WORLD VIEW OF PLANTATION GROWN WOOD[1]

by
Chris Brown and James Ball
Forestry Department, Food and Agriculture Organization of the United Nations (FAO), Viale delle Terme di Caracalla, 00100 Rome, Italy.
Fax (0039) 06 570 55137: e-mail james.ball@fao.org chris.brown@fao.org
http://www.fao.org/WAICENT/FAOINFO/FORESTRY/forestry.htm

ABSTRACT

The world's natural forests are under increasing pressure to meet demands for wood and fibre, while continuing to provide a vast array of environmental and social services. Future increases in demand for wood are likely to be met largely from forest plantations. This paper reviews the current extent of the global forest plantation resource, provides an assessment of the key wood production parameters (species, growth rates, rotation lengths), identifies a range of priority areas for future plantation research, and provides discussion and assessment of likely future wood supplies from plantation forests.
Keywords: plantation forests, resources, wood production, scenarios.

INTRODUCTION

Globally, the dominant trends for forest products are an increasing demand for wood (resulting from increased populations and incomes) from a diminishing, or more restricted, forest supply base. As forests are cleared, degraded, or withdrawn from production for conservation purposes or other reasons, the burden placed on the remaining production forest increases commensurately. Questions consequently arise as to the capacity of forests to continue to meet consumption demands, and these can only be answered by increasingly detailed analyses of sources of supply. During the past thirty years an evident decline in natural forest resources in a number of countries and the difficulties in accessing increasingly remote areas of natural forest available for wood supply, has resulted in an intensification in the focus on plantation forests. Plantations provide a potential means for alleviating potential future wood shortages and providing continuity of supply for existing industrial enterprises or household woodfuel needs.

Over the past several years FAO has intensified its efforts to quantify the potential extent of future wood supplies from forest plantations. Considerable effort has been applied to collating and refining data on forest plantation areas, species, age-classes and yields. Nonetheless, the ideal of global plantation woodflow modelling being done with real precision remains elusive. Not only is much of the base national forest inventory data (area, age-class, increment, species, yield) incomplete, inaccurate, obsolete or otherwise unreliable in many countries, but many of the other key variables, for example, impacts of intensified management regimes, genetic gains from tree improvement programmes, and harvesting and processing technologies remain unmeasured or unreported. Data relating to qualitative change in forest resources and wood and fibre production are particularly scarce.

The data collection and refinement process is, however, ongoing and provisional data must necessarily be used in modelling to enable progress and key trends to be benchmarked and disseminated.

CURRENT PLANTATION FOREST RESOURCES: SPECIES AND AREAS

The Global Forest Resource Assessment 1990 estimated the world's total forest area to be 3.4 billion hectares with an additional 1.7 billion hectares classified as Other Wooded Land[2]. Plantation forests make up only a very small proportion of global forest area. It is estimated[3] that in 1995 the global area of plantation forests totalled 123.7 million hectares, approximately 3.5 percent of global forests.

Table 1 shows that the Asian region has the largest proportion of plantation forests, with 45 percent of the total. More revealing is the dominance of a handful of countries in global plantation forest establishment. Five

[1] This paper represents the views of the authors and not necessarily those of the Food and Agriculture Organization of the United Nations.
[2] Other wooded land: Land either with a crown cover (or equivalent stocking level) of 5-10 percent of trees able to reach a height of 5 m at maturity *in situ*; or a crown cover (or equivalent stocking level) of more than 10 percent of trees not able to reach a height of 5 m at maturity *in situ* (e.g. dwarf or stunted trees) ; or with shrub or bush cover of more than 10 percent.
[3] Sources: Pandey (1997) for tropical countries; ECE-FAO (1998) for temperate countries.

countries - China, United States, Russian Federation, India and Japan - have each established more than 10 million hectares of plantation forests. These five countries collectively account for 65 percent of the global plantation resource. The overall concentration of plantation resources in a handful of countries is further shown by the fact that only an additional 13 countries have an area of plantation forest exceeding one million hectares. Thus, 18 countries account for 87 percent of the world's plantation forests. Note, however, a number of European planted forests have reverted to semi-natural status due to the time elapsed since establishment.

