very low level in most States.

CONCLUSIONS

The Australian plantation industry and Australian governments are stalled at an intersection of many paths and are confronted by many conflicting signals. Key among them is issue of how much of the short rotation hardwood plantations planted for woodchip or pulping will continue to be replanted and managed after initial harvesting, how much will be converted to softwoods, and how much will change land use to agriculture or other uses? Until that issue is resolved, a national policy proposed by de Fegely *et al*. (2011) that envisages expanding the softwood resource in strategic regions through farm forestry seems unlikely.

There is no silver bullet to solve the policy problems pertaining to plantations and plantation establishment in Australia. The problems are too complex, inter-related and yet spread so widely and thinly. Ironically, the perverse outcomes bear heaviest on the Australian Government's climate policy, because the loss of plantation area could represent a material change in the Government's estimates of improvement in the carbon budget by 2020.

The political magnitude of the structural adjustment problem for farmers is likely to become an increasingly important issue and will influence trends in land prices. Any major downturn in agricultural prices will likely trigger a major response from those farmers seeking to retire or lessen their workload. Hence industrial plantation growers need to recognize the scope for farm forestry. Diversification to encourage farm forestry in key regions offers a means of increasing key regional supply levels to make the processing industry more internationally cost-competitive. It also offers diversification of income to farmers, among other advantages, and is a political necessity if continuing friction with the agricultural lobby is to be reduced. It requires revitalization of extension services to promote appropriate programs and to accept that uptake will be slow and require long-term assistance to have a significant impact.

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The contribution of tree plantations to household welfare: case study of Piet Retief and Iswepe communities

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SUMMARY

This paper examines the contribution of industrial tree plantations to the welfare of rural households in villages located in Iswepe and Piet Retief communities of Mkhondo local municipality, South Africa. Systemic random sampling was used to administer questionnaire survey on 120 households. Findings shows that household in these communities enjoy direct benefits such as employment opportunities, and indirect benefits such as provision of housing linked to the social responsibility spending of tree plantation companies operating in the locality. However, households in the study area expressed concern with issues such as lack of access to electricity, poor health and sanitation services. There is therefore a need to address issues of concern raised by households in this study in order to improve the overall contribution of tree plantations to rural households' welfare in South Africa.

Keywords: tree plantation, forest resources, household, livelihood, rural community

Contribution des plantations d'arbres au niveau de vie des foyers: étude-cas des communautés Piet Retief et Iswepe

C. OFOEGBU

Cet article examine la contribution des plantations d'arbres industrielles au niveau de vie des foyers ruraux dans des villages des communautés Piet Retief et Iswepe de la municipalité locale de Mkhondo en Afrique du Sud. Un échantillonage systématique pris au hasard a été utilisé pour soumettre un questionnaire d'enquête à 120 foyers. Les résultats montrent que les foyers de ces communautés ont recueilli des bénéfices directs. tels que des opportunités d'emploi, ainsi que des bénéfices indirects, comme l'octroi de résidences, associé aux efforts des compagnies de plantation d'arbres opérant dans la localité d'assumer des responsabilités sociales. Les foyers de l'étude ont toutefois exprimé leur inquiétude quant aux questions du manque d'accès à l'éléctricité et des carences des services de santé et sanitaires. Il existe par conséquent un besoin de faire face à ces questions posées par les foyerrs de l'étude, afin d'améliorer la contribution totale des plantations d'arbres au niveau de vie des foyers ruraux en Afrique du Sud.

La contribución de las plantaciones de árboles al bienestar del hogar: estudio de caso de las comunidades de Iswepe y Piet Retief

C. OFOEGBU

Este artículo estudia la contribución de las plantaciones industriales de árboles al bienestar de hogares rurales en aldeas situadas en las comunidades de Iswepe y Piet Retief, en el municipio de Mkhondo (Sudáfrica). Se empleó un muestreo aleatorio sistemático para seleccionar los 120 hogares encuestados. Los resultados muestran que los hogares en estas comunidades disfrutan de beneficios directos tales como oportunidades de empleo, y beneficios indirectos, como la obtención de una vivienda ligada al gasto en responsabilidad social que hacen las empresas de plantación de árboles que operan en la localidad. Sin embargo, los hogares en el área de estudio expresaron su preocupación por cuestiones tales como no tener acceso a suministro eléctrico y deficiencias en los servicios de salud y de saneamiento. Por tanto, existe la necesidad de abordar las cuestiones planteadas por los hogares de este estudio, con el fin de mejorar la contribución global de las plantaciones de árboles para el bienestar de los hogares rurales en Sudáfrica.

INTRODUCTION

Tree plantations provide benefits and key resources, able to help satisfy many human needs, such as socioeconomic requirements e.g. as employment, food, health etc.; and material needs e.g. timber, paper etc. (Richardson 2005). In most rural communities across South Africa forest products are found to be a significant contributor to household's welfare and livelihood (Shackleton *et al.* 2007). In some instances, forest resources serves as a reserve of products upon which households fall back on for either subsistence or income in times of hardships, e.g. crop failure or unemployment (Maduekwe 2008). Firewood, charcoal, poles, timber, mushroom, edible insect, weaving fibre, thatch grass, fodder for livestock, to mention but a few, are some of the forest resources that have been identified to be a major sustainers of rural lives and livelihood in South Africa (Ham 2000, Shackleton 2004 and Mayers 2006).

Moreover, numerous studies have explored the dependency of humans on forest resources (e.g. Ham and Theron 2001, Shackleton 2004 and Chamberlain *et al.* 2005). Rural households are often involved in harvesting, collecting, processing, consuming and selling tree plantation products and resources to complement outputs from agricultural activities. For some households tree plantations-based income generating activities can be a major source of income. In addition, there are several indirect benefits attributable to tree plantations. Ham (2000) observed that supply of firewood and poles from tree plantations in the Kentani area of the eastern Cape Province South Africa contributes significantly in reducing the deforestation rate of indigenous forests and woodlands in the area. Reduced deforestation has had a significant positive impact in the maintenance of forest ecological diversity (Lewis *et al.* 2005). However there has been increasing interest in understanding the specific contribution of tree plantation to rural households' welfare and livelihoods (Mamo *et al.* 2007).

While there are many benefits that rural households derive from tree plantations, there are also costs associated with tree plantations that are often borne by poor rural communities sited in tree plantation area. Globally, there is a growing concern about household welfare and dependence on tree plantations (Fonta *et al.* 2011). Experience from USA, South America, and Australia shows that tree plantations establishment on private lands often leads to land ownership concentration in the hands of a few people, which frequently leads to displacement of small landowners and landless people (Charnley 2005). In the South African context, Lewis *et al.* (2005) reported some common costs of tree plantations, which include: losses resulting from run-away forest fires; damage to crops by wild animals and livestock living in the plantation areas; noise and air pollution associated with certain plantation activities (e.g. tree felling, fires, etc); and increasing threats to security attributed to criminal elements taking refuge in tree plantations. In the same vein, Cairns (2000) reported on conflicts in some rural communities of South Africa over competing land use interest for tree plantation and livestock grazing. In a related development, tree plantation industries are often charged with perpetuating low-wage labour and poor conditions of employment in some rural communities in South Africa (Mayers 2006). At the same time, there are increasing concerns that job creation through tree plantations are irregular and cannot sustain rural livelihood development (Mayers 2006).

However, most efforts until now to investigate the contribution of forestry to households' welfare and livelihoods in South Africa have focused on natural forests, particularly in the Eastern Cape Province (e.g. Shackleton 2004). Only very limited work has tried to investigate the contribution of tree plantations to households in South Africa (e.g. Chamberlain *et al.* 2005). However such studies tend to focus mainly on job creation and the contribution of tree plantations to the national GDP.

This study was designed to fill this gap by focusing on the overall contribution of tree plantations to households in rural communities of South Africa. The main purpose of the study thus was to investigate the contribution of tree plantations to rural household welfare and livelihood.

The study was based on a case study analysis of villages sited in the industrial tree plantations areas in Piet Retief and Iswepe area of Mkhondo local municipality, Mpumalanga Province, South Africa. The study addresses the following research questions:

1. Are there direct benefits accruing to households in adjacent communities from tree plantations in their locality?
2. Are there indirect benefits accruing to adjacent communities from tree plantation in their locality? If so, how do these benefits affect households' welfare?
3. Are there issues of concern expressed by communities as a result of tree plantation in their locality? If so, how do these concerns affect households' welfare?

MATERIALS AND METHOD

Study Area

There is a combined total of 56 villages located in the industrial tree plantations in Piet Retief and Iswepe area of Mkhonda local municipality, South Africa. Base on the settlement pattern and nearness to plantations, 12 villages were selected for this study. Ten households were randomly selected per village for sampling, resulting in a total sampled population of 120 households. The name of the selected villages and the total number of household contained in each is presented in (Table 1) below.

Questionnaire design

The questionnaire contained both open- and close-ended questions. The questions were clear and simple and were aimed at providing information on the extent of household dependence on tree plantation resources vis-à-vis employment, dependence on timber resources, dependence on non-timber plantation resources, and overall direct and indirect

TABLE 1 *Sampled villages and corresponding total number of households*

Municipality	Main Community	Villages	No. of household per village
VHEMBE	**Piet Retief**	Mooihoek	48
		Old Belfast	65
		Welverdiend	39
		Bon Esperence	34
		Athalia	51
		New Belfast	37
	Iswepe	Zoar	32
		Riverside	37
		Watersmeet	42
		The Bends Jabulani	30
		New plaas Ingwempisi	45
		Geluk	49

Source: MBP (2005)

benefits accruing to households from tree plantation companies operating in their locality. Questions to capture issue of concern associated with living in these tree plantations dominated village were also asked. In general the questions were designed in line with guidelines for questionnaire design recommended by Babbie and Mouton (2008).

Survey process

The interview team for the study comprised of the study facilitator and an interpreter. Given the strategic importance of the interpreter input in ensuring that the study questions were communicated to respondents in their mother tongue (Swanepoel and Beer, 2006); the interpreter was briefed days before the commencement of the study, about the study aims and objectives and also taken through the questionnaire in detail so as to ensure that he had a good understanding of the study objective. Following the approach pattern used by Ham and Theron (2001), the villagers were first briefed about the study objectives, before the actual survey processes started. Direct observation, face-to-face interview and administration of the questionnaire form were the method applied in gathering required data for this study. As recommended by Bless and Smith (1995) the survey process was thoroughly and critically carried out in order to avoid possible bias either from respondents or interpreter (Ofoegbu 2010).

RESULT

Direct benefits from plantation establishment

The direct benefits that rural households derive from industrial tree plantations in their localty are outlined below.

Employment opportunities

Employment opportunity is a major direct benefit that households derive from tree plantations in their locality. While some of the respondents were directly employed by forest companies operating in their locality, the majority were employed by contractors contracted to the forest companies. Nevertheless 75% of the respondents were employed in tree plantation-related establishment. The type and category of work that rural households benefits from tree plantation establishments varied: 26% were engaged in silviculture (tending and maintenance) works, 15% worked as debarkers, 7% were chainsaw operators, 1% worked as log pushers, 3% worked as drivers, 3% worked as log stackers, 3% were engaged in nursery operations (tending and planting of seedlings in the nursery), 3% worked as markers while 1% worked with charcoal producing companies. The workers also enjoyed high levels of employment security; 60% of workers were permanently employed, 32% were casuals and only 8% were seasonal workers. The different category of tree plantation jobs enjoyed by households is shown in (Figure 1) below.

The number of people working in tree plantation-related jobs when looked at across villages was found not to be significantly different (p=0.24), thus employment opportunities were fairly equally distributed across the villages. On average, one person per household was found to be employed in tree plantation-related jobs. However, Riverside had the highest mean number of 2.5 person per household employed in tree plantation-related jobs. The mean number of household engaged in tree plantation related jobs is shown (Figure 2) below.

Utilization of woody plantation resources

Households in the study area enjoyed the benefit of free collection and utilization of woody resources. The common woody resources being utilized were timber, pole and harvest residue. Harvest residue gathering was found to be one of the major benefits that the communities derive from the plantation (Plate 1). All households in the villages were involved in collection and utilization of harvest residues, used mostly as

FIGURE 1 *Category of Plantation work*

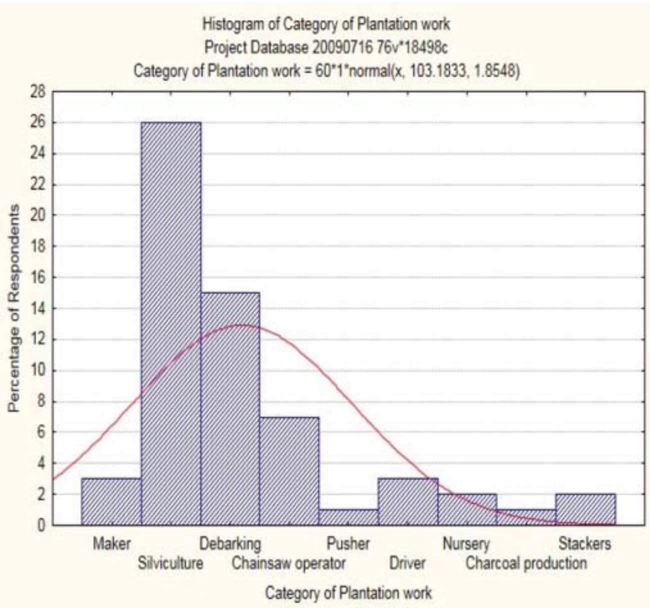
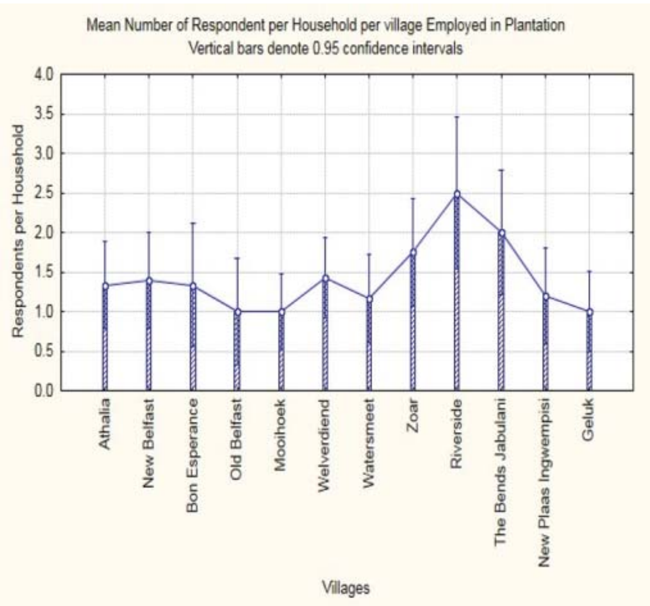


FIGURE 2 *Mean number of household per village in Plantation work*



firewood, but also used for construction of pens for livestock, fencing and house building. On average 740 kg of residue was consumed per household per village on a monthly basis for agricultural purposes (garden fencing etc). 1,317 kg of residue was consumed per household per village per month for house building, and 946 kg of residue was consumed per household per month as firewood for cooking.

Utilization of the non-wood plantation resource

As observed by Sunderland *et al.* (2003) plantation forestry provides non-timber resources either as a co-product or byproduct. Households in this study were observed to derive benefits from harvest and utilization of non-wood plantation resources prevalent in tree plantations in their locality. The most prevalent non-wood resources which the villagers collect were thatch grass, edible fruits and vegetables, livestock fodder and mushroom. Thatch grass collection and utilization is not a popular activity among the villagers, with only 23% of the respondents being involved, because it is mostly done in winter. On average people utilize 4 kg of thatch grass per month per household.

Mushroom collection was practised only at Zoar village and it was reported that 10 kg of mushrooms were collected per household per month. Fodder collection was only done at Zoar and Geluk where people collect on average 11 kg of fodder per household per month. Collection of edible fruits and vegetables was practiced only at Old Belfast, Welverdiend, Watersmeet and Geluk. Consumption was on average of 3.5 kg per household per month. The frequency of collection of these resources varied between villages. Mushroom, thatch grass and edible vegetable and fruit collections were practised three times per week per household.

Indirect benefits from plantation establishment

The indirect benefits that rural households derive from the industrial tree plantations in their localty are mostly linked to social responsibility spending of forest companies. Such benefits include the following:

Provision of free accommodation

The provision of housing in the villages for employees of tree plantation companies in the study area is a significant benefit that households derive from tree plantation companies in their locality. However the nature of these benefits differs immensly. In some villages, the people live in mud/wattle houses while in other villages families live in brick houses provided by the company. In some other villages households are granted controlled access to construction wood and land which they use to build their own houses. Some of the respondents valued access rights to harvest timber/construction wood and permits to build house as the same as living in Mud/or brick houses (Plate 2).

The percentage of respondents who expressed free accommodation as a benefit they enjoy from the tree plantation companies in their locality is presented in Figure 4.

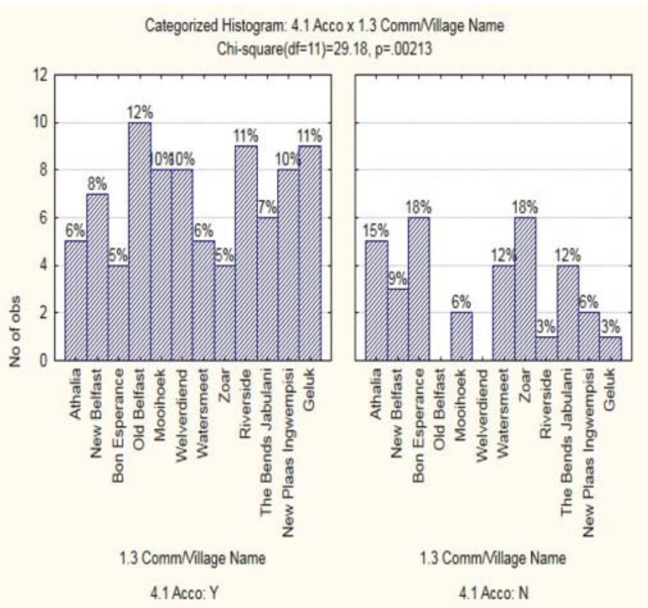
Provision of water supply

Availability of borehole water is one of the indirect benefits that households derive from forest companies operating in their locality. All the villages are provided with borehole water; however the efficiency of these boreholes and their location relative to respondents' houses differs from one village to another. Overall water supply to the villages in the study area was rated as satisfactory by 70% of respondents although some villages experienced supply difficulties. Watersmeet (67%) and Bon Esperance (50%) were the villages with the highest level of water supply difficulty.

FIGURE 3 *Pictures of typical house provided by tree plantation companies*

Source: MBP (2005)

FIGURE 4 *Accommodation benefit*



Provision of farmlands

Free access to farmland is one of the indirect benefits that households in this study enjoy. Fourty-seven percent of respondents practice farming (farming in the study context means cultivation of crops). The number of people practicing farming was found to differ significantly when compared on a village to village basis. Welverdiend had no farming activity and only 10% of the respondents in Athalia, New Belfast and Bon Esperance were practicing farming. In contrast at Zoar 40% of the community was involved in farming while at Riverside and Geluk 90% was involved and all respondents were involved in farming at New Plaas Ingwempisi.

Livestock grazing benefit

Free grazing of livestocks on open field within the plantations in the villages is of a huge value to households in the study area. livestock keeping is a big part of livelihood diversification strategy that is being practiced by most households in the study area. Tree plantations resources therefore provide household with an economically efficient means of feeding their livestock, e.g. 48% of respondents graze their cattle in tree plantations in their area. Few villages, e.g. New Belfast and Bon Esperance, do not have households that keep livestock. However, Riverside and New Plaas Ingwempisi have a high proportion of households practicing livestock keeping. Specifically, all respondents in these villages were involved in livestock keeping. Livestock keeping in the rest of the villages were found to be in the order of 10% in Old Belfast, 40% in Mooihoek, 13% in Welverdiend, 78% in atersmeet, 50% in Zoar, 60% in Bends Jabulani and 80% in Geluk.

Social responsibility spending benefit

Other indirect benefits that households in the study area enjoy that are strongly linked to the social responsibility spending of companies operating in their locality include: provision of subsidized health services, provision of educational infrastructures such school buildings etc., and the provision of cemetries.

Issues of concern expressed by respondents

The issues of concern expressed by respondents in this study include the following:

Poor power supply

Apart from Watersmeet where nearly all houses are connected to the national electricity grid, all of the other sampled villages are not connected to national power grid. Access to electricity was a concern expressed by the communities, however in some places it appears the people were used to living without electricity and hence it was no longer an issue to them. This may possibly explain the reason why only 50% respondent were found to express lack of access to electricity as a concern. The number of people that noted lack of access to electricity does not differ significantly (p = 0.011) from those that did not acoross all villages.

Poor sanitation and health service delivery

Twenty-two percent of the repondents expressed their concern about sanitation and health service delivery in their communities. In some villages health care workers visit only once a week, which people complained is not enough especially when there is an emergency or when someone is sick and in need of regular attendance.

The sanitation issues expressed by the villagers was based mainly on lack of toilets in the area. Some houses in the village do not have a toilet, forcing people to use open spaces around their dwellings as a toilet. This also poses a challenge of its own especially where some have to use the toilet at night. The statistical test shows that expression of sanitation and health service delivery challenge do not differ significantly (p = 0.697) among villages.

Poor transportation services

Thirty percent of the respondents expressed their disapproval of the transportation system to and from work to their villages. Transportation challenge includes poor road conditions, long walking distances to collection points, long waits at the collection points before being transported by contractors to their place of work, and low number of taxis plying the route to the villages.

The transportation problem is highly evident in the difficulty experienced by people in getting to work. In most villages it takes between four and five hours to get to their place of work. The long hours spent in going to work and coming back home forces the people to spent large proportions of their time away from home. In trying to solve this challenge people build houses farther into the forest close to their work place but away from social infrastructures and amenities.

DISCUSSION

The creation of employment and business opportunities within the study villages was one of the most significant contributions that tree plantations make to rural lives and livelihoods. Forest companies provide secure jobs; up to 65% of the employee are in permanent position, with only 32% in casual positions. This dismisses the notion that plantation jobs in rural South Africa are mostly casual and seasonal which cannot provide households with secure source of income. The study found that forest companies in the sample area comply with the national minimum wage regulation and hence contribute significantly in providing households with secure and improved income. This is particulalry important because villages in the study area lack employment opportunities due to their geographical location and lack of infrastructures, a situation replicated in other areas of South Africa (Shackleton 2004, Chamberlain *et al.* 2005).

The consumption of abundant forest resources, both woody and non-timber resources, in the area provides households with cash saving benefits. Although households are not allowed to sell woody resources such as firewood, poles, timber and construction wood collected from the plantations, they play a significant role in providing households with cash saving benefits. Most households in the study area use firewood for cooking, heating and lighting, which is a significant activity in their daily living. This translates to a significant cash saving benefit since the money they would have used in buying such commodities are transferred to other household needs. Moreover cultivation of food crops on farmland freely made available by companies contributes significantly in providing households with secure livelihoods. Households are able to grow their own food which provides them with cash saving benefits, and on a few occassions they are able to sell their excess harvest. This also provides households with income diversification benefits while helping to improve their resilience to shocks and uncertainties. Free grazing of livestock in plantaions also provides housholds with a good income diversification strategy. Livestock are often used by households as stock which are Frequently traded for cash in times of crisis or need. Cash saving benfits of tree plantation as observed in this study correspond with the safety net and poverty reduction roles of plantations forestry observed by Vedeld *et al.* (2004) and Shackleton (2004), where forestry plays a major role in helping rural communities survive periods of food scarcity and low income. It can thus be said that tree plantations contribute significantly to household income in the study area either directly through cash saving mechanisms or indirectly by providing them with free fooder for their livestock which are then traded for income generation.

Social responsibility spending of companies on infrastructures and services such as electricity, boreholes, cemeteries and health care in the study villages were found to be one of the dominant benefits that endeared the rural communities to forest companies operating in their locality. Social spending of companies in most cases provides a win-win scenario; serving as essential tool for companies to manage social risk in order to maintain forestry activity (Cairns 2000). Most plantation workers are housed in company houses, which are serviced with water and sanitation, and in few instances with electricity. This corresponds with the findings of Cairns (2000) who reported that forestry companies in South Africa are often the dominant social and development services providers in the villages where they operate. This finding also relates with Ham's (2008) observations where it was reported that through social responsibility programmes, forest companies work with local communities to establish for instance gardening groups, sports programmes and small business ventures in order to promote cordial relationship.

Challenges associated with electricity provision as identified in this study include: unavailability of electricity for cooking and house heating and the resultant inability to use facilities such television, radio etc. It is however difficult to determine the extent to which challenges of electricity provision have affected rural life in a broader context. Though electricity provision was an issue it was not significant. This correlates with Gugushe (2006) where it was reported that in some villages in the former Ciskei area of South Africa, most villagers prefer firewood for cooking and house heating despite the fact that they have access to electricity. Therefore it is possible that even if villagers in the study area are provided with electricity, they might still not be able to afford it.

The main concern with transportation as observed in this study is centered on the difficulty in getting commercial taxis to commute between the villages and Piet Retief or Iswepe main town, and also on the poor condition of some of the roads that link the villages with the main town. Transportation concerns such as the difficulty in getting commercial vehicles to ply village routes is an issue that characterizes most rural communities around the world (Irwin 1978). However, this type of challenge can be solved through an integrated approach by both forest companies and the municipality.

While there are concerns about living in tree plantation villages as expressed by respondents in this study, it can be conclusively stated that households in this study enjoy both direct and indirect benefits from tree plantation companies in their locality which out-weigh the cost of tree plantations operations in their area. However, in order to improve the benefits that households derive from tree plantation companies operating in their locality the following recommendations are made:

- Enabling access to forest resources alone cannot solve the livelihood problems of the communities (Gugushe 2006). Because of the important role of forestry in integrated rural development, it is thus recommended that forest companies and the Mkhondo municipality improve on their partnership in addressing the need of the rural communities.
- There is a need for forest companies to put measures in place for monitoring contractors contracted to them in order to ensure that the contractors comply with national working conditions regulations and minimum wage requirements.

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Local institutions, social capital and their role in forest plantation governance: lessons from two case studies of smallholder plantations in Paraguay

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SUMMARY

Forestry activities are not implemented in a vacuum, but highly interlinked with other domains: social, cultural, institutional, economic, and political. Good governance that builds on effective local institutions and social capital enhancement becomes one of the key issues in studying and implementing forestry projects locally. The paper presents empirical evidence from a social forestry project implemented in the poorest departments of Eastern Paraguay. It provides a descriptive comparison of two neighbouring communities characterized by different institutions. There is a large difference in project performance in both areas in socio-economic terms. One community displayed high levels of social capital and was better prepared to take advantage of extension aid and "store" the acquired know-how. The other community, with low levels of social capital, benefited from the project activities only temporarily. The role of local institutions as project channels and the development of social capital are indicated as key factors for plantation projects to work effectively.

Keywords: social capital, local institutions, plantation governance, social forestry, Paraguay

Institutions locales, capital social et leur rôle dans la gestion des plantations de bois de coupe: leçons tirées d'une étude-cas comparative de plantations de petits exploitants au Paraguay

J. SZULECKA et L. SECCO

Les activités de foresterie ne sont pas mises en pratique dans un vide social, mais fortement liées à d'autres secteurs et domaines: sociaux, culturels, institutionnels, économiques et politiques. La gestion prenant appui sur des institutions locales efficaces et une amélioration du capital social devient par conséquent une des questions-clés dans l'étude de la mise en pratique des projets de foresterie sur le terrain.

Cet article présente des preuves empiriques recueillies dans le projet de foresterie sociale mis en place dans les départements les plus démunis de l'est du Paraguay. D'un point de vue socio-économique, les différences de performance des projets dans les deux zones sont conséquentes. Une communauté présentait de hauts niveaux de capital social et était mieux préparée à prendre avantage de l'offre d'aide et à emmagasiner le savoir-faire acquis. L'autre communauté, d'un faible capital social, ne bénéficiait des activités du projet que temporairement Le rôle des institutions locales comme conduits des projets, et le développement du capital social sont considérés comme l'un des facteurs clé pour une conduite efficace des projets de plantation.

Instituciones locales, capital social y su papel en la gobernanza de plantaciones de madera: lecciones de dos estudios de caso de plantaciones de pequeños propietarios en Paraguay

J. SZULECKA y L. SECCO

Las actividades forestales no se ejecutan en un vacío social, sino en estrecha relación con otros ámbitos: social, cultural, institucional, económico y político. Así pues, la buena gobernanza, basada en instituciones locales eficaces y la mejora del capital social, constituye una de las cuestiones clave en el estudio y la ejecución de proyectos forestales a escala local. Este articulo presenta pruebas empíricas de un proyecto de silvicultura social ejecutado en los departamentos más pobres de Paraguay oriental. Proporciona una comparación descriptiva de dos comunidades vecinas, caracterizadas por poseer instituciones diferentes. Se observó una gran diferencia en términos socio-económicos en el resultado de los proyectos en ambas áreas. Una comunidad mostró altos niveles de capital social y una mejor preparación para aprovechar el apoyo de los servicios de extensión y "almacenar" el conocimiento adquirido. La otra comunidad, con bajos niveles de capital social, se benefició de las actividades del proyecto tan solo de manera temporal. El papel de las instituciones locales como canales de ejecución y el desarrollo del capital social se señalan como factores clave para la efectividad de proyectos de plantaciones forestales.

INSTITUTIONS, SOCIAL CAPITAL AND FORESTRY GOVERNANCE

Many different factors add to a forestry project's success of failure (Sargent and Bass 1992). It is already widely acknowledged that among these diversified elements, institutions are crucial in shaping, determining and influencing both practices and outcomes of forestry projects (Ojha *et al.* 2008). Literature on institutions stresses multiple meanings of the concept, but a common ground may be the emphasis on both formal and informal rules that organize and structure social interaction (Hodgson 2006, North 1991). Rules, according to Ostrom (1986), are prescriptions commonly known and used to order repetitive, interdependent relationships. Rules are to define which actions are required, prohibited or permitted and assure order and predictability of the system. Vatn (2005, 2009) proposed institutions-as-rationality-contexts to point out that institutions create an order and define a context, especially important in environmental questions. What is more, institutions are further linked to more formal self-organization of groups, as well as to the notion of social capital. Social capital is an non-material form of capital, a cultural asset based on networks of civic engagement, shared norms, values and understanding that facilitate cooperation and coordination within or among groups for mutual benefit (OECD 2001, Putnam 1993). Ostrom (2000b) studied the variance of performance of self-organized groups and linked it to social capital and attributes of the resource system. Plummer and FitzGibbon (2006) provide empirical evidence that social capital plays a fundamental role in developing co-management of natural resources, such as land and forests.

The causal arrow between institutions and social capital can point in both ways. Some authors suggest that a certain level of social capital is a prerequisite for the effective functioning of local level political and social institutions (Coffe and Geys 2005). Others in turn ask about the role of local level institutions in enhancing social capital (Lowndes and Wilson 2001, Schneider *et al.* 1997), and show that in a weak institutional setting, social capital matters greatly for economic development (Ahlerup *et al.* 2009).

Forest resources, including plantations, require cooperation at many levels and in a long time-horizon. Underdeveloped institutions or low social capital levels increase transaction costs for cooperation and bring large uncertainties, particularly constraining long-term and often expensive forestry investments in developing countries. Therefore the link to social capital should be more significant than in other on and off farm activities. A recent study of the first CDM project in China concluded that social capital was critical for the success of CDM forestry projects (Gong *et al.* 2010). Authors were able to prove that high social capital levels meant better conflict resolution, even in overcoming a sensitive issue of the lack of clearly defined property rights (*Ibidem*: 1301). Social capital formation can also influence preferences in forest management outcomes (Smith *et al.* 2012). It can therefore be assumed that local level institutions and levels of social capital are mutually supportive and should enhance good forestry governance as well as benefit sharing (Kanowski *et al.* 2011). The success of interaction between actors and institutions in terms of trust, coordination, participation, legality, effectiveness, efficiency, responsiveness and others contribute to determine the governance capacity (Arts and Goverde 2006). Mutually supportive local institutions and social capital enhance the level of forestry governance (Coffee and Geys 2005).

But measuring social capital is a difficult task, with methodological and logistical challenges (Ostrom and Ahn, 2003). Key elements that together account for social capital that can be identified in the literature and used for operationalization in this article are: trust, rules and sanctions, reciprocity and exchange as well as connectedness (O'Riordan and Voisey 1998, Pretty 1998, Smith *et al.* 2012). These will be discussed in some detail in the methodological paragraph on assessing the development of social capital.

At the intersection of forestry and development studies, many reports and analyses from around the world point to the importance of empowering community level organizations to become equal partners, effective in forest management. However, development assistance has been accused of paying too little attention to social and human capital (Pretty and Ward 2001).

This paper looks at the outcomes of an externally supported smallholder plantation project in Paraguay through an institutional governance perspective. Selecting two different communities for a descriptive comparative study it shows to what extent the local institutional context can be seen as influencing the implementation, performance and continuation of timber plantations locally as well as the quality of plantation governance. The role of institutions in plantation performance is theorized through the concept of social capital. The study traces the degree in which the different elements of social capital have emerged in both communities, arguing, that this can be the explanatory factor in the apparent variation in performance.

THE PMRN REFORESTATION PROJECT IN PARAGUAY

Background

Paraguay possesses one of the lowest plantation areas in Latin America, estimated at 66 000 hectares followed only by Bolivia (with a big percentage of natural forest cover), and the much smaller French Guiana and Surinam (FAO 2006; INFONA 2011). At the same time, the country has seen huge deforestation rates in the second half of the 20th century (2.65% annually according to the WRI estimations) (cf. Huang *et al.* 2009), with a massive decrease and degradation of natural forests (Quintana and Morse 2005: 67). This was the result of the dominant national development mind-set, in which "the existence of forests is a sign of backwardness" (Sobrevivencia 1999). Forests were accordingly seen as 'unproductive' lands that must be cleared and turned into something useful – *mejora,* generally meaning fields for agriculture (Hetherington 2009). Paraguay thus faces significant fuel wood and timber shortages, apart from the irreversible environmental degradation. Forest plantations in Paraguay can be regarded as critically needed to fill the gap and offer the necessary wood products at the local and national markets, as well as adding to the development of the national economy through raw material or wood product exports. Corporate plantation investments are limited, despite attractive internal rates of return exceeding 15%. This is a result of political and commercial risks, the risk of expropriation, war and transfer risks, corruption, poor infrastructure, bureaucracy and lack of confidence (Cubbage *et al.* 2010). Plantation initiatives, especially grassroots smallholder projects, are therefore a particularly important land use pattern for rural Paraguay (Grossman 2012, Monges Zalazar *et al.* 2012, 2013). Smallholder plantations are also an important tool for addressing other major problems in rural Paraguay, such as livelihood diversification (Ellis 1998), reduced labour availability on farm (plantations are less labour absorbing than agriculture), or mitigation and adaptation to environmental uncertainties (Finnis *et al.* 2012). Even fast-growing tree plantations can achieve significant levels of local recognition of the ecosystem services they provide, as the study by Vihervaara *et al*. (2011) in neighbouring Uruguay has shown.[1]

The PMRN – *Proyecto de Manejo Sostenible de Recursos Naturales* (Project for Sustainable Management of Natural Resources) of the German Development Agency (GTZ/GIZ) and the public German development bank KfW (*Kreditanstalt für Wiederaufbau*), supported by the Paraguayan Ministry of Agriculture and Livestock, started in the year 2000. It was initiated under the idea of a sustainable management of natural resources in the poor areas of Eastern Paraguay's seven departments: Concepción, San Pedro, Canindeyú, Caaguazú, Guairá, Paraguarí and Caazapá. It channelled resources, technology and know-how through participatory rural development methods with field extension workers. The total project span was 10 years (October 2000–October 2010) with a budget of 3.3 million euro for technical cooperation (Sylla 2010). One of the project activities has been the reforestation/afforestation with both exotic and native tree species.[2] This part of the project and field activities started in 2003 and continued until the project's end. It is estimated that under the scheme about 2676 hectares of plantations were originally planned and 2087 hectares have been effectively reforested (PMRN 2009:13). PMRN also promoted sustainable management of natural forests (with total real coverage of 2758 hectares) and agroforestry systems. About 9000 farmers participated in forestry activities, including 5500 participating in forest plantation establishment (PMRN 2011). The beneficiaries of the project received the coverage of initial plantation costs, plants and trainings. The specific on-farm interventions and activities have been planned according to the owner's objectives and his or her land availability. Therefore different species were planted, with an estimated proportion of 70% exotics (including 50% Eucalyptus genera) and 30% natives. The species included exotics such as *Eucalyptus grandis*, *Eucalyptus camaldulensis*, *Melia azedarach* (Paraiso gigante) and natives *Cordia trichotoma* (Peterevy), *Tabebuia impetiginosa* (Lapacho), *Cedrela fissilis* (Cedro) among others (PMRN 2011:108).

Project implementation

The project was implemented by engaging the local *committees of producers*[3] – established by local farmers to receive technical assistance in small groups. This was meant as a measure enhancing a certain minimum level of formal social organization, at least in the areas where committees or other forms were previously not established. Also this grassroots organization form helped the local extension workers to provide guidelines and assistance both individually and in small groups. Extension workers have been hired by the project regionally and appropriately trained. They were locally trusted and got to know the farmers in the project area well. *"The farmers made their decisions concerning species and size for the plantation. Extension agents helped them to follow the plans by visiting them once or several times per month"* (local expert interview, 25.01.2012). Each producer could apply with up to 3 hectares of land to be covered with the project's forestry measures. During the implementation, PMRN supported the establishment of local nurseries. 88 such units were created in total with the capacity to provide between 5 000 and 20 000 seedlings per year. A number of committees, after establishing their plantation establishment plans, kept the nurseries to sell the seedlings to other producers, organizations and municipalities. Some tools for plantation management have also been given to the committees to be used by all its members.

Particular plantation characteristics depended on the species and farmers' individual priorities. Stocking density ranged between 2x2 and 4x4 meters with the stocking rates between 625 and 2500 plants per hectare (PMRN 2011: 109). The extension measures included help in soil preparation, planting, plantation management, pest control, thinning and pruning advice. One of the preferred species used for plantation establishment was *Eucalyptus grandis*. The project's documents show its management in a 12 year rotation with two thinnings: at 4 and 6 years (both removing 30% of the

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[1] Having said that, it needs to be stressed that plantations' functions are always case-specific and should be judged accordingly.

[2] Plantation of exotic species as 'reforestation' can be contested. However, according to the usual definition, 'afforestation' means establishing forest stands in areas that were previously or for a long time – not forests. In the study areas, the fact that the native Atlantic Forest was once abundant and then slashed and burned is still part of living memory. That is one of the reasons for using the term 'reforestation'; the other is the Spanish word *reforestación* which is the only one used to describe the project's forestry activities. Where possible 'plantation establishment' is used as a neutral term.

[3] Committees of producers (*comités de productores*) are the most basic legally recognized form of farmers' organizations in Paraguay. They are followed by pre-cooperatives and fully developed cooperatives.

standing volume). Pruning was recommended until the trees reached a height of 8 meters, to obtain high quality wood (*Ibidem*).

Results of the project

It was estimated that the production potential of fast-growing plantations in the project is about 20 m^3 ha^1 $year^1$ (Grulke 2006). However, due to the variety of species used, different locations and individual management capacities, it is difficult to estimate the actual average growth rates. Project documents point to the important constraints that could also be observed on site – a management deficit as well as the lack of motivation among farmers to conduct thinning and pruning. Especially thinning is widely perceived as a production loss. Such management and expert knowledge deficits can lead to frustration in the future, when the plantation's output and its economic value will fall below the initial projections. Plantations have mainly been established for timber production and fuel wood, as well as some additional own use by the producers (construction etc.), to be sold on the local and national markets. The owners are free to decide when and where to sell the plantation products. Generally they tend to sell the wood too early and to middlemen. Trees were often cut and sold having reached diameters between 15 and 25 centimetres, and the farmers were often not willing to wait for an optimal diameter and better price (the final dbh recommended by the project is 40–45 cm) (PMRN 2011:114). From one hectare of an exotics plantation, the owner can earn USD 155 per year.[4] But as was already mentioned, after 12 years a well-managed plantation, subjected to thinning and pruning would produce wood worth much more (about double the price) than the same plantation without appropriate silvicultural management.

An internal project survey conducted among farmers showed their positive attitudes to tree planting and indicated their willingness to work with plantations in the future (over 95% respondents) and their willingness to share such knowledge with their children (over 90% respondents) (PMRN 2009: 19).

A COMPARATIVE CASE-STUDY OF TWO COMMUNITIES IN THE PMRN: *CUATRO VIENTOS* AND *15 DE AGOSTO*

The puzzle and background

While the conditions and assistance provided to all the communities under the PMRN project were very similar, after the project's lifespan has ended, a clear difference between the socio-economic impacts on different localities can be observed. It can be therefore hypothesized, that local conditions influenced performance. To control for physical conditions such as climate, soils, or even differences in socio-political conditions between various regions, the study looked at two communities which by Paraguayan standards are considered "neighbouring" – that is, they are both located in the same department, about 40 kilometres apart (Table 1). In the remainder of this section, the region as well as the two communities are briefly discussed. Subsequently the method of the comparative case study is presented followed by the theoretical approach, based on which the hypotheses explaining the divergent project results were derived. The article ends with the discussion of results and evaluation of hypotheses.

The department of San Pedro, where both communities are located, is situated in the centre of the Paraguay's Oriental Region (Map 1). It has a humid and rainy climate with the average temperature of 23 degrees. Land use in the area is dominated by cattle farming and agriculture, there is almost no industry. Known as one of the poorest and most conflicted regions of the country (expert interview, 19.01.2012), it is the seat of modern *campesino* (peasant) unrest, especially regarding land reform issues (Hetherington 2009; Hebblethwaite 2010).

Cuatro Vientos

The community of Cuatro Vientos (District Villa del Rosario, Department San Pedro) is located in the direct neighbourhood of the Mennonite colony Volendam,[5] established in 1947. The village of Cuatro Vientos was itself established only three years before that, in a centrally planned settlement rush in Eastern Paraguay. The question of indigenous rights is therefore not an issue in this case, as all inhabitants are descendants of the 1940s settlers. After decades of conflicts between the local Latino farmers and the "foreign" Mennonite colonists, in 1999 cooperation between the two settlements started, initially to reconstruct a local school and improve infrastructure (expert interview, 20.01.2012). This model of cooperation did not involve any direct financial transfers to Cuatro Vientos, but rather access to trainings, technology and education programs, as well as a gradual improvement in local schooling (a secondary school is now functioning in the village). One of the results was a gradual process of self-organization in the community, at the beginning as a pre-cooperative and now as a full legal cooperative of producers. A leader of the neighbouring Mennonite colony commented on the cooperative in Cuatro Vientos: "Firstly it started as a distant idea and only the committees were formed at the beginning. Later on, a pre-cooperative was formed. It functioned just like a cooperative, but was not registered. It all happened in stages. We have no interference in the cooperative Cuatro Vientos, they have their own board, their own monitoring. This is a difference to many

[4] With an average wood price estimated at PYG 35000/m^3, productivity of 20 m^3 ha^1 $year^1$ and exchange ratio USD 1 to PYG 4500.

[5] The Mennonites are a protestant religious group which fled Europe in the 19th and 20th century and settled in the Americas. Although originating in the Netherlands, most of the Mennonite colonists are of German descent and until today use either literary German or the Low German dialect at home, while being now fully bilingual (Spanish) or tri-lingual (Guarani) in Paraguay. The numerous Mennonite colonies in Paraguay vary in their religious and cultural attitudes, as well as policies towards non-members. The Volendam community is considered moderate and relatively liberal.

TABLE 1 *Cases in comparison and methods for data gathering*

Community	Cuatro Vientos	15 de Agosto
Smallholder plantation selected	13 (20% of smallholders)	13
Sampling	Stratified, purposive	Stratified, purposive
Local expert interview	Extension agent	Extension agent
National expert interview and data	INFONA, PMRN	
Similar background conditions:	Climate, soil properties, crops cultivated, subsistence farming, land size and titles, limited market access, low education level, out-migration, poverty thresholds, income, family model, culture	

MAP 1 *Map of Paraguay with San Pedro department and the analysed communities*

projects that want to impose the organizational forms and additionally do it in just a few years" (expert interview, 19.01.2012). The studied households consisted on average of 5 people and worked the plot of 10.3 hectares (mean) with an average of 0.8 hectare reforested under the plantation scheme. Local farmers adopt very similar land management schemes with houses close to the roads, encompassed by small home gardens and livestock (mostly chicken and pigs), corn, beans and manioc planted as subsistence crops and cotton, corn, beans, sesame and peanut planted as cash-crops. Remittance economy used to play a significant role for the community, when (mostly) men travelled to the cities or to Argentina and Brazil to work, but its role decreases with the first successes of the local cooperative.

15 de Agosto

The community of 15 de Agosto (District Chore, Department San Pedro) lies in the proximity of similar local farmer settlements. The studied households in this locality were almost equally numerous (4.92 people per household) but worked slightly larger plots of land (12.1 ha) and dedicated larger areas to tree plantation establishment (1.2 ha). The community possesses analogous land management schemes with two additional cash crops: manioc and tobacco. Remittance economy was and remains a crucial source of income for most of the local households. It has also been affected by external development aid projects, but organized in a very top-down approach. They were short term and concentrated on certain issues (mainly agricultural production trainings) rather than on the general improvement of local conditions according to the local needs and did not mobilize local organizations. In the community of 15 de Agosto, some farmers were part of committees prior to the implementation of the PMRN project; others joined the groups established in response to the project. Yet, after the project expired many of these *ad hoc* committees dissolved and the farmers' participation was on average limited. In terms of infrastructure and service access, however, the inhabitants of 15 de Agosto are in a much better situation than their counterparts from Cuatro Vientos. The village is located near a major national highway, which makes exchange and access to goods easier. It is also in the vicinity of the municipality of Chore, the district capital, and home to both administrative and educational institutions, including an agricultural university college. The main source of income apart from agriculture is wage labour at a local tobacco manufactory. The deforestation in both localities, before reforestation measures were taken, was almost complete. This was up to the point where soil erosion was becoming a major issue, and the lack of natural barriers for wind carrying dust and pesticide was harmful for the local communities (expert interview, 20.01.2012). This also meant that fuel wood and construction timber became scarce and growingly difficult to access.

Research design and data collection methods

The analysis is based on a comparative case-study approach, where two communities with divergent local institutional contexts are contrasted regarding their results in PMRN plantation project participation. In the first community of Cuatro Vientos the project has been institutionally anchored in the local organizational structures of the producers' cooperative, while in the community 15 de Agosto the project created a completely new institutional layer in the form of committees of producers. Some results from the questionnaires and narratives of farmers are provided to illustrate the local reception of the project.

The reforestation project was layered on different initial institutional/ social capital conditions in both communities. However, as the earlier discussion has shown, there are no other significant differences between the communities apart from the divergent institutional setup and social capital development. Geographical, social and cultural background conditions are very similar and for the purpose of the study are treated as constant. Also the initial income and poverty levels are analogical. The cooperative establishment in Cuatro Vientos improved farmers' market access for the local products with collective bargaining, but in 15 de Agosto the local industry (especially the tobacco company) also provided some advantageous market access.

The data gathering for the two case studies was conducted in 2012 as part of a wider study of seven different forest plantation efforts in different localities across Paraguay. Fieldwork questionnaires were designed to study local socio-economic and environmental plantation performance (48 questions in total) and contained 7 open and closed questions linked to social capital and institutions in relation to plantation performance, plantation gains, access to project's services, role of the local institutions and farmers' individual perceptions on tree planting. During the fieldwork concerning PMRN, 13 households were selected from each community (about 20% of farmers benefiting from the extension project in both villages) for detailed semi-structured interviews (in Spanish or Guarani) on their plantation plots (Table 1). The interview questionnaires were filled out by two members of the research team, and were also recorded for reference and the transcription of the open questions. Further data were acquired through in depth local expert interviews and meetings with local leaders, as well as plantation document analysis and on-site observation. Expert interviews were recorded and transcribed in full. The research in both communities was conducted by the same research team over the course of two weeks. Data gathered locally was complemented by interviews with national experts as well as secondary data from the project and the National Forestry Institute. This information is then structured according to the conceptualization of four elements of social capital discussed in the following section.

Theoretical approach and hypotheses

Having established that the background conditions in both communities are analogous, it is suggested that the local institutional (pre-existing and emergent) landscape had an influence on the overall plantation establishment project performance. The on-site observation and interviews have shown that there are considerable differences in perceived socio-economic impact and attitudes to the plantation. Drawing on the existing theories of institutions and social capital, it is proposed, that the more robust institutional setup in one of the analysed communities – Cuatro Vientos – enhanced the increase of social capital among farmers, and this in turn can account for the better performance of the PMRN-inspired reforestation project in that area. As Edillon (2010) points out, based on an empirical study conducted elsewhere in the developing world, "social capital, which includes networks, membership in organizations, and other social structures that lead to collective action, increases the likelihood that a farmer will adopt the new technology". Therefore one can assume that the community with better social capital will be more successful in acquiring knowledge from the plantation project and more eager to continue work with new technologies after the project intervention is finished. In the following section, the operationalization of social capital used in the study is described.

Assessing the development of social capital

In order to analyse the difference is social capital and refer it to the project's implementation, different aspects of that phenomenon identified by Pretty (1998) and O'Riordan and Voisey (1998) will be taken into account. The authors list *trust*, *rules and sanctions*, *reciprocity and exchanges* as well as *connectedness* as elements building social capital (Table 2). *Trust* is a factor that points to the trusted actors and institutions, which in the reforestation project context will start from neighbours, committees of producers, cooperative, extension agents, government officials etc. *Rules and sanctions* refer to mutually agreed behaviour patterns and the degrees of compliance of individual behaviour. *Reciprocity and exchange* is about sharing responsibilities and benefits and creating mutual support when necessary. It is widely discussed in the literature on public goods games as the situation when actors are willing to share resources and cooperate under the condition that others do the same (Ostrom 2000a). Finally *connectedness* refers to linkages that exist within the group that may be both formal and informal but assure good communication and information flows. The elements of social capital were used in the assessment of both communities and their interactions with the reforestation project. Here mostly qualitative data was collected in semi-structured interviews, on-site observations, informal exchange with local population, but also expert interviews and local documentation.

Comparing social capital elements

In both communities different *trust* levels could be observed. Generally, all interviewed smallholders in that area distrust the national and regional politicians and government officials. In both localities even the national forestry institutions, supposedly important points of reference in forest plantation establishment, were either not known or not trusted. On the other hand, the project's extension agents were welcomed and trusted in both areas, and that engagement has expanded beyond the project's span. Their technical knowledge is praised, so is the personal continuity that the project assured for several years. However, in Cuatro Vientos people predominantly declared trust in their own cooperative. "Not everyone was convinced at first but with time people got used to the idea of the cooperative, saw that it works and even the sceptical ones joined" (local community leader, interview, 19.01.2012). Agricultural thefts (crops and animals) that used to be a problem in the past completely disappeared once the common supervisory body had been established. "Earlier, people were so afraid of thefts that they stopped planting anything. Now we are making economic plans for every household. When everyone has enough, no one will go and steal" (local expert interview, 20.01.2012). In 15 de Agosto many project participants distrusted their own neighbours and complained that the project established the committees of producers, where there are power struggles and conflicts of interest. As one of the interview partners confessed: "there are problems with the PMRN project, it is difficult to work with the neighbours, to establish committees" (Farmer interview II-5). Many committees did not survive after the project terminated.

Another social capital factor, *rules and sanctions* that guide compliance of individual actors, are also visibly different in both communities. It could be clearly observed that the cooperative in Cuatro Vientos established its own rules and is strictly executing them. The strict treatment of thefts was already mentioned, and rule executions can also be illustrated by the fact that the all the loans from the cooperative were repaid fully (local expert interview, 20.01.2012). Individual members have been temporarily expelled from the cooperative due to the violation of common rules (i.e. individual selling of crops if a joint contract was signed or not paying the membership fees). In 15 de Agosto project rules have not been implemented that well. Freeriding on the project could be observed. Furthermore, one of the farmers mentioned corruption and clientelism claiming that "one needs to pay to participate in the project" which was discouraging from participation.

Similarly, *reciprocity* can be observed in Cuatro Vientos. Neighbourly help and voluntary work was used to construct and repair roads in the community, something unimaginable in 15 de Agosto. This was also reflected in plantation work, where farmers in the first community often reported joint plantation work with neighbours, i.e. pruning one farmer's plot on one day in a group, or otherwise helping each other with plantation management. This may be seen as returning to

TABLE 2 *Social capital elements in comparison*

Social capital elements	Cuatro Vientos	15 de Agosto
Trust	Towards the cooperative, neighbours and extension agents	Towards extension agents
Rules and sanctions	Clear rules and sanctions executed	Rules not executed, freeriding
Reciprocity	Community joint initiatives to enhance road conditions, neighbourly help	Individualism at work
Connectedness	Various local organizations (Women's Committee etc.), social centres (school, cooperative), local pride and sense of belonging	Alienation, dissolution of the local organization forms created for the project

the traditional Paraguayan practice of *minga* that built on group labour on each of the participants' individual parcels.[6]

Finally *connectedness* in Cuatro Vientos was high due to many other forms of self-organization in place – for example Women Committees, School Parents' Groups etc. School and the cooperative's shop, offices and storage play the role of social centres. What is more, the farmers developed a strong sense of belonging and pride of being a community that others around the country look up to. Cuatro Vientos is the first community in Paraguay which is not inhabited by colonists of European decent to receive formal cooperative status since the end of the Stroessner dictatorship.[7] Other case studies from Paraguay on sugar and banana cooperatives prove that this institutional form helped farmers to organize and secure better markets, increase their incomes and build internal solidarity (Vasquez-Leon 2010a). Collective organizations bring advantage in economic, social and human capital terms (Vasquez-Leon 2010b). In 15 de Agosto there are no similar local initiatives and the interviewed smallholders and their neighbours tend to wait for external help, an attitude well illustrated by one of the farmers: "we don't have the conditions, it all depends on training and projects" (Farmer interview II-7). This attitude was combined with the more visible socio-political tensions, and frequent references to the wider *campesino* category and identity by the interviewees in 15 de Agosto. It could be said that the farmers in the latter community perceived their situation as class-determined. The self-organization forms, the committees, were to a large extent established instrumentally for the purpose of a project. This approach was noted elsewhere in Paraguay by a U.S. Peace Corps volunteer, who was told that "if we are a formal group, it is easier to get things from the government" (Pattullo 2013: 29).

The descriptive comparison of the four social capital elements shows that the communities are highly different not only in terms of the organizations in place, but also in terms of the social capital that, as the evidence seems to show, results from the self-organization. With the institutional and social capital differences, the projects reception and results will be shortly presented.

Comparison of project implementation and continuation possibilities

The interview results (Figure 1) show that although in both communities a vast majority of farmers have a very positive attitude towards tree planting (92% of the interviewees), the projects implementation and outcomes vary significantly. In the community with established institutions, farmers claimed to have better and a more frequent access to training programs, a more positive opinion on cooperation in the community, double the number of respondents wanted to continue tree planting with their families after the project ended, they also looked for better markets and prices for wood, thought about adding value to plantation wood and felt more influence in village and infrastructure development.

Economic survey-data indicate, that prices for wood are better in Cuatro Vientos. This may be the result of collective bargaining, but it can also be the effect of awareness raising within the cooperative. The farmers in Cuatro Vientos were more conscious of the relationship between good plantation maintenance and the price of the final product. They thus more often reported selling their trees for timber while fuel-wood dominated in 15 de Agosto, which in general saw lower internal rates of return (Table 3).

Also the discursive, open parts of the interviews confirmed, that in the community that had its own efficient institutional setup and high social capital levels, farmers were creative in using the plantation project. At the same time, farmers from the other community tended to be very passive and sceptical, awaiting continuous external help to cope with the planting activities. Extension agents praised work where the cooperative could "store" the knowledge and the information sharing and communication flow was efficient. On the other hand, in 15 de Agosto farmers did not trust the neighbours and adapted new technologies only when they were permanently visited by extension agents but abandoned their plantations later on, so the knowledge transfer that accrued in the project was limited and temporary.

LESSONS FROM THE COMPARATIVE CASE STUDY: THE ROLE OF LOCAL INSTITUTIONS AND SOCIAL CAPITAL ACCUMULATION

Generally, the PMRN project had positive socio-economic and environmental results in both areas and all farmers had positive attitudes towards plantation establishment. However, the community of Cuatro Vientos was successful in the integration of tree planting in local producers' "portfolios" and ideas for value added and scaling-up emerged during the project. The community also kept the local tree nursery after the project support had expired, and turned it into a self-standing business, catering for local and regional markets. For many farmers trees started to play a role of something similar to otherwise inaccessible "saving accounts". Under conditions of trust and increasing levels of community-based economic security, they were able to plan ahead, sometimes beginning to think in terms of 7–10 years long rotation cycles already. Knowing the relatively low costs of plantation establishment and maintenance, compared to the high income from well managed timber, several farmers reported this "saving account" function – very important in an area with no access to financial institutions such as banks. In the community 15

[6] The authors thank one of the IFR anonymous reviewers for pointing this out.

[7] Turner (1998) provides important historical analysis of decades of repressions of farmers' organizations under the Stroessner regime. Cooperativism promoted by aid agencies (USAID) was officially tolerated by the regime to secure transfer payments but in practice it was subjected to financial manipulations and repression, as cooperative members were arrested and labelled "communists".

FIGURE 1 *Results of stakeholder interviews*

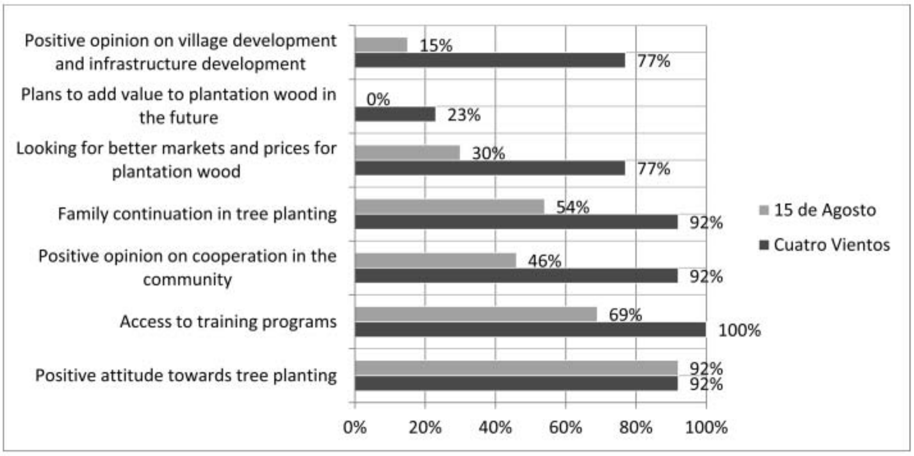

TABLE 3 *Economic performance in comparison (Monges* et al. *2012)*

Community	Cuatro Vientos	15 de Agosto
Price (USD/m^3)	26	15
IRR (constant prices)	13%–16%	10%–13%

de Agosto, tree plantation activity remained superficial. Many farmers neglected their plots after the project finished and were clearly looking for continuous external help.

The overall economic performance of the project in both sites was slightly different. Although the farmers in 15 de Agosto had better initial infrastructural conditions (a relatively easy access to timber markets beyond their community because of the nearby highway) and they also had a stable market for fuel wood (which could always be sold to the local tobacco manufactory – a private business which benefited greatly from the increased local supply of wood caused by the PMRN project), they were not able to use this potential. The farmers in Cuatro Vientos were at a less advantaged position to start with, and their market access had to be secured by the cooperative, but they achieved higher wood prices and higher IRR. Understanding the way value is added to wood products along the commodity chain, they were already mentioning plans for the construction of a community lumber-mill and carpentry workshop.

The distribution of power in its different forms does not seem to be a factor influencing the self-organization of both groups in this context, as both villages are largely homogenous peasant communities, not dominated by any local political or popular leaders. However, the impact of the Mennonite colony, displaying high levels of self-organization and social capital as well as financial resources, on the neighbouring Cuatro Vientos, is clear. It should, however, better be understood in terms of role-modelling, which enhances emulation of governance and technical innovation, than in terms of competition or pressure.

The analysis points to the importance of local institution and social capital while implementing social forestry projects. Yet, the significant question, raised already in the important study of local forest-related institutions– why are some communities better at institutions building, why do they self-organize in the first place? (Gibson *et al.* 2000: 229). In the cases analysed, external help and especially their *continuity* seem to play a major role – because they reduce transaction costs and allow for more actors to enter an institutionalized cooperative scheme, and provide stability. In Cuatro Vientos, the continued support of the neighbouring Mennonite community (although gradually phased out) is an example of such long term external engagement. 15 de Agosto in turn, although it benefitted from a larger number of foreign development aid and governmental extension initiatives, was left alone without long-term assistance. The length of external assistance should be planned in such a way as to maximize the grassroots institution-building processes, while it is clear that abrupt withdrawal of both technical agents and financing can jeopardize the entire effort and funding invested in a project.[8] For long term benefits, reforestation projects should be anchored within the local structures. This should be particularly considered in CDM and REDD pilot projects that are being implemented with sophisticated carbon methodologies but may overlook institutional and social capital issues that mediate between the external help and local practices. Local institutions are key factors for anchoring the social capital and store forestry knowledge in the communities.

[8] The development and diffusion of agroforestry innovation and the role of good institutional and organizational structure in Paraguay as well as the importance of continuity with reference to the withdrawal of the Swiss Technical Mission are discussed by Evans (1988).

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ABBREVIATIONS

CDM – Clean Development Mechanism
FONASO – Forest and Nature for Society
GIZ – Deutsche Gesellschaft für Internationale Zusammenarbeit (the German Society for International Cooperation)
INFONA – Instituto Forestal Nacional (National Forestry Institute)
IRR – Internal rate of return
KfW – Kreditanstalt für Wiederaufbau (Reconstruction Credit Institute)
PMRN – Proyecto de Manejo Sostenible de Recursos Naturales (Project for Sustainable Management of Natural Resources)
PYG – Paraguayan guarani (currency)
REDD – Reducing emissions from deforestation and forest degradation
UNA – Universidad Nacional de Asunción (National University of Asunción)
USAID – United States Agency for International Development
WRI – World Resources Institute

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Climate change impacts on species planting domains: a preliminary assessment for selected plantation forests in Fiji, Papua New Guinea and the Solomon Islands

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SUMMARY

A simple method is applied to provide a preliminary assessment of climate change impacts on the species planting domains for *Tectona grandis* (teak), *Swietenia macrophylla* (mahogany) and *Pinus caribaea* (Caribbean pine) in Fiji and *T. grandis* in Papua New Guinea and Solomon Islands. Climate values in a 10 minute grid (approximately 18 km spacing) are used to identify locations with climatically suitable conditions for the species. The impacts of climate change on plantations of all three target species in Fiji are considered to be low in 2030 and 2050. However, impacts may become medium for *S. macrophylla* and *P. caribaea* in 2080 using an A2 'business as usual' scenario, as some areas begin to fall outside climatically suitable limits for these species. The likely impacts of climate change on *T. grandis* sites in PNG and Solomon Islands are also assessed as low, as the main plantation areas remain largely in climatically suitable areas until at least 2050 under the A2 scenario. The implications for vulnerability of these plantations are discussed, along with strengths and weaknesses of the method, and possible further analyses.

Keywords: *Tectona grandis*, *Swietenia macrophylla*, *Pinus caribaea*, species selection, Pacific islands

Impacts des changements climatiques sur les espèces domaines de plantation: une évaluation préliminaire pour les forêts de plantation sélectionnés dans les îles Fidji, la Papouasie-Nouvelle-Guinée et les îles Salomon

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Une méthode simple est appliquée pour fournir une évaluation préliminaire des impacts du changement climatique sur les domaines d'implantation d' espèces pour *Tectona grandis* (teck), *Swietenia macrophylla* (acajou) et *Pinus caribaea* (pin des Caraïbes) à Fidji et *T. grandis* en Papouasie- Nouvelle-Guinée et Salomon Îles. Valeurs climatiques dans une grille de 10 minutes (à environ 18 km de distance) sont utilisés pour identifier les endroits avec des conditions climatiques appropriées pour les espèces. Les impacts du changement climatique sur les plantations des trois espèces cibles à Fidji sont considérés comme faibles en 2030 et 2050. Toutefois, les impacts peuvent devenir moyen pour *S. macrophylla* et *P. caribaea* en 2080 en utilisant un 'business as usual' A2 scénario, comme certaines régions commencent à tomber en dehors climatiquement limites appropriées pour ces espèces. Les effets probables du changement climatique sur *T. grandis* sites PNG et les Îles Salomon sont également jugés faibles, comme les principales zones de plantation restent largement dans les zones climatiquement adaptées au moins jusqu'en 2050 selon le scénario A2. Les implications de la vulnérabilité de ces plantations sont discutés, avec les forces et les faiblesses de la méthode, et d'éventuelles nouvelles analyses.

Impactos del cambio climático sobre las especies dominios de siembra: una evaluación preliminar de los bosques de plantaciones seleccionadas en Fiji, Papua Nueva Guinea y las Islas Salomón

T.H. BOOTH y T. JOVANOVIC

Un método simple se aplica para proporcionar una evaluación preliminar de los impactos del cambio climático en los dominios de la plantación de especies de *Tectona grandis* (teca), *Swietenia macrophylla* (caoba) y *Pinus caribaea* (pino caribe) en Fiji y *T. grandis* en Papua Nueva Guinea y Salomón Islas. Los valores climáticos en una rejilla 10 minutos (unos 18 km separación) se utilizan para identificar lugares con condiciones climáticamente adecuadas para la especie. Los impactos del cambio climático en las plantaciones de las tres especies objetivo en Fiji se considera que son bajos en 2030 y 2050. Sin embargo, los efectos pueden llegar a ser medio para *S. macrophylla* y *P. caribaea* en 2080 utilizando un 'business as usual' A2 escenario, ya que algunas zonas comienzan a caer fuera climáticamente límites adecuados para estas especies. Los probables impactos del cambio climático en *T. grandis* sitios en PNG y las Islas Salomón también se evalúan tan bajo, ya que las principales áreas de plantaciones siguen en gran medida en las áreas climáticamente adecuadas por lo menos hasta 2050 bajo el escenario A2. Se discuten las implicaciones para la vulnerabilidad de estas plantaciones, así como las fortalezas y debilidades del método y los posibles nuevos análisis.

INTRODUCTION

The global mean surface temperature has risen by 0.89°C over the period 1901–2012 and each of the last three decades has been successively warmer than any previous decade since 1850 (IPCC 2013). If current trends in population growth and emissions of greenhouse gases continue, mean annual temperatures may rise by up to 4.8°C by 2100 at some locations.

The origin of this study was a request to provide information for part of a report on climate change to be prepared for the Secretariat of the Pacific Community (SPC). A chapter being prepared by Dr Lex Thomson will consider "Vulnerability of native forests, plantations and trees outside forests to climate change". A recent survey of 152 tropical production forest professionals has indicated that they perceive a lack of available information to help them understand the possible impacts of climate change on their forests (Guariguata *et al.* 2012). Forest owners and managers need to consider the potential implications of climate change as part of whole system considerations of forest management. It may well be that other factors, such as soil conservation or pest and disease problems, require more urgent action (Nambiar and Brown 1997, Nambiar 2008). However, it is worthwhile for managers to be aware of where and when particular plantations may begin to experience conditions outside the range of conditions currently known to be climatically suitable for the planted species, so such sites can be monitored for any signs of potential problems. A relatively quick and inexpensive method to identify such regions and provide a preliminary assessment of climate change impacts on species planting domains has been proposed and was applied here (Booth *et al*. submitted).

This paper considers tree plantations in Papua New Guinea (PNG) and the Solomon Islands as well as Fiji, as these countries are often considered together in SPC and FAO reports (see, for example, FAO 2002). Three tree species are assessed: *Tectona grandis* L.f. (teak), *Swietenia macrophylla* King (mahogany) and *Pinus caribaea var. hondurensis* Morelet (Caribbean pine). All three species are considered in Fiji, while only *T. grandis* is assessed in PNG and the Solomon Islands. Like PNG and the Solomon Islands, plantations in Fiji represent a small proportion of land area in comparison to the remaining native forest (Leslie and Tuinivanua 2010). Though the areas of these plantations are small in global terms, they are locally significant for the countries concerned.

T. grandis is one of the most valuable timbers in the world (Monteuuis *et al*. 2011) and FAO (2002) reported on hardwood programmes in PNG, Solomon Islands and Fiji. The FAO (2002) report mentioned that about 2000 ha of *T. grandis* were planted in the Brown River region (9°20'S, 147°14'E, 400 m) of PNG near Port Moresby and about 1000 ha in the Kerevat area (4°20'S, 152°1'E, 150 m) near Rabaul (see Figure 1). The report also mentions a PNG Resource Inventory Report from 1994 that recorded 1264 ha of *T. grandis* plantation in the Hohora (9°13'S, 147°15'E, 247 m) and Edevu (9°12'S, 147°18', 241 m) regions near Port Moresby, as well as a further 284 ha in the Kuriva region (10°37'S, 151° 18'E, 50 m). Recently the total area of *T. grandis* plantation in PNG has been assessed at 3627 ha and it is expected to be more widely planted there in future (Saulei *et al*. 2012).

The FAO (2002) report mentions that over 20 000 ha of hardwood plantation have been established in the Solomon Islands since 1967, with *T. grandis* plantations at Viru (New Georgia, Western Province)(8°30'S, 157°41'E, 100 m) and the Saenaua plantation on Malaita Island (8°47'S, 160°44'E, 190 m). In 2009 the area of teak plantation in the Solomon Islands was conservatively estimated at 4500 hectares (Midgley and Laity 2009), comprising Kolombangara Forest Products Limited (650 ha) and government plantings on Shortlands (248 ha) and Viru (100 ha), as well as community smallholder plantings which are scattered throughout the Solomon Islands. However, since that time the area of teak established has grown substantially both by commercial companies, including Eagon Pacific Plantations, and through the Government National Forest Plantation Development program. The planted teak area in 2013 now exceeds 8 000 ha mostly in commercial and smallholder plantings in the Western Province (L. Thomson, pers. comm.). The FAO (2002) report provides general background information on site conditions, management, pests and diseases and economics of these plantations.

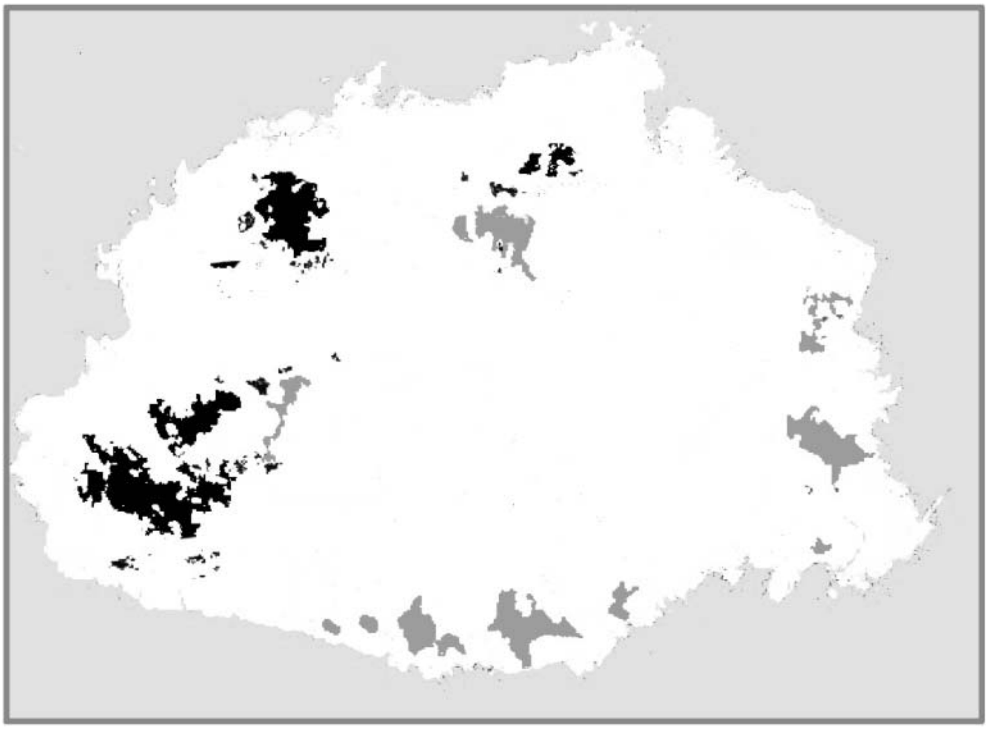
Future Forests Fiji Ltd has established over 200 hectares of teak plantations in the provinces of Ra (northern Viti Levu) and Nadroga (southwestern Viti Levu). It is planned to thin the plantations at about nine years of age with a final harvest being after about 20–25 years. The company plans to expand its teak plantations over the next 30 years to reach a minimum target of 3 000 hectares. Plantations are to be established on Viti Levu, Vanua Levu and other islands.

Data supplied by the Fiji Hardwood Corporation indicates the area of *S. macrophylla* plantation is 42 419 ha (L. Thomson, pers. comm.). This is distributed in more than 14 mahogany plantations ranging in size between 2500 and 12 200 ha spread across Fiji's two largest islands, Viti Levu and Vanua Levu (Figures 2 and 3). *S. macrophylla* is generally grown on rotations of 30 to 35 years and management practices in Fiji have been described by Swarup (2000).

P. caribaea was chosen for the ambitious Fiji Pine Scheme which was established in 1972 initially to meet local sawn timber demands, but later to also develop a wood pulp export industry (Rennie 1974). Plantations were initially established in the western parts of Viti Levu and Vanua Levu (see map in

FIGURE 1 *Papua New Guinea and Solomon Islands locations mentioned in the text*

FIGURE 2 *Viti Levu, Fiji –* Swietenia macrophylla *(mahogany) plantations (grey shading) and* Pinus caribaea *(Caribbean pine) plantations (black shading)*



Rennie 1974). According to Fiji Pine Limited and the Fiji Hardwood Corporation there are now about 47 011 ha of *P. caribaea* plantations mainly in the dry western areas of Viti Levu and Vanua Levu, with smaller plantings on the outer islands such as Gau and Kadavu (L. Thomson, pers. comm.).

This paper focuses on assessing the impacts of climate change on species planting domains in terms of changes in mean temperature and rainfall variables. It does not consider the impacts of more extreme events such as wind damage to plantations associated with cyclones or local landslips during intense rainfall events. The 5th Assessment Report of the Intergovernmental Panel on Climate Change indicated that there is low confidence in attribution of changes in tropical cyclone activity to human influence (IPCC 2013).

FIGURE 3 *Vanua Levu, Fiji* - Swietenia macrophylla *(mahogany) plantations (grey shading) and* Pinus caribaea *(Caribbean pine) plantations (black shading)*

MATERIALS AND METHODS

Climate change data

Data from the CliMond database described by Kriticos *et al*. (2012) were used for this study. These are at 10 minute resolution (about 18 km spacing) and are freely available from www.climond.org. Data from the CSIRO Mark 3.0 general circulation model (GCM) and the A2 climate change scenario were used for current conditions as well as climate change projections for 2030, 2050 and 2080. The A2 scenario provided the basis for the most pessimistic 'representative concentration pathway' scenario (RCP8.5) of the four used in the latest report of the Intergovernmental Panel on Climate Change (IPCC 2013). This assumes that current trends continue with increasing global population and increasing greenhouse gas emissions. Using this model and scenario the increases in mean annual temperature across Fiji are 0.7, 1.1 and 2.0°C in 2030, 2050 and 2080 respectively. The comparable increases across Papua New Guinea are 0.9, 1.4 and 2.6°C respectively.

An advantage of using the CliMond dataset is that factors important for tree species selection have already been calculated. These include the following BIOCLIM factors (Nix 1986): annual mean temperature (Bio1), mean maximum temperature of the warmest period (Bio5), mean minimum temperature of the coldest period (Bio6) and mean annual precipitation (Bio12) (see Xu and Hutchinson 2011 for definitions of all 35 BIOCLIM variables). Following Xu and Hutchinson (2011) Kriticos *et al*. (2012) used the warmest and coldest weeks as the relevant periods rather than the warmest and coldest months as used in the original BIOCLIM package (Nix 1986, Booth *et al*. 2014) and tree species selection systems (e.g. CAB International 2005). However, for locations close to the equator, such as the countries considered here, there are minimal differences between these values and for the purposes of this study they were assumed to be the same.

The Pacific Climate Futures (PCF) program (www.pacificclimatefutures.net) has run 14 GCMs for various regions in the Pacific. The CSIRO Mark 3.0 model used here produced climate change projections that are broadly similar in terms of temperature change, but wetter than the 'most likely climate future' for Fiji produced by the PCF program. This was for 'hotter and little change to wetter' conditions, which were represented by 9 of the 14 models and corresponded to annual mean air temperature increases of 2.5°C and annual mean rainfall increases of 4% relative to 1980–1999 (A2 scenario for 2090). The comparable mean changes across Fiji using the CSIRO Mk 3.0 model with the A2 scenario for 2080 were 2.0°C and 22%. Allowing for the ten year difference in the sampling times (i.e. 2080 rather than 2090) the actual difference in projected temperatures would be slight. The difference in projected rainfall is much greater, but some additional rainfall should not adversely affect tree growth. The PCF program has reported that some increase in wet season rainfall is possible, but model results are not consistent (Anon. 2011).