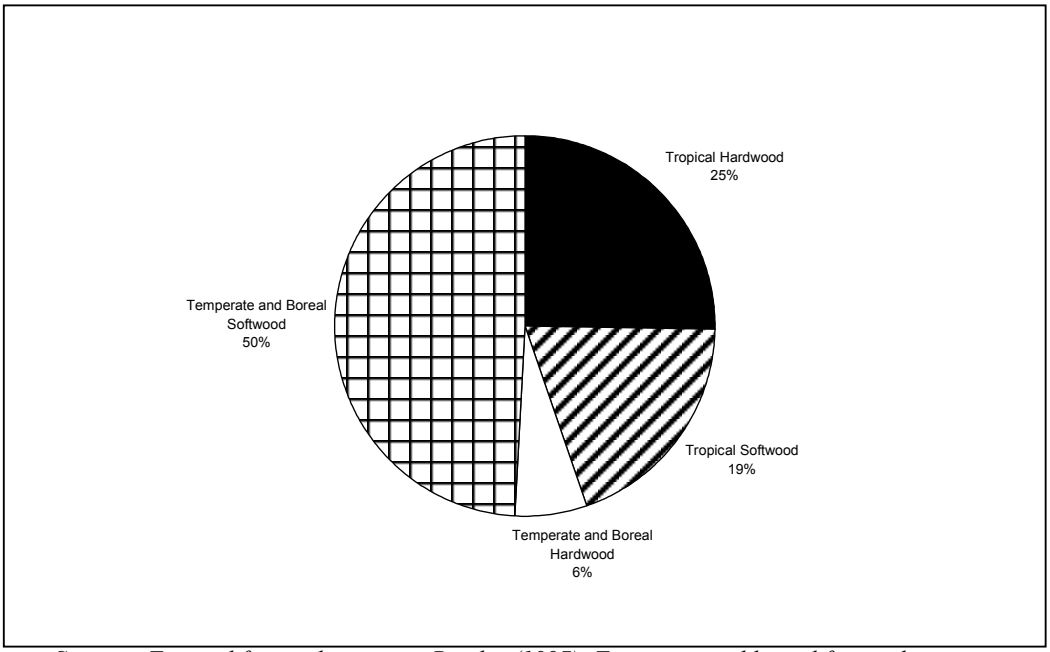
Table 1: Estimated regional distribution of plantation forests in 1995

Country or region	Industrial plantation area (million ha.)	Non-industrial plantation area (million ha.)	Total plantation forest area (million ha.)
North America	**18.4**	**0**	**18.4**
United States	*18.4*	*0*	*18.4*
Central America	**0.5**	**0.3**	**0.8**
South America	**5.4**	**2.8**	**8.2**
Asia	**41.8**	**15.1**	**56.9**
China	*17.5*	*3.9*	*21.4*
India	*4.1*	*8.3*	*12.4*
Japan	*10.7*	*0*	*10.7*
Oceania	**2.7**	**0.01**	**2.7**
Africa	**3.6**	**2.2**	**5.7**
Europe	**8.7**	**0**	**8.7**
Former-USSR	**22.2**	**0**	**22.2**
Russian Federation	*17.1*	*0*	*17.1*
TOTAL	**103.3**	**20.4**	**123.7**

Sources: Pandey (1997), ECE-FAO (1998).

At the broadest level, global plantation forests can be separated into tropical (including sub-tropical) and non-tropical plantations, and into hardwoods and softwoods. The global distribution of these areas is illustrated in Figure 1. Plantation forests in temperate and boreal countries are reported to cover 68 million hectares. Softwood species dominate in temperate and boreal plantation forests. Temperate and boreal softwoods are estimated to cover 61 million hectares and constitute 89 percent of the temperate and boreal plantation forest resource. Temperate and boreal hardwood plantations are estimated to cover almost 8 million hectares.