The 'most likely' change for Papua New Guinea from Pacific Climate Futures was for hotter and much wetter conditions, which were represented by 8 of the 14 models. This corresponded to a 2.7°C increase in annual mean air temperature and a 16% in rainfall (A2 scenario for 2090). The comparable changes across PNG using the CSIRO Mk 3.0 model with the A2 scenario for 2080 were 2.6°C and 6%. The temperature change is very similar. The increase in rainfall is less, but as it is an increase rather than a significant fall it would not be likely to make many areas unsuitable for *T. grandis.*

TABLE 1 *Estimates of species climatic requirements (from Booth and Jovanovic 2000). 'Max temp. hottest month' is the mean daily maximum temperature of the hottest month (°C) and 'Min temp. coldest month' is the mean daily minimum temperature of the coldest month (°C)*

	T. grandis	***S. macrophylla***	***P. caribaea***
Mean annual temp. (°C)	22–28	22–28	20–27
Max. temp. hottest month (°C)	25–39	24–32	28–34
Min. temp. coldest month (°C)	12–24	11–22	8–23
Mean precipitation (mm)	1200–4000	1400–4200	660–4000

Climatic requirements of the target species

Climatic requirements of the three target species had previously been examined (see Booth and Jovanovic 2000) and the values from that report which were used here are shown in Table 1.

RESULTS

Climate change analyses

CliMond data for the four key climatic factors were brought into the ArcGIS™ system, so that climatically suitable areas could be mapped. Figure 4 shows the climatically suitable areas for *T. grandis* in Papua New Guinea and the Solomon Islands under current conditions and projected conditions for 2030, 2050 and 2080 using the CSIRO Mark 3.0 GCM and the A2 climate change scenario. *T. grandis* is mainly grown in PNG in areas to the north of Port Moresby and on East New Britain. Figure 4 shows the Brown River and Honora areas to the north of Port Moresby remain largely climatically suitable until at least 2050, as does much of the Kerevat area near Rabaul (East New Britain). Though areas where *T. grandis* is currently grown remain in largely climatically suitable areas it is worth noting that large areas which are currently suitable for the species in other parts of PNG may become climatically unsuitable, particularly in 2080. So some care should be taken in locating new teak plantations in PNG especially if greenhouse gas emissions continue at high levels.

Similarly in the Solomon Islands most of the current plantation areas in Western Province, Guadalcanal, Malaita and elsewhere remain climatically suitable until at least 2050.

Figure 5 shows the climatically suitable areas for *T. grandis* in Fiji. The climate change scenario has no effect on reducing the suitable areas for *T. grandis* in the western coastal areas where most of the plantations are located even up to 2080. Figures 6 and 7 show somewhat similar trends for both *S. macrophylla* and *P. caribaea*, some high elevation areas in the centre of Viti Levu become more climatically suitable as conditions warm. There is little loss of climatically suitable areas in 2030 or 2050 and only small losses of climatically suitable areas in 2080, particularly on Vanua Levu.

DISCUSSION

It is clear from Figures 5, 6 and 7 that the potential impact of projected climate change on the planting domains for Fiji's three main forest plantation species is low. Using even the most pessimistic climate change scenario there is little or no loss of climatically suitable areas in 2030 or 2050. It is only in 2080 that some plantation areas may fall outside the range of suitable climatic conditions for *S. macrophylla* and *P. caribaea* in particular. There is little change in the climatically suitable areas for *T. grandis* in PNG and Solomon Islands in the regions where the main plantations are currently located until 2080 using the pessimistic A2 climate change scenario (see Figure 4). If anything, plantation productivity may increase slightly as a result of increasing atmospheric carbon dioxide stimulating photosynthesis and increasing water use efficiency (Booth *et al*. 2010, Warrier *et al*. 2013).

It should be emphasized that this is a simple analysis using only one general circulation model and one climate change scenario. It is worth looking at the Pacific Climate Futures website and examining the range of climate change outcomes possible using 14 GCMs and a variety of climate change scenarios. However, the A2 scenario used here is equivalent to the most pessimistic scenario used in the IPCC (2013) report (RCP8.5), so if impacts are assessed here as low they should be even less under the less extreme three scenarios used in the IPCC (2013) report (i.e. RCP2.6, RCP4.5 and RCP6.0).

The purpose of this study was to assess possible impacts of climate change on species planting domains. However, as the SPC is concerned with vulnerability this is discussed briefly here. Vulnerability of forest plantations can be determined by consideration of both potential impact and adaptive capacity (Booth 2013). Impact is related to exposure and sensitivity, while adaptive capacity reflects the ability of a system to change in a way that makes it better able to deal with external influences such as climate change. Booth *et al*. (2010) have outlined possible adaptation options for plantation forests under climate change, with the most obvious being to plant genetic material adapted to warmer conditions if this becomes necessary. This preliminary analysis of climate change impacts on planting domains suggests that there will be little need for adaptation options for the species and regions considered. As described in the opening paragraph of this discussion, impacts should be low at least until 2050 and

FIGURE 4 *Grey shaded areas of Papua New Guinea and the Solomon Islands are climatically suitable for* Tectona grandis *(teak)*

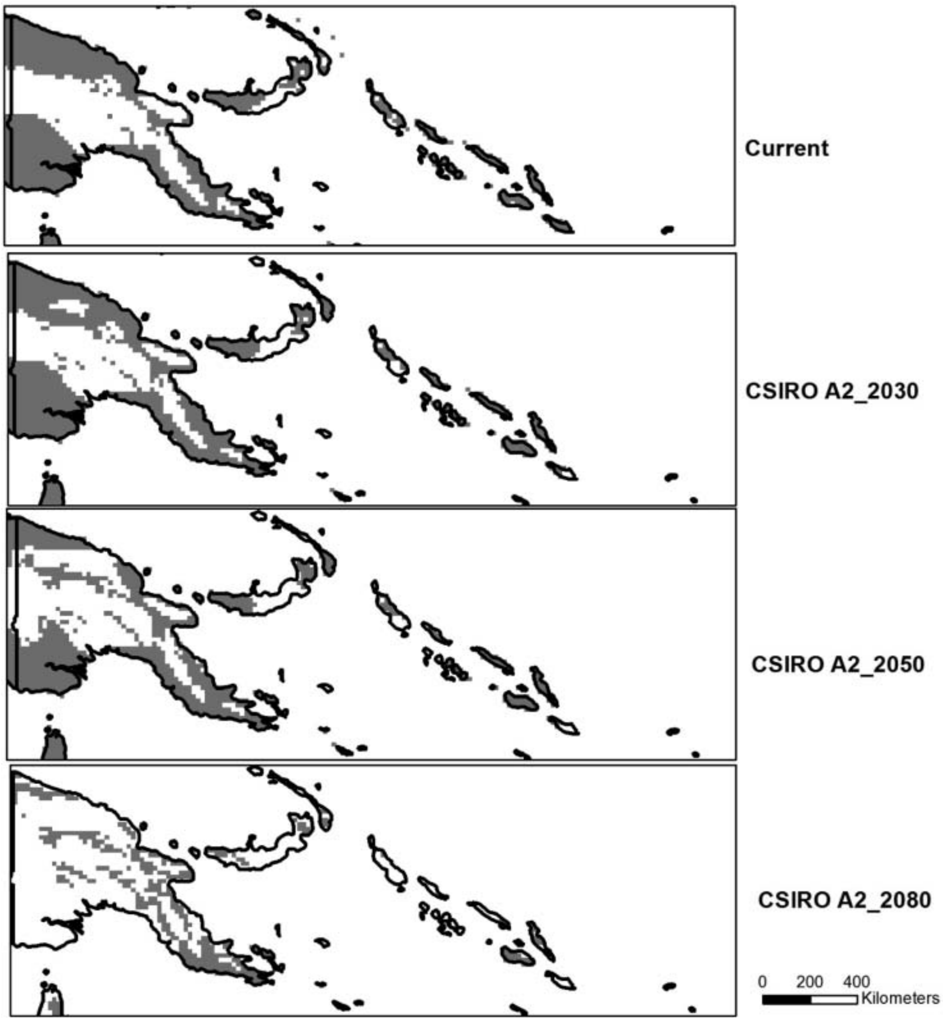
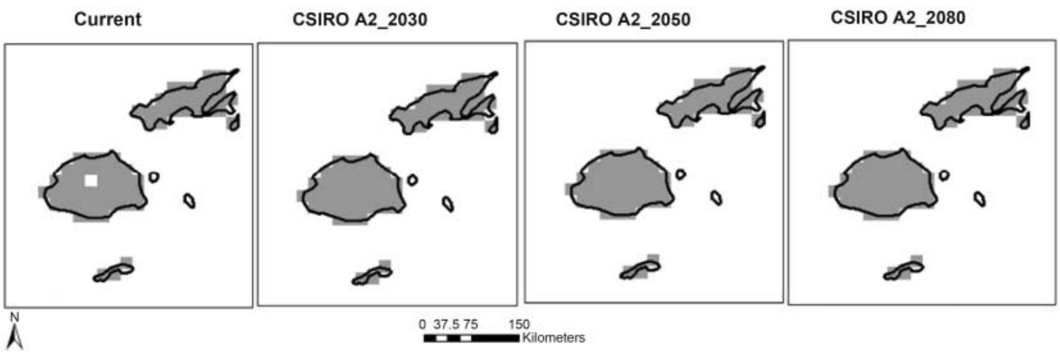


FIGURE 5 Grey shaded areas of Fiji are climatically suitable for *Tectona grandis* (teak)



there should be little or no need for adaptive responses until then, so vulnerability related to potential loss of species planting domains as a result of climate change is likely to also be low until 2050.

It is interesting to compare the results of this study with the previous application of this simple analysis method (Booth *et al*. submitted). The previous study examined three *Acacia* plantation species in parts of South East Asia and southern China. Using an A2 scenario some species planting domains, for example for *Acacia mangium* in southern Sumatra, fell outside climatic conditions known to be currently suitable as early as 2030. This would suggest that there may be a more urgent need to carry out detailed studies for these species and regions than for those considered here.

FIGURE 6 *Grey shaded areas of Fiji are climatically suitable for* Swietenia macrophylla *(mahogany)*

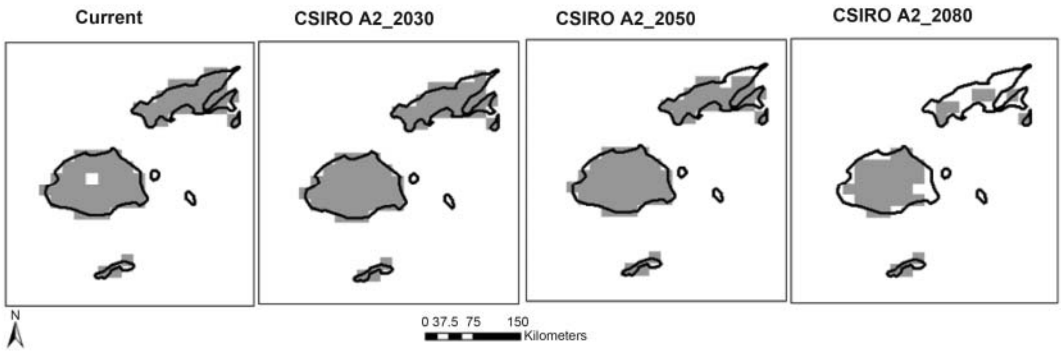
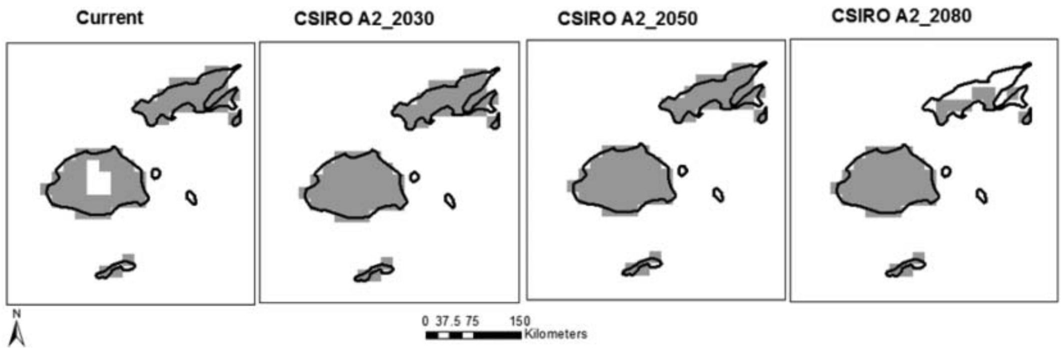


FIGURE 7 *Grey shaded areas of Fiji are climatically suitable for* Pinus caribaea *(Caribbean pine)*



The simplicity of the impact analysis method used here is both a source of strength and weakness. The use of a small number of simple climatic variables makes the analyses presented here relatively easy to carry out and easy to understand. However, if funds were available more sophisticated analyses, including the assessment of outputs from multiple GCMs and scenarios as well as complex response functions, would be useful to assess how actual growth rates might be affected by climatic and atmospheric change (see, for example, Battaglia *et al*. 2009, Fairbanks and Scholes 1999, Gopalakrishnan *et al*. 2011). Similarly, a full vulnerability analysis would be worth considering if funds were available. The value of the simple analysis method used here is in providing a basis for deciding if the expense of more complex analyses is likely to be worthwhile.

Given the low impacts on species planting domains assessed here, more detailed analyses may not be considered to be warranted. However, if they are to be considered Booth and Williams (2012) describe a range of modelling procedures to assess climate change impacts on forests from the simplest methods, as used here, to complex simulation models run for hundreds of thousands of times to assess the impact of various uncertainties (see, for example, Battaglia *et al*. 2009).

Even though impacts on planting domains are assessed here as likely to be low, particularly in the period to 2050, it would still be recommended to carry out some monitoring of representative sites to provide early detection of any unexpected problems associated with changing climatic conditions.

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Institutional and political assessment of forest plantations in Turkey

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SUMMARY

The objectives of this study were to provide information on the history of forest plantations and the institutions responsible for plantation works in Turkey, and to make recommendations for the solution of problems relating to plantations.

Plantation activities can be divided into three periods in Turkey according to the legislation, starting in 1937. Under the Forest Law 3116 plantation activities were implemented systematically by the General Directorate of Forestry between 1937 and 1956. In the second period (1956–1986), plantation activities increased as industrial plantations were initiated. The third period, covering 1986 to the present-day, saw, in addition to afforestation, plantation establishment for non-timber purposes such as erosion control, range improvement and energy.

There are many political problems as well as institutional ones that have influenced plantation activities in Turkey and these have on occasion led to a reduction in forestry activities during certain periods. Although the Development Plans and the report of the Turkish National Forestry Program and the Forestry Special Expertise Commission include many objectives and policies regarding forest plantations the majority of these have not been fulfilled.

Keywords: plantation, institutional assessment, political assessment, legislation, Turkey

Evaluation institutionelle et politique des forêts de plantation en Turquie

T. DENİZ et H.T. YILDIRIM

Les objectifs de cette étude étaient de fournir des informations sur l'histoire des forêts de plantation et des institutions responsables des travaux de plantation en Turquie, et d'offrir des recommandations pour essayer d'aboutir à un résolution des problèmes liés aux plantations.

Les activités des plantations en Turquie peuvent être divisées en trois périodes selon la législation, en commençant en 1937. Sous l'égide de la loi de foresterie 3116, les activités de plantations étaient mises à l'oeuvre systématiquement par le Directoire Général de Foresterie entre 1937 et 1956. Dans la seconde période (1956 à 1986), les activités de plantations augmentèrent alors que survenaient les plantations industrielles. La troisième période, de 1986 à nos jours, vit, en addition à la reforestation, un établissement de plantations à buts autre que la production de bois, tel que le contrôle de l'érosion, une amélioration de l'envergure et pour l'énergie.

Les problèmes politiques autant qu'institutionnels ayant influencé les activitiés de plantations en Turquie sont nombreux et ont parfois conduit à une diminution des activités de foresterie durant certaines périodes. Malgré le fait que les Plans de Développement et le rapport du Programme National de Foresterie Turc et la Commission d'Expertise Spéciale de Foresterie incluent plusieurs objectifs et politiques concernant les forêts de plantation; la majorité de ceux-ci n'ont pas été atteints.

Evaluación institucional y política de las plantaciones forestales en Turquía

T. DENİZ y H.T. YILDIRIM

Los objetivos de este estudio fueron proporcionar información sobre la historia de las plantaciones forestales y de las instituciones responsables de los trabajos de plantación en Turquía, así como ofrecer recomendaciones para solucionar los problemas relativos a las plantaciones.

En Turquía, las actividades de plantación se pueden dividir en tres períodos de acuerdo a la legislación, a partir de 1937. En virtud de la Ley Forestal 3116, la Dirección General Forestal aplicó sistemáticamente las actividades de plantación entre 1937–1956. En el segundo período (1956–1986), las actividades de plantación aumentaron a medida que se iniciaron las plantaciones industriales. El tercer período, que abarca desde 1986 hasta la actualidad, vio, además de la forestación, el establecimiento de plantaciones con fines no maderables, tales como el control de la erosión, la mejora de los pastizales y la energía.

Son muchos los problemas políticos, así como los institucionales, que han influido en las actividades de plantación en Turquía y estos han ocasionado a veces una reducción de las actividades forestales en determinados períodos. Aunque los planes de desarrollo y el informe del Programa Forestal Nacional de Turquía y de la Comisión Especial de Expertos Forestales incluyen muchos objetivos y políticas relativas a las plantaciones forestales, la mayoría de estos aun no se han implementado.

INTRODUCTION

In spite of increasing population growth in Turkey it was not until the period of the Republic that significant technical and administrative developments took place in afforestation (Boydak 2008). Prior to that Turkish forests had been denuded through the combined effects of conflicts, fire, overgrazing, illicit cutting and encroachment (Özdönmez *et al.* 1996, Yildirim 2005). During the period of the Ottoman Empire there was no recorded evidence of systematic or organised forest maintanence and afforestation until the proclamation of the Second Constitutionalist Period (1908) (Ekizoğlu and Erdönmez 2011), although some attempts related to planting trees not aimed at afforestation are mentioned (Kutluk 1948, Diker and İnal 1945), including Bricogne (1940) who mentioned that trees were planted in rows in Belgrade forest in Istanbul but no detail is provided.

The afforestation of maritime pine which was practiced by the French for the protection of sand dunes around Terkos Lake in 1880 and the eucalyptus afforestation which were planted as the decoration plant in the stations of Adana-Mersin railway line in 1885 are considered to be the first indications of afforestation in Turkey.

THE HISTORICAL DEVELOPMENT OF AFFORESTATION ACTIVITIES IN TURKEY

Afforestation which has taken place since the proclamation of the Republic in Turkey can be divided into three periods.

Afforestation activities 1937–1956

In 1937, the Forest Law 3116 came into force in Turkey, which indicated that the State had begun to acknowledge the need to address afforestation and to take effective steps. With this law, the General Directorate of Forestry (GDF) was established with the responsibility for afforestation. The GDF's first role was to establish eucalyptus forests and initiate afforestation of village and cities, in addition to which there was a need to develop a programme to meet the rapidly increasing demand for timber used in mining. The focus on afforestation of villages and municipalities led to the development of tree nurseries in 1938. However, even though in 1943 this programme was given priority and received significant funding, it was deemed to be unsuccessful (Özdönmez 1971).

Investigations began at Istanbul University, Faculty of Forestry, Department of Forest Economics into the establishment of plantations of eucalyptus in 1948, followed by more work on maritime pine in 1951, and a hybrid between *Populus deltoides* and *Populus nigra*, *P. x euramericana,* in 1958. Research looking at the value of hybrid poplar in Turkey began in 1952 carried out in Belgrade Forest by the Department of Silviculture from Istanbul University (Boydak 2008, Ekizoğlu and Erdönmez 2011).

A new law came into being in 1950 (Law 5653) which provided for further help from the State towards afforestation in villages and municipalities, which when coupled with subsidies from the Marshall Relief Fund was expected to lead to a significantly improved forest resource. However, weak administration and maintenance meant that results were poor. One of the primary reasons was a lack of technical appreciation of the factors surrounding seed sowing. Issues such as poor understanding of seed development and collection times, seed handling and nursery practice, along with inappropriate sowing techniques led to disappointing results (Asan 1998, Boydak and Dirik 1998).

Forest Law 3116 encouraged planting of poplars, a tree with a long history in Turkey, and since 1950, when the GDF took over the work, poplars have become increasingly common (MoEF 2004).

Activities between 1956 and 1986

In 1956, Forest Law 6831 was enacted which brought in certification for seed collection and initiated a five-year plan of afforestation. The Afforestation Group Directorates were set up shortly after, and the İzmit Research Institute of Poplar Plantation was founded in Izmit in 1962 for developing the culture of poplar (Yildirim 2004). The Institute's responsibility to trial exotic species in which interest was rapidly emerging led to a name change in 1968 to the İzmit Research Institute of Poplar and Forest Trees which are Fast Growing Foreign Species.

The First Technical Congress of Forest Engineering was held in 1966, which led to the establishment of project groups for studying fast growing species, a five-year afforestation plan and the development of the Afforestation Group Directorates (MoEF 2004).

The Izmit Research Institute carried out a project, 'The Development of Turkish Poplar Plantations', between 1962 and 1966 and the results led to test plantings beginning in 1968, with results published in 1972. The Institute also conducted a comprehensive FAO-funded project entitled 'Industrial Forest Plantations' to accelerate the process of gaining economic and technical information in the establishment of industrial plantations (Boydak 2008). The project was planned to lead into a second five-year development program and looked at the correct methods for establishing large-scale industrial plantations with exotic species in order to attract investors. The coastline of Marmara, the Black Sea, and Aegean and Mediterranean regions were chosen for the project and species such as maritime pine, calabrian pine and black pine were used (FAO 1977).

In 1981, the Symposium of Industrial Afforestation with Fast Growing Species was held in Izmit. This was followed by national and international meetings related to industrial plantations held in 1995 in Balıkesir, in 1998 in Ankara and in 2002 and 2003 in Izmit (Boydak 2008). These congresses highlighted the need to transfer results into practice.

Activities since 1986

The development of Forest Law 6831, 'The Fund for Afforestation', encouraged the development of tree planting, particularly on abandoned or infertile land (Durkaya 2001, Ekizoğlu and Erdönmez 2011) and assisted the forestry sector to produce 90 million m^3 of industrial wood and 256 million m^3 of fuelwood during the 1980s. However, imports of wood continued to dominate exports (Geray and Ok 2001). Between 1990 and 2000, a total of 169 865 000m^3 wood products were produced, 70 037 000m^3 of which was industrial wood. Between 1990 and 2000, the consumption of industrial wood increased in 26 % while, in contrast, the consumption of fuel wood decreased by 15% (Özkurt 2002, Koçer 2006). The consumption of wood in Turkey between 2002 and 2011 is given in Table 1.

Table 1 illustrates the annual deficit between wood consumption and wood production in Turkey every year, highlighting the need to develop plantations. In order to provide a stronger legal basis for the establishment of plantations 'The Law of National Afforestation and the Mobilization of Erosion Control' was enacted in 1995. This law had the aim of creating new forest fields in Turkey, founding and developing the natural balance between plants and soil. In the period between 1986 and 2005 some improvements were seen particularly in green belt afforestation, specific afforestation, range improvement, artificial regeneration and the development of forests planted for energy production.

Afforestation policies in development plans

Before the initiation of the first planned development period in 1963 a total of 110,000 ha of afforestation had been carried

TABLE 1 *Trends in consumption and production of industrial wood in Turkey 2002–2011**

Production-Consumption Sources	**Years**										**The annual average**
	2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	
The production of industrial wood by the State (1000 m^3)	8,005	7,320	8,253	8,100	9,299	10,053	11,541	11,463	12,569	13,532	10,014
The production of industrial wood by the private sector (1000m^3)	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300
The Total Supply Of Industrial Wood (1000 m^3)	11,305	10,260	11,553	11,400	12,599	13,353	14,841	14,763	15,869	16,832	13,314
The consumption of industrial wood from State forests (1000 m^3)	7,809	7,420	8,139	8,287	9,121	10,243	10,763	11,730	12,988	13,301	9,985
The consumption of industrial Wood from private forests (1000 m^3)	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300
Net Imported Industrial Wood (1000 m^3)	1,200	1,060	1,750	1,960	2,019	1,839	1,234	913	1,167	1,104	1,425
The Total Demand Of Industrial Wood (1000 m^3)	**12,359**	**11,780**	**13,189**	**13,547**	**14,440**	**15,382**	**15,297**	**15,943**	**17,455**	**17,705**	**14,710**
The Balance Of Demand-Supply (1000 m^3)	**–1,054**	**–1,160**	**–1,636**	**–2,147**	**–1,841**	**–2,029**	**–456**	**–1,180**	**–1,586**	**–873**	**–1,396**

*Adapted from, Ministry of Development, 2013, Sustainable Forest Management Special Expertise Commission Report, Ankara.

out throughout the country (Anon 1987). This number reached 1,893,024 ha with the addition of 148,529 ha in the 1st Development Plan. A further, 94,257 ha was added in the 2nd Development Plan, 134,855 ha in the 3rd, 214,669 ha in the 4th, 555,894 ha in the 5th, 226,865 ha in the 6th, 132,342 ha in the 7th, 173,906 ha in the 8th (Güney 2003), and according to GDF (2012), 211,707 ha in the 9th Development Plan including afforestation until the end of 2012.

The objectives of the nine Development Plans were:

1st Development Plan (1963–1967): Policies aimed at constructing and improving poor forests, enhancing the features of current forests, increasing their productivity and managing forests rationally.
2nd Development Plan (1968–1972): Policies aimed at establishing new forests through afforestation, and constructing and improving current forests. Also, with the aim of the support of afforestation, policies intended to found tree nurseries.
3rd Development Plan (1973–1977): Policies aimed at developing existing forests and establishing new forests using fast-growing species.
4th Development Plan (1979–1983): Develop policies based on the demand of the forest products industry and the energy sector, and the needs of sustainability.
5th Development Plan (1985–1989): Policies to develop afforestation particularly in the private sector.
6th Development Plan (1990–1994): Policies aimed at decreasing the negative effects of disasters such as deforestation, desertification, soil erosion and flood.
7th Development Plan (1996–2000): Policies based on establishing forests which are able to withstand attacks by insects and diseases.
8th Development Plan (2001–2005): Policies aimed at preventing disasters such as deforestation, desertification, flood, landslide and avalanche.
9th Development Plan (2007–2013): Policies aimed at developing natural forests and those using fast-growing species.

It is noteworthy that statements highlighting the importance of afforestation appear in all nine Development Plans yet the concept of the industrial plantation is mentioned in only fourth and ninth Plans in spite of an average annual supply deficit of 1.4 million m^3 illustrated in Table 1. Matters are predicted to get worse with estimates indicating that in 2023, the demand of industrial wood in Turkey will reach approximately 15.6 million m^3 but the supply of wood is predicted only to be rise to 12.3 million m^3, resulting in a predicted supply deficit of 3.3 miilion m^3 (Özkurt 2002, Yildirim 2012).

INSTITUTIONAL AND LEGAL STATUS

Institutions involved in establishing industrial plantations

The activities of afforestation are the responsibility of a range of institutions as shown in Table 2.

The total afforestation which were made by the institutions reached 2.2 million ha over 65 years in Turkey although the establishment of new forests still remains a relatively low proportion, at only 7% of total afforestation.

The legal foundations of industrial plantations

In 1937, the Law of Forestry number 3116 came into force and with it the State began to be interested in afforestation issues on a large-scale. This piece of legislation stated an aim 'to increase production as contributing to the industrial activities and meeting continually the needs of wood and timber of communities'. Further laws, for arranging bases and provisions belonging to the afforestration activities (Law number 6831), and the Law of Natural Afforestation and Mobilization (number 4122) were enacted (GDF 2013a). In addition to laws and by-laws related to afforestration, 'Notes of Afforestation, the Control of Erosion and Range Improvement' was published by the General Directorate of Afforestation and Erosion Control in 1994.

With the exception of legal regulations, statements related to the issue of afforestation appear regulalry in plans and programs of forestry in Turkey. For example, in the Turkish National Forestry Program (2004–2023), the following objective appears - 'for increasing the suppy of wood and decreasing the pressures on the natural forests, the works of industrial afforestration with fast growing tree species are given special importance in the deteriorated forest areas'.

In the Strategic Plan of the General Directorate of Forestry (2013–2017), the necessity of the foundation of the industrial plantations with fast growing species is mentioned under the title of the strategic aim of development, although the production capacity of the industrial plantations is not enough to meet the market demand. It is planned that industrial plantations are established in a total area of 15,000 ha by the end of 2014, and a total of 66,750,000 m^3 of industrial wood will be produced from these plantations by the end of five years (GDF 2013b) (Table 3).

The importance of the foundation of industrial tree plantations in Turkey was highlighted in the Main Plan of Turkish Forestry, the Decisions of the Forestry Council, the Reports of the Forestry Specialization Commission, the Master Plan of Forestry and the 9th Development Plan which reflect Turkish forestry policies. It is also noteworthy that at the 11th World Forestry Congress which was held in Turkey in 1997, the 'Antalya Declaration' which was published at the end of congress, emphasized the importance of establishing industrial plantations (GDF 2013a).

RESULTS AND DISCUSSION

In order to meet the demand for wood raw materials and their derivatives in Turkey and to enable sustainable management of natural forests it has become essential to establish industrial plantations with fast growing species. This will not only reduce the need to import wood but assist in the conservation of existing forest resources.

TABLE 2 *Afforestation by different institutions in 1946–2010**

Institution	Afforestation	Reforestation	Private afforestaion and reforestation	Total afforestation and reforestation
GDF (ha)	1,217,225	43,202	3,378	1,263,805
GDF/GDoAEC (ha)	274,750	0	28,348	303,098
GDoAEC (ha)	471,866	6,845	76,346	555,057
GDoSHW (ha)	5,969	0	0	5,969
Others (ha)	62,046	0	0	62,046
Total (ha)	**2,031,856**	**50,047**	**108,072**	**2,189,975**
GDF (%)	59.9	86.3	3.1	57.7
GDF/GDoAEC (%)	13.5	0	26.2	13.8
GDoAEC (%)	23.2	13.7	70.6	25.3
GDoSHW (%)	0.3	0	0	0.3
Others (%)	3.1	0	0	2.8
Total (%)	**100.0**	**100.0**	**100.0**	**100.0**
GDF (Annual average) (ha)	18,726,.54	664.65	51.97	19,443.15
GDF/GDoAEC (Annual average) (ha)	4,226.92	0.00	436.12	4,663.05
GDoAEC (Annual average) (ha)	15,728.87	228.17	2,544.87	18,501.90
GDoSHW (Annual average) (ha)	102.91	0.00	0.00	102.91
Others (Annual average) (ha)	969.50	970.50	971.50	972.50
General Annual Average (ha)	**31,259.32**	**769.95**	**1,662.65**	**33,691.92**

GDF – General Directorate of Forestry
GDoAEC – General Directorate of Afforestation and Erosion Control
GDoSHW – General Directorate of State Hydraulic Works
*Source: GDoCDE, 2012. General Directorate of Combating to Desertificationand Erosion Control Official Website, http://www.cem.gov.tr/erozyon/AnaSayfa/istatistikler.aspx?sflang=tr (31.08.2012)

TABLE 3 *The amounts of industrial plantation and wood planned in the scope of strategic plan**

	Years					
	2010	**2011**	**2012**	**2013**	**2014**	**Total**
Industrial Plantations (ha)	1,000	2,000	3,000	4,000	5,000	15,000
Industrial Wood (m^3)	11,000,000	11,625,000	13,125,000	14,500,000	16,500,000	66,750,000

*Adapted from (GDF, 2010) General Directorate of Forestry, Sustainable Forest Management and Strategically Plan Applications Service Education Seminar, 18–20 October 2010, Antalya.

Although there is some cultural opposition to the establishing of plantations with exotic species the major limiting factors to the development of the plantation sector are largely political, institutional, economic and legal. Changes in political departments responsible for forestry have led to a decrease in forestry activity at times and this, coupled with weak relations between forests owned by State and the mainly privately owned forest industries, has led to overall sub-optimal productivity of the forest sector. However, the importance of industrial plantations has remained in Turkish forest policy as there is great enthusiasm to increase the domestic forest production capability.

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Market failure for plantations: past experiences and emerging trends for delivering wood production and ecosystem services in Australia

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SUMMARY

Planted forests have increased globally in area in recent decades and are used for productive purposes such as wood production and ecosystem services such as soil conservation and biodiversity. Historically, these purposes have been largely regarded as mutually exclusive, reflecting market failure in the ability of investors to capture the benefits from ecosystem services. Trade liberalisation and global trade has also inhibited new plantation investment for wood in high land cost countries such as Australia. It is argued that market based mechanisms for ecosystem services may help overcome investment hurdles for private wood plantations, while delivering multiple benefits. An Australian case study is used to describe these trends and opportunities, including shifts away from direct wood plantation promotion to emerging policies for carbon, water and biodiversity. It is important that policy settings are designed to promote the potential net benefits from joint production and avoid any unintended negative environmental consequences.

Keywords: plantations, market failure, ecosystem services, carbon, incentives

Echecs de marché pour les plantations: expérience passées et courants émergeants pour aboutir à des fonctions productives et protectrices en Australie

M.L. STEPHENS et P. GRIST

Les forêts de plantation ont globalement accru en superficie au cours de ces dernières décennies et sont utilisées en des buts productifs tels que la production du bois, ainsi qu'en des service protecteurs tels que la conservation du sol et la biodiversité. Historiquement, ces buts ont été longtemps considérés comme mutuellement exclusifs, réfléchissant l'échec du marché dans l'inaptitude des investisseurs à glaner les bénéfices des services protecteurs. La libéralisation du commerce et le commerce global ont également inhibé de nouveaux investissemente en bois dans les plantations où le coût de la terre est élevé, comme en Australie. Le débat indique que les mécanismes pour les services protecteurs basés sur le marché pourraient aider à surmonter les obstacles à l'investissement dans les plantations privées, tout en débloquant de nombreux bénéfices. Une étude-cas australienne est utilisée pour décrire ces courants et opportunités, en incluant les mouvements s'écartant d'une promotion directe de la plantation de bois pour se concentrer sur les politiques émergeant pour le carbone, l'eau et la biodiversité. Il est important que les bases de la politique soient formées pour promouvoir les bénéfices nets potentiels résultant d'une production jointe et évitant toute conséquence environnementale négative non intentionnée.

El fracaso del mercado para las plantaciones: experiencias pasadas y nuevas tendencias para el objetivo de funciones productivas y protectoras en Australia

M.L. STEPHENS y P. GRIST

Las plantaciones forestales han aumentado en superficie a nivel mundial en las últimas décadas y se utilizan con fines productivos tales como la producción de madera, y servicios de protección como la conservación del suelo y la biodiversidad. Históricamente, estos propósitos han sido considerados ampliamente como mutuamente excluyentes, lo que refleja el fracaso del mercado en cuanto a la capacidad de los inversores para aprovechar los beneficios de los servicios de protección. La liberalización del comercio y el comercio mundial han inhibido también las nuevas inversiones en plantaciones de madera en países con un alto costo de la tierra, como Australia. Se argumenta que los mecanismos basados en el mercado para los servicios de protección pueden ayudar a superar los obstáculos de las inversiones en las plantaciones de madera privadas, al tiempo que ofrecen múltiples beneficios. Se emplea un estudio de caso de Australia para describir estas tendencias y oportunidades, entre ellas los cambios que se alejan de la promoción de plantaciones directas de madera y las políticas emergentes para el carbono, el agua y la biodiversidad. Es importante que los parámetros de las políticas estén diseñados para promover los beneficios netos potenciales de la producción conjunta y evitar las consecuencias ambientales negativas no deseadas.

INTRODUCTION

The FAO (2010) defines a planted forest as those forests 'composed of trees established through planting and/or through deliberate seeding of native or introduced species', which includes forest plantations[1] and planted semi-natural[2] forests. Globally, planted forests have increased in area by just over 8% per cent between 2005 and 2010 to a total of 264Mha (FAO 2010). These planted forests have been established for a variety of purposes with relatively intensive management compared to many natural forests. Internationally, plantation forests have been classified as falling within two broad categories:

- productive plantation: forest plantations predominately intended for the provision of wood, fibre and non-wood forest products; and
- protective plantation: forest plantations predominantly for the provision of services such as the protection of soil and water, rehabilitation of degraded land and combating desertification (FAO 2006).

Historically, planted forests have been developed for a single or narrow range of related purposes, primarily wood and fibre production. This is reflected in the main purpose of global planted forests, where it is estimated that 76% of planted forests have production as their primary goal (FAO 2010). However, it is expected that the relative importance of planted forests for environmental purposes will increase in the future, given their contribution to the provision of ecosystem goods and services, such as restoration of degraded land, regulation of watersheds, biodiversity and carbon sequestration (Kanninen 2012). This has been the case in China, for example, which has tripled the area of protective forest between 1990 and 2010 to 60Mha, through large scale planting aimed at desertification control and conservation of soil and water (FAO 2010).

Within Australia, the development of plantation forest has followed a similar pattern, with an initial emphasis in the 1970s through to the early 2000s on wood plantations and the more recent emergence of policies for ecosystem services from planted forests.

Plantings for ecosystem services have evolved from government sponsored schemes (e.g. grants, community education) in the 1980s for land rehabilitation and biodiversity to broader carbon mitigation based schemes. These latter schemes reflect international trends in carbon offsets trading and the promotion of land based sequestration, which has generated carbon plantings.

In this paper, we review the literature and opportunities in Australia for promoting an efficient level of plantation development for joint wood production and ecosystem services. Given the shift away from direct incentives for wood production, and the relatively high cost of land, investment in new wood plantations has fallen. This is despite their potential multi-functionality and ability to deliver a suite of goods and environmental services at a range of spatial scales (Baral *et al*. 2013). Concurrently, markets have emerged for some ecosystem services, such as carbon sequestration, water quality and in some cases biodiversity, given a range of previous land degradation and environmental issues (Keenan *et al*. 2004).

It has been argued that further development and access to these markets may help address some of the investment hurdles for new wood plantations while delivering multiple economic, social and environmental benefits (de Fegely *et al*. 2011). Some of the lessons from these policies are discussed in terms of their transaction costs, net social benefits and need to avoid negative environmental consequences.

MARKET FAILURE

Forest plantations, as an investment class, have typically struggled to attract large scale private investment without some form of Government intervention or subsidy (Nielson 2007). This is primarily because of the time value of money with high up front establishment costs and long period until harvest returns. This results in a lower rate of return for plantations compared with other investments excepting where there is other comparative advantage (e.g. high product prices, low transport costs, high yields).

It is for these reasons that most successful large scale plantation developments internationally have required some form of Government assistance (Enters and Durst 2004, Nielson 2007) either by direct intervention (i.e. state ownership) or by direct policy instruments such as taxation relief, access to land or other subsidies. For example:

- in Brazil, over 6Mha were established between 1967 and 1987 through a program of taxation incentives of up to 75% of the value of the project;
- from 1974 to 1994, the Chilean government provided subsidies of up to 75% of the establishment cost, as well as exemptions on property and inheritance taxes, which supported the establishment of over 1.5Mha of plantations;

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[1] Forest plantations, a subset of all planted forests, are defined as forests of introduced species and in some cases native species, established through planting or seeding, with few species, even spacing and/or even-aged stands (FAO 2006a).

[2] Semi-natural forests are defined as forests of native species, established through planting, seeding or assisted natural regeneration. This definition includes areas under intensive management where native species are used and deliberate efforts are made to increase/optimise the proportion of desirable species, thus leading to changes in the structure and composition of the forest, with possible presence of naturally regenerated trees from other species than those planted/seeded. This may include areas with naturally regenerated trees of introduced species and areas under intensive management where deliberate efforts, such as thinning or fertilising, are made to improve or optimise desirable functions of the forest (FAO 2006b).

- in Uruguay, incentives provided through the National Forest Plan included subsidies of up to 50% of the average cost of planting, no taxes on the planted forest or land, and low interest loans, which supported the development of around 2.5Mha of plantations; and
- between the 1960s and early 1980s, the plantation forest estate in New Zealand was expanded by almost 700 000 hectares through a range of programs including forestry encouragement grants, low interest loans and taxation deductions of up to 100% of planting costs to support private investment, as well as government planting programs through the New Zealand Forest Service (de Fegeley *et al*. 2011).

In pursuing plantation development, many Governments have not limited their policy goals to wood production and downstream processing. Interventions by Governments in a regionally based industry such as forestry often relate to a broader range of economic, social and environmental objectives, such as regional development, decentralisation, land rehabilitation and biodiversity (Stephens and Laughton 2003). The economic costs and benefits of plantation versus natural forest derived products may also be unpriced in the global market (e.g. illegal logging). Governments have therefore been prepared to financially assist the development of plantations due to the existence of market failure, given a range of public benefits that may not be captured by private investors.

Enters and Durst (2004) have characterised an international model of plantation development practices, based on a review of development policies over time. The model is described as comprising three distinct phases: initiation, acceleration and maturation. During the initiation phase, governments rely on direct incentives such as grants, taxation relief and land access to establish economies of scale. This is followed by growth and processing facilitation in the acceleration phase and finally maturation, whereby governments rely on indirect measures such a removing trade barriers and other regulation to improve efficiency. This model is reflected in the Australian case study described below.

AUSTRALIAN CASE STUDY

Wood production

The area of commercial wood plantation in Australia is just over 2Mha, with 1.02Mha of coniferous plantation and 980 000 ha of broadleaved plantation (Gavran 2012). Australia's commercial plantations are located mainly in the north-eastern coastal, southern and eastern regions of Australia.

The coniferous plantation is dominated by *Pinus radiata* or radiata pine (75.5%) and *Pinus elliotti* and *Pinus caribaea* hybrids known as southern pines (14.7%). Most radiata pine is located in Victoria, New South Wales and Tasmania, and most southern pines are located in south east Queensland. The broadleaved plantation is dominated by *Eucalyptus globulus* (55.1%) and *Eucalyptus nitens* (24.1%), which are primarily managed for short rotation pulpwood production.

In the seasonally dry tropical regions of northern Australia, there is also around 10 000 ha of planted African mahogany (*Khaya senegalensis*) which has considerable potential as a high value timber plantation species (Dickinson *et al*. 2011), as well as over 7 600 ha of Indian sandalwood (*Santalum album*) which is used in the global fragrance market.

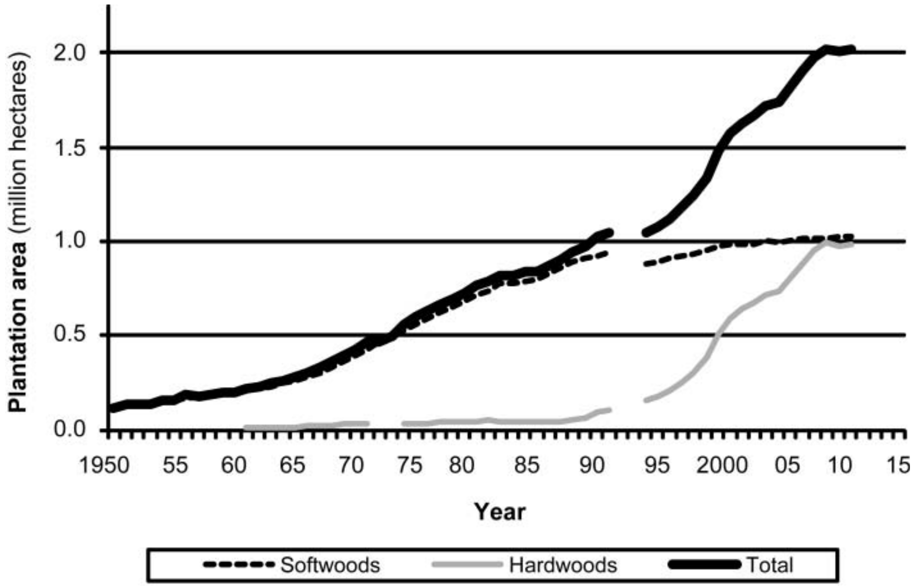
Large scale plantation development for wood production began in the late 1960s, through the use of concessional loans from the federal government to the state governments which established and managed the development of long rotation (e.g. 35 year) coniferous plantation. The major goals of this expansion were to promote regional development and increase wood and fibre productivity. These loans led to the establishment of 1Mha of coniferous plantation for integrated sawlog and pulpwood, used for domestic sawntimber and pulp and paper production. The harvest and management rights to the coniferous plantations were subsequently sold in the 2000s to private institutional investors as part of the commercialisation of government owned assets. The management of these plantations is undertaken by timber investment management organisations on behalf of investors, consistent with recent trends in North America.

The other major trend that occurred from the 1990s was the emergence of Managed Investment Schemes (MIS) which took advantage of existing taxation incentive provisions and pooled capital from a large number of small investors. This led to the rapid rise of mostly short rotation hardwood (*Eucalyptus*) plantations for woodchip export markets, which increased from a relatively low base to over 800 000 ha by 2012.

These trends are observed in the annual area of plantation established in Australian since 1950 (Figure 1), which saw a steady rise in coniferous plantings from the 1970s through to the mid-1990s as a result of the concessional loans and direct state ownership. This was followed by the move away from direct incentives to indirect measures and policy support. The Plantations for Australia: 2020 Vision, launched by Governments in 1997, aimed to enhance wealth creation and international competitiveness through a notional target of trebling the area of wood plantations by 2020. This policy has focused on improving competitiveness through research and development, improving information on markets and prices and streamlining planning and regulation. Since the 1990s private sector planting rates for coniferous plantations has plateaued. However, these coniferous plantations have reached maturity and help contribute to a domestic forest, wood and paper processing industry with a $21billion annual turnover (ABARES 2013).

The major increase in new plantings since the mid-1990s occurred through the MIS model, with planting rates averaging over 70 000 ha per year between 1997 and 2007. However, problems with the structure of the financial arrangements and access to suitable land led to the collapse of many private companies, with some areas planted on uneconomic sites. To avoid such problems, industry has recognised the need for the MIS model to have appropriate financial due diligence controls in the future (Australian Forest Products Association 2012).

FIGURE 1 *Plantation forest area in Australia, 1950–2011*



Source: Australian Bureau of Agricultural and Resource Economics and Sciences.

Following the collapse of many MIS companies, most of this estate has been acquired by long term institutional investors which has provided relative stability to the plantation sector. Further rationalisation of the former MIS estate is projected, with some areas not expected to be commercially replanted as a consequence of being established on poor quality sites or other factors such as long distances to markets (Australian Forest Products Association survey of members, unpublished data). These marginal areas are largely being converted back to agriculture following harvest.

The net outcome from these policies has been the development of a sizeable wood plantation resource and associated downstream processing. However, once Governments have transitioned away from direct incentives to an enabling policy environment there has been little new plantation investment. This can be attributed to relatively high land costs and market failure arising from an inability for investors to significantly capture non-market ecosystem services or other social benefits from plantations.

Ecosystem services

When assessing the scope for forest plantings in Australia for ecosystem services, it is important to note the previous environmental degradation of land, water and vegetation, primarily as a result of agricultural development and other settlement patterns since the arrival of Europeans in 1788. It is estimated that around 13% or 100Mha of land has been cleared of native vegetation, mostly eucalypt woodlands, with a further 65% subject to disturbance pressures such as livestock grazing (State of the Environment Committee 2011). This has led to a range of natural resource management problems, including soil and water erosion, sedimentation, acidification, dryland salinity and loss of plant and animal diversity.

Over 30 Mha of public natural forest (20% of the total forest area) in Australia is managed primarily for ecosystem services, including biodiversity and soil and water values, which includes public conservation reserves and multiple-use forest areas where timber harvesting is precluded by prescription (Commonwealth of Australia 2008).

It is difficult to ascertain the extent of planted forest for ecosystem services, which is undertaken by a range of individuals such as farmers, community based organisations, private businesses, family trusts and local governments. A national survey of farmers identified that, depending on farm type, between 80 and 90% of farmers planted trees for the provision of shade and shelter, 40 to 50% for rehabilitation of degraded land, 1 to 4% for wood production and 25 to 30% for conserving vegetation and wildlife Wilson *et al*. (1995). These trends are expected to have continued, given a national policy focus on landscape restoration for both farm productivity and broader conservation.

There have been three distinct trends for promoting ecosystem services from planted forests, comprising:

- programs for landscape restoration and farm productivity;
- greater recognition of biodiversity values, landscape connectivity and the use of market based instruments (e.g. tenders, auctions); and
- the emergence of carbon markets for forestry and land sector activities (e.g. tradable credits from sequestration).

In the 1980s a number of national community based groups were established with Government support to address tree cover decline and foster greater restoration of Australia's environment, including Greening Australia in 1982 and Landcare in 1989. Landcare, for example, has 4 000 local community groups and both organisations have supported a range of education and restoration projects for raising farm productivity and improving the environment through revegetation. Direct grants from Governments have been used for activities such as new plantings, fencing of remnant vegetation and weed and pest control.

Since the 1990s, market based instruments have been trialled to achieve conservation outcomes. These instruments mainly relate to the use of auctions and tenders for the purchase of remnant vegetation and some revegetation as a proxy for biodiversity (e.g. Bush Tender scheme in Victoria and Environmental Services Scheme in New South Wales).

A third major development has been the creation of a national crediting mechanism for carbon sequestration from land sector activities including afforestation, through the Carbon Farming Initiative. This has allowed for the development of internationally verifiable and tradable carbon credits in any voluntary or future compliance market (e.g. cap and trade system).

Water quality

In a dry continent such as Australia there is considerable experience in the allocation of scarce water resources and tradable water rights for consumptive uses (e.g. irrigated agriculture) from public waterways, most notably in the Murray Darling Basin.

It is also recognised that plantations, like all forms of agricultural land use, intercept water and that plantations generally use more water than pasture (Zhang *et al*. 2003). However, plantations occupy less than a few per cent of most large catchments and given variability in rainfall and hydrological factors, impacts on water yield are difficult to detect if reforestation is less than 15–20% of total catchment area (Parsons *et al*. 2007). At higher levels of plantation land use, there can be reduced mean annual runoff and less groundwater recharge (Zhang *et al*. 2007). Plantations can also play an important role in improving water quality through reduced use of chemicals and pesticides, reduced erosion and soil salinity and flood control (Zhang *et al*. 2007).

Water policy in Australia has therefore been directed at achieving an appropriate balance between managing the impacts of plantations on both water yield and quality. The interaction of plantations on both these variables is important, as the costs and benefits of reduced run-off and/or lower water tables will depend on the salinity of the groundwater, its potential to contribute to waterlogging or inundation and its potential for productive use (Zhang *et al*. 2007). In the south-east region of South Australia, for example, groundwater is a highly valued freshwater resource, while in Western Australia there is high saline groundwater and dryland salinity issues from previous land clearing.

At a national level, dryland salinity is a particularly important water management issue, which arises from the removal of vegetation and rising saline water tables that causes land to be unproductive. The National Land and Water Resources Audit (2001) estimates that 5.7Mha of land is adversely affected by dryland salinity which is forecast to increase to 17Mha by 2050 in the absence of amelioration.

Zhang *et al*. (2007) suggest that afforestation could play a significant role to reduce dryland salinity, given the ability of trees to manage recharge through their deep rooting habit and high perennial water use. Considerable work has been undertaken in assessing and trialling salt tolerant tree species to ameliorate dryland salinity in a range of geographic regions and sites, which can also produce other related benefits such as the harvest of biomass for fodder or bioenergy (Dale and Dieters 2007, Sochaki 2012).

At a large catchment scale in Western Australia, Townsend *et al*. (2012) evaluated the net benefits from bundling payments for environmental services from watershed restoration in a dryland salinity affected region, including the potential market benefits from carbon sequestration, wood production and water quality improvements. The modelling of management scenarios indicated that 70% reforestation was required to restore a potable threshold of 500 mg/L total dissolved salts in the 105 000 ha watershed and that carbon payments could help offset the opportunity costs from land use change.

White *et al.* (2012) evaluated the Australian market for salinity benefits from planted forests and noted that while markets exist, they tend to be fragmented and usually exist for a single pollutant or discharge of saline water from point sources such as coal mines and power stations. There is therefore some potential for dryland salinity market payments, but this will be variable and dependent upon regional conditions.

Carbon

Australia has been an early mover in the development of carbon trading systems and links to the land sector through several state and federal government schemes. These have included the New South Wales Greenhouse Gas Reduction Scheme (GGAS), the Australian Government's Greenhouse Friendly voluntary program and the Carbon Farming Initiative, the latter which links as a land crediting mechanism to the national Emissions Reduction Fund (ERF). The ERF is a reverse auction market mechanism to buy low cost emission reduction activities in the Australian economy, with the Australian Government initially allocating $1.55 billion to the Fund over a three year period commencing 1 July 2014 (Commonwealth of Australia 2013).

Mitchell *et al*. (2012) provide a summary of the evolution of carbon forestry schemes and their uptake in Australia, which has resulted in the establishment of 65 000 ha as at March 2012 (Table 1). The main schemes have generally been aimed at Kyoto Protocol compliant activities, such as afforestation and reforestation activities on cleared agricultural land post-1990.

Most carbon plantings have been for not-for-harvest projects, either mixed plantings of eucalypt species, or plantings of mallee eucalypts in low rainfall areas which are multi-branched trees with a height rarely exceeding 6 metres. Some wood production plantations have participated in the GGAS scheme. Overall the uptake of wood plantations has been minimal given uncertainty in the carbon market settings and scheme design issues.

Planted forests for wood production can provide multiple carbon sequestration and fossil fuel displacement benefits,

TABLE 1 *Carbon forest plantings in Australia*

	Number of entities	Type of entity	Planting type	Area (ha)
	3	For-profit company	Mallee	24 413
	2	For-profit company	Biodiverse	5 500
	2	Government business enterprises	Maritime pine, mallee, hardwood, *Pinus radiata*	14 600
	5	Not-for-profit	Biodiverse, mallee	8 840
	2	Individuals	Mallee	11 775
Total	14			65 128

Source: Mitchell *et al*. (2012). Notes – Mallee and hardwood include a range of *Eucalyptus* specie*s*, biodiverse refers to mixed species such as *Eucalyptus* and *Acacia*, maritime pine is *Pinus pinaster.*

through the carbon stored in the forest and harvested wood products, the substitution of more energy intensive products with wood products and the use of woody biomass for renewable bioenergy (Malsheimer *et al*. 2011, Lippke *et al*. 2011). Despite these carbon abatement opportunities, the domestic schemes are yet to fully develop underlying methodologies and accounting rules for the inclusion of these carbon pools at a project level. Further development work is needed to capture the full range of sequestration and abatement benefits, which would allow greater participation in carbon market schemes.

However, given the large area of previously cleared land, there has been strong interest in the potential for sequestration from planted forests under a range of carbon price and land availability scenarios. Several spatial analyses at a national scale have assessed the economic potential for plantations under a carbon market using physiological growth models or assumed growth parameters and agricultural land opportunity costs, including Polglase *et al*. (2008), Lawson *et al.* (2008), Polglase *et al*. (2011) and Burns *et al*. (2012). It is clear from these studies that the potential uptake is highly dependent on the modelling assumptions used, including projected carbon prices, establishment costs, discount rates and eligible planting activities, with estimates ranging from less than 350 000 ha up to 9Mha by 2050. These plantings comprised either not-for-harvest plantings or combinations of not-for-harvest and wood plantations.

In a more recent analysis, Paul *et al*. (2013) specifically looked at the potential for wood plantations to benefit from a carbon market and contribute both joint wood production and carbon sequestration benefits. It was found that establishment of new plantations for wood production on agricultural land was not presently viable given current costs of establishment. However, on average, for scenarios of hardwoods (*Eucalyptus spp.*) and softwoods (*Pinus radiata*), a payment of about \$10 and \$30/t CO_2 respectively would be required to make plantation expansion viable assuming a 4% carbon price increase per year, with an initial price above \$20/t CO_2 needed in the majority of scenarios for south-eastern Australia. The scenarios included short and long rotation plantations for pulpwood and sawlogs and the crediting of carbon stored in wood products and soils. The findings are consistent with de Fegeley *et al*. (2011) who suggested that without a carbon price wood plantations would not be able to meet the investment hurdle rate. Further analysis by White *et al*. (2013) suggests that the internal rate of return (IRR) after taxation for a typical long rotation plantation in Australia may be as low as 3.8% for softwood and 2.6% for hardwood, assuming a land cost of \$5 000/ha.

There is therefore considerable scope for carbon markets to provide additional payments for ecosystem services not presently captured by investors in wood plantations and promote joint production. This potential will depend on carbon scheme design rules, including the treatment of additionality, carbon pools (e.g. inclusion of wood products) and crediting periods. For example, the proposed design of the ERF is to have five year contracts, which may seriously disadvantage land based sequestration such as forestry projects, which typically have low early growth but higher longer term sequestration rates.

Biodiversity

As discussed above, the main drivers for biodiversity plantings have been local community driven and on-farm projects relying on direct grants from Governments, with some trialling of market based instruments for land purchase or conservation management covenants. Windle and Rolfe (2008), for example, assessed competitive tenders and fixed price grants for rangelands biodiversity improvements and found that due to the heterogeneity of landowners a tender process proved more efficient in achieving environmental outcomes.

The bundling of biodiversity outcomes with carbon markets has also occurred to some extent in Australia through the \$1billion Biodiversity Fund, which has provided direct payments for carbon sequestration projects that also deliver biodiversity benefits.

Research has found that plantations can provide habitat benefits for a number of species compared to agricultural and pastoral land (Lindenmayer and Hobbs 2004, Baral *et al.* 2013). Many of the opportunities for biodiversity enhancement include the utilisation of non-commercial areas of wood plantation estates. These areas include remnant vegetation, streamsides, firebreaks, setbacks from utilities and roads and steep or unproductive sites, which can also have landscape connectivity with adjacent natural areas (Stewart *et al*. 2006, Archibald *et al*. 2011). However, in terms of capturing non-market biodiversity benefits from wood plantations, this type of ecosystem service is considered less amenable to a market solution given the range of site specific outcomes and conditions. This is only likely to increase transaction costs and does not tend to meet the desirable property right characteristics for creating markets, including that they be verifiable, enforceable, transferable and with low scientific uncertainty (Murtough *et al*. 2002). For small scale and farm forestry type projects, the transaction costs for biodiversity outcomes could be lower and more suited to the individual goals of the forest owner.

The other issue with respect to biodiversity is the potential for poorly defined markets and incentives for ecosystem services leading to unintended environmental outcomes. Lindenmayer *et al*. (2012) discuss this issue with respect to carbon policies that promote large scale plantations without considering some of the downside risks, including the potential for clearing natural vegetation, invasive taxa and impacts on fire and water regimes as part of key ecosystem processes. It is suggested that appropriate ways to reduce these risks include improved ecological risk assessments, full carbon accounting of land use practices and broad evaluation of proposed incentives including consultation with local policy makers.

DISCUSSION

Market based mechanisms are recognised as an alternative approach to direct regulation (e.g. standards) for achieving desired environmental goals. If well designed, they can lower the costs to government and the community of achieving environmental goals and link with potential sources of capital including regulated private investment, industry, individuals (e.g. farmers) and private voluntary organisations (Binnings *et al*. 2002).

Keenan *et al*. (2004) identified the early potential for market based mechanisms to encourage small scale private landowners in Australia to deliver environmental services, such as to retain existing forest, establish forests on previously cleared land and integrate trees more fully with farming systems. It was argued that while forest owners can make a profit from the sale of wood and other commercial products, environmental services (e.g. clean water, dryland salinity mitigation, soil protection, carbon sequestration or biodiversity conservation) were not effectively valued or traded as market goods.

This paper expands on the early conclusions of Keenan *et al*. (2004) and Harrison *et al*. (2003) that developing markets for ecosystem services can provide a basis for harnessing private capital for environmental outcomes. We argue that such markets should be harnessed for both small and large scale plantation investments where appropriate, recognising the joint wood production and environmental benefits that can be generated from increasing scale at a regional level. Many of the environmental issues encountered in Australia occur at a regional or water catchment scale, and so a regional approach can provide an efficient solution (Townsend *et al*. 2012).

It is important to note that planted forests can have both positive and negative environmental consequences such as the introduction of pests and water use impacts, but through careful design and planning can help address landscape management issues at a strategic scale (Nambiar and Ferguson 2005, Kanowski 2010).

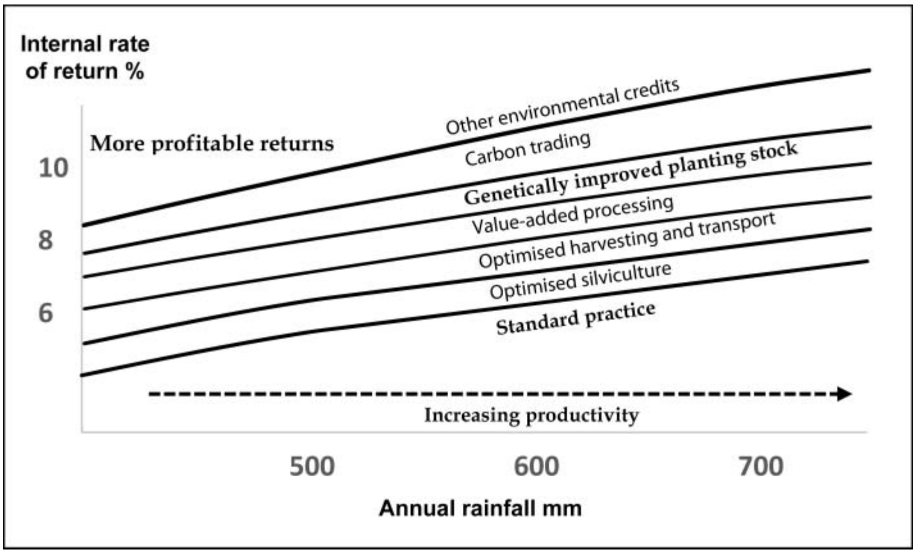
Plantation investment can also occur across a continuum of planting types from monocultures of exotic species to stands of mixed native species; and varying scales from broad scale plantations to small farm woodlots and riparian plantings. The planting design and species mix will have direct impacts on the costs to the forest owner or investor. To date, the majority of wood plantations in Australia have been large scale and restricted to a select number of species for high productivity and commercial purposes. In this case the ability to capture a range of non-market benefits necessarily requires trade-offs, which need to be weighed against the commercial costs and benefits from environmental services such as carbon sequestration, water quality and biodiversity.

A key step in the diversification and expansion of wood plantations in Australia for both wood production and ecosystem services is to identify the range of productivity improvements and products available for each particular site, using the type of conceptual model outlined below (Figure 2). The model highlights the potential multi-functionality of plantations and returns across an annual rainfall gradient as an indicator of site productivity. Profitability can be improved through the stepwise application of best practice silviculture, efficient harvesting and transport, value added processing and use of better genetic stock, as well as the development of new products and services such as carbon trading and other environmental credits.

In assessing impediments to investment in long rotation wood plantations in Australia, White *et al*. (2012) applied such a model to the potential economic performance of a 35 year rotation eucalypt hardwood plantation in Queensland. The land expectation value was calculated using a 7% discount rate for a range of mean annual increment (MAI) growth classes and a bundled set of timber and non-timber values, including carbon sequestration, salinity amelioration and other ecosystem services. It was found that sites with an MAI above 20 m^3/ha/yr produced the highest return and were viable at current land prices, assuming a carbon price of \$20/t CO_2. Sites with a lower MAI were unviable notwithstanding additional values from carbon, salinity and other environmental services. This result is consistent with Paul *et al*. (2013) who identified that the higher rainfall sites produced the highest net returns and required lower carbon price scenarios to be viable.

To date, most carbon plantings in Australia have focused on lower rainfall regions such as mallee plantings, which can have lower opportunity costs such as land. However, it is apparent that higher productive sites for joint wood production and carbon may be viable in the future assuming increasing carbon price trajectories of above \$20/t CO_2 (Paul *et al*. 2012).

FIGURE 2 *Conceptual model for multi-functional plantations*



Source: Adapted from Chris Harwood, CSIRO, in Keenan *et al*. (2004).

There can also be uncertainty in carbon markets and volatility in carbon prices, particularly until underlying national and international carbon regulatory frameworks are fully developed. In Australia, for example, there has been considerable complexity and uncertainty in the development of national carbon policy (Mitchell *et al.* 2011). This has included a variety of mechanisms to promote transparency in voluntary markets such as the Greenhouse Friendly voluntary program and National Carbon Offsets Standard (Australian Government 2012) through to the establishment of a fixed carbon price (or cost) on liable entities for an initial three year period transitioning to a national cap and trade system under the *Clean Energy Act 2011*. The carbon price and the cap and trade system is presently subject to new legislation to be repealed in the Australian Parliament. Concurrently, the Australian Government is developing an incentives based reverse auction scheme for the purchase of low cost emissions abatement, which links to the Carbon Farming Initiative as a crediting mechanism for land sector projects (Commonwealth of Australia 2013). A direct implication of the proposed repeal of the cap and trade system is a shift away from a compliance market with a large number of liable entities to a voluntary auction scheme where the Government is a large purchaser of emissions reductions in the economy. These changes serve to illustrate some of the uncertainty caused from underlying regulatory changes that have taken place with regard to national carbon policy in Australia over the past few years.

Another feature of the Carbon Farming Initiative, that has potentially limited access to carbon markets for wood plantations, is the inclusion of additional regulatory provisions targeted at forestry projects. This includes the need for water access property rights or regulatory approval from the National Water Commission for plantings established on lands receiving more than 600 mm average annual rainfall. It has been argued that such requirements add transaction costs to projects and duplicate existing natural resource management and environmental planning regulations for land use activities in Australia (Australian Forest Products Association 2013).

In this regard, the issues raised by Lindenmayer *et al.* (2012) on the potential environmental risks from poorly designed incentives for plantations are valid considerations. From an efficiency perspective, the use of existing regulation such as legislated codes of forest practice and other market mechanisms such as voluntary third party certification may help address ecological risks at low cost. In Australia, over three quarters of the total area of wood plantation is certified under either or both of two internationally recognised certification schemes for sustainable forest management, these being the Australian Forestry Standard endorsed under the Programme for the Endorsement of Forest Certification; and the Forest Stewardship Council.

CONCLUSIONS

Australia has followed a similar pattern to other countries of state intervention for the development of a sizeable wood plantation estate of around 2Mha, relying on direct incentive measures that have gradually shifted to more indirect polices aimed at improving regulatory efficiency and international competiveness.

A direct implication of this policy shift has meant that in high land cost countries such as Australia there has been minimal new private sector investment, particularly for long rotation plantations. This is partly attributed to market failure arising from an inability for investors to significantly capture non-market environmental benefits or other social values from plantations.

There is therefore considerable interest in addressing market failure through the use of emerging markets for ecosystem services in Australia and the joint production of wood and environmental values. A market based solution for ecosystem services in wood plantations has the added potential benefit of increasing economies of scale and competitiveness in wood resource availability and associated downstream processing.

A key question that arises is which ecosystem services are most amenable for joint production? In an Australian context, there are underlying opportunities in the areas of biodiversity, dryland salinity mitigation and carbon sequestration. However, given the complexity of capturing the benefits and transaction costs for biodiversity, there is relatively less scope at least in the short term. There is greater potential for salinity mitigation, which could be important in a regional context where markets do exist at a catchment scale and there is greater market development as part of the national water market for consumptive uses.

Over the short to medium term, carbon markets would appear most prospective for wood plantations for sequestration offsets, given the development of a domestic crediting and verification mechanism via the Carbon Farming Initiative and the fungibility of tradable carbon credits. There is scope for carbon markets to provide additional returns to meet present hurdle rates for new wood plantation investment, assuming carbon prices higher than \$20/t CO_2 into the future. However, there can be uncertainty in carbon markets and volatility in carbon prices, particularly until underlying national and international carbon regulatory frameworks are fully developed.

Furthermore, it will be important to ensure the design of carbon schemes and accounting rules adequately recognise the wide range of sequestration and abatement benefits from growing and using wood products. Careful attention should also be applied to addressing the risks for unintended negative environmental consequences, given the potential for carbon markets to drive land use change. Better risk assessments and policy evaluation may be needed to ensure sustainable practices, drawing as much as possible on existing regulatory frameworks and voluntary market certification schemes so as to avoid duplication, lower investment costs and improve efficiency.

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Clones or improved seedlings of Eucalyptus? Not a simple choice

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SUMMARY

The industrial use of hybrid eucalypt clones has been hugely successful in Brazil and a limited number of other countries but there are many circumstances where it is less risky and more economically sustainable to plant seedlings. This is particularly true for difficult-to-root pure species and for organizations which do not have the financial and technical resources to manage a sustainable clonal program. Type of planting stock does not add value *per se*; it is the ultimate return from the harvested crop which matters to growers. Case-by-case analysis of deployment options is recommended, taking into account the growers' objectives; species biology; technical capabilities and budget for R&D; and the scale of nursery production which greatly affects plant unit costs.

To assist such decisions pros and cons of clonal forestry are presented together with the technical requirements for clonal and seed production programs and for the middle course of vegetative multiplying tested superior families. Some case study examples are discussed.

Keywords: *Eucalyptus*, clones, seedlings, vegetative propagation, deployment, seed orchards

Clones ou jeunes plants améliorés d'eucalyptus? Un choix difficile à prendre

A.R. GRIFFIN

L'utilisation industrielle des clones hybrides d'eucalyptus a eu énormément de succès au Brésil et dans un nombre limité d'autres pays, mais il existe d'autres circonstances où il est moins risqué et plus soutenable économiquement de planter des semis. Cette dernière alternative est particulièrement vraie pour les espèces pures ayant des difficultés à établir des racines et pour les organisations ne possédant pas de ressources financières et techniques pour gérer un programme de clones soutenable. Le type de plantation n'a pas de valeur intrinsèque; c'est le bénéfice ultime résultant de la récolte qui compte pour les exploitants. Une analyse cas par cas des options de déploiement est recommandée, prenant en compte les objectifs des exploitants, la biologie des espèces, les capabilités techniques et le budget pour le "R&D", ainsi que l'échelle de la nurserie, qui affecte énormément le coût des plants individuels.

Le pour et le contre de la foresterie de clones est présenté, afin de faciliter de telles prises de décisions, ainsi que les nécessités techniques que requièrent les programmes de production de clones et de graines et le stade intermédiaire de multiplication végétative des familles supérieures testées. Des exemples d'étude-cas sont examinés.

¿Clones o plántulas mejoradas de eucalipto? Una elección nada simple

A.R. GRIFFIN

El uso industrial de clones de eucalipto híbrido ha tenido un enorme éxito en Brasil y otros pocos países, pero son muchas las circunstancias en las que emplear plántulas de vivero es menos arriesgado y, en lo económico, más sostenible. Esto es particularmente cierto para especies puras de enraizamiento difícil y para las organizaciones que no cuentan con los recursos financieros y técnicos con los que gestionar un programa clonal sostenible. El tipo de material de plantación no añade valor de por sí; lo que importa a los productores es el rendimiento final tras el aprovechamiento. Se recomienda analizar, caso por caso, las opciones de plantación, teniendo en cuenta los objetivos de los productores, la biología de la especie, las capacidades técnicas y el presupuesto para I+D, y la escala de producción en vivero, la cual afecta en gran medida los costos unitarios por planta.

Para facilitar este tipo de decisiones se presentan los pros y contras de la silvicultura clonal, junto con los requisitos técnicos de los programas de producción de clones y semillas y para la opción intermedia de reproducción vegetativa de familias superiores controladas. Se discuten algunos ejemplos de estudios de caso.

INTRODUCTION

The aim of commercial forestry is to grow the highest value crop in an often variable and uncertain environment. Because industrial forestry companies in Brazil have had spectacular success with clonal plantations of hybrid eucalypts (Dehon *et al*. 2013) there is a strong tendency to assume that clonal deployment is optimal for all eucalypts growing in all other environments and with different production objectives. It is sometimes even assumed that cloning will somehow overcome problems which are more correctly addressed through management practices and better species-site matching. The severe cold damage experienced over large areas of the predominantly clonal plantation estate in China in 2008 (Xu *et al*. 2008) is a pertinent example.

Currently there is no choice but to clone if a grower wishes to plant hybrids but in many environments pure species are highly productive and it is the choice of deployment strategy for these which is my concern.

My career has been spent in planning and supporting eucalypt improvement programs around the world and it is very clear that many organizations have embarked on clonal forestry without a full appreciation of the costs and risks involved and without adequate consideration of the technically more simple option of producing and using **high quality** seeds (as opposed to the poor inbred and/or hybridized seed which may be raised where genetics is misunderstood or ignored in a search for low cost planting stock (Griffin 1987)). The optimal choice of deployment system depends on many factors including the growers' objectives; species biology; technical capabilities and budget for R&D; and the scale of nursery production which greatly affects unit costs of plants. In this paper I want to explore these issues in order to encourage a more objective case-by-case analysis of options. The arguments are equally relevant to other genera where cloning is "possible but not easy". For a thorough exposition of the different deployment options for forest trees see Chapter 16 of White *et al*. (2007)

GENETIC DIFFERENCES BETWEEN CLONAL AND SEEDLING PLANTATIONS

There is no genetic variation within a monoclonal stand so diversity must be managed at the estate level. If a set of selected clones are truly the best adapted high yielding individuals then they ought to out-produce seedlings. However various genotype x environment (GxE) effects can be expressed as well as C effects (those induced by the process of propagation). Since even the best resourced clonal development program is unlikely to test under all possible site types, silvicultural regimes and biotic and abiotic stresses which may be experienced during the rotation, there is inevitable risk of making sub-optimal selections. This may be mitigated by planting intimate mixtures of clones as is mandated in some countries (Muhs 1993) but since this really only simulates the structure of a seedling plantation it is unclear how the cost of cloning can be justified. At the estate level planting a mosaic of clones also manages risk. White *et al*. (2007) concluded that "7–20 clones are appropriate for deployment in a given cycle of breeding within a single breeding unit for short rotation species planted in areas where there is no known risk of catastrophic loss". Dehon *et al*. (2013) make a similar statement "nurseries should operate with 5 to 10 operational clones, with 2 to 5 top candidates for pre-commercial pilot plantations every three or four years. . .(this will result in) full replacement of the clonal nursery portfolio every 10 to 15 years and means that it is unlikely that any one specific clone will be in use in a specific area for more than 2 operational rotations". Modelling of risk by Bishir and Roberts (1999) suggests that the plantation estate should contain 30–40 clones. Many organisations and even countries growing eucalypt clones are working at the low end of this diversity spectrum (Table 1) and it is not obvious that they are investing sufficiently to meet the turnover criteria, particularly in the stressful environments which are most usually available for forestry in Asia. Over-reliance on planting a few "old faithfuls" until such time as the inevitable new pest or disease or extreme environmental condition forces change, is a high risk strategy.

The genetic variation within seedling plantations depends on the type of material deployed (see White *et al*. 2007 Table 16.1). Bulk open pollinated orchard seed will contain most of the total additive genetic variation present in the selected population, a single open pollinated family about 75% and a single full sib about 50%. If families are well tested prior to deployment *en masse* it is quite possible to maintain this genetic variance while still producing a stand of highly uniform trees more or less indistinguishable from a clonal plantation (Figure 1). The advantage of the more genetically heterogeneous seedling plantation is that in an uncertain environment there is more chance of stable yield per hectare. Becker and Leon (1988) cite many examples from crop breeding where mixtures of homozygous lines have higher yield stability than their components grown in pure stands.

FIGURE 1 *A uniform monoprogeny (full-sib) stand of* E. grandis *in Brazil (courtesy Suzano)*

TABLE 1 *Status of eucalypt breeding and deployment in selected Asian countries in 2013 (pers. comm. CE. Harwood. from discussions with leading tree breeders in each country)*

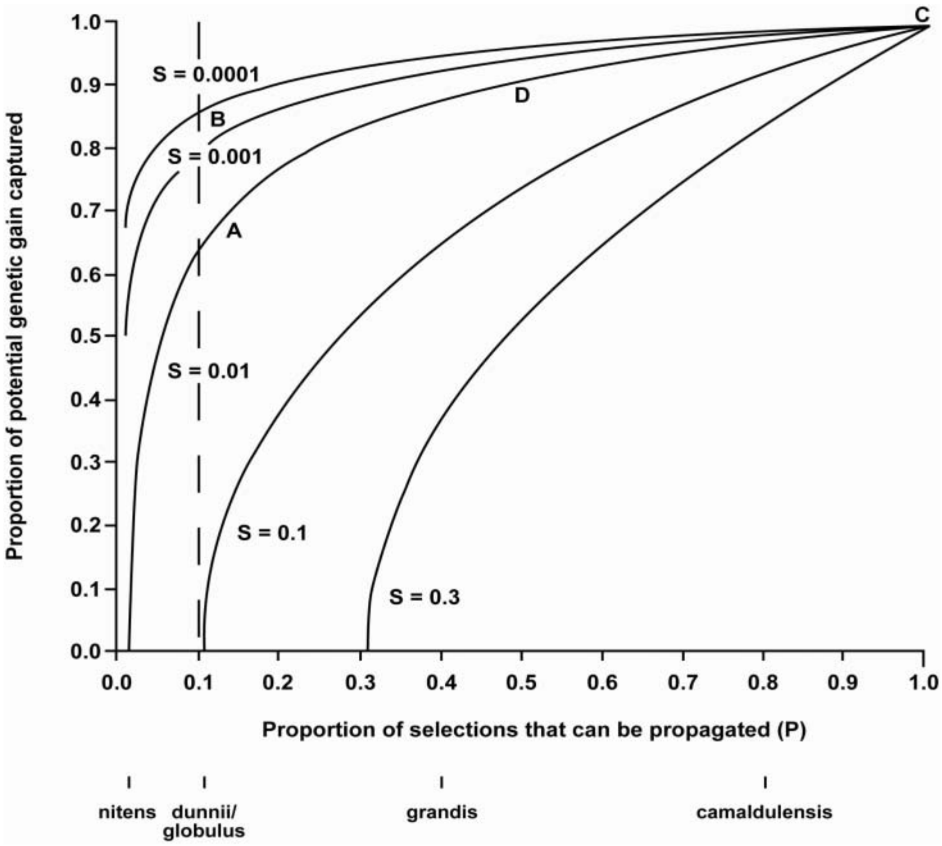
Country	Species	Area of plantation (ha)	Size of breeding population[1]	Generations of breeding[2]	% clonal	No. of clones deployed operationally
China	*E. dunnii*	60,000	300	1	0	0
	E. grandis	60,000	>300	2	80	8
	Eucalyptus hybrids[3]	2.5 M	>500[3]	2	100	20
	E. globulus	120,000	200	1	0	0
Southern India	*E. camaldulensis* &	>1M	150	2	25	40
	E. tereticornis		40	2		10
Thailand	*E. camaldulensis* & hybrids	500,000	300	2	>90	10
Vietnam	*E. urophylla*	200,000	140	2	<10	6

[1]number of unrelated open-pollinated families from above-average provenances.
[2]1 = first-generation progeny trials established, 2 = second-generation progeny trials established.
[3]combinations of *E. grandis*, *E. urophylla*, *E. camaldulensis* and/or *E. tereticornis.*

Only genotypes with good rooting potential can be cloned

No matter how good the growth, adaptation and wood properties of a tree, it cannot be used as an operational clone unless it can be propagated economically. The lower the rooting percentage the higher the cost per plantable plant and nursery managers are understandably reluctant to propagate anything with less than about 50% rooting. It is possible to find rootable genotypes in virtually all eucalypt taxa and if growers insist on clonal plantations then there is an almost irresistible pressure to place a heavy weight on this trait rather than on the production traits which actually create value (White *et al.*

FIGURE 2 *Expected capture of potential genetic gain with varying overall selection intensities (S) and proportion of propagable individuals (P) (after Figure 2 Haines and Woolaston (1991)). Average rooting % of some important species is indicated*



2007). By contrast virtually all selections made in a pure species breeding program can be induced to produce useable seed. The problem of loss of potential realized gain from cloning was explored by Haines and Woolaston (1991) (Figure 2). The lower the proportion of genotypes which will root the larger the population which needs to be screened in order to find a selection which is both rootable and of high value, to the point that one has to ask whether it is practicable to run such an expensive program. Unfortunately many important taxa (e.g. *E. nitens*, *E. globulus*, and *E. dunnii*) are not as easy to clone as the hybrids of *E. grandis*, *E. urophylla* and the red gums which are widely used in sub-tropical plantations, so this is a very important question.