Figure 1: Global plantation forest resources by type and area 1995 (123.7 million hectares)

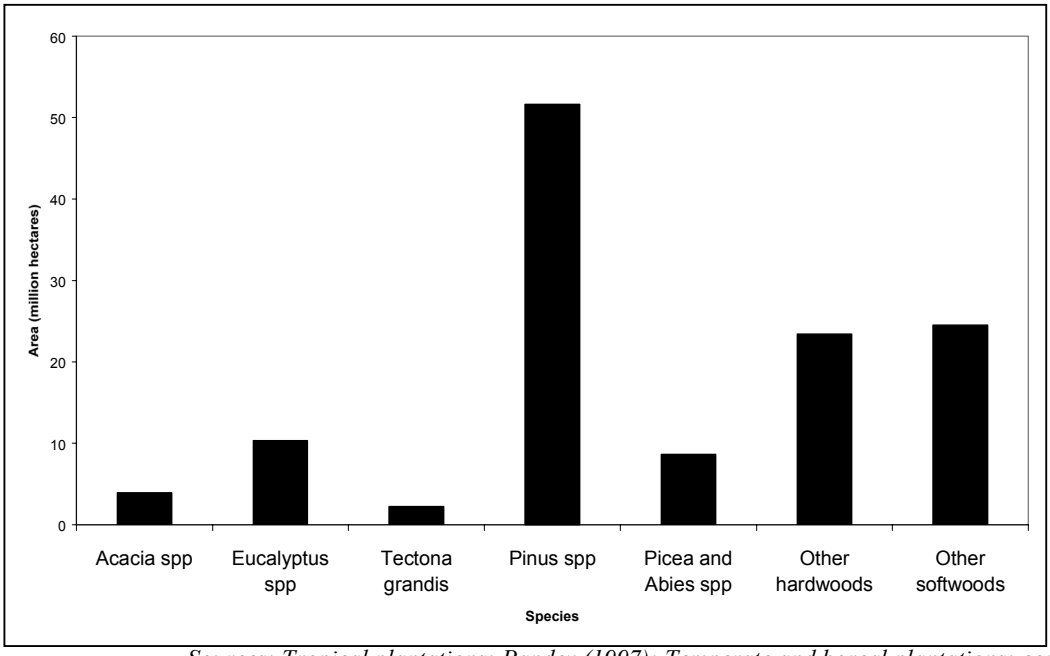


Sources: Tropical forest plantations: Pandey (1997): Temperate and boreal forest plantations: compilation

Tropical and subtropical forest plantation resources are estimated[4] at 55 million hectares, (about 45 percent of the global resource) for 1995. Tropical hardwood species are estimated to occupy 31 million hectares (about 57 percent of tropical plantation forest area). Tropical softwood species cover 24 million hectares.

Globally, the dominant forest plantation genus is *Pinus*. More than 40 percent of the world's forest plantations are planted with pines. This dominance largely emanates from temperate regions where large pine estates in the United States, the Russian Federation, and the southern plantation countries: Australia, New Zealand, South Africa and Chile, collectively contribute to a temperate pine plantation estate of almost 40 million hectares. *Eucalyptus spp*. are the most common tropical forest plantation species, with 10 million hectares planted. Brazil and India account for more than half of this area. Other major forest plantation genera include *Picea*, *Abies*, *Larix*, *Acacia*, and *Tectona*, while the more than 6 million hectares of *Cunninghamia lanceolata* planted in China may make this the single most extensively planted forest plantation species. Figure 2 illustrates an approximate global species distribution for plantation forests.