To illustrate the practical implications, consider a typical requirement for 10 operational clones to be selected from a breeding population of 1000 genotypes i.e. (S = 0.01). If only 10% of the trees are rootable (P = 0.1) then selection pressure on economically important traits must be sacrificed and only about 65% of the gain potentially available can be captured (A). At this value of P we would need to screen 10000 (S = 0.001) trees to increase the proportion of potential gain captured to 80% (B) and over 100000 (P = 0.0001) to achieve 90%. As P increases the problem becomes progressively less until at P = 1 there is no propagation constraint and 100% of the potential gain is achievable irrespective of the overall selection intensity (C). For a variety with P = 0.5, screening1000 to find 10 will yield about 85% of potential gain (D) and this degree of effort is within the range of many clonal development programs although the cost and technical expertise required is still not trivial.

Table 2 further illustrates the constraint imposed by rooting ability. For the *E. dunnii* example and a target of 10 clones P = 0.03. Applying the logic of Figure 2 the best 10 clones of the 8% of the *E. dunnii* population which passed the rooting hurdle would average about 70% of the potential gain. In this example none of the rootable clones were sufficiently superior on an index of volume and density to make it into operational use. The model may actually underestimate the problem because quality of root system is also critical. Poorly developed roots can have a lasting effect on ability of a genotype to express its full genetic potential and is a factor which is rarely considered in evaluation trials. Borralho (1997) also modelled the expected genetic gains from clones and CSOs of *E. globulus* and concluded that for rooting success of 10%, clonal forestry would return less gain than orchard seed.

PROS AND CONS OF CLONAL FORESTRY

"We are technologically advanced and now plant clones rather than seedlings". I have encountered versions of this view on more than one occasion though it is obvious that cloning *per se*, whether by cuttings or micro-propagation does not add value. In fact clonal plants are always more expensive than seedlings and propagation of the wrong genotype can seriously reduce value (Clarke 2000). Technological sophistication is best measured through demonstrated choice of whatever is the best deployment system for the circumstances! It is of course true that clonal plantations can sometimes be highly profitable. The major benefits are summarised in Table 3.

Each grower organization must consider each factor and weigh against the costs of developing a clonal program, accessing clones from a third party source or making use of seedling options.

Commentary to points in Table 3:

1. This is the main theoretical driver for clonal deployment. The key issue is that it requires a high level of sustained investment to identify high yielding clones which are propagable at an acceptable cost. In an environment where any form of stress is an issue it is particularly difficult to quantify GxE effects and this can lead to selection of sub-optimal clones (Reis *et al.* 2011).
2. A nice uniform stand is pleasing to the eye but the dollar value is by no means obvious. A fibre crop is not sold as individual trees it is the combined tonnage of billets or chips per hectare which determines the return to the grower. At the estate level uniformity within clones but diversity between can actually make wood flow planning and mill processing more difficult and expensive (Clarke 2000). Paradoxically, although it is the large fibre growers who have championed clonal forestry, it is the saw and veneer log grower who gains the most obvious benefit from uniformity of both piece size and heritable traits such as splitting which affect product recovery during processing. It is also a fallacy that because a clonal plantation is genetically uniform it will necessarily be phenotypically more uniform than seedlings. Data from an extensive series of Yield and Progeny Trials of *E. globulus* in Chile (Table 4)

TABLE 2 *Historical data (1996–2006) for scale of a clonal development program (courtesy of Forestal Oriental SA, Uruguay)*

Species	Trees selected	Clones in Trials		Clones w. >50% rooting	
	#	#	% of select population	#	% of select population
E. grandis	2113	1230	58	604	29
E. dunnii	3186	758	24	252	8
Hybrids (various)	891	318	36	187	21
E. benthamii	100	37	37	11	11

TABLE 3 *Major potential benefits of clonal forestry*

	Potential Benefits	Threats to Realisation
1	Increased yield of high quality wood	"Best" genotypes are not easy to define (gxe risk) – and may not propagate
2	Increased crop uniformity	Looks nice but is there real added $ value? – can be uniformly bad as well as good
3	Lower initial stocking and establishment/ harvesting costs	Significant benefits only for large scale intensive and mechanised management regimes
4	Shortest route to pest/disease resistance	Need resistance genes in **productive** clones (challenge to breeders)
5	Access to hybrid varieties	A complex breeding challenge. Propagability of poor rooting taxa still an issue
6	Access to new biotechnologies	Cost and regulatory issues. Genetic variation in response to manipulations may constrain use of most productive clones

shows that clonal plots are on average as variable in tree diameter as a good seedling plantation. In fact the best full-sib families are substantially more uniform in diameter, as determined by the within-plot Coefficient of Variations, than the average clone. Such families can be selected for operational use. The high uniformity of a good full-sib family of *E. grandis* is shown in Figure 1.

3. For large companies using highly mechanized systems, cost savings may ensue if fewer plants can be established per hectare and at harvest pieces sizes are relatively uniform. Benefits for smaller growers are less obvious.
4. If there is a serious pest or disease problem then a clonal approach certainly offers the best chance of growing a resistant stand. It was the problem of *Cryphonectria* canker which drove Aracruz to switch from pure *E. grandis* to resistant clones of the *urograndi*s hybrid (Alfenas *et al*. 1983) and the same issue arose in Zululand RSA (van Heerden *et al*. 2005). By definition a "serious" problem will affect most if not all individuals in a population, so finding clones which are both resistant and highly productive is a technical challenge which may require the development of sophisticated screening techniques as well as a really large population of candidate clones. "Living with the problem" may be a more practical solution unless economic impact is very clearly demonstrated. If seedling populations are not uniformly damaged then some self thinning of the stand may occur while overall yield remains acceptable. Again case-by-case analysis is required.

5/6 - As noted, if we need hybrids there is currently no seedling option. Application of recombinant gene technology to eucalypts is still very much in its infancy but the shortest route to commercialization will be as improvements to already proven and productive clones grown by large companies who can both bear the costs and reap the benefits of large scale production (Griffin 1996). It will probably be decades before this issue concerns any but the largest and best resourced companies.

TABLE 4 *Within-plot Coefficients of Variation (CV) for DBH from 7 progeny trials age 5 yrs and 32 yield trials age 2 to 14 yrs (courtesy Forestal Mininco, Chile)*

Plant Type Progeny Trials:	Mean	CV DBH		
		Min	Max	Range
Orchard Bulk	20.7	10.4	40.1	29.7
OP families	19.2	9.2	28.4	19.2
CP families	18.1	6.9	38.4	31.5
Yield Trials:				
OP families	26.7			
CP families	20.4			
Clones	20.2			

Requirements for a Sustainable Clonal Development Program

Clonal development is a numbers game. A rule of thumb from many companies is that, for easily cloned varieties such as *E. grandis* hybrids, around 1 in 100 phenotypically selected individuals make it through the progressive filters of coppicing/rooting/growth and wood/pulp characteristics to operational use. For difficult to root species the ratio is greater because more are lost at the rooting stage (Table 2).

Teotonio de Assis (pers. comm.) provides a good summary of the technical steps required in one cycle of a typical robust clonal development program in Brazil "produce and test from 6000 to 30000 plants in hybrid progeny tests established in different environment; select around 500 candidate clones; establish clonal trials using single tree plot and 20 replications and reduce to 200 at about half harvest age; screen wood and reduce to 50 clones; inoculate and screen for disease resistance reducing to 20 clones which are characterized for pulping and tested for rooting and plant production, resulting in 3 to 5 new pre-recommended clones which are planted in expanded clonal trials against current operational controls and, if superior are incorporated to the commercial nursery program". It takes a minimum of 10 years from production of new seeds to operational deployment of a commercial clone, perhaps somewhat less if starting with phenotypically selected plus trees.

For the long term it is pertinent to note that many crop plants have been successfully selected for clonal propagability through generations of domestication (McKey *et al*. 2010) and it may be that this will happen with our (still more or less wild) eucalypts, thus simplifying the clonal option.

SYSTEMS FOR PRODUCING IMPROVED SEED

There is a range of options available for producing improved eucalypt seed (Eldridge *et al*. 1993). In order of increasing genetic gain (and of technical inputs required) seed may be produced from Seed Production Areas (SPA); Seedling Seed Orchards (SSO) or Clonal Seed Orchards (CSO). For any of these seed production facilities it is essential that the orchards are planted in areas where good reliable seed production can be expected. This obvious point can sometimes be overlooked in the interests of planting at logistically convenient sites. Conditions which are good for wood production are not always good for flowering, for example *E. dunnii* and *E. globulus* only seed sporadically in Uruguay and southern Brazil. It is clearly convenient to have the orchards within the plantation estate, but if the conditions are not right then it is advisable to make third party arrangements at national or even international levels.

An **SPA** is simply a plantation of genetically good quality seed from a diversity of parent trees, thinned to favour open pollinated seed production from phenotypically good individuals. It is the most simple first step in producing locally improved germplasm as it is not uncommon to be harvesting commercial quantities of seed within 5 years from planting. If there is already a plantation resource then an area of good plantation can be treated immediately. If not then best available 3rd party orchard seed can be bought in. An SPA generally has a relatively short useful life and can then be harvested for wood production like any other stand.

An **SSO** will produce higher quality seed because individual family identity is retained, with thinning and seed collection on the basis of within and between family performance. The best possible seed should be obtained as a starting point. The selection intensity and hence genetic gain obtainable from the SSO is less than a CSO because the stand must be managed on a silvicultural as well as genetic basis e.g. it is necessary to retain around 150 final crop trees more or less evenly distributed across the site, whereas it may be that the best genotypes are grouped in particular areas. Seed production per hectare is also less because the trees must be allowed to grow normally, but the upside of that is they can be harvested for wood at the end of their seed producing life.

A **CSO** is made with grafted ramets of trees selected at high intensity. An open pollinated CSO needs around 20 clones at full production. It is common to plant over 50 clones and progeny test to identify the poorer seed parents which can then be culled to increase the average genetic gain. In a CSO both the female and male contributions are more highly selected than the SSO, so gain will be greater. A CSO can also be used to produce controlled pollinated (CP) seed for use in Family Forestry, and intensive crown management procedures can be applied to increase seed yield per hectare and also accessibility for harvest.

Requirements for sustainable management of an improved seed program

An improved seed program is technically less complex than the clonal option and offers more flexibility in terms of recurrent expenditure and input of technical expertise. Any level of seed demand can be made simply by planting sufficient areas of SPA or orchard. Worthwhile genetic gains can be made with an SPA with little more than normal plantation management expertise, providing that a breeder is consulted to assist with selection of a good seeding environment, choice of a good genetically diverse seedlot and prescription of a thinning regime which will favour crown retention and heavy seeding. Seed can be harvested either by climbing or by felling enough trees each year to produce the target amount of seed.

SSOs are a better option if associated with ongoing investment in breeding. Thinning can be made at both the family and individual tree level based on performance at the site and other progeny trials. Technical skills required in addition to those for SPA are the ability to design and implement a randomised planting design, to collect performance data and to conduct an analysis to identify the best trees. The planting of deployment trials (OP seed from the putative best parent trees) will increase the genetic gain delivered by the orchard over the long term.

Once genetically superior individuals are identified it is possible to propagate these by grafting or cuttings and plant a CSO. Tree crowns are usually managed to promote heavy accessible seed production. The trees are less suitable for ultimate harvest of wood than an SSO or SPA and the increased opportunity cost of the land may be an issue for some growers. The need to isolate the orchard from contaminating pollen of lower genetic quality is also an important factor in site selection. Given these costs it is important to extract all possible genetic gain from the seed. This requires commitment to deployment testing and also acquisition of a good knowledge of the flowering phenologies and seed production attributes of individual clones. For many species it is not necessary to rely on open pollination but to mass produce and test polymix or full-sib families for use in Family or Clonal Family Forestry. Such a step requires the full time attention of skilled staff with timeline pressures closely akin to a clonal development program.

FAMILY FORESTRY AND CLONAL FAMILY FORESTRY

Family forestry (FF) is the large scale deployment of the best individual tested families from CSOs in order to gain a further level of genetic gain (White *et al.* 2007). With the exception of *E. globulus* it is currently too expensive to produce large quantities of controlled pollinated eucalypt seeds so the scale of planting stock production needs to be increased by using the seedlings as mother plants for production of cuttings. The plantation in Figure 1 is an example. This vegetative multiplication with genotype identity retained at the family rather than individual clone level can conveniently be termed Clonal Family Forestry (CFF). CFF can be used with species such as *E. grandis* and *E. dunnii* for which clonal propagation is difficult, because seedlings are generally easier to root than coppice derived clones. The argument also applies to a number of other commercially important tree species. For example Lindgren (2008) has argued the case for use of families rather than clones for *Picea abies* as is common for some pine species (White *et al*. 2007) and at least one major industrial grower of *Acacia mangium* in Indonesia is using CFF with CSO seed as mother plants.

A CFF program needs to be intimately linked to an active breeding and CSO program and is unlikely to be an option in the early years of a project unless third party seed is accessed. Skills are required for controlled pollination and the nursery must be designed for vegetative propagation.

SOME CURRENT DEPLOYMENT DECISIONS FOR KEY SPECIES

For pure species both clonal and seedling deployment options are available. If resources permit it is a good idea to develop both clones and seed orchards in parallel and to plant objective yield trials to help long term decision making. Decisions are not clear cut and may change in either direction over time although not with symmetry. A seed based program can easily be used for the selection of clones but not vice versa. Consider three important species as examples. For *E. grandis*, Rockwood (2012) provides a summary of the excellent genetic gains achieved in a simple seed based multi-generational program in Florida USA from which a small number of superior clones have now been selected. In South Africa this species is now mainly propagated by seed. Having persevered with clones during the 1980/90s the growers, including the large pulp and paper companies, appear to be happy to plant tested CSO seed except where there is a major specific disease problem. A similar view is emerging with *E. globulus* where the biology particular favours the commercial scale production of controlled cross seed (Harbard *et al*. 2000). An informal survey conducted in 2011 showed that there is no clear "best" deployment decision for this species (Table 5).

In southern India the local landrace (Mysore Gum) variety of *E. tereticornis* has been planted for many years using very cheap and readily available unimproved seed (Eldridge *et al*. 1993). Clones of this and the closely related *E. camaldulensis* are more productive than Mysore Gum and now form an estimated 25% of the estate (Table 1). However studies by Varghese *et al*. (2008, 2009) suggest that improved seed of these species can perform as well as commercial clones, raising the possibility that this might be a cheaper and more robust option for farmers.

CONCLUSIONS

As demonstrated, the choice of deployment system is not clear cut and may indeed vary over time as circumstances change and progress is made with breeding programs. Large vertically integrated companies are more likely to follow the clonal route but even those would benefit from a periodic review. It is recommended that, having made the basic decision regarding use of hybrids or pure species, there is an orderly cost benefit analysis of options. Since it is always desirable to have an objective demonstration of benefits, the planting of Yield Trials is highly recommended whatever deployment system is chosen (White *et al*. 2007).

In developing countries wood is commonly produced by large numbers of small growers who do not have the resources and technical expertise to develop sophisticated breeding and

TABLE 5 *Representation of planting stock types in* E. globulus *plantations (best estimates from one or more correspondents in each country in 2011)*

Country	**Grower type**	**Estate (K ha.)**	**% Planting Stock Type***		
			OP seed	**CP seed+**	**Clones**
Australia	All	540	90	10	0
Chile	*Major industrials*	*130*	*22*	*24*	*54*
	other	330	100	0	0
Spain	*Major industrials*	*120*	*65*	*0*	*35*
	other	280	100	0	0
Portugal	*Major industrials*	*150*	*55*	*10*	*35*
	other	500	100	0	0
Uruguay	All	350	95	0	5

*some areas coppiced rather than replanted.
+Family Forestry.

deployment programs or even to carry out site matching trials with existing clones. Here the cheapest and most robust way of producing good quality planting stock may be to install SPAs or SSOs. Management prescriptions are easy to follow and production can be decentralised so that, providing that there is ongoing access to genetic advice, seed production, nurseries and plantation can all make a solid contribution to local economies.

Worldwide, the land available for expansion of eucalypt plantations is increasingly in arid, frost susceptible or saline areas. Immediate transfer of operational clones from more mesic environments is a highly risky strategy and it will be prudent to take advantage of the genetic buffering offered by seedling crops no matter how well resourced the grower organization, at least until clonal trial data is available.

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Productivity of acacia and eucalypt plantations in South-east Asia. 1. Bio-physical determinants of production: opportunities and challenges

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SUMMARY

Acacia and eucalypt plantations, managed over rotation cycles of 5–8 years, are important resources for wood production in Southeast Asia. This paper reviews the processes that determine the productivity of successive crops under tropical environments and how the local management impacts on them. Experimental results show that if plantations are managed according to recognised scientific principles, productivity can be sustained and improved and the properties of the soil can be conserved. Field visits and review have identified key risks, the critical constraints on production and the challenges for improving system management. Sustaining production will be strongly dependent on developing an integrated approach to management, bringing together the best outcomes from genetic improvement, coordinated efforts on resource protection and site and soil management which conserves and enhances the productive capacity of soils. This requires both new investments in and redirection of research and development, and stronger partnerships amongst all stakeholders committed to sustainability.

Keywords: acacia, eucalypt, plantation, production, sustainability

Productivité des plantations d'acacia et d'eucalyptus en Asie du sud-est. 1. Agents bio-physiques de production déterminants: opportunités et défis

E.K.S. NAMBIAR et C.E. HARDWOOD

Les plantations d'acacia et d'eucalyptus gérées dans des cycles rotatifs de 5 à 8 ans sont des ressources importantes pour la production de bois en Asie du sud-est. Cet article examine les processus déterminant la productivité des récoltes successives dans les environnements tropicaux, et la manière dont la gestion locale les impacte. Des résultats expérimentaux montrent que si les plantations sont gérées selon des principes scientifiques reconnus, la productivité peut être soutenue et améliorée et les propriétés du sol préservées. Des visites et des rapports effectués sur le terrain ont identifié les risques clé, les contraintes critiques sur la production et les défis auxquels une amélioration de la gestion du système doit faire face. Une production soutenue sera fortement dépendante d'un développement d'une approche intégrée de la gestion, réunissant les meilleurs résultats de l'amélioration génétique, des efforts coordonnés pour protéger la ressource et une gestion du sol conservant et encourageant sa capacité de production. Ceci requiert de nouveaux investissements et un changement de direction dans la recherche et le développement, ainsi qu'un partenariat plus étroit entre toutes les parties prenantes désireuses d'obtenir la durabilité.

Productividad de plantaciones de acacia y eucalipto en el sudeste asiático. 1. Determinantes bio-físicos de la producción: oportunidades y retos

E.K.S. NAMBIAR y C.E. HARWOOD

La plantaciones de acacia y eucalipto, cuando son gestionadas en turnos de rotación de 5 a 8 años, son recursos importantes para la producción de madera en el sudeste de Asia. Este artículo revisa los procesos que determinan la productividad de los cultivos sucesivos en ambientes tropicales y los impactos de la gestión local sobre ellos. Los resultados experimentales muestran que si las plantaciones se gestionan de acuerdo con principios científicos reconocidos, la productividad puede sostenerse y mejorarse y se pueden conservar las propiedades del suelo. Mediante visitas de campo y revisiones se han identificado los principales riesgos, los factores limitantes críticos de la producción y los desafíos para mejorar la gestión del sistema. Mantener la producción dependerá en gran medida del desarrollo de un planteamiento integral de la gestión, que reúna los mejores resultados de la mejora genética, los esfuerzos coordinados en materia de protección de los recursos y una elección del sitio y un manejo del suelo que conserve y mejore la capacidad productiva de los suelos. Esto requiere tanto de nuevas inversiones en investigación y desarrollo, como de su redireccionamiento, así como de alianzas más fuertes entre todos los actores comprometidos con la sostenibilidad.

INTRODUCTION

Areas of acacia and eucalypt plantations in tropical Southeast (SE) Asia have expanded during the last two decades and there are now at least 2.6 million ha of acacias and 4.3 million ha of eucalypts (Harwood and Nambiar 2014a). These plantations are managed in short rotation cycles typically of 5–8 years, with large areas moving into successive rotations. They are managed to supply wood for the processing industries, mostly pulp and paper production. However, use for eucalypt sawn timber, veneer and composite products (such as medium-density fibreboard) is increasing, for example in China and large volumes of acacia wood are sawn for furniture making in Vietnam. Poles for construction work and firewood are other important uses.

Apart from limited data from experimental studies, there is no consolidated account of management practices and their impacts on the productivity of short-rotation plantations in the region. It is therefore timely to review the available knowledge and management practices of short-rotation forestry as a sustainable land use for wood production. Recognising this, The Australian Centre for Agricultural Research (ACIAR) commissioned CSIRO to undertake such a review (Harwood and Nambiar 2014a), through the following interrelated activities:

- review of the relevant scientific information on the processes that determine sustainability of wood production over successive short rotations, and especially the way inter-rotation management impacts on production
- visits to plantations in the region, guided by local scientists and managers, to view management practices and explore opportunities and challenges
- collection, collation and analysis of wood inventory data from companies to examine trends in production over one or more rotations
- synthesis of this information, identifying major issues and making recommendations for management and future research.

The field work and gathering of productivity data targeted the following selected regions: China (the southern provinces of Guangxi and Guangdong), Indonesia (south and central Sumatra), Malaysia (Sabah), Thailand (central) and Vietnam. To assist readability, they are collectively referred to as SE Asia in the text; noting that not all regions in these countries were covered, and that other SE Asian countries plant acacias and eucalypts. Issues related to afforestation are not explicitly dealt with. Neither are plantations on peat ecosystems, which are largely confined to Indonesia, and face a different set of management challenges. The focus was on acacia and eucalypt plantations grown for wood production on short rotations and on issues related to successive rotations, current and future.

Sustainable production in context

Sustainability of plantation forestry can be judged by the degree of alignment among relevant variables aggregated at an appropriate level (Nambiar 1996; Nambiar and Sands 2013). In the broad sense, the variables determining sustainability include the ecological capability of a site (climate, soil, available water and nutrients), landscape and environmental values, community and social expectations and economic outcomes for investors. When alignment among the variables is strong, risks to sustainability are low, when it is weak, risks are higher. Some of these considerations are outside the scope of this study.

In the specific context of managing acacia and eucalypt plantations for sustainable wood production, the key variables which need to be integrated and examined here are the genetic potential and performance of one or more plantation species, managing threats from disease and pests, impacts of management on site resources and the management intensity required for the desired business outcomes. In this paper, these variables are analysed and their interrelationships discussed in the context of integrated management. Where appropriate, published work from countries such as Australia, Brazil and South Africa, where short rotation forestry is widely practiced, are included. In the companion paper (Harwood and Nambiar 2014b) current patterns of productivity in operational forestry in SE Asia, based on company inventories, are presented.

SPECIES SELECTION AND GENETIC IMPROVEMENT

This section provides a summary of the advances made in species selection and breeding in the region.

Choice of species

The first step towards sustainable production is to ensure that a correct species or inter-specific hybrid varieties that are well suited to the plantation environment and the intended use of wood are chosen. In plantations in SE Asia, eucalypts and acacias are exotics, originating from tropical/subtropical Australia and adjacent Papua New Guinea and eastern Indonesia. Commencing in the 1980s, extensive field testing of many candidate species was undertaken. Interestingly, out of hundreds of species tested, only three acacia and five eucalypt species, together with some hybrid combinations within both genera, now dominate the plantations of SE Asia (Table 1, compiled by the authors from discussions with government agencies, researchers and industry).

Climatic information provides an initial set of criteria for matching species with sites. The acceptable ranges of mean climatic parameters, such as annual rainfall, mean annual temperature and length of the dry season, for good plantation growth are determined from the climates of the natural range of the species, together with those of locations in which the species has grown well in trials or plantations. For example, *Eucalyptus dunnii* Maiden is suited to subtropical climates and grows well in the highlands of southern China (Jovanovic *et al.*, 2000), while *E. pellita* F. Muell. is suited to hotter, wetter tropical climates, such as low-elevation sites in Sumatra and southern Vietnam (Harwood 1998). Areas with climates

TABLE 1 *Status of acacia and eucalypt breeding in selected SE Asian countries in 2013*

Country	Species	Area of plantations (ha)	% of area clonal	Size of breeding population[1]	Generations of breeding[2]	No. of clones deployed operationally
China	*E. dunnii*	60 000	0	300	1	0
	E. grandis	60 000	80	>300	2	8
	Eucalyptus hybrids[3]	4 M	100	>700[3]	2	20
	E. globulus	120 000	0	200	1	0
Indonesia	*E. pellita*	300 000	80	225	2	20
	A. *mangium*	500 000	0	660	2	0
	A. crassicarpa	700 000	0	300	2	0
Malaysia	*A. mangium*	250 000	0	200	1–2	0
Thailand	*E. camaldulensis* & hybrids	500 000	>90	300	2	10
Vietnam	*E. urophylla*	200 000	10	140	2	6
	A. auriculiformis	90 000	1	150	2	2
	A. mangium	600 000	0	120	2	0
	Acacia hybrid	400 000	100		2	12

[1]number of unrelated open-pollinated families from above-average provenances.
[2]1 = first-generation progeny trials established, 2 = second-generation progeny trials established.
[3]combinations of *E. grandis*, *E. urophylla*, *E. camaldulensis, E. tereticornis* and *E. pellita* population size for breeding includes all parental species.

suitable for a species can be mapped using interpolation techniques (Jovanovic *et al.* 2000). Climatic extremes can cause plantation failures. For example, the tropical acacias do not tolerate frost, or prolonged exposure to cold temperatures just above freezing. Thus, 10 000 hectares of *Acacia mangium* Willd. and *A. crassicarpa* A. Cunn. ex Benth, in southern Guangxi province, China, were killed by a cold spell in the winter of 2008. While *E. urophylla* x *E. grandis* eucalypt hybrid clones were also damaged, they were more tolerant to cold and were planted to replace acacia. In some regions such as coastal southern China, the risk of typhoon damage also affects choice of species and varieties, and may reduce production (Harwood and Nambiar 2014a).

Species planted beyond their suitable climatic range may be highly prone to diseases. *Eucalyptus camaldulensis* Dehnh., which in its natural range receives from 250 to 1250 mm/yr (Doran and Turnbull 1997), was planted in the 1990s in central and southern Vietnam, where rainfall commonly exceeds 2000 mm/yr. There, it failed due to attack by leaf blight diseases such as *Cylindrocladium quinqueseptatum* Boedijn and Reitsma (Booth *et al.* 2000) and has been replaced by *A. mangium* and clonal acacia hybrid (*A. mangium* x *A. auriculiformis* A. Cunn. ex Benth.). The coastal areas of Binh Thuan and Ninh Thuan provinces in SE Vietnam, which receive 800–1400 mm/yr rainfall, are too dry for these acacia species (Harwood *et al.*, 2007), but suitable for *E. camaldulensis* to grow well, free of leaf blight (Kien *et al.* 2008).

Soil type is another criterion to consider in species-site matching. Acacia and eucalypt species planted commonly in SE Asia can grow on a range of soil types; however, there are some notable differences. For example on sandy, seasonally waterlogged soils *A. crassicarpa* grows faster than do *A. auriculiformis* and *A. mangium*, and it can grow well on peat lands. *Eucalyptus camaldulensis* has greater tolerance of seasonal water logging and soil acidity than most other eucalypt species and is planted on acid sulphate soils in the lower Mekong delta, Vietnam.

Progress in breeding

Intensive testing of species and provenances of acacia and eucalypts has confirmed the suitability and good growth of the widely planted species for their target planting ranges in SE Asia, and also identified superior natural provenances for different sub-regions. Highlights of progress follow.

Provenance selection is an important first step after species selection, as illustrated with *A. mangium* in Sumatra (Table 2). The fastest-growing natural provenance from Papua New Guinea produced 45% greater volume relative to the local Subanjeriji seed source (commonly planted in the first rotation), and 40% over the southernmost natural provenances from Tully, Queensland (E.B. Hardiyanto, pers. comm. 2013). After suitable provenances of *A. mangium* were identified (Harwood and Williams 1992), plantations were established using seed from those provenances, and they also provided the genetic base of subsequent breeding programs. There were similar gains from provenance selection for other species.

Breeding programs follow multi-trait improvement objectives that vary from species to species and among organisations. Growth rate has been an important trait in all cases, together with one or more additional traits including stem and branch form, wood properties and disease resistance. Most of these programs started with a genetic base using seed families from more than 100 unrelated parent trees from superior natural provenances. Programs for major acacia and eucalypt species have now advanced to the second generation of breeding (Table 1), and some have entered the third (Luangviriyasaeng *et al.* 2010).

In eucalypt and acacia, inbreeding (particularly selfing, the extreme of inbreeding) results in loss of vigour of the offspring, regardless of the genetic ranking of the parent tree. Rates of selfing were as high as 50% in natural populations of *E. pellita* (House and Bell 1996). Reductions in inbreeding contributed to the growth improvement obtained from the first generation of breeding (Brawner *et al.* 2010). Light or asynchronous flowering of the acacia and eucalypt species discussed here, or seed collection from isolated trees, can result in highly inbred and poorly performing seed, as was shown for *A. mangium* in Vietnam (Harwood *et al.* 2004). This points to the importance of good seed collection practices.

In addition to growth, breeding and clonal selection have improved tree form and wood quality. For example, *A. auriculiformis* clones now planted in Vietnam have improved stem straightness as well as vigour, relative to previously planted seed sources (Hai *et al.* 2008). Acacia hybrid clones that are planted in Vietnam were selected from many candidate hybrid genotypes for their superior form, disease resistance and growth (Kha 2001). Some eucalypt clones in China have been ranked for suitability for veneer production as well as pulpwood (Luo *et al.* 2013).

Evaluating productivity gains from genetic improvement

Differences in growth among genetic treatments in typical breeding trials that test many varieties using small plots are accentuated because of competitive effects, as faster-growing varieties dominate slow-growing ones (Stanger *et al.* 2011). Results from such trials cannot reliably predict the growth advantage of improved material in operational plantations. Genetic gain trials are required to compare the improved varieties with controls representing those previously deployed, using large plots to minimise competitive interactions. They need to be conducted on the major soil and terrain types, and managed as operational plantations.

Significant increases in growth were achieved by using superior provenances and first-generation improved seedlots, compared to locally available unimproved seed sources. For three genetic gain trials of *A. auriculiformis* (Hai *et al.* 2008), conical stem volume at age 4 years averaged 13 m^3 ha^{-1} for a local seed source, 19 m^3 ha^{-1} for a mix of the best natural provenances and 28 m^3 ha^{-1} from select trees in a seed orchard. These seedlots ranked in the same order at three sites in central and northern Vietnam under local management practices. Another trial in northern Vietnam compared the growth of *A. mangium* seedlots and acacia hybrid. Clones of acacia hybrid grew faster than all *A. mangium* seed sources. At age 8 years an *A. mangium* seedlot from selected trees in a seed orchard grew fastest, followed by a seed mix of superior natural provenances and a local commercial seed source. Stem volume of acacia hybrid was 138 m^3 ha^{-1}, 89% greater than 73 m^3 ha^{-1} for the commercial *A. mangium* source (N.D. Kien, pers. comm. 2013). These results demonstrate the potential for improving growth through the use of genetically improved planting stock (Table 2).

Genetic parameter estimates from progeny trials of *E. pellita* (Leksono *et al.* 2008; Brawner *et al.* 2010), *A. auriculiformis* (Luangviriyasaeng and Pinyopusarerk 2003; Hai *et al.* 2008) and *A. mangium* (Arnold and Cuevas 2003; Nirsatmanto *et al.* 2004) suggest that for these species the second generation of breeding will give no more than 5–10% in volume gain over the first-generation improved material. This is not unexpected, because provenance selection and reduced levels of inbreeding contributed to the large improvements in growth achieved in the first generation.

TABLE 2 *Stem volumes over bark for different genetic treatments in trials comparing improved and unimproved genetic stock of acacias*

Region and country	Species	Genetic treatments[1]	Assessment age (yr)	Wood volume (m^3/ha)
South Sumatra, Indonesia[1]	*A. mangium*	Local seed source	5.5	172
		Best natural provenance		250
Central and northern Vietnam[2]	*A. auriculiformis*	Local seed source	4	13
		Best natural provenance		19
		Best seed orchard seed		28
Northern Vietnam[3]	*A. mangium*	Commercial seed source	8	73
	A. mangium	Best natural provenance		106
	A. mangium	Seed orchard		124
	Acacia hybrid	Mix of hybrid clones		138

[1]E.B. Hardiyanto, pers. comm. (2013). Volume over bark estimated from height, diameter and form factor.
[2]Hai *et al.* (2008a). Mean of three trials in central and northern Vietnam. Conical tree volumes, calculated from height and dbh.
[3]N.D. Kien, pers. comm. (2012). One trial in northernVietnam. Volume over bark estimated from height, diameter and form factor.

Clonal versus seed-based deployment

Clonal forestry enables multiplication and planting of selected genotypes to capture both non-additive and additive genetic gain, whereas use of open-pollinated seed from seed orchards deliver only additive gain (White *et al.* 2007). It has the potential to grow stands with uniform tree size, stem form and wood properties. However, overall plantation uniformity depends on site conditions and management as illustrated by the high spatial variability in growth rates found in clonal plantations of eucalypts and acacia (Harwood and Nambiar 2014b).

Over half of the total plantation area reviewed in this study is clonal (Table 1). The current genetic diversity of clonal plantations of both acacias and eucalypts in SE Asia is low; some growers plant only two or three clones across the entire estate, increasing the risk of severe loss of production to disease or pest attacks.

Pure-species clones of *A. auriculiformis* (Hai *et al.* 2008), *E. camaldulensis* (Kien *et al.* 2008), *E. pellita* (Brawner *et al.* 2010) and *E. urophylla* S.T. Blake (Kha *et al.* 2003) have been developed. However, where the environment is well suited to a pure species, breeding programs can provide improved seeds several years before they can deliver thoroughly tested clones. Seeds from seed orchards displayed similar growth rates to selected clones in *A. auriculiformis* trials in Vietnam (Hai *et al.* 2008). In South Africa, growers of *E. grandis* are reverting from clones to improved seed as they provide seedlings with good growth potential at lower cost (Griffin 2014). Some species that are widely planted, including *A. crassicarpa*, *A. mangium* and *E. dunnii*, are not amenable to clonal forestry. So deployment of seed-based planting material will continue in SE Asia. Limited quantities of seed from selected families can be multiplied by clonal propagation of seedlings (without subsequent testing of individual clones). This strategy is now used to mass-propagate selected *A. crassicarpa* and *A. mangium* families for large-scale planting in Sumatra, Indonesia (Wong Chin Yong, pers. comm. 2013).

Inter-specific hybrids

Inter-specific hybrids can combine complementary traits of the parents. An example is the *E. grandis* x *urophylla* hybrid which combines the disease resistance and higher wood density of *E. urophylla* and the higher growth potential of *E. grandis* Hill ex Maiden (Assis 2000). Inter-specific hybrids dominate the eucalypt plantations of China and are important in Thailand, while acacia hybrids are important in Vietnam (Table 1). Hybrids must be planted as clones, not as seeds.

In northern Vietnam, hybrid combinations among *E. camaldulensis*, *E. exserta* F. Muell. and *E. urophylla* grew faster than pure-species crosses involving the same parent trees (Kha *et al.* 2003). In each of six clone trials in southern China, clones of pure species had markedly inferior growth compared to the fastest-growing inter-specific hybrid clones including the same taxa (R. Arnold, pers. comm., 2013). In a trial at Ba Vi, northern Vietnam, at age 4 years, mean annual height increment was 2.9 m for acacia hybrid clones, compared with 2.2 m for *A. mangium* seedlings and 1.5 m for *A. auriculiformis* seedlings (Kha *et al.* 2012). Acacia hybrid grew faster than the parent species in several other trials in Vietnam (Kha 2001). However, in one trial in southern Vietnam, genetically improved seedlots of *A. mangium* grew at rates similar to acacia hybrid clones (Kha *et al.* 2012).

IMPACT OF DISEASES AND PESTS

Some of the diseases and pests of acacia and eucalypts have co-evolved with them in the natural range and move to new areas with the host trees, while some are encountered for the first time in the new environment. Reviews (Dell *et al.* 2008; Wingfield *et al.* 2008; Wingfield *et al.* 2011; Garnas *et al.* 2012) suggest that pests and diseases pose serious and increasing threats to plantation forests globally as the areas under plantations are increasing. The reasons suggested include:

- Increasing global trade and travel leading to the spread of pests and diseases despite quarantine regulations.
- Plantations are based on a relatively narrow genetic base, and clonal forestry is becoming a norm. The same genetic material may be planted in adjacent countries.
- Species planted to a new environment are exposed to new pests and diseases. For example, guava rust, also known as eucalypt rust (*Puccinia psidii* Winter), is a disease native to Latin America, which has severely affected eucalypt plantations in Brazil and neighbouring countries (Alfenas *et al.* 2004) and has appeared in Australia (Kriticos *et al.* 2013). Similarly, stem wilt/canker disease, caused by the fungi *Ceratocystis acaciivora* sp.nov., has spread and is a serious threat to acacia plantations in Sumatra (Wingfield *et al.* 2011) and Sabah, and has now been identified in Vietnam (Dr Pham Quang Thu, pers. comm., 2013).

As the area of plantations expanded in SE Asia, the potential spread and impacts of diseases and pests were recognised and manuals of damage symptoms caused by them have been published (Old *et al.* 2000; Old *et al.* 2003; Thu *et al.* 2010). Diseases and pests have different modes of action on plants and pathways for spreading. Most insect pests typically consume part of the tree, especially the foliage, whereas a disease affects the physiological functioning of the tree and may kill it. Of course, the two do interact; for example, insect pests may carry disease spores from one tree to another, spreading the disease (Ploetz *et al.* 2013).

Diseases

Fungal root rots, predominantly *Ganoderma* species (Eyles *et al.* 2008) and stem wilt/canker caused by *Ceratocystis* (Tarigan *et al.* 2011) are now causing major loss in production of *A. mangium* plantations in Sumatra and Sabah. Root rot kills trees in patches and sometimes in large areas. Surveys in second-rotation *A. mangium* plantations in Sumatra found that from 3 to 29% of trees showed symptoms of root rot (Irianto *et al.* 2006). In a subsequent survey of 109 compartments in different regions in Indonesia, the percentage of trees with root rot symptoms increased from 5% in the first rotation to 15% and 35% in the second and third rotation, respectively (Mohammed *et al.* 2012). These data was collected in young stands and, since mortality increases with stand age, losses would be higher by the end of the rotation. Thus mortality due to root rot tends to increase in successive rotations. Because of the impact on productivity, *A. mangium* is being progressively replaced by eucalypts in Sumatra. A similar change has commenced in Sabah.

Heart rot diseases are a threat particularly to acacia sawlog and veneer log production (Potter *et al.* 2006) because the recovery and quality of sawn boards or veneer is reduced if the log is decayed. The percentage of logs with some heart rot at harvest ranged from 7% to 47% in five regions of Indonesia (Barry *et al.* 2004). However, the impact on pulpwood production may be less, because most of the affected trees only had discolouration or incipient decay; less than 10% of the trees had advanced decay or hollows (Barry *et al.* 2004)). Whether heart rot reduces growth rates of trees is not clear.

In Vietnam, pink disease caused by the fungus *Erythricium salmonicolor* (Berk. & Br.) Burds. occasionally infests *A. mangium* and acacia hybrid, killing up to 70% of trees. Infected stands are salvage-logged and the site is replanted to acacia. This is an intermittent threat (Thu *et al.* 2010), and does not appear to have substantial impacts on productivity.

Fungal diseases that affect the leaves and branches of eucalypts have caused serious damage in some countries. In Thailand, thousands of hectares of clonal plantations were killed by an epidemic of *Cryptosporiopsis eucalypti* Sankaran & B. Sutton leaf blight fungus in one year (Luangviriyasaeg 2003). In central and southern Vietnam, large areas of *E. camaldulensis* plantations were lost to attack by leaf blight diseases, notably *Cylindrocladium quinqueseptatum* (Booth *et al.* 2000). Another leaf blight, *Kirramyces destructans* M.J. Wingf. &Crous, has severely reduced productivity in Vietnam and Thailand (Dell *et al.* 2008). A *Botryosphaera* canker which attacks stems and twigs seriously reduced growth of a widely planted eucalypt clone in Sumatra (observations by authors). Other diseases, such as the bacterial wilt *Ralstonia solanacearum* (Yabuuchi *et al*. 1995) Smith appear sporadically and cause mortality in eucalypt plantations in China (Dell *et al.* 2008), but so far this has not become a major problem.

Insects

An insect of Australian origin, the eucalypt gall wasp *Leptocybe invasa* Fisher &LaSalle, was first observed attacking eucalypts in the Mediterranean Basin in 2000, and it spread from there to Asia in less than a decade. Gall wasp infests the growing shoots and leaves, stunting new growth and preventing leaf expansion (Mendel *et al.* 2004). Severe attack will greatly reduce the canopy and wood production. It has severely damaged plantations in many countries (Dittrich-Schroder *et al.* 2012), including Laos, Vietnam, southern China and Thailand (Dell *et al.* 2008), where the parasitoids that keep it under control in Australia are not present (Mendel *et al.* 2004). Different eucalypt clones planted in Thailand vary in their susceptibility to gall wasp (Vitoon Luangviriyasaeng, pers. comm., 2012). This is consistent with the variation among species and clones found in experiments (Dittrich-Schroder *et al.* 2012). A range of other pests are found in most acacia and eucalypt plantations in SE Asia (Thu *et al.* 2010). However, other than gall wasp, most do not currently inflict major damage.

Mammals

Monkeys have become a significant pest of *A. mangium* plantations in parts of Sumatra. Their populations have increased in their habitat, the protected native vegetation areas within or adjacent to the plantations. They ring-bark the young acacia trees to feed on the sweet-tasting cambium and outer wood. This can kill trees outright, as well as creating wounds which form entry points for *Ceratocystis*. Elephants also damage acacia plantations in parts of Riau, Sumatra.

WOOD PRODUCTION OVER SUCCESSIVE ROTATIONS: IMPACTS OF MANAGEMENT

In plantations in temperate environments managed on rotations spanning 25–40 years, stands are thinned to harvest logs two or more times, and then clear felled. Thinning is a mild disturbance to site and stand. Thus, these plantations are subjected to major disturbance only once every 25–40 years. In contrast, acacia and eucalypts plantations in SE Asia are currently clear cut every 5–8 years, a major perturbation event, and often intensively managed, exposing the sites to more frequent risks. Even when forests are managed on rotation cycles in decades, management of the inter-rotation phase is critical for sustainability (Nambiar 1996; O'Hehir and Nambiar 2010; Brandtberg and Olsson 2012; Ponder *et al.* 2012; Wall 2012). In short rotations the options for interventions beyond the establishment phase are very limited. Thus, the management decisions implemented during the inter-rotation phase are critical for subsequent production.

A synthesis of the processes governing sustainable wood production in plantation forests in subtropical and tropical environments and the impacts of management on them (Nambiar and Brown 1997) provides the key principles of management. Selection and deployment of the most suitable genetically improved planting material and its protection from biological threats are essential and these aspects have been reviewed above. Other key interrelated principles for sustainable management follow:

- plantation management operations should ensure that the soil base is protected and disruptions to ecological processes (carbon, nutrients and water cycles) are held

within known boundaries of resilience to support long-term productivity, avoiding extreme soil perturbations and conserving site organic matter pools
- due accounting and management of nutrient inputs and exports can inform practices that will enable adequate nutrient-cycling processes within the ecosystem
- the period of inter-rotation management is a window of high risk to the site but also a time of opportunity to correct past mistakes and set the course for sustainable production,

The following sections discuss how the different harvesting and subsequent management practices employed in various regions of SE Asia measure up to those principles and impact on key processes that drive plantation growth.

Harvesting operations

Methods of harvesting and hauling logs to the log dump or road may be fully mechanical, a combination of mechanical and manual, or simply manual. All these systems are practised in different regions of SE Asia (Harwood and Nambiar 2014a). Their impacts may be directly related to the logging technology and practices, the nature of the terrain, the intensity of biomass removal, and the level of disturbance and damage imposed on soil.

Harvesting practices can influence plantation productivity through soil compaction and loss and displacement of surface organic matter and the nutrients it contains and damage to soil (Powers 2006). However, multi-site studies across the USA and Canada have not found a consistent effect of compaction *per se* on biomass growth at age 10 years among the common species planted (Powers *et al.* 2005; Ponder *et al.* 2012). Harvesting would not compact soil throughout the area; compaction occurs along machine paths and snig tracks. Studies in South Africa have found that the effects of compaction on the growth of eucalypts depend strongly on soils: growth reduction in compacted areas compared with non-compacted area ranging from 2% to 25% depending on soil types. Impacts of deployment of forwarders, loggers, tractors and extraction/snig tracks varied depending on terrain and soils (du Toit *et al.* 2010). In general, effects of machinery-induced compaction on soil bulk density, strength, porosity, and water-holding capacity have been more demonstrable than effects on long-term stand growth (Ilstedt *et al.* 2004).

Mechanical harvesting of short-rotation plantations in terrain that is flat or moderately steep can be done with little damage to sites, if slash and litter are retained, operations minimise machine movements across the site and machines traffic over the logging slash. These practices are in operation in *A. mangium* plantations in Indonesia (Harwood and Nambiar 2014a) where they facilitate subsequent site management for planting.

Biomass displacement and removal

The current post-harvest practices for managing biomass in SE Asia lead to a wide range of impacts (Harwood and Nambiar 2014a). In Indonesia, companies harvesting *A. mangium* remove only merchantable stem wood, in some cases after debarking at the site, and retain other biomass *in situ*. At the other extreme, in some regions of China, Thailand and Vietnam all above ground biomass from eucalypt plantations is removed, and in some operations stumps are uprooted and removed as well, for local use as firewood or for bio-energy. Slash burning is not practiced in Indonesia but it is common elsewhere. Biomass export out of the site depends on the harvesting intensity. If slash biomass and litter are burned or displaced (e.g. by windrowing), nutrient losses are unavoidable and nutrient cycles are disrupted. The shorter the rotation, the greater will be the frequency and intensity of export and the degree of perturbation (Folster and Khanna 1997; Mackensen and Folster 1999). The general impacts of such practices are discussed below. In order to follow the fate of above-ground biomass and the nutrients in them during the post-harvest operations, an illustrative summary from a range of sites is given in Table 3.

The amounts of biomass accumulated during stand growth vary according to species, site and rotation length. Management decisions about whether to harvest wood alone or whole trees, and how they are harvested, will impact on nutrient pools. Data in Table 3 show the distribution of biomass and nutrients in stands near harvest age, which allows estimation of export in relation to the intensity of harvest. The amount of wood as a proportion of the total above-ground biomass ranged from 66% to 89% but contained much lower proportions of the nutrients. In contrast, bark mass was 10% or less of above-ground biomass (except for *E. tereticornis* where it was 28%), but contained much higher proportions of all nutrients. For example, in *E. globulus* bark accounted for only 10% of the mass but contained 50% of the calcium (Ca), and in two acacia plantations bark accounted for 7% of the mass but 36–39% of the Ca (Table 3).

Whole trees harvest removes the entire live biomass from a site. In other cases slash may be piled at the landing where it may be left, burned, sold off or redistributed back to the plantation. The increases in nutrient removal from whole-tree harvest are two-to-four-fold higher than harvesting wood alone, depending on species, site and nutrient (Table 3). In order to manage the impact of these operations, managers should recognise the amounts of nutrients exported from sites in relation to expected growth rates in the next rotation and the capacity of the soil-species combination in question to cope with such levels of depletion. The progressive increase in the amounts of nitrogen (N) phosphorus (P) and Ca (as examples) removed from sites as a consequence of four intensities of biomass removal from stands of *A. mangium* in Sumatra and *E. grandis* in Brazil is illustrated in Figure 1.

Note that the nutrient axes have different scales for the species and nutrients. The patterns of export are similar in both cases but the net amounts and biomass components in which they are accumulated are different. Amounts of N removed from the acacia are far higher than those from the eucalypt. The amounts of P removed for the eucalypt at the Brazilian site are notably higher than those for the acacia in Indonesia. As the amounts and kind of biomass removed

TABLE 3 *Nutrient contents and distribution in selected acacia and eucalypt short-rotation plantations of near-harvest age*

		A. auriculiformis[1]	*A. mangium*[2]	*E. globulus*[2]	*E. grandis*[3]	*E. tereticornis*[4]
		Vietnam	**Indonesia**	**Australia**	**S. Africa**	**India**
Stand age (yr)		6	6	13	7	7
	Bark	8.0	14.2	26.9	12.8	17.9
AGB (t ha^{-1})	Stem	76.6	124.7	186.9	107.4	46.8
	AGB	107.5	189.5	256.9	133.8	64.8
	Bark	116.5	139.0	51.1	42.6	32.5
N (kg ha^{-1})	Stem	136.5	236.0	114.0	77.3	74.6
	AGB	475.2	661.0	465.8	249.2	178.6
	Bark	8.1	1.5	3.4	6.3	11.0
P (kg ha^{-1})	Stem	47.7	7.8	49.0	4.1	20.7
	AGB	76.8	14.3	68.7	17.8	42.4
	Bark	38.7	35.6	50.6	52.9	70.7
K (kg ha^{-1})	Stem	116.4	37.4	104.7	81.6	90.3
	AGB	231.5	191.2	309.5	189.0	229.9
	Bark	24.4	163.7	582.9	101.0	170.8
Ca (kg ha^{-1})	Stem	15.9	103.5	214.9	80.8	91.2
	AGB	67.1	415.8	1167.5	248.1	409.1

Source: [1]Vu Dinh Huong, pers. comm.; [2]Yamada *et al.* (2004); [3]du Toit *et al.* 2004; [4]Sankaran (1999).

increased from merchantable wood only (with debarking at the stump) to whole trees, or the extreme case of complete above-ground biomass including litter, export of N, P and Ca progressively increased (Figure 1) so also for potassium (Nambiar and Kallio 2008) and magnesium (E B Hardiyanto and E K S Nambiar, unpublished). This pattern of nutrient depletion in relation to the harvesting regimes has been demonstrated in other cases, for example, *A. mangium* in Sumatra (Siregar *et al.* 2008, S. Siregar pers. comm. 2012) and *E. urophylla* in China (Xu and Dell 2003). If harvest also included removal of stumps, as is done in some regions, further loss from the site would follow, but there are no estimates of this additional loss for any plantations in SE Asia. Debarking at stump (which is sometimes practised, manually or mechanically) enabling retention and distribution of bark would improve the supply of nutrients (Figure 1 and Table 3).

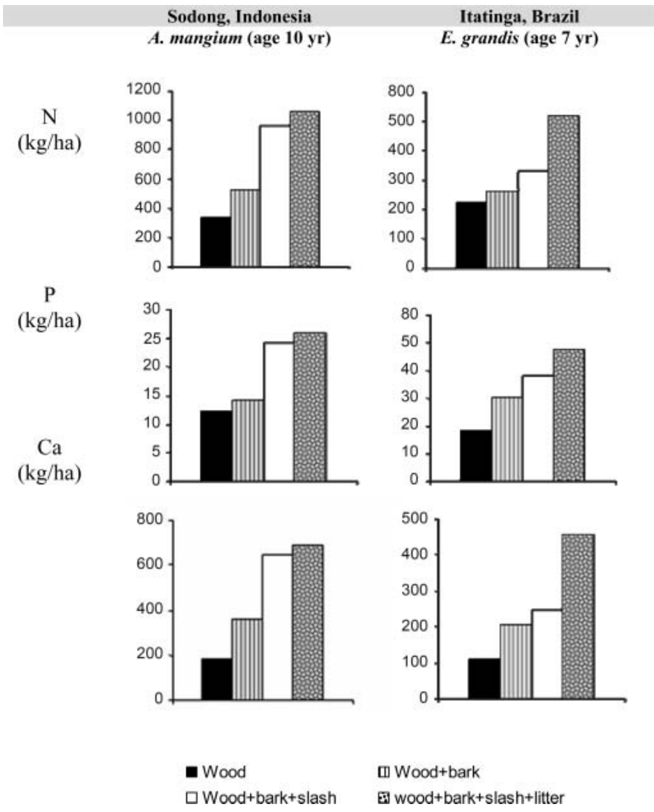
Site management for the next rotation

Export of biomass and nutrients in merchantable stem wood is inevitable in commercial forestry, but on its own it rarely leads to site degradation. The critical factor is the manager's decision on above-ground biomass utilisation or management and how the site will be prepared for replanting. In regions other than in Sumatra, even when harvesting is largely manual, inter-rotation management often start with practices which include removal of all biomass (including stumps), or burning slash. In some cases, slash and litter are removed by bulldozer to create a clean planting surface (Harwood and Nambiar 2014a), although litter has irreplaceable roles in the healthy functioning of ecosystem processes (O'Connell and Sankaran 1997). These practices do not occur universally in SE Asia, but are widespread enough to warrant discussion and attention in the future.

In subtropical plantations in South Africa, practices such as ripping and sub-soiling gave erratic results – effectiveness, if any, being dependent on soil type, soil water availability and design of the cultivation implements. In some of the terrains in SE Asia (e.g. parts of China, Vietnam and Laos) such operations carried out up and down the slope (rather than along the contour) may do more harm than good. Tree growth in some soils of high bulk density can benefit from ripping, which assists root growth, if carried out with due consideration of the terrain, soil type and the operating season (Gonçalves *et al.* 2013).

Burning slash and litter after harvest, depending on the fuel load, its moisture content and the wind speed, can lead to near complete loss of N in smoke and volatilisation, and partial loss of nutrients including P, Ca and K as particulates. Post-fire ash remaining on the soil surface can be blown away by wind or be washed away with the onset of rains, especially from exposed slopes, as illustrated in Harwood and Nambiar (2014a). Site-specific estimates of potential losses in relation to harvesting intensity can be made from data of the type described in Table 3 to assist management decisions. As an example, in eucalypt plantations, the amounts of N in the slash and litter vulnerable to loss if sites are windrowed or

FIGURE 1 *Nutrient export in biomass harvest: two case studies from Sumatra and Brazil (source: Nambiar and Kallio 2008)*



heaped and burned may be between 125 and 500 kg ha^{-1}, depending on the biomass and the productive capacity of soils (Fig 1, Nambiar and Kallio 2008). These N losses could be more limiting to production for eucalypts which, unlike acacias, do not fix N symbiotically. Loss of slash and litter will aggravate not only the deficiency of N but also those of P and Ca in some soils. Burning slash and litter may sometimes improve tree growth (compared to their total removal) in the short term (Gonçalves *et al.* 2008; du Toit *et al.* 2008) because of the ash effect (ash has high concentrations of P and base cations Ca, K and Mg) and higher rates of mineralisation. However, repeated burning would degrade sites in the long term (Gonçalves *et al.* 2007; Gonçalves *et al.* 2008; du Toit *et al.* 2008; Laclau *et al.* 2010; O'Hehir and Nambiar 2010).

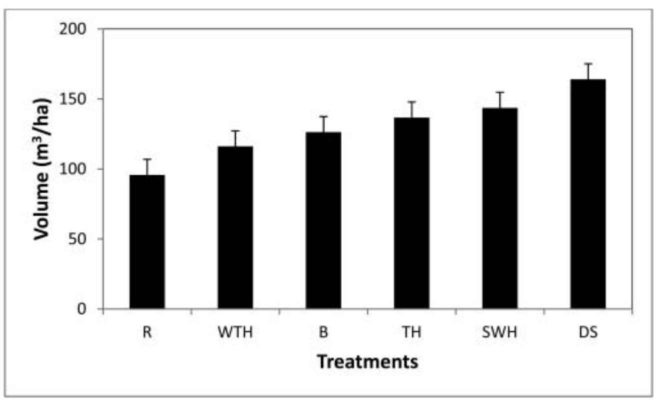
In plantation soils, the surface 0–5 cm soil horizon has the highest concentration of soil organic carbon and nutrients (see Gonçalves *et al.* 2008; Smith *et al.* 2008 for examples). It was observed during the field visits that when the heavy blade mounted on a bulldozer pushes forward the slash, it gathers most of the litter and scalps the soil surface. Displacement of even a thin layer of surface soil would have adverse effects on productive capacity of the soil in the long term. Uprooting of stumps is bound to aggravate the problem. If these operations are conducted when the soil is dry, large amounts of fine soil particles (≤ I mm fraction) are unearthed, lifted and blown away by wind. If biomass harvest is done in wet weather, soil compaction and erosion are common outcomes. These are damaging practices in tropical plantations (Sim and Nykvist 1991; Panitz and Adzmi 1992; Mackensen *et al.* 1996; Folster and Khanna 1997; Ilstedt *et al.* 2004), and pose risks in other ecosystems (Wall 2012; Persson 2013).

Clear cutting and site preparation practices increase mineralisation in soils. When rates of mineralisation are higher than uptake by trees (and associated vegetation at the site), nutrients can be leached if there is water movement. Most of SE Asia receives torrential rains in the wet season. The risk of leaching is moderate to high from harvest and during site preparation and initial growth after planting, but very low or nil once trees reach the sapling stage or close canopy. Risk will be less if the understorey is not completely eliminated, as both growing trees and understorey retained at low density serve as nutrient sinks. If the terrain is steep and exposed to run-off after rains, nutrients and soil may be transported off site with water flow. Removal of slash and litter and inappropriate site cultivation leading to soil and nutrient runoff have been identified as a reason for the site decline in eucalypt plantations in southern China (Xu *et al.* 2000).

A clear example of the importance of proper management of site organic matter after harvest to the productivity of the next crop of eucalypt hybrids is seen in a study in Congo (Figure 2). Treatments in Figure 2 which resulted in progressive increase from the lowest to the highest volume in a second-rotation stand were: all above-ground biomass including litter removed (R); whole-tree harvest (WTH); wood and bark harvested, slash and litter burned (B); only merchantable wood and bark harvested (TH); wood alone removed, debarked at stump (SWH); slash removed from WTH transported and added on top of the *in situ* slash = double slash (DS) (Laclau *et al.* 2010).

When all the slash and litter were removed, stem volume growth declined by 44% in comparison with retention of all but wood on site. Growth increased progressively as the amount of organic matter (and nutrients) retained increased with different management practices. Plots in which the slash

FIGURE 2 *Impacts of sequential removal and changes to above-ground biomass after harvest of the first rotation on the growth of the next stand of eucalypt hybrids at the end of the rotation in Congo. Revised from Laclau et al., (2010); Jean-Paul Laclau (pers. comm.) Error bars show standard error of difference of treatment means*



and litter were burned grew more wood compared to those in which they were removed, partly because of the nutrients supplied from the ash, but the wood growth was significantly lower than that obtained by retaining the slash. Whole-tree harvesting substantially reduced growth of the subsequent rotation, compared to the best yield at this site, as was also observed for acacia plantations in Sumatra (Hardiyanto and Nambiar 2014).

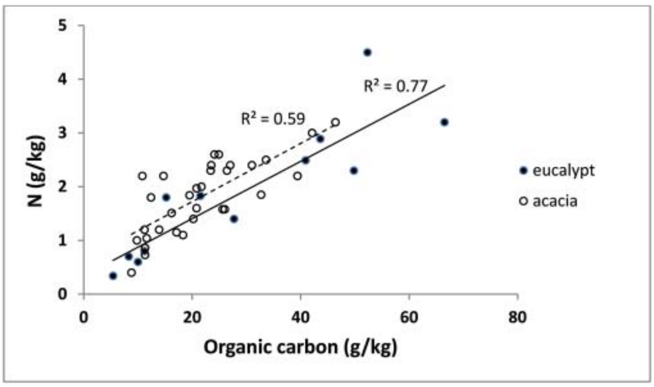
The results from an international network project including 16 sites in the sub tropics and tropics (Nambiar 2008) found that at a majority of sites there was a reduction in growth rates, in some cases severe, if whole-tree harvesting was practised, even when the litter layer was retained. Conversely, conservation of site resources after wood harvest of the first rotation mostly improved production of the second-rotation eucalypts, acacia, pine and Chinese fir (Nambiar and Kallio 2008). These results have been further confirmed by several experiments in diverse environments and with a range of species (e.g Nambiar and Kallio 2008; Tiarks and Ranger 2008; Tutua *et al.* 2008; Hardiyanto and Nambiar 2014) and recent reviews (Gonçalves *et al.* 2013; Titshall *et al.* 2013).

Litter and slash are major sources of nutrients in tropical plantations (Nambiar 2008; Gonçalves *et al.* 2013; Titshall *et al.* 2013). Their conservation is critical for eucalypts (which unlike acacia species, do not fix atmospheric N because soil organic carbon (SOC) is the primary repository of soil N. Figure 3 shows a strong linear positive correlation between SOC and N in both acacia and eucalypt plantations. There were significant positive correlations between surface SOC and N (R^2=0.89), effective cation exchange capacity (eCEC) (R^2=0.97), exchangeable bases K (R^2=0.81), Ca (R^2=0.50) and Mg (R^2=0.91) in second-rotation subtropical pine plantations (Smith *et al.* 2008). Furthermore, soil organic matter has a strong influence on key biological, chemical and physical properties including soil strength, porosity and soil water holding capacity.

The benefit of organic matter retention on growth is more than what can be gained by fertiliser application even at sites where SOC concentration levels are relatively modest to high. For example, at an *A. mangium* site removal of above-ground biomass reduced volume production by 18–20%, compared to retention, but application of P, Ca or K gave no significant growth response to the same stands (Hardiyanto and Wicaksono 2008; Hardiyanto and Nambiar 2014). Similar results have been found with *A. auriculiformis* in south Vietnam (Huong *et al.* 2008). These results suggests that slash and litter retention conferred benefits beyond what can be attributed to improved nutrient supply although the exact mechanism is not yet clear.

Site deterioration induced by total biomass removal cannot be compensated simply by adding fertiliser. There are critical questions of efficiency of uptake of nutrients by young trees and losses from the soil which are not understood for the environments in SE Asia. It is not practical to add high rates of fertilisers within a short rotation period without risking off-site impacts, nor is it likely to be feasible or economically sensible under the prevailing conditions of management (Harwood and Nambiar 2014a). Judicious use of fertilisers has a role in sustainable wood production. Many companies are applying fertilizers (Harwood and Nambiar 2014a) but the response to fertilizers in the second and subsequent rotations are uneven (unpublished reports and discussions during field visits 2012–13), partly because of the lack of site specific approaches to fertilizer trials and inadequate understanding of the constraints to production including the availability of soil water. Acacias in Sumatra and Vietnam respond to application of a small dose of P at planting, but a significant volume increase seldom persists to the end of rotation and there has been little or no response to Ca and K in the second rotation (Huong *et al.* 2008; Hardiyanto and Nambiar 2014). Management of nutrition in the future rotations of eucalypts requires well-designed experimental work.

FIGURE 3 *Relationship between organic carbon and nitrogen in the surface soils in subtropical and tropical short second-rotation plantation sites. Compiled from various sources including Nambiar (2008); and personal communications*



Repeated ploughing to control vegetation: effectiveness and impacts on trees and soil

Field visits and discussions with managers (Harwood and Nambiar 2014a) identified an important issue: the practice of repeated soil cultivation throughout the rotation and its potential impacts on the ecosystem. In Indonesia, companies who have adopted minimum-tillage practices do not plough plantations. However, elsewhere repeated ploughing to control weeds and to reduce the vegetative fuel load for fire control is common; it is a near-universal practice in block plantations in central Thailand and common in parts of China and Vietnam where the terrain permits. At the current frequency of ploughing (e.g. in Thailand), during the growing of a planted eucalypt crop and the following coppice harvest, together spanning 8–10 years, many sites had inter-rows ploughed up to 20–30 times. At some sites in Thailand and in Vietnam, soil was ploughed when wet, leading to slicing and turning of the clayey soil. These slices turned into hard clods with smooth glazed surfaces when they were exposed and dried. Displaced soils were turned over, creating mounds along the tree rows and 1.0–1.5 m wide depressions, up to 20 cm in depth, between the rows. These became pathways for surface water flow and soil erosion or were prone to waterlogging, depending on topography and soil type. For an illustrated account, see Harwood and Nambiar (2014a).

Is ploughing an effective weed-control practice to improve tree growth and reduce fuel loads?

Ploughing reduces weed growth at best only on about 50–60% of the planted area, because in order to avoid damage to trees the implements cannot approach close to the tree rows. The 1.0–1.5 m wide strips centred on the tree rows remain unweeded. For effective weed control, the spatial location of the weedy and weed-free areas should be the opposite of what is achieved. What is required is an appropriately wide weed-free strip centred along the tree rows, and some vegetation remaining in the inter-rows to minimise soil exposure and erosion.

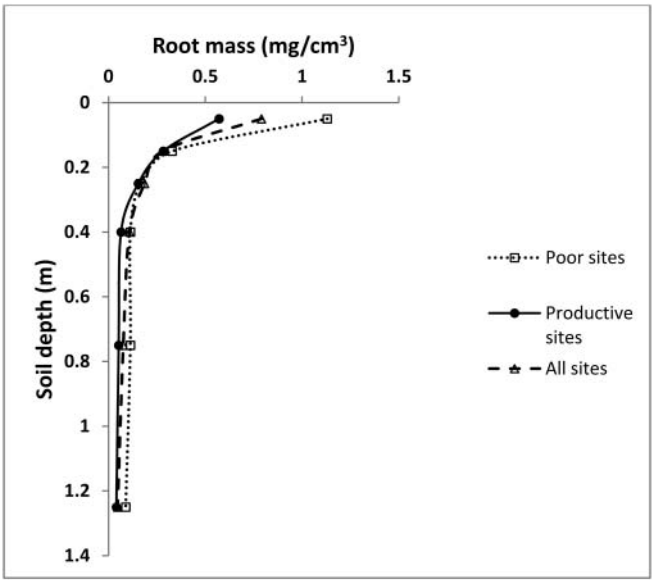
However, in the absence of any objective appraisal of the biophysical and social aspects of fire risks, repeated ploughing of the entire plantation area continues as the only weed management and fire reduction strategy in many SE Asian landscapes.

Impacts of repeated soil cultivation on root systems

If root growth is not restricted by soil penetration strength, tree root systems in fast-growing plantations will occupy the area between and within tree rows by age one year. This review found no information on root systems in plantations in SE Asia. So a typical distribution of fine roots in soil profiles under *E. grandis* plantations in Sao Paulo state, Brazil is shown in Figure 4. This study included 16 sites where Site Index (SI measured as mean dominant height) ranged from 22 to 32 m at age 6 years. The three lines in Figure 4 represent the root distribution as means of all 16 sites, the three with the highest SI, and the three with the lowest SI. Root concentrations in the soil both in the surface layer and at depth increased as the SI decreased; that is, the lower the productivity of the stand, the larger the amounts of fine roots produced (Gonçalves and de Miranda Mello 2000). In all cases, amounts of fine roots were highest in the top soil layers and decreased exponentially with depth (Figure 4). Despite the two-fold difference in the amounts of roots between site types at 0–10 cm soil, all values decreased substantially below 20 cm depth. This pattern of distribution characterised by the highest root density in the top soil and a near exponential decrease with depth has also been found in plantations of *Pinus radiata* D. Don (Nambiar 1990) and eucalypt species grown in a wide range of soils and environments (Bouillet *et al.* 2002; Falkiner *et al.* 2006; Grant *et al.* 2012).

Where repeated ploughing may have induced the formation of an indurated soil layer below about 25 cm the soil surface (Harwood and Nambiar 2014a), it may impede root growth. Subsoil compaction can affect stand growth, through the reduction in root extension to deeper levels from where young plantations take up water during dry months, as was shown for *P. radiata* plantations in South Australia (Nambiar and Sands 1992). Because the fine roots are predominantly in

FIGURE 4 *Distribution of fine roots in E. grandis plantations at age 6 years in Brazil (from Gonçalves and Mello 2000)*



the top soil, regardless of soil type and age of the stands, repeated ploughings will continually mutilate and cut back most of the fine root network in the inter-rows. The effects of this on tree growth may be severe during the dry season, which is a feature of the climates of SE Asia. Potential impacts on coppicing and survival are not known. Furthermore each time roots are cut, trees will have to invest more assimilate for new root growth and this can be at the expense of growth above ground. Repeated ploughing largely eliminates the development of the litter layer, which is important for a number of ecosystem processes.

What are the likely effects of repeated ploughing on soil organic carbon?

There is no experimental work which has examined the impacts of repeated ploughing on soil properties in forestry in SE Asia. Neither is there any information from countries such as Brazil because there zero tillage practices have been the norm for well over a decade. However, there is information from agriculture about the impacts of cultivation and on soil carbon and other soil properties.

What can we learn from crop agronomy? When a forest in Sao Paulo, Brazil was cleared, converted to sugarcane and cultivated regularly, the SOC decreased from 43.4 g/kg to 13.2 g/kg in 22 years and 16.1 g/kg in 60 years, with corresponding declines in labile carbon; reductions in soil carbon pools approaching 63% of their base levels (Lefroy *et al.* 1995). Some estimates suggest that many soils in the USA may have lost 30–50% of the SOC they held before they were cultivated (Kucharik *et al.* 2001). A comprehensive review of soil carbon sequestration potential in Australian agriculture concluded that conversion of native land to agriculture involving cultivation and repeated cropping has resulted in decreases in SOC stocks in the order of 40–60% from pre-clearing levels (Sanderman *et al.* 2009). Among the many studies included in the Sanderman *et al.* (2010) review, two examples are relevant to this discussion: (i) a chronosequence study which showed that when land was continually cultivated, SOC dropped from a base level of 22 g/kg to 15 g/kg in 10 years and to 6 g/kg by 45 years, a 73% reduction and (ii) applying a single tillage to a plot which was not tilled (NT) for the previous 14 years resulted in large losses of SOC from the soil but applying NT to a previously tilled plot resulted in no significant gain in SOC. Soil cultivation (tillage) disrupts soil aggregate structure which would increase decomposition rates of carbon pools but the re-formation of stable aggregates which protects carbon pools is a much slower process even after tillage is completely ceased (Balesdent *et al.* 2000). Field observations at the plantation sites which were repeatedly ploughed confirmed that at some sites soils have lost all structural elements including aggregates to a depth of 25 cm (Harwood and Nambiar 2014a).

A number of studies in agricultural systems show that the rates of decline in SOC in response to soil management is faster than rates of recovery from reduced levels (Sanderman *et al.* 2010). Based on modelling studies on *Pinus radiata* and *E. globulus* plantations grown in Australia, the predicted general rate of decrease in SOC during the first ten years after planting was 0.79 t C ha/yr (1.7% per year) and the predicted rate of increase from age 10 to 40 years was 0.46 t C ha/yr (0.82% per year), much slower than the rate of decrease (Paul *et al.* 2003)). Many of the sites contributing to the database for the studies of Paul *et al.* (2002; 2003) studies were disturbed, sometimes intensively, before afforestation or reforestation. The discussion above shows that repeated ploughing in short (5–8 year) rotations may be leading to declining soil organic matter levels in the soil, which would likely have a negative effect on productivity. However, as discussed below, if aboveground biomass (other than stems) is retained at sites and the site is not cultivated for replanting, SOC levels can be maintained or slightly improved (Table 5).

Soil-available water and plantation growth

Tree species have specific climatic requirements, especially in their physiological ability to cope with stresses such as water deficits. Even when soils low in chemical fertility can be supplemented to a certain extent with nutrient additions in fertilisers to improve production, a growth response can occur only if there is adequate soil-available water and if there are no constraints in soil physical properties such as compaction that impair root growth. Soil-available water is often an overriding factor determining variation in the productivity of plantation forests across local landscapes. For example, in *E. globulus* Labill. plantations in Western Australia nearly all the variation in volume growth rates across sites could be explained by a combination of climate wetness index and soil depth (White *et al.* 2009). Similarly, two key variables – atmospheric vapour pressure deficits and soil water availability – accounted for most of the variation in growth across a large area of eucalypt plantations in eastern Brazil (Almeida *et al.* 2010). Further work from Brazil (Stape *et al.* 2010) showed that soil-available water can be an overriding site variable determining growth rates in areas with seasonal water deficit, a common feature in plantations areas in SE Asia. For example, at a site in South Vietnam with an annual rainfall of 2500 mm/yr, stem diameter growth of *A. auriculiformis* between 3 and 4 years of age ranged between 2–3 mm/month during the rainy season but declined to 0.5 mm/month or zero during the dry months from December to March (Huong *et al.* 2008).

Total annual rainfall is not a reliable measure to explain growth rates or to understand the scope for improving production with management inputs, because the net water available to the stand throughout the rotation depends on factors including frequency and seasonality of rain, evapotranspiration, soil properties determining water-storage, and stand management. Some options for managing available soil water and improving production include: conserving organic matter, especially on moderate to steep slopes; managing soil in ways that do not cause erosion or degrade soil structure; and, under some circumstances, improving water infiltration in soil and rooting by deep ripping. Controlling competing weeds is an assured way to increase the share of soil water and nutrients available to planted trees. Studies on the relationship between site factors controlling available soil water and tree growth is a critical area of research in SE Asia.

MAINTAINING PRODUCTIVITY AND SOIL PROPERTIES OVER SUCCESSIVE SHORT ROTATIONS: EXPERIMENTAL EVIDENCE

In the previous sections, the impacts of some of the common site management practices deployed for harvesting and replanting on productivity of successive rotations have been discussed. Recognition of the importance of building knowledge of the biophysical processes governing the productivity of tropical plantations (Nambiar and Brown 1997) and the rate of expansion of plantation forestry in the sub-tropics and tropics prompted the development of a coordinated network project under the aegis of Centre for International Forestry Research (CIFOR 1997 to 2008) in partnership with local public institutions, universities and companies in Australia, Brazil, China, Congo, India, Indonesia, South Africa and Vietnam with supporting sites in Southern USA. The core aims were to examine questions about the productivity of successive rotations and to support capacity building among some partners. The project included 16 sites,14 in the subtropics and tropics and two in Mediterranean environments (see Nambiar and Kallio 2008 for details). A unique feature of the study was that a set of core treatments was implemented uniformly across all sites with optional treatments appropriate for the local situations. Results from this study have been cited in some contexts earlier. Although the project was formally completed in 2008 and final proceedings were published (Nambiar and Kallio 2008), work has continued at several sites. Using more recent and updated results (through personal communications by the authors) and recent published research from other sources, three key questions relevant to sustainability can be addressed:

- Can productivity of tropical plantations be maintained at sites for more than one rotation?
- What is the scope for increasing production with management and across key species?
- What types of changes might there be in soil properties?

Can productivity be maintained?

Questions about productivity across multiple rotations in the tropics cannot be answered in detail, because the history of tropical plantations is recent and relevant data are not easy to find (see (Harwood and Nambiar 2014a). Such comparisons are scant, even for temperate plantation forestry systems, despite their long history. An example for *P. radiata* is provided by O'Hehir and Nambiar (2010). The CIFOR network project examined the productivity of first-rotation (1R) and second-rotation (2R) stands in commercial management units across ten eucalypt, four acacia, one hybrid pine and one Chinese fir site. Earlier results (Nambiar and Kallio 2008) showed that 11 out of 16 sites grew at faster rates than in the corresponding previous crop, some substantially so. When earlier results were summarised (Nambiar and Kallio 2008), none of the four acacia sites were at the end of the second rotation. Full rotation results for 1R and 2R for all eucalypt and acacia sites are now available, and are presented in Figure 5. The genetics of planting stock changed from 1R to 2R which also received, in general, better weed control than in 1R. The MAIs for 2R are the mean of several experimental treatments, so they represent the mean effect of a range of management practices at each site. The dotted line in Figure 5 shows the 1:1 parity. Second-rotation yields for the majority of sites were higher (in some cases nearly three times higher) than the first, and others were close to the 1:1 line with no case where there was a clear decline in production.

There are several limitations in interpreting the differences in growth rates and net production between rotations (O'Hehir and Nambiar 2010). For example, growth rates are influenced by factors including the planting of different genetic material, climate, stocking, pests and diseases and management and these cannot be held constant across rotations. However, if genetically improved planting stock is used and management practices which conserve site resources are applied, productivity can be maintained and enhanced. For example, in experimental studies of *A. mangium* in Sumatra, MAI increased from 29.4 m^3/ha/yr (1R) to 43.0 m^3/ha/yr (2R) at one site and from 29.7 to 47.8 m^3/ha/yr at a second site (Hardiyanto and Nambiar 2014). Similarly, an experimental study on *A. auriculiformis* in south Vietnam demonstrated the progressive improvement in MAI from 11.0 m^3/ha/yr (1R) to 28.3 (2R) and 33.0 m^3/ha/yr (3R) (Vu Dinh Huong *et al*. 2014 unpublished report, Vietnamese Academy of Forest Science). The potential for increasing production and the net benefit of improved management on production are high. Such studies are much needed on eucalypt plantations in SE Asia.