Figure 2: Global distribution of plantation genera and species



Sources: Tropical plantations: Pandey (1997): Temperate and boreal plantations: compilation

CURRENT PLANTATION RESOURCES – AGE CLASSES, VOLUME INCREMENTS, ROTATIONS AND PLANTING

Discussion of roundwood production, and the key variables that determine it (age-class, increment and rotation) is primarily relevant for the production of industrial wood. Fuelwood production is often much less concerned with stem harvest volume, than with biomass production, notably branches, twigs and tops. The discussion here will, consequently, focus only on forest plantations with a primary purpose of supplying roundwood for sawntimber, veneer and pulp (industrial plantations). If all forest plantations in Europe and the former-USSR are

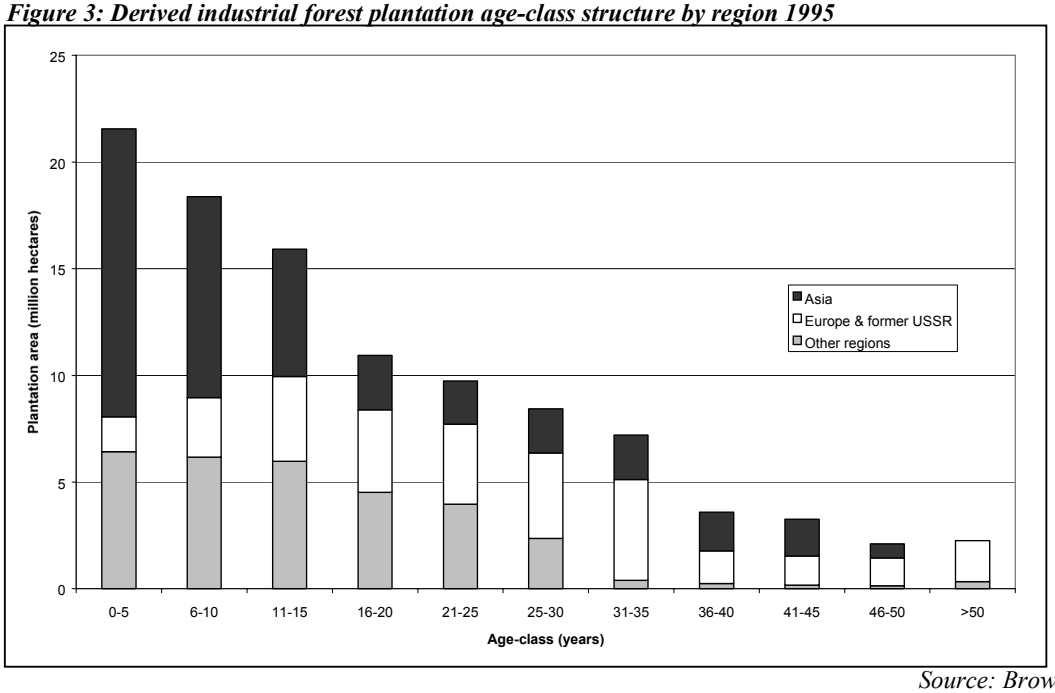
[4] Tropical and subtropical plantation areas are drawn from Pandey (1997). The areas quoted throughout this paper are Pandey's Net Areas as opposed to Reported Areas. In an attempt to provide more accurate assessments of actual plantation areas Pandey, in some instances, applies a net down factor to the area of plantations reported to be present in particular countries. "Estimation of the net area, that is, the actual area of the stocked plantations excluding failed, harvested or doubly counted plantations, has been done by applying a reduction factor/success rate derived from inventory or survey of plantations″. A more complete description of the process is provided in Pandey (1997).

assumed to be for industrial purposes[5], then global area of industrial forest plantations in 1995 is estimated at 103.3 million hectares (83.5 percent of the total forest plantation area).

Age Classes

An absence of aggregated national plantation inventories for most countries means there are considerable difficulties in compiling detailed age-class structures on a regional or global basis. Nonetheless, forest plantation age-class information is of considerable importance since it enables more accurate assessment