What are the prospects for increasing production within a rotation?

Table 4 summarises the changes in wood production in response to management inputs at ten eucalypt and three acacia sites at the end of the second rotation across a range of

FIGURE 5 *Relationships between growth rates of first (1R) and second (2R) rotation plantations in experiments of the sub-tropical and tropical network project. Source: Nambiar 2008, Nambiar and Kellio 2008)*

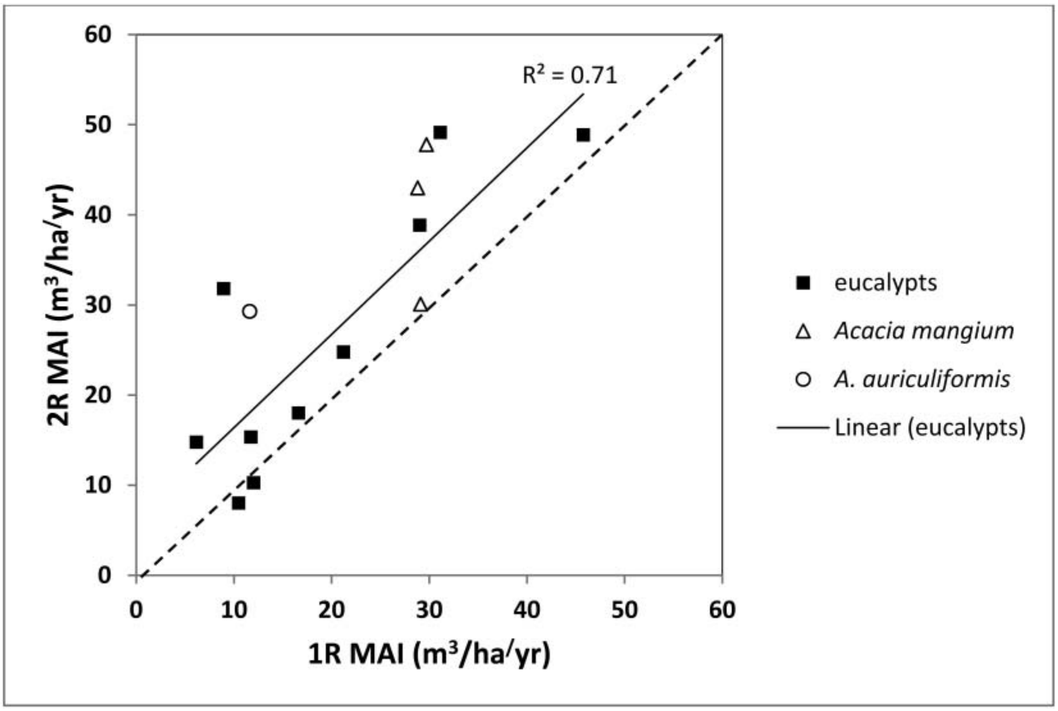


TABLE 4 *The lowest and highest amounts of wood produced in response to inter-rotation management treatments at a range of second-rotation sites*

Site	Species	Stand age (y)	Lowest volume (m^3/ha)	Highest volume (m^3 /ha)	Gain (%)
Congo: Pointe-Noire	*E. hybrid*	7.0	84.1	160.9	91
India: Kerala					
Punalla	*E. tereticornis*	6.5	78.2	278.0	256
Surianelli	*E. grandis*	6.5	166.7	269.5	62
Vattavada	*E. grandis*	6.5	328.4	350.0	7
Kayampoovam	*E. tereticornis*	6.5	87.4	140.0	60
China: Guangdong	*E. urophylla*	7.5	38.9	52.5	35
Brazil: Itatinga	*E. grandis*	8.7	176.2	276.7	57
South Africa: KZ-Natal	*E. grandis*	5.5	123.0	146.0	19
Australia					
Busselton (WA)	*E. globulus*	10.0	74.0	122.0	65
Manjimup (WA)	*E. globulus*	10.0	434.0	487.0	12
Indonesia: Sumatra					
Riau	*A. mangium*	8.0	247.0	297.6	20
Sodong	*A. mangium*	7.0	314.0	366.0	18
Vietnam: Binh Duong	*A. auriculiformis*	6.0	165.2	197.7	20

Source: Revised and updated from Nambiar and Kallio (2008).

environments and growth rates. Results show opportunities for improvements at most sites. The lowest and the highest volumes were obtained from the range of treatments (planting stock remained the same within each site); the lowest was usually associated with depletion of organic matter and the highest with the retention of organic matter and supply of additional nutrients in some cases. The main points are that the prospects of increasing production with better site management vary but are often high, and that opportunity for increasing production applies to both low- and high-quality sites and across a range of species and growing environments.

What are the trends in changes in soil properties?

A common concern about forestry in the tropics has been the consequences for the soil of the removal of biomass and nutrients by harvests at intervals of 5–8 years. Several reviews have summarised the potential depletion of nutrients, especially base cations (K, Mg and Ca), and raised the prospect of increasing soil acidity (Folster and Khanna 1997; Nykvist 2000; Mackensen *et al.* 2003).

Based on earlier results, Tiarks and Ranger (2008) concluded that, across all sites (Table 4), changes over the rotations in soil organic matter (SOC), N, pH and exchangeable cations were small and transient and there was no indication of a decline in surface soil properties, unless extreme treatments were applied such as total removal of above-ground biomass. Using their summary and updated results obtained through personal communication with partners, trends in the direction of the changes (across core treatments) for six eucalypt and three acacia sites for a full rotation period are summarised in Table 5.

In general, changes in soil properties were small and none were consistent across sites. Soil pH remained stable over the rotation length. There were indications of reduction in exchangeable K in four out of nine sites and a trend in decline in extractable P for the acacia sites. Soil organic carbon levels remained relatively unchanged or increased at four sites (Table 5). At an *E. grandis* site in Brazil, Gonçalves *et al.* (2008) followed SOC annually at 0–5 cm and 5–10 cm depths from planting to the end of the rotation at age 7 years. The site was replanted under minimum tillage according to local operational practice. In both the soil layers, SOC concentration remained stable (close to 20 g/kg in 0–5 cm and 10 g/kg in the 5–10 cm) from clear-cutting the first rotation to the end of the second rotation. This result is consistent with that found in a study in a *E. globulus* plantation in Western Australia (Mendham *et al.* 2008) and from a range of other sites (Table 5).

Concerns about soil acidification (declining pH) in acacia plantations have been raised, although seldom substantiated by reliable data. The suggested reasons are these species can grow fast, enabling uptake of large amounts of mineral nutrients in the biomass which may be removed at harvest, and they fix atmospheric N which in turn may increase N leaching and carry bases in the leachate. Because this concern

TABLE 5 *Change in soil properties in the surface 10 cm from the end of the first rotation to the harvest of the second rotation. Revised from Tiarks and Ranger (2008) and updated from personal communications from network partners. See Nambiar (2008) for experimental details*

Site	Species	Stand age (yr)	SOC (g /kg)	Total N (g /kg)	Extr. P (mg/kg)	pH	K	Ca	Mg
							(c mol/kg)		
Congo: Pointe-Noire	*E. hybrid*	7.0	↔	↔	NR	NR	↔	↓	↔
China: Guangdong	*E. urophylla*	7.5	↑	↓	↔	↔	↑	↑	↔
Brazil: Itatinga	*E. grandis*	8.7	↔	↔	↓	↔	↑	↔	↑
South Africa: KZ-Natal	*E. grandis*	5.5	↑↑	↑	↔	↔	↔	↔	↔
Australia									
Busselton (WA)	*E. globulus*	10.0	↔	↔	↔	↔	↓	↔	↔
Manjimup (WA)	*E. globulus*	10.0	↔	↔	↔	↔	↓	↔	↔
Indonesia: Sumatra									
Riau	*A. mangium*	8.0	↑	↔	↔	↔	↓	↓	↓
Sodong	*A. mangium*	7.0	↔	↔	↓	↔	↔	↔	↔
Vietnam: Binh Duong	*A. auriculiformis*	6.0	↑↑	↑↑	↓	↔	↓	↔	↓

↔ no change ↑ increased ↓ decreased ↑↑ statistically significant NR not reported.
Increases and decreases are only trends and not statistically significant unless specified.

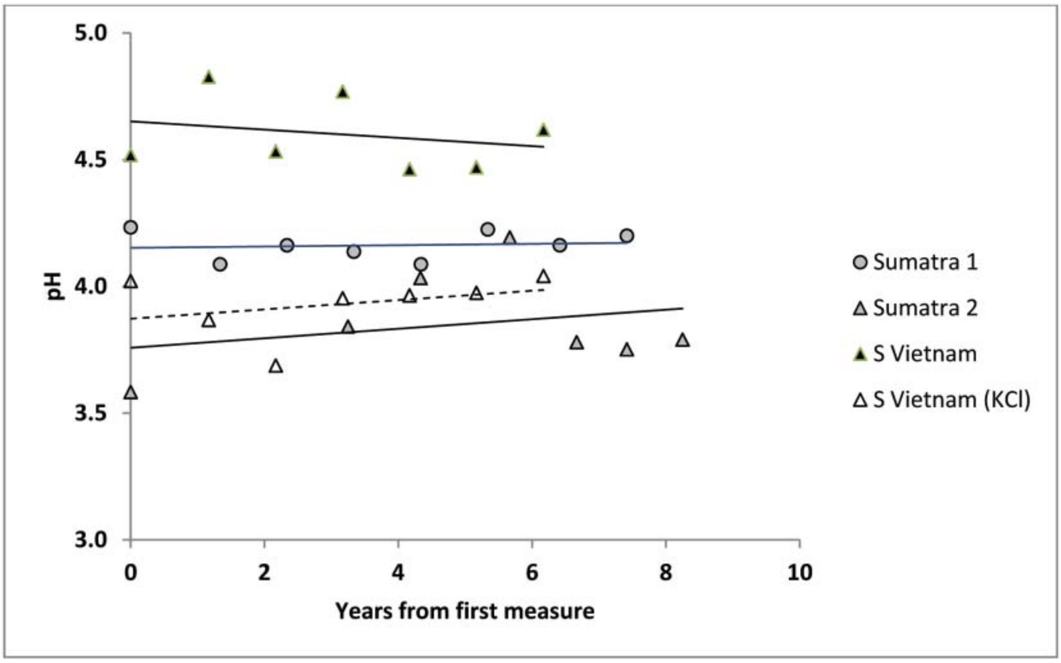
is recurring in SE Asia (Yamashita *et al.* 2008; Sang *et al.* 2013; Dong *et al.* 2014) a discussion is appropriate. Yamashita *et al.* (2008) compared soil pH under stands of first-rotation *A. mangium* with those from secondary forests and *Imperata* grasslands in south Sumatra. They found no significant difference in soil pH_{H2O} up to 30 cm depth between secondary forests and *A. mangium* plantations. In fact, pH_{H2O} in *A. mangium* was slightly higher than in secondary forests, and pH_{KCl} under *A. mangium* was generally higher than in both secondary forests and *Imperata* grasslands. The difference in pH between grassland and acacia may be due to a pH rise under grass (possibly an ash effect arising from frequent burning by farmers) and not a real decline under acacia, where pH was slightly higher than under secondary native forests. Distribution of exchangeable bases in the profile showed similar patterns to those of pH and bases in soils under native forest and acacia were identical. Thus, these results do not support the conclusion by Yamashita *et al.* (2008) that acacia plantations *per se* reduced soil pH in one rotation.

Dong *et al.* (2014) compared fallow shrub lands in central Vietnam below overhead powerlines, with a chronosequence of adjacent acacia hybrid plantations from age 0.5 years to 5 years. To start with, fallow land had soil properties very different from the land under the acacia series. For example, total SOC in the upper 20 cm of soil in the fallow land was 12.99 ± 1.75 (SE) Mg/ha and that in the plots of 0.5 year old acacia was 21.76 ± 0.72 (SE) Mg/ha, some 40% higher. This large difference in SOC cannot be attributed to 0.5 years of growth of an acacia stand. Despite such serious confounding, and based on a difference of 0.1–0.2 units of pH, it was concluded that soil acidity increased under acacia plantations. In another matched-plot study in Vietnam, Sang *et al.* (2013) found that the mean pH_{H2O} across several sites were: plantations 4.4, secondary forests 4.5 and pastures 4.9. The pH difference between plantations and secondary forests was not statistically different, but that between plantations and pastures was. This small difference, with pastures higher by 0.6 pH units, could have been due to practices common in local farms (e.g burning) and is not a reliable measure of decline in pH under plantations or native forests. The cation exchange capacities for plantations, secondary forests and pastures did not differ significantly. Yet, it was concluded that 'all plantations, but not secondary forests, caused increases in soil acidity'.

The pH measured annually during the full second-rotation period for three acacia plantations at two sites in Sumatra (Site 1 is a red yellow podzol and Site 2 is a Ferric Acrisol) and one site in southern Vietnam (Chromic Acrisol) is presented in Figure 6. Data are from plots where stem wood (with bark) was harvested, and slash and litter were retained, as is the common practice in Indonesia. The first data point is the measurement at the end of the first rotation. Soil pH fluctuated through the years, in some sites more than in others, but there was no indication of pH changing with stand age during the full rotation period. Similar results were found at two *E. globulus* sites in contrasting soils in Western Australia measured over ten years (Mendham *et al.* 2008).

Studies using chronosequences and paired sites that have concluded that acacia plantations acidify soil overlooked the serious confounding effect of differences between land types and their history and that conclusions drawn from one-time measurements can be misleading, as the pH fluctuates in time (Figure 6). The idea that acacia plantations acidify soils appears to be widespread, yet measurements over a rotation

FIGURE 6 *Changes in the pH of the surface 0–10 cm of soil over a full second rotation of* A. mangium *at two sites in Sumatra, and* A. auriculiformis *in southern Vietnam. Linear regressions shown by the lines were not significantly different from zero. Source: Hardiyanto et al. (2008); Siregar et al. (2008); Huong et al. (2008) and updated data in pers. comm. to SN*



from a set of designed experiments (Figure 6, Table 5) do not support that conclusion. It is important to build a long-term database from appropriate experiments to monitor and understand the impacts of management on soils over several rotations, and to use such information to improve management and to address questions from communities.

WAYS FORWARD FOR PLANTATION RESEARCH AND MANAGEMENT

Sustainable wood production with economic viability and environmental care provide the foundation for successful plantation forestry. For achieving this goal, managers in temperate zones, for example, Australia, New Zealand and SE USA have been backed by more than a century of experience and substantial investments in R&D. Elsewhere, short rotation forestry with eucalypts and pines had the support of high quality research, technology adoption mechanisms and decades of experience, as illustrated in South Africa (Morris 2008; Titshall *et al.* 2013) and Brazil (Alfenas *et al.* 2004; Stape *et al.* 2004; Gonçalves *et al.* 2013). In comparison, large scale development of eucalypt and acacia forestry in SE Asia is recent with some estates less than 10 years old, and informed by modest and fragmented research (Harwood and Nambiar 2014), some of it not easily transferable between countries as it is reported in different languages.

Because the history of forestry of SE Asian countries and regions within them, ownership of the land base, the species grown, investments in management, the degree of vertical integration and cultural backgrounds all differ, an analysis does not yield conclusions uniformly applicable to all. For example, a strategy for dealing with serious threat of diseases of *A. mangium* including change of species, bio-control and genetic selection is among the highest priorities for Sumatra and Sabah. In comparison, pests and diseases of eucalypts in China or Thailand, while warranting close surveillance, are not currently an over-riding threat, whereas the need for major improvements in site management for improving productivity is clear (Harwood and Nambiar 2104a). Pre-emptive strategy to prevent the spread of diseases and substantial efforts to avoid site-damaging practices are high priorities for Vietnam. Special challenges for adoption of improved practices arise from that country's highly dispersed pattern of plantation ownership, over 40% of plantations being managed by smallholder farmers.

The preceding sections have identified issues which, while not universally holding across all regions in SE Asia, are important enough to warrant analysis based on available information.

Future contributions from breeding

The last two decades of selection and breeding has laid a strong foundation to support decisions made on the choice of species suitable for the goals of forestry in SE Asia and there has been notable progress in developing improved genotypes which have been taken up for operations in small and large companies (Table 1). Three key issues for the future are:

- The need to provide stronger evidence of the value added by deployment of genetically improved planting to stock to production at operational scale

- Constraints on the quality and supply of improved materials to all growers
- The need to re-prioritise breeding objectives

In experiments, genetically improved planting stock has consistently given higher growth than unimproved material. What is not clear is its contribution to increased production in operational forestry, partly because few results from genetic gain trials are available for acacias and eucalypts in SE Asia. It is necessary to establish ongoing evaluation of improved genetic material covering the spatial variability and management across the estate to benchmark progress in breeding and justify ongoing investments in breeding.

While virtually all eucalypt planting stock in some countries is now clonal (Table 1), in parts of SE Asia (e.g. for *A. mangium* and *E. urophylla* in Vietnam), a major proportion of the planting materials are still raised from seeds collected from natural provenances or from unimproved local plantations. This is particularly the case for smallholder growers, and efforts to provide them with genetically improved seed or well-tested clones should continue.

Diseases and pests pose severe risks to production in SE Asia. This calls for a revision of breeding objectives. Future breeding should give high weighting to traits that reduce risks to sustainable production, rather than primarily targeting further major increase in growth potential, which is in any case unlikely to be achieved now that improved varieties from the first one or two generations of breeding are widely available. Breeding should of course also continue to improve value and profitability, through improvement to traits such as tree form and wood quality.

Resistance to diseases and pests can be improved by (i) selection within species or (ii) inter-specific hybridisation. Changing to a more resistant species is another option.

Eucalyptus pellita is resistant to a range of tropical diseases (Harwood *et al.*, 1997; Harwood, 2008, Guimaraes 2013). It can be hybridised with less-resistant species such as *E. camaldulensis*, *E. dunnii*, *E. grandis*, *E. tereticornis* Smith and *E. urophylla.* This offers the prospect of incorporating resistance to disease in multi-species hybrid combinations, along with desirable characteristics from the other parent species. This approach has been implemented in Brazil (Resende and Assis, 2008) and should be considered in SE Asia. Differences in susceptibility to the eucalypt gall wasp among eucalypt species, provenances, inter-specific hybrids and individual clones (Pham *et al.* 2009; Chang *et al.* 2012; Dittrich-Schroder *et al.* 2012; Kriticos *et al.* 2013; Luo *et al.* 2013) can also be exploited through breeding.

Acacia mangium and *A. crassicarpa* are highly susceptible to *Ganoderma* root rot and *Ceratocystis* stem wilt/canker. Initial indications are that there appears to be little genetic variation within *A. mangium* in susceptibility to root rot (Eyles *et al.* 2008) or *Ceratocystis* (J. Brawner, pers. comm. 2013). No acacia species with superior disease resistance appear to be available for planting or hybridisation with *A. mangium*.

In Brazil, before large-scale release, eucalypt clones are systematically screened for resistance to major diseases by inoculating young trees with the diseases and monitoring their tolerance to infection under controlled conditions and in the field (Dehon *et al.* 2013). Systematic screening is strongly recommended for SE Asia, given the increasing problems from serious diseases such as eucalypt rust (*Puccinia psidii*) which are spreading globally (Kriticos *et al.* 2013) and can be expected to reach SE Asian countries.

Pathogens can evolve rapidly, attacking previously resistant eucalypt genotypes (Graca *et al.*, 2011). Thus it is essential to maintain ongoing selection and breeding, based on diverse populations of the parental species. Unless supported by an ongoing breeding and clonal testing program, clonal plantations represent a genetic dead-end, with no capacity to adapt. Ongoing pure-species breeding and maintenance of a wide genetic base are also needed for development of new inter-specific hybrid varieties. It is important that SE Asian breeding programs retain the genetic diversity of the original base populations, to access genetic variability to counter emerging risks or meet new market requirements.

Clones developed in one region should not be planted in commercial scale outside that environment without rigorous testing in the new region. An example illustrates the high risk: clones of the *E. urophylla* x *E. grandis* hybrid, developed in subtropical southern China, have repeatedly failed in the equatorial environments of Sumatra and Borneo, because of their high susceptibility to fungal leaf blight diseases.

Managing impacts of diseases and pests

Acacia and eucalypt plantations straddle the land borders between several SE Asian countries. Large volumes of logs are traded within the region (e.g. *A. mangium* logs with bark are transported from Malaysia to Vietnam) and these could carry fungal diseases and insect pests. The eucalypt gall wasp has spread from country to country within the last decade. In view of the major economic importance of plantations in the region and the current serious disease threat to acacia plantations there is a clear need for governments and the private forestry sector to develop coherent surveillance programs within and across national boundaries. Within a country or local region, quarantine regulations can also reduce the rate of spread. International quarantine regulations play key roles in containing or slowing the spread of diseases and pests around the world (Garnas *et al.* 2012).

Investments in R&D in biological control of root rots using *Trichoderma* fungi may offer a partial solution to root rot (Eyles *et al.* 2008; Mohammed *et al.* 2012). Similarly introduction of Australian insect parasitoids of the eucalypt gall wasp has been successful in Israel (Kim *et al.*, 2008). Parasitoids indigenous to the environment where gall wasp outbreaks occur may also eventually control gall wasp to low levels, although biological control should be integrated with tree breeding to improve resistance to wasp attack.

Sustaining production over successive rotations

The productivity of a plantation site is not an immutable reference point; it is a snapshot in time because site productive capacity can be upgraded by good management or downgraded by poor management (Nambiar 1999). Similarly, changes in species or varieties in successive rotations can influence productivity, so too incidence of diseases, pests and changes in climate. Results from studies on long-term productivity of plantation forests trace back trends in production to factors including the choice of species and varieties (Turnbull 2007), soil- site management practices and overall quality of the management adopted by the enterprise (Nambiar 1999; Powers 1999; Morris 2008; O'Hehir and Nambiar 2010; Nambiar and Sands 2013). Some argue that short-rotation forestry involving large-scale planting with a single species will inherently face high risks. There is no evidence to back this assumption as a global case (Powers 1999; Nambiar and Sands 2013). There are several successful plantation ventures in temperate regions with one species (e.g. *P. radiata* plantations in Australia, New Zealand and Chile), and with short-rotation eucalypt plantations over several decades in tropical and subtropical countries such as Brazil and South Africa. However, the recent experience with disease outbreaks in *A. mangium* plantations in Indonesia suggests that as well as breeding and management to address risks to widely planted species, there is an ongoing need to develop alternative plantation species in case species changes are necessary.

The productivity trends from operational inventory (Harwood and Nambiar 2014b) indicate significant risks and constraints to achieving the goal of sustainable production in SE Asia, unless cohesive and coordinated efforts to address the constraints to production are put in place. Expectations of ongoing high rates of growth and productivity cannot be met if management practices damage ecosystem properties and processes in ways that are hard to reverse. The loss of productive capacity of soils through practices which deplete soil organic matter and cause losses of surface soil in parts of SE Asia is detailed in field reports (Harwood and Nambiar, 2014a) and discussed earlier in this paper.

Multi-site experiments in subtropical and tropical plantation sites with key species provide evidence to explore three issues critical for successive rotations. If management practices which conserve site resources are employed, productivity can be maintained and often improved over successive rotations (Figure 5). Within a rotation there is much scope for improving productivity of both eucalypts and acacia (Table 4, Figure 2). Overall results and the review of published information show that key properties of soil can be maintained across rotations (Table 5, Figure 6) if proper site management practices are followed. These important findings are supported by long term growth studies in temperate forestry (O'Hehir and Nambiar 2010) and by research in short rotation eucalypts forestry in South Africa (Titshall *et al.* 2013) and Brazil (Gonçalves *et al.* 2013).

The major challenges in the context of SE Asia have multiple dimensions that require integrated rather than fragmented action. These include:

(i) avoiding practices which, by all known accounts, impose high risks of long-lasting soil degradation;
(ii) developing applied research on key issues; and
(iii) integrating inputs from genetics, crop protection and system management into locally specific packages of practices and achieving their operational application.

Avoiding damaging practices: There is an adequate body of information and experience to conclude that bulldozing, removal of total biomass at harvest, including stumps, burning of slash and litter and intensive site disturbance especially on steep land with shallow soils are operations that pose high risks to processes that govern sustained productivity. Evidence is strong that depletion of site organic matter and associated nutrients will result in loss of production in subsequent rotations under a wide range of conditions. It is also suggested that, in general, forestry in SE Asia will be better served in the long term by further developing and adopting management practices that promote conservation of site resources, augmented by site-, species- and problem-specific use of fertilisers, based on evidence. It is essential to recognise that investments in advanced breeding will be of no avail if site resources are depleted and soils damaged during harvest and inter-rotational management. Therefore, it is important to act on this now, using the best information available, while setting in place applied research which will also serve to demonstrate the impacts of site management practices and generate long-term data to quantify these effects.

What are the key research questions? These have been discussed in detail elsewhere (Harwood and Nambiar, 2014a) and only key issues are highlighted here.

Inventory data from Sumatra suggest that when eucalypts are planted as a replacement for *A. mangium*, the growth rate of eucalypts is lower than that obtained from *A. mangium* before encountering the disease problems (Harwood and Nambiar, 2014a). Studies on constraints on the productivity of eucalypt in humid tropics would be of much benefit.

Commercial plantation forestry has not been possible, anywhere, without proper methods for managing vegetation. Currently, use of herbicide technology is the most common practice in Indonesia. Companies are committed to repeated applications and a zero weed tolerance policy. However, contemporary approaches in vegetation management do not aim for zero tolerance of all vegetation other than the commercial trees; they aim to achieve balance between production goals and acceptable limits to vegetation. Under such management, some weeds can serve as a source of organic matter and contribute to nutrient cycling.

In other regions ploughing remains very common both for weed control for improving tree growth and also as the sole fuel reduction strategy, giving rise to repeated ploughing every year as the sole fire reduction activity. While there is no local research on the comparative merits and demerits of this practice, evidence from agriculture is strong that repeated soil cultivation leads to loss of soil organic matter and soil structure. The field observations reported by Harwood and

Nambiar (2014a) suggest that integrated research aimed at (i) systematic analysis of the cause and spread of fire, (ii) testing the effectiveness of repeated ploughing on plantation growth including the long term impacts on soils and (iii) exploring the judicious adoption of herbicide technology is among the high priority areas for some regions in SE Asia.

There is very little knowledge on the factors determining soil available water and their likely strong influence on the eco-physiology of productivity in most plantation areas in SE Asia. Large regions within SE Asia have pronounced dry seasons, and site management practices may have significant effects on soil water storage. Silvicultural inputs such as fertilizer application and weed control are likely to be more effective if they are implemented with knowledge of the spatial and temporal variations in soil available water.

Integrated management is the way forward

The critical step required for future success is to develop an integrated approach to plantation system management that takes into account, simultaneously, the major determinants reviewed in this paper, rather than focussing on one at the expense of others. In countries such as Vietnam where a significant part of plantation forestry is in the hands of many thousands of small growers and farmers, assisting them to adopt this approach will be no small task.

Several examples illustrate the necessity for an integrated approach. Given the strong evidence that inter-rotation management is a critical phase of risks and opportunity for the sustainable management of short rotation forestry, harvesting practices should make subsequent management for planting more efficient, biologically and economically. It is neither biologically sensible nor practical to expect that loss of total biomass and the nutrients in it by whole tree harvest with the non-wood components going to bio-energy production can be compensated by addition of fertilizers, without economic and environmental costs. Many managers in SE Asia view genetic improvement as a panacea for securing improved productivity. However, no matter how much is invested in breeding, clonal plantations cannot provide uniform and high growth rates unless the clones have been rigorously tested across the range of site types in the target landscape and in relation to major pests and diseases, and plantations have been managed so as to maintain and where possible enhance site quality.

The productivity of eucalypt plantations has been advanced in Brazil by deploying genetically advanced planting stock integrated with minimum- or zero tillage, effective weed control and fertilizer application informed by research-based understanding of stand nutritional requirements (Gonçalves *et al.* 2013). This is somewhat paralleled by long-term improvement of eucalypt productivity in South Africa (Morris 2008; Boreham and Pallett 2009). Second rotation decline in *P. radiata* in South Australia was reversed and overall regional scale site productivity upgraded, not by any single solution but by implementing a science-based, integrated package of practices operationally (O'Hehir and Nambiar 2010).

This review has focused on what need to be done. It is not within its scope to analyse strategies to bring about these changes in SE Asia, as they will depend heavily on several factors including ownership, investment models in operation and policies. Forestry is a long-term business, and can be viable and successful only if the fundamentals of sustainable production over multiple rotations are understood and managed wisely. It is specially so with short rotation forestry. If productivity fails, the objective of forestry will be lost with it. In simple terms, informed decisions in unison on applications of species selection and genetic improvement, disease and pest management, and soil management especially inter-rotational practices with due care for the environmental values of the landscape, will together determine whether plantations in SE Asia struggle, survive or succeed.

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Productivity of acacia and eucalypt plantations in Southeast Asia. 2. trends and variations

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SUMMARY

Productivity of commercial acacia and eucalypts plantations in Southeast Asia was analysed using company inventory data to assess growth rates and their variation and trends. Growth rates of *Acacia mangium* in Sumatra, Indonesia ranged between 22 and 35 m^3/ha/yr before impacted by fungal disease, which reduced growth to 15 m^3/ha/yr or lower. The first rotation of *Eucalyptus pellita*, which replaced *A. mangium* in Sumatra, produced 16–18 m^3/ha/yr. In south Vietnam, growth of acacia hybrid in the second rotation averaged 23 m^3/ha/yr and generally exceeded that of acacia plantations in the first rotation. Growth of acacia hybrid in north Vietnam was slower, at 18 m^3/ha/yr. Eucalypts in China grew at between 15 to 28 m^3 ha/yr. Growth rates were highly variable spatially within estates managed by individual companies for both eucalypts and acacias. Understanding this variation spatially and in time is critical for developing holistic management and better targeting of research efforts.

Keywords: plantation productivity, acacia, eucalyptus, sustainability, Southeast Asia

Productivité des plantations d'acacia et d'eucalyptus. 2. courants et variations

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La productivité des plantations d'acacia et d'eucalyptus dans l'Asie du sud-est a été analysée en utilisant des données d'inventaires de compagnies pour évaluer leur taux de croissance et leurs courants et variations. Les taux de croissance de *l'Acacia mangium* à Sumatra, en Indonésie, allaient de 22 à 35 m^3/ha/an avant qu'il ne soit atteint par une mycose qui réduisit la croissance à 15 m^3/ha/an, ou moins encore. La première rotation de *l' Eucalyptus pellita*, qui remplaça *l'A. mangium* à Sumatra, produisit de 16 à 18 m^3/ha/an. Au Vietnam du sud, la croissance d'acacia hybride atteignait une moyenne de 23 m^3/ha/an en seconde rotation, et excédait généralement celle des plantations d'acacia en première rotation. La croissance des acacias hybrides au Vietnam du nord était plus lente, à 18 m^3/ha/an. Les taux de croissance connaissaient de grandes variables spatiales au sein des propriétés gérées par des compagnies individuelles, pour les eucalyptus autant que pour les acacias. La compréhension de ces variations spatiales et dans le temps est cruciale pour développer une gestion holistique et donner aux efforts de la recherche des buts plus précis.

Productividad de plantaciones de acacia y eucalipto en el sudeste asiático. 2. tendencias y variaciones

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Se ha analizado la productividad de las plantaciones comerciales de acacia y eucalipto en el sudeste de Asia, por medio de datos de inventario de empresas, con los que evaluar las tasas de crecimiento, su variación y sus tendencias. Las tasas de crecimiento de *Acacia mangium* en Sumatra (Indonesia) se situaron entre los 22 y 35 m^3 por ha y año, antes de ser afectadas por una enfermedad fúngica, que redujo el crecimiento a 15 m^3/ha/año como máximo. El primer turno de *Eucalyptus pellita*, que ha reemplazado a *A. mangium* en Sumatra, produjo entre 16 y 18 m^3/ha/año. En el sur de Vietnam, el crecimiento de un híbrido de acacia en el segundo turno fue en promedio de 23 m^3/ha/año y, en general, sobrepasó el de las plantaciones de acacia en el primer turno. El crecimiento del híbrido de acacia en el norte de Vietnam fue más lento, de unos 18 m^3/ha/año. Los eucaliptos crecieron en China entre 15 y 28 m^3/ha /año. Las tasas de crecimiento fueron muy variables espacialmente dentro de fincas administradas por empresas individuales, tanto para eucaliptos como acacias. La comprensión de esta variación en el espacio y en el tiempo es fundamental para el desarrollo de una gestión integral y una mejor dirección de los esfuerzos de investigación.

INTRODUCTION

In tropical Southeast (SE) Asia, plantation forests of acacia and eucalypt species now exceed seven million hectares. They are managed on short rotations, typically 5–8 years, for wood production. Their main purpose is to supply wood for the large regional processing sectors, so their productivity is of critical importance to the region. Despite the increasing importance of these resources, there is little information on their productivity, beyond some experimental studies such as those reported by Nambiar (2008). There is no published information on productivity at a broad scale and its patterns in space and time. A recent multidisciplinary review of the challenges and prospects for sustainable wood production over successive plantation rotations in this region (Harwood and Nambiar 2014) included two components, both informed by field visits to assess current plantation management practices in selected regions. The first was a review of the processes determining sustainable production and how the current management practices impact on them, reported in the companion paper (Nambiar and Harwood 2014). The second component, an examination of spatial and temporal trends and patterns in wood production in plantations using inventory data supplied by collaborating organisations, is the core of this paper. The objectives were to:

- examine the range and variation in plantation productivity from acacia and eucalypt plantations in selected regions of SE Asia;
- analyse the distribution of productivity classes based on mean annual increment (MAI) within estates;
- examine the trend in growth rates across two or more rotations wherever possible; and
- identify factors that may have had major impacts on production and identify areas for future research.

Results of this analysis are discussed in relation to local management and key issues warranting attention are highlighted.

METHODS

Regional coverage

The areas in selected regions of five SE Asian countries based estimates from the authors' discussions with government agencies, companies and researchers are shown in Table 1. There are other plantations in these five countries outside these selected regions and in neighbouring countries.

Most collaborators were private companies, with the exception of a few government enterprises in Vietnam and China. They manage about 20% of the plantation area in each of the regions reviewed (Table 1), except in Vietnam where ownership is highly dispersed in small estates.

Plantations were visited, guided by local managers and researchers, to understand management practices and discuss inventory systems. Inventory data were provided on the condition that: (i) they are commercially sensitive and must remain confidential to CSIRO, and (ii) there would be no explicit link between a set of data and ownership or precise geography in the presentation of results. These conditions were accepted because it is very rare that such data are available for publication although the second condition limits the interpretation of results. Data are used to describe productivity at sub-regional or regional scales, avoiding direct details of the locations of stands. Data from each region (Sumatra, Sabah, Vietnam, China and Thailand) are reported by sub-regions 1, 2, 3, etc, within regions. Within each ecological region, most sub-regions are geographically separate, but in southern China, they overlap to some extent. The plantations within each sub-region in China, Indonesia and Sabah were managed by a single company. In Vietnam and Thailand data from several growers contributed to each sub-region. Some growers operate in more than one sub-region.

Methods of inventory

From each data source (company), a subset of inventory data from that estate was requested. Data were collected using one of the three following methods:

TABLE 1 *Countries, regions and sub-regions covered*

Country	Region	Latitudinal range	Total area of plantations (ha)		No. of sub-regions
			Acacia	*Eucalyptus*	
China*	Seasonally dry tropics/ subtropics	21–23°N	<50 000	3 350 000	9
Indonesia (Sumatra)	Equatorial humid tropics	6°S–6°N	800 000	300 000	6
Malaysia (Sabah)	Equatorial humid tropics	4°N–6°N	49 000	20 000	2
Thailand	Sub-equatorial seasonally dry tropics	13°–15°N	<20 000	500 000	1
Vietnam	Sub-equatorial seasonally dry tropics	10°N–22°N	1 100 000	200 000	3

*Guangdong and Guangxi provinces only.

1. *Pre-harvest inventory (PHI) from randomly located inventory plots*: These were from sample plots (typically 0.05 ha), located in different blocks (management units) in the estate. Some growers in China and Indonesia provided these types of data.
2. *Cruising inventory at block level:* These were volume estimates at the block (typically 1–10 ha) level. They were estimated from inventory of plots or rows that account for 3–5% of the block area, measured usually at pre-harvest, but in some cases earlier. These types of data were provided for some plantations in Vietnam, and some in China.
3. *Wood weighed on trucks at the weighbridge*: These are total green weight of truckloads of wood from blocks of known area, provided by one grower in Sabah and some growers in Thailand.

Each of these methods involves some approximations. For methods 1 and 2, all trees in plots were measured for diameter at breast height. Height was either measured on all trees, or in some systems only on a proportion of trees in the plot. From these data, individual tree volumes were calculated using a stem form factor or volume equation for the species developed locally. Some differences in stem form due to genotypes, stocking and soil fertility are likely but are not accounted for. In most cases, volume over bark was calculated to 4 cm top end diameter, although top end diameters varied by 1–2 cm with changes in harvesting practices. Individual tree volumes were summed to obtain total volume/plot (method 1) or total volume/ block (method 2). Rotation length was calculated from the time of planting to inventory (both adjusted to the nearest month). Mean annual increment expressed as m^3/ha/yr was estimated at the level of the plot (method 1) or block (method 2). The volume estimates provided by collaborators were used in most cases, checking the methods and calculations as much as was practical. Method 3 assumes that there was correct matching of truckloads to specific compartments of known area. Conversion from green weight to volume over bark used approximate green wood densities, and assumed retention of all bark on the logs, which may not always be the case. All data, volume or weight, are reported as over bark.

Methods of volume estimates used for different data sources did not follow a standard inventory protocol, but were consistent over time within each company. Not all of the sub-sets of data given were drawn by unbiased statistical sampling or a defined proportion of the estate. Blocks which were not harvested, as a result of typhoon, fire or other problems may not been included in the inventory of some companies, but discussions with collaborators suggested that such omissions would account for only a small proportion of the total area in any one year of inventory.

There are differences in soils and climate between some of the sub-regions within a region, but these are in general less than the corresponding differences between the regions (Table 1). Detail on stocking was often included in the inventory. Other information sought included genetic base of planting stock (at least to the level of species or hybrid variety), soil properties, the history of previous rotations, management practices including fertilizer application, and the incidence of pests and diseases and their impacts. The details and quality of such information varied and was of limited value for quantitative interpretation of growth rates. Inventory information was seldom linked to soils, terrain and other productivity variables, except in a general way. Variation in climate, particularly distribution of rainfall, affects productivity, but an evaluation of this was not within the scope of this study. Collaborators provided adequate responses to subsequent questions on errors, representativeness of the data sample and other points, strengthening confidence in the data.

Data analysis

Growth rate expressed as MAI is influenced by the stand age and thus the age at inventory. Review of available information suggests that for acacia and eucalypt plantations established at initial stockings ranging from 1100 to 1600 stems/ha, the common planting rate in SE Asian plantations, MAI increases from planting to age 3 years, plateaus and then declines from about age 7–8 years. For example, in an experiment with a hybrid eucalypt clone at a site in southern Guangxi Province, China, MAI varied between 25.0 and 30.5 m^3/ha/yr over the age range 3.1 to 7. 3 years (Chen *et al.* 2011). For *A. mangium* Willd. in South Sumatra, MAI varied between 47.7 and 54.2 m^3/ha/yr from 3 to 7 years (Hardiyanto and Nambiar 2014). Similarly, with *A. auriculiformis* Cunn. ex Benth. in southern Vietnam, MAI varied between 28.6 and 30.4 m^3/ha/yr between 3 to 6 years (Vu Dinh Huong pers. comm. 2014). In all these cases MAIs were lower before age 3 years. For this study, only inventory in the age range 3.0 to 8.0 years were included in the analysis, unless specified otherwise. Average year of inventory is given in all cases in the results section.

In Sumatra and Sabah, data were available for two rotations of *A. mangium* from the same land base within sub-regions, but not from the same sample plots or blocks measured over successive rotations. For eucalypts in China, data were mostly from the first crop planted by the current management, although many of these sites were previously under plantation forests. A comparison of growth rates over two rotations from the same blocks was possible from a limited dataset of acacia sites from Vietnam.

For each sub-region, MAIs of individual plots or blocks were calculated if necessary from volume/inventory age, and then checked for any outlying and anomalous values which were clarified with data providers. Coefficient of variation (c.v.) is the standard deviation of plot MAIs expressed as a percentage of the mean. The results of analysis were shared with respective collaborators for their review. The authors are responsible for the final analysis, interpretation and conclusions.

RESULTS

Acacia mangium: equatorial humid tropics (Sumatra, Indonesia and Sabah, Malaysia)

Growth rates of *A. mangium* from sub-regions 1, 2 and 3 are summarised in Table 2. Mean age at inventory ranged from

TABLE 2 *Summary of plantation productivity in Sumatra, Indonesia: sub-regions 1–3:* A. mangium

	Rotation	No. of plots	Mean age (y)	Mean stocking (stems/ha)	MAI (m^3/ha/yr)		
					Mean	S. d.	C.v.
Sub-region 1	1	98	7.5	1061	32.5	7.3	22
	2	35	5.9	834	33.9	6.8	20
Sub-region 2	1	69	8.3	828	22.4	6.0	27
	2	24	5.6	863	35.0	10.2	29
Sub-region 3	1	176	8.1	1194	35.2	5.1	14
	2	52	5.9	1043	34.0	6.5	19

Note: s.d. = standard deviation; c.v. = coefficient of variation.

7.5 to 8.3 years in the first rotation and 5.6 to 5.9 years in the second rotation, indicating that second rotation stands were harvested 1.8 to 2.7 years earlier than the first. Growth rates ranged from 22.4 to 35.2 m^3/ha/yr in the first rotation, and from 33.9 to 35.0 in the second (Table 2), closely similar. The coefficient of variation of MAI ranged from 14 to 27% with no consistent pattern between rotations.

Figure 1 shows the MAI and s.d. for each planting year, averaged across the sub-regions, for stands planted over 15 years, covering the two rotations. There was high variability in MAI within each of the years, as shown by the standard deviations. The last two years of plantings in the first rotation (1993–94) had lower MAIs than those measured for all other years of plantings (Figure 1), the reason for this is not clear. Over the 15 planting years and two rotations annual mean MAIs ranged from 22.4 to 36.9 m^3/ha/yr indicating a wide temporal range. The rates of growth in the first and second rotation were, in general, similar, given the variations (Table 2, Figure 1).

The frequency distribution of yield classes (defined by MAI) for sub-regions 1–3 combined is shown in Figure 2 shows the variation in MAI across the estate. The wide range of productivity classes is evident, the patterns being very similar in both rotations. In the first rotation, 50% of plots grew between 30 and 40 m^3/ha/yr and 14% exceeded 40 m^3/ha/yr. The corresponding percentages in the second rotation were 54% and 16%. There is no evidence of reduction in variability in growth rates (Figure 1 and 2) with time although local management reported introduction of improved genotypes and improvements in management practices over time.

Table 3 summarises MAIs for *A. mangium* and *E. pellita* F. Muell. plantations in sub-regions 4, 5 and 6 of Sumatra. In these areas, *A. mangium* is being progressively replaced with eucalypts in response to the fungal disease threat to acacia by *Ganoderma* root rot and *Ceratocystis* stem wilt/canker (Nambiar and Harwood 2014). Data from these sub-regions included plots measured at earlier stages of the rotation, as well those at PHI. Data from age 3.0 to 7.0 years are included

FIGURE 1 *Mean Annual Increment by planting year, for first (R1) and second (R2) rotation* A. mangium *plantations, sub-regions 1–3, Sumatra (data from sub-regions combined, vertical bars show standard deviations)*

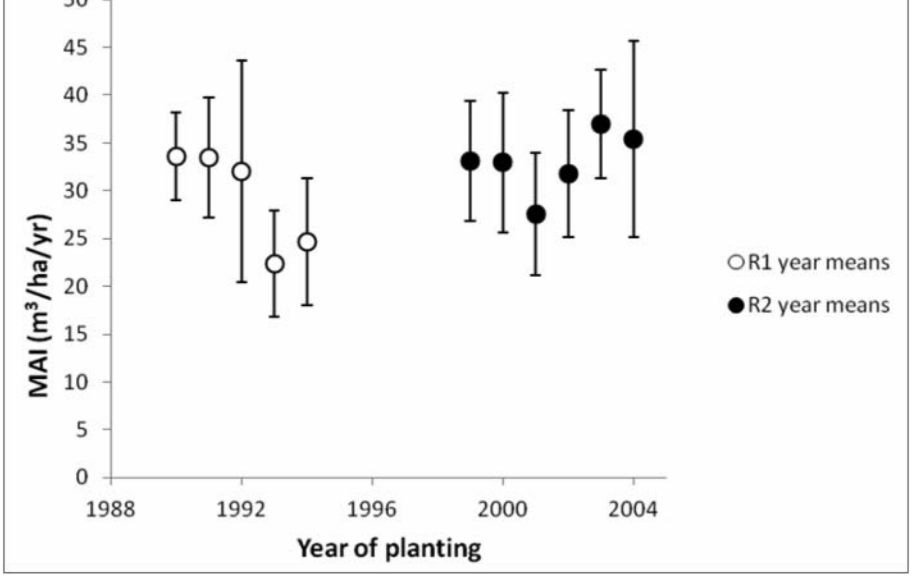
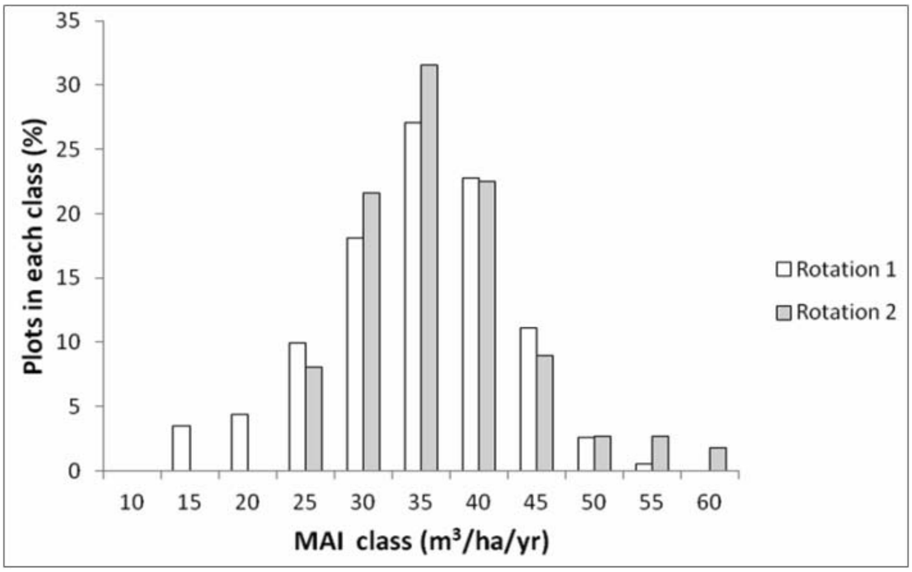


FIGURE 2 *Proportions of inventory plots in different MAI classes for first and second rotations of* A. mangium*, sub-regions 1–3, Sumatra (the x-axis labels give the upper bound of each MAI class; data from sub-regions combined)*



here. In sub-region 4, *A. mangium* MAIs for first, second and third rotation were 27.2, 28.6 and 11.2 m^3/ha/yr respectively, showing a 60% reduction from second to third rotation (Table 3). In the second rotation, *A. mangium* growth in sub-region 4 was high, at 28.6 m^3/ha/yr, but in sub-regions 5 and 6 it declined to 14.5 and 16.6 m^3/ha/yr respectively (Table 3). This sharp decline was also associated with an increase in the coefficient of variation, from 28–35% to 70–72%.

Frequency distributions of MAIs for these sub-regions (Figure 3) show that in both rotations, there was a wider spread of MAI classes than for sub-regions 1–3 (Figure 2). The proportion of inventory plots with MAIs below 15 m^3/ha/yr was much higher in the second rotation (22%), compared to the first (4%). The decline and high variability in production in the second and third rotations were due to the tree mortality caused by *Ganoderma* root rot, followed by the rapid spread of *Ceratocystis* stem wilt/canker, commencing in 2010.

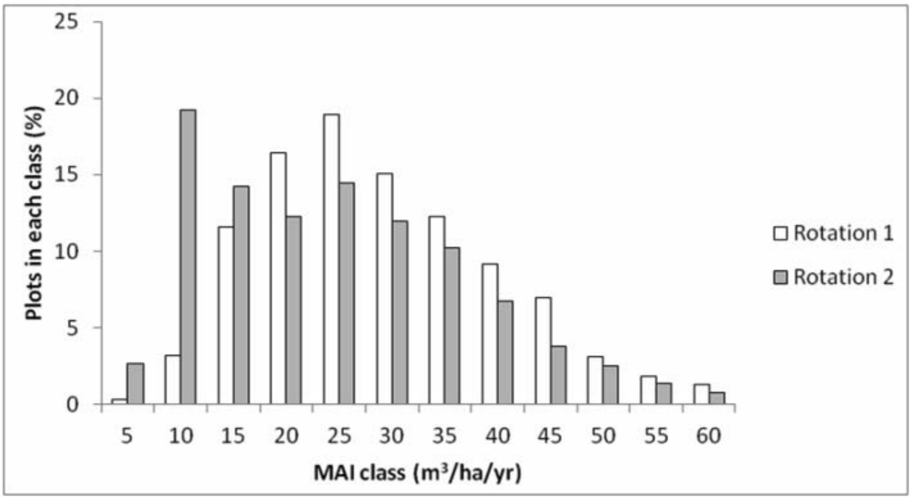
From one sub-region of Sabah for *A. mangium*, weighbridge data for log load weights was available from 178 blocks, comprising 146 blocks from the first rotation and 32 from the second. Figure 4 illustrates the trend in MAI as a function of stand age and rotation. Overall production ranged from 13 to 28 t/ha/yr. There was no notable difference in production between first- and second-rotation for the limited data sets (ages 8 and 12 years), where comparisons could be made. Over-bark volume in cubic metres would have been about 5%

TABLE 3 *Summary of plantation productivity in Sumatra, Indonesia: sub-regions 4–6:* A. mangium *and* E. pellita

	Species	Rotation	No. of plots	Mean age (y)	Mean stocking (stems/ha)	MAI (m^3/ha/yr)		
						Mean	S. d.	C.v. (%)
Sub-region 4	AM	1	1270	3.6	1092	27.3	10.9	40
	AM	2	1132	4.5	1158	28.6	10.4	36
	AM	3	60	4.9	643	11.2	4.7	42
	EP	1/2	1766	4.2	937	15.6	8.9	57
Sub-region 5	AM	1	36	6.7	641	27.1	7.7	28
	AM	2	747	5.0	723	14.5	10.5	72
	EP	1/1	1156	4.3	868	17.6	9.5	54
Sub-region 6	AM	1	153	5.7	838	33.6	11.7	35
	AM	2	481	4.5	708	16.6	11.6	70
	EP	1/1	852	4.3	758	16.7	12.0	72

Notes: AM= *A. mangium*, EP = *E. pellita;* for *E. pellita,* rotation 1/1 indicates the first rotation of this species after one rotation of *A. mangium*, rotation 1/2 the first rotation of *E. pellita* after two rotations of *A. mangium.*

FIGURE 3 *Proportions of inventory plots in different MAI classes for first and second rotations of* A. mangium*, sub-regions 4–6, Sumatra (the x-axis labels give the upper bounds of each MAI class; data from sub-regions combined)*



higher than the green weight productivities in tonnes shown in Figure 4; on this basis volume MAIs for 7- and 8-year-old stands ranged from 19 to 28 m^3/ha/yr. This was somewhat lower than those achieved in sub-region 1-3 in Sumatra (Table 2).

Plot based inventory data was also available across two rotations in the Sabah. At 8 years MAI was 25.0 ± s.d. 8.1 m^3/ha/yr. The numbers of plots, 22 in first-rotation and 12 in second, were too small and for a reliable comparison of first- and second-rotation productivity. Across the two rotations the linear relationship between stocking at inventory and MAI accounted for 52% of the variance, and the *t*-probability for stocking was <0.001 (Figure 5).

***Eucalyptus pellita*: equatorial humid tropics (Sumatra, Indonesia)**

Companies in Sumatra have been progressively replacing *A. mangium* with *E. pellita. Eucalyptus pellita* sites in Table 3 were previously under one or two rotations of *A. mangium*. Growth rates of *E. pellita*, ranged from 15.6 to 17.6 m^3/ha/yr compared to a range of 27.3–33.6 m^3/ha/yr in the first *A. mangium* rotations in the area (Table 3). The coefficient of variation ranged from 54 to 72%, which was much higher than for *A. mangium*. The productivity class distribution of *E. pellita* was skewed towards lower classes, with 30% of plots having MAI below 10 m^3/ha/yr and only 10% above

FIGURE 4 *Productivity of first- and second-rotation* A. mangium *blocks, determined from green wood weights at the weighbridge, for different rotation ages, sub-region 1, Sabah. Lengths of error bars above each column show standard deviations, and downward error bar standard errors; each age-by-rotation class shown by a column represents six or more plantation blocks*

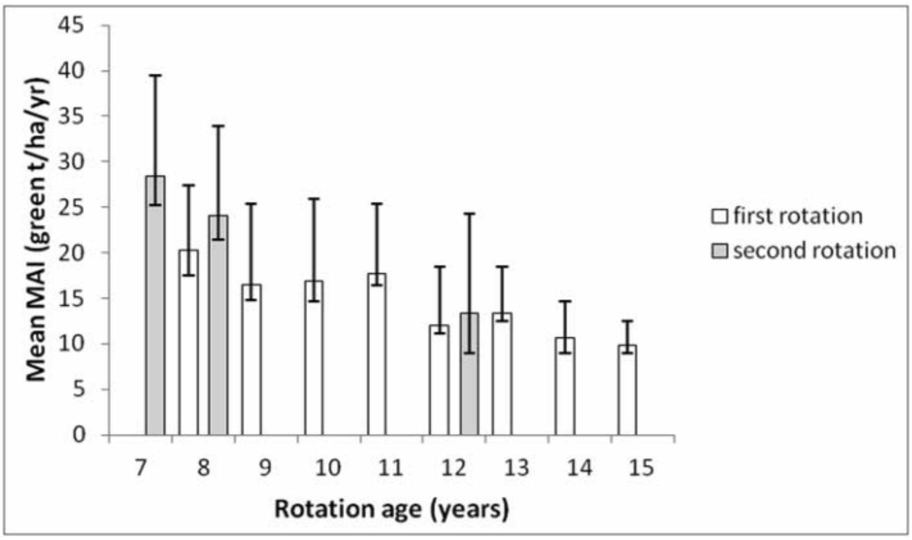
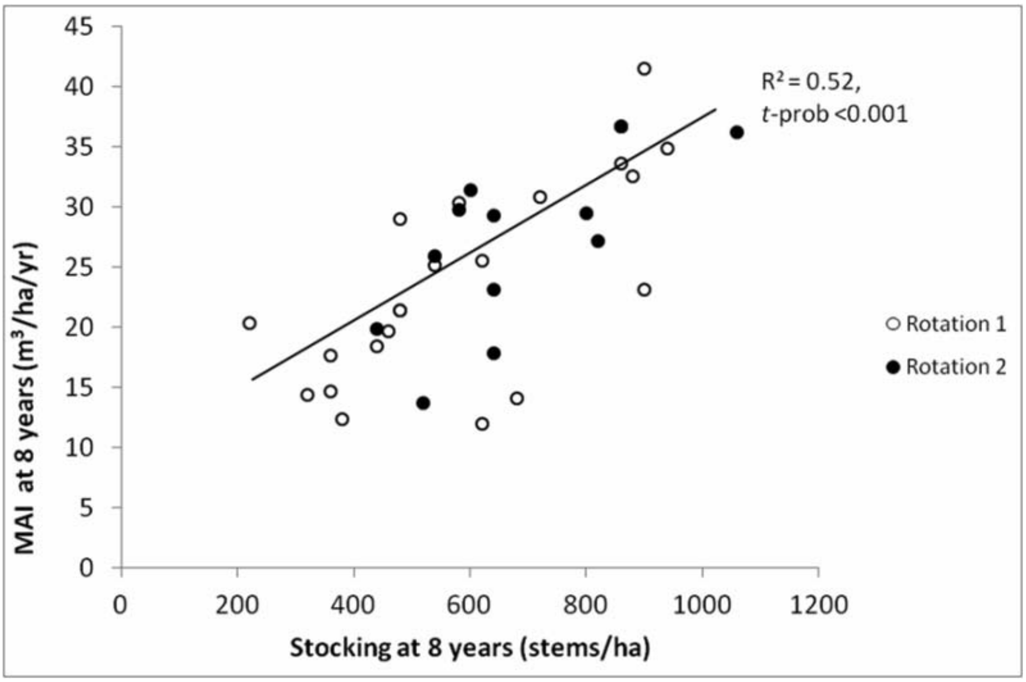


FIGURE 5 *Relationship between stocking at inventory (age 8 years) and MAI for first- and second-rotation inventory plots of* A. mangium*, sub-region 1, Sabah, showing linear regression of MAI on stocking for both rotations combined*



30 m^3/ha/yr (data not shown). The linear regression of MAI on stocking at inventory showed that stocking accounted for 47% of the variance in MAI, illustrating, as with *A. mangium* (Figure 5) the critical importance of maintaining high stocking to achieve good productivity (data not shown).

Acacia: seasonally dry sub-equatorial tropics (Vietnam)

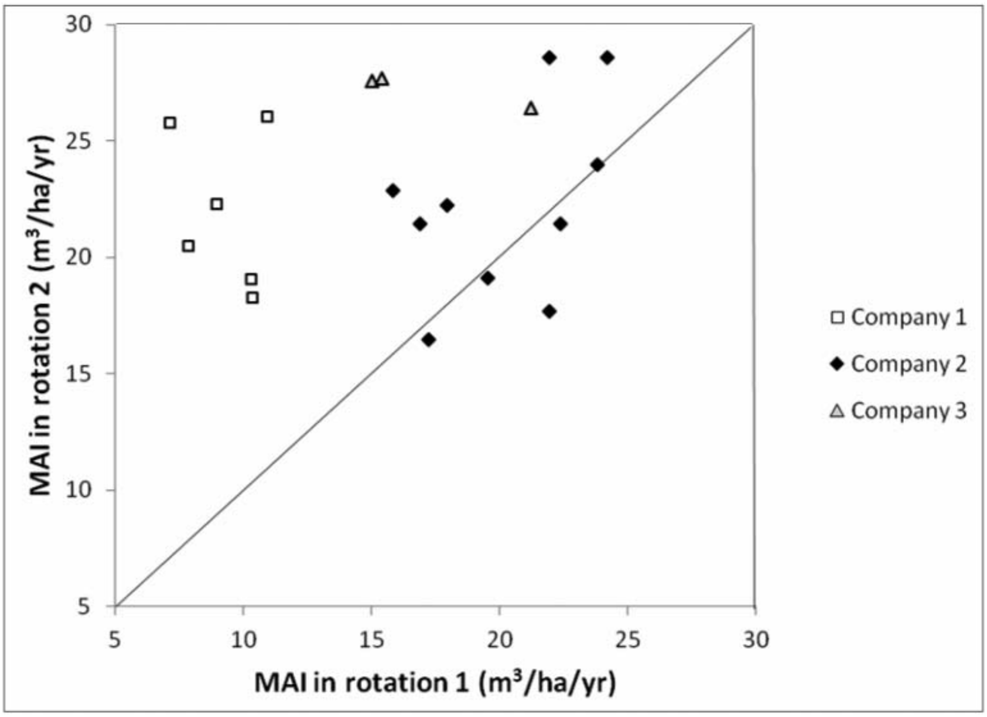
Productivity data are presented in Table 4 for three geographic regions of Vietnam; north (21–22°N), central (16–17°N) and south (10–12°N). All blocks had been planted to one or more previous rotations of acacia. Mean age at inventory was in the range 5.8 to 7.5 years. Stocking at inventory was not available for some blocks. Acacia hybrid (*A. mangium* x *A. auriculiformis*) grew at a lower rate in the north (MAI 17.6 m^3/ha/yr ± s.e. 1.5) than in the south (MAI 23.0 m^3/ha/yr ± s.e. 0.8). This difference is not attributable to genetics, as these plantations used a mix of production clones that are grown in both regions and have all given similar growth rates in experiments (Kha *et al.* 2012). Growth of *A. mangium* was low in the north (mean of 4 blocks 11.4 m^3/ha/yr, range 8.0–15.8). Two blocks of *A. mangium* and one of acacia hybrid in central Vietnam had low growth rates of about 11 m^3/ha/yr.

Growth rates from two successive rotations of acacia from the same set of blocks is compared in Figure 6. The MAIs of 14 out of 19 blocks are above the 1:1 parity line, four are close to parity and only one is below, indicating that growth rates in general were higher in the second rotation than the first. In the first rotation, Company 1 grew *A. auriculiformis*, and company 2 grew *A. mangium*, both changed to acacia hybrid clones for the second rotation. Stocking did not change between rotations in these cases. Company 3 grew acacia hybrid in both rotations but increased stocking at planting from 1111 trees/ha in the first rotation to 1666 trees/ha in the second. Several factors would have contributed to this improvement in production, especially the planting of

TABLE 4 *Mean and range of second-rotation MAI for production blocks of different acacia species in three regions of Vietnam*

Sub-region	Species	No. of blocks/ treatments	Mean age (yr)	MAI (m^3/ha/yr)			
				Mean	Range	S. d.	C.v. (%)
Northern Vietnam (21–22°N)	*A. mangium*	4	5.8	11.4	8.0–15.8	3.3	19
	Acacia hybrid	10	6.6	17.6	14.3–22.5	3.2	16
Central Vietnam (16–17°N)	*A. mangium*	2	7.5	11.2	11.0–11.4		
	Acacia hybrid	1	7.0	11.8	–		
Southern Vietnam (10–12°N)	*Acacia hybrid*	19	6.4	23.0	16.5–28.6	3.7	16

FIGURE 6 *Productivity of two successive rotations in acacia plantation blocks of three companies in southern Vietnam. Diagonal line shows 1:1 equivalence of first and second rotation productivity*



improved genetic stock and management practices such as weeding and fertiliser application. Thus although the reasons for the improvements may vary between sites, Figure 6 shows that productivity mostly increased from the first to the second rotation or remained the same, demonstrating good opportunities for increasing production.

Eucalyptus: seasonally dry tropics/subtropics (Guangdong and Guangxi provinces, southern China)

Plantations in Guangdong and Guangxi provinces, China, were predominantly planted with *E. urophylla* x *E. grandis* and *E. urophylla* x *E. tereticornis* hybrid clones. Details of inventory including MAI, stocking and age of inventory are given in Table 5. Data were from the first rotation stands, each sub-region encompassing many small plantation units (Table 5).

The growth rates in sub-regions 1–4 ranged from 16.3 to 19.7 m^3/ha/yr (Table 5). These values are likely to be representative of these areas because there were large number of inventory plots located randomly across all compartments. Growth rates in sub-regions 5–8 were higher, at 23.8 to 28.3 m^3/ha/yr. These rates were based on a smaller data base of blocks compared to much higher number of plots in sub region 1–4. Larger samples, totalling 547 blocks, were available from sub-region 9. Here, MAI site class B, at 17.4 m^3/ha/yr and site class C (16.3 m^3/ha/yr) were similar, although these classes were based on soil depth, soil type and rainfall. Coppiced stands had MAI of 22.3 m^3/ha/yr, higher than that of the planted blocks, but coppice in this case is not a follow-on of the Site class B planted stands in Table 5 and hence the two results should not be compared. In all block based inventories, small proportions of the estates which were damaged by typhoons or other causes and yielded MAI < 10 m^3/ha/yr were not included in the estimates.

Coefficients of variation for MAIs for sub-regions 1–4 were high (47–56%). The lower variation for sub-regions 5–9, ranging from 15 to 37%, are partly because the data are measured at block rather than plot levels. The patterns of MAI class distribution in sub-regions 2 and 4 data are shown in Figure 7. The high coefficients of variation in growth rates across these estates (47–50%, Table 5) should be noted, given that about 60% of the area was planted with a single hybrid clone. It shows that the use of clones is not of itself sufficient to give uniform plantation growth. The potential for productivity improvement is indicated by the fact that 10–12% of plots had MAIs exceeding 30 m^3/ha/yr. This can be further explored only if the spatial patterns of variation and the reasons for them are well understood.

Eucalyptus: seasonally dry sub-equatorial tropics (Thailand)

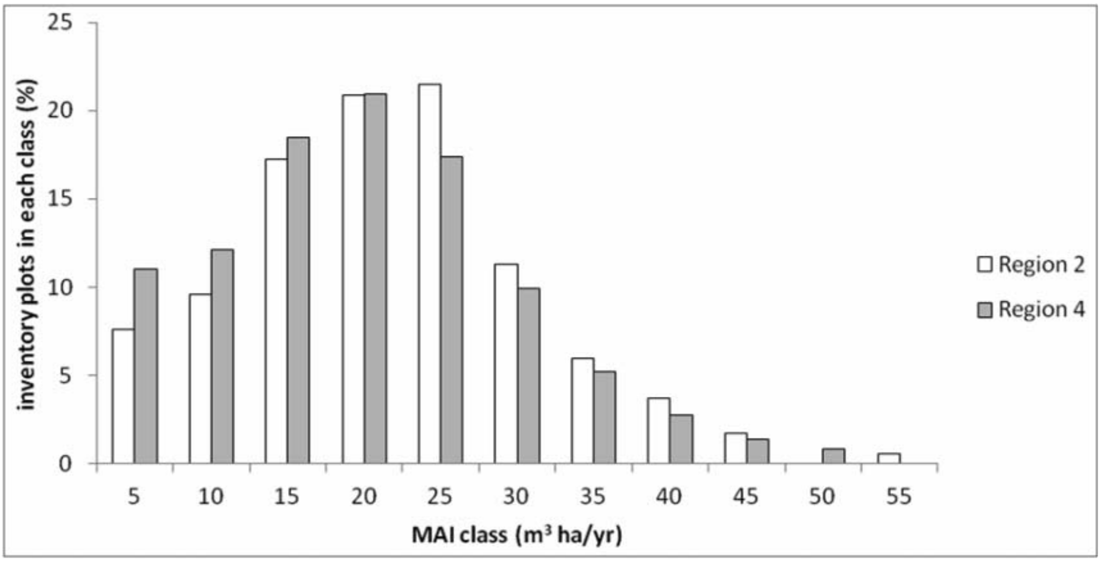
Data from central Thailand were very limited. Most plantations surveyed were clonal, either *E. camaldulensis* Dehnh., or interspecific hybrids between this species and other eucalypts. Green harvest log weights (Table 6) indicates that growth rates ranged from 15–20 t ha/yr, the corresponding MAI in volume over bark would be about 5% higher, since the green wood density is about 1050 kg/m^3. Variation in growth was high, for example ranging between 7 and 23 t/ha/yr within one sub- region.

TABLE 5 *First-rotation eucalypt plantation productivity for three groups of sub-regions in Guangdong and Guangxi provinces, China*

Sub-region/ site class	No. of plots/ blocks	Mean stocking (stems/ha)	Mean age (y)	MAI (m^3/ha/yr)		
				Mean	S. d.	C.v.
Sub-region 1	201	1189	4.0	19.7	9.3	47
Sub-region 2	354	1444	3.9	18.8	9.5	50
Sub-region 3	71	1534	3.8	16.3	9.3	57
Sub-region 4	363	1221	3.9	17.4	9.8	56
Sub-region 5	30 (blocks)	1612	5.9	28.3	8.6	30
Sub-region 6	32 (blocks)	1215	5.3	27.5	4.1	15
Sub-region 7	12 (blocks)	1180	5.4	25.2	5.6	22
Sub-region 8	25 (blocks)	1155	5.9	23.8	3.7	16
Sub-region 9 Site class B (planted)	429 (blocks)	1035	6.8	17.4	5.0	29
Site class B (coppiced)	79 (blocks)	1135	5.6	22.3	8.2	37
Site class C (planted)	39 (blocks)	926	6.7	16.3	8.5	34

Note: For Sub-region 9, blocks with age greater than 8 years were excluded.

FIGURE 7 *Proportions of inventory plots in different MAI classes for first-rotation eucalypt plantations in two planting sub-regions in China (the x-axis labels give the upper bounds of each MAI class)*



DISCUSSION

It is well recognised in SE Asia that access to additional land for plantation forestry by converting native forests is unacceptable, and conversion of agricultural land is increasingly contentious and often restricted by law. Therefore, the future of wood supply depends on maintaining and where possible increasing production per unit area from the existing land under plantations, with environmental care. Living with declining productivity over successive rotations, or simply maintaining production at low or mediocre levels in estates in which production potential is high, represent a lost opportunity in land use and value to society (Nambiar and Sands 2013).

The inventory of yield from commercial acacia and eucalypts plantations in diverse regions presented here provides the first realistic assessment of productivity and its variations and trends, of this important resource. They represent the current rates of growth from plantations managed by large companies with reasonable research and development (R&D)

TABLE 6 *Wood production from first-rotation eucalypt harvests from plantation blocks in Thailand*

Sub-region	Length of rotation (y)	No. of blocks	Productivity (green tonnes ha/yr, mean and range)
1	4	8	19 (7–23)
2	4.2	2	31 (27–34)
3	3–5	3	23 (18–28)
4	5–6	3	12 (10–13)
5	4.9	1	15

capacity and also from growers who manages much smaller land base with little or no R&D capacity. They also encompass diverse growing environments, soil, landscape and management cultures (Harwood and Nambiar 2014). Because of this diversity, there is no standardised methodology exploring spatial and temporal variations in productivity between regions as in experimental research (e.g. Nambiar 2008), or as employed in other studies elsewhere for understanding productivity at the operational scale (Morris 2008; O'Hehir and Nambiar 2010). The value of the analysis presented here is in enabling a general overview of the current on-ground situation, despite the limitations of the data described in the methods. It is also unique in the sense that we are not aware of any work in the literature in which such significant amounts of commercially sensitive data have been provided by companies for an independent analysis. In the discussion below the key aspects of the trends and variations are discussed, identifying pathways for meeting future challenges by applying known principles of sustainable management and by pursuing new R&D.

The lack of increase in productivity from first to the second rotations for *A. mangium* plantations in Sumatra, even before the onset of diseases impacts is noteworthy, given that the first rotation was planted using unimproved local seed sources but the following one was planted with improved seeds which in experiments have volume growth 40% or greater than the unimproved seed sources (Otsamo *et al.* 1996; Nambiar and Harwood 2014). This points to the need for caution in extrapolating genetic gain determined in experiments to operations, raising unrealistic expectations of productivity gains from breeding. Productivity of two successive crops was maintained (Table 2 and Figure 1) but the arrival of fungal diseases and their adverse effects on tree survival have undermined this prospect in recent years. In some sub-regions of Sumatra, negative impacts of diseases on productivity were significant in the second rotation. In the third rotation, they are now severe in all sub-regions of Sumatra and also in parts of Sabah, Malaysia (Harwood and Nambiar 2014).

In the absence of disease impact, experiments on *A. mangium* in South Sumatra show that with site management which conserves site resources and planting of genetically improved stock productivity increased from first to second rotation, reaching 43.0 and 47.8 m^3/ha/yr at two sites (Hardiyanto and Nambiar 2014, and unpublished). The high growth potential of this species is also seen from the MAI distribution classes with 10–15% of the inventory plots in having MAI higher than 40 m^3/ha/yr (Figures 2 and 3).

Results from Vietnam show opportunities for increasing the production there, where the second rotation stands in general grew at a faster rates than the first (Figure 6). This is also confirmed by experimental work on individual species. In a study on *A. auriculiformis* in south Vietnam, Huong *et al.* (in press) reported the following MAIs for successive rotations: 1R 11.0 m^3/ha/yr, 2R 28.5 m^3/ha/yr and 3R 33.0 m^3/ha/yr, when stands are managed with the currently available knowledge and technology. The low productivities from the very small sample of commercial blocks in central Vietnam are not representative of the growth potential there. In an experimental study with acacia hybrid with slash and litter retention and proper management at Dong Ha, Quang Tri province, the second-rotation MAI was 20 m^3/ha/yr at age 5-years (Harwood *et al.* 2014), much higher than that achieved in adjacent operational blocks. In another study in this region by Dong *et al.* (2014) with acacia hybrid plantations the MAI was 28.7 ± 6.9 (s.d.) m^3/ha/yr.

Provided that disease and pest impacts can be kept at the current relatively low levels (Thu *et al.* 2010), the main challenges in Vietnam are posed by poor site management practices (Nambiar and Harwood 2014) and failure to apply integrated management practices.

The first rotation *E. pellita* in Sumatra had MAI ranging from 15.6 to 17.6 m^3/ha/yr significantly lower than that of *A. mangium* grown previously in the same areas (Table 3). Clearly, the change from one species to another has not been without challenges and suggest that significant research would be required to upgrade this productivity. However, *E. pellita* has the potential for higher growth: 17% of plots had MAI greater than 25 m^3/ha/yr. According to local managers a major reason for the poor growth in the first *E. pellita* plantations was that a widely planted clone was highly sensitive to attack by *Botryosphaeria* stem canker. Rigorous testing of new acacia and eucalypt germplasm to determine their resistance to major pests and diseases in the local environment, and improvement of resistance through breeding, are essential tasks for tree breeders and forest pathologists to underpin future plantation productivity in SE Asia as has been practiced with eucalypts in Brazil (Dehon *et al.* 2013).

The growth rates in five sub-regions in China ranged from 16 to 23 m^3/ha/yr (Table 5). In the other subregions MAI s were higher, ranging from 24 to 28 m^3/ha/yr (Table 5), having lower c.v.s. These were based on a smaller data set compared to the other sub-regions and based on block level data, and elimination of areas which may have been damaged by typhoon and other causes may have been higher than in other sub-regions and these may have biased these estimates upwards. In the absence of results from experimental work on eucalypts in the region examining the potential productivity under a range of management options, it is not possible to benchmark the rate of growth reported here against the scope for estate-wide improvements. Growth class distributions showed MAI classes ranging from 5 m^3/ha/yr to 45 m^3/ha/yr (Figure 7). This wide range occurred despite some 60% of the estates represented being planted with one hybrid clone.

Field observations indicated several potentially site-degrading practices including total biomass removal, slash burning in steep terrain and repeated ploughing are widespread (Harwood and Nambiar, 2014) and there is little research on assessing the impacts of these. Unless they are replaced with practices that conserve site quality, expectations of increases in productivity are unlikely to be realised in eucalypts plantations (Nambiar and Kallio 2008; Gonçalves *et al.* 2013; Titshall *et al.* 2013). Site management which conserves site organic matter and nutrients, judicious weed control and fertilizer application supported by genetically improved planting stock will be required (Nambiar and Kellio 2008; Nambiar and Harwood 2014). Managing the nitrogen cycle efficiently will be more critical for eucalypts than for acacias, which fix atmospheric nitrogen, and soil nitrogen is strongly related to soil organic matter in tropical plantation soils (Nambiar and Harwood 2014). Data from Sumatra (Table 3) which show significantly lower production of eucalypts at ex- *A. mangium* sites point to the challenges ahead for some parts of SE Asia.

The high variation in MAI across the land base within the area planted in any one year (Figure 1), and the persistence of that variation in the second rotation is a common feature of the analyses (Figures 2, 3 and 6). Such variation occurs even in areas planted primarily with a single clone (Figure 7) and despite many managers reporting that management practices have improved over time. What is clear is that no matter how well clones have performed in trials, they will not be able to deliver uniform, high productivity in operational plantations in the absence of integrated plantation management.

It was beyond the scope of this project to evaluate the contributions of various site and stand factors (e.g. soil, slope, aspect, elevation) to productivity. Nor was there adequate information available to this study to relate management practice including methods of harvesting and site preparation, vegetation management and planting stock to the levels of productivity in commercial plantations. One relationship commonly identified here is that between stocking at pre-harvest inventory and MAI or net volume applicable to acacias (Figure 5) and eucalypts. In the case of eucalypts in China sites the linear regressions between stocking and MAI had R^2 values ranging from 0.30 to 0.37 (data not shown). Clearly, research and management to improve survival throughout the rotations would be valuable.

A central issue which would hold back further progress in improving and sustaining productivity is the widespread lack understanding of the soil and eco-physiological factors which determine productivity and how management influences stand growth. In the absence of this, the wide variation in productivity often found in adjacent compartments or in larger land units remains unexplained. Spatial mapping of productivity and analysis of relationships between growth and site factors will provide key information for improving management and tailoring it to different site types.

Experience with long term trends in productivity of short rotation eucalypts forestry in South Africa (Morris 2008) and reviewed for Brazil by (Gonçalves *et al.* 2013), makes it clear that success is not from any single input but by applying integrated management addressing key variables determining production. In SE Asia, efficient systems for monitoring productivity (including Permanent Sample Plots and systematic pre-harvest inventory) and effective data capture and retrieval are still evolving. Hence it is not yet possible to explain the long term trends in production and the possible negative or positive impacts of management practices as has been done in other plantation ecosystems (Morris 2008; O'Hehir and Nambiar 2010; Gonçalves *et al*. 2013).

At present, most growers in SE Asia consider the purpose of inventory as simply a stock-take of harvestable wood. This is important but serves the management only one purpose. Inventory data that are accurate, well captured, organised and readily retrievable, together with corresponding information on biophysical attributes and management practices, creates a repository of information that is central to supporting sustainable production. Appropriately analysed, it can lead to an understanding of how productivity is varying in space and time. This in turn can help managers set realistic production goals and direct research investments towards those constraints on production from which the best returns are likely.

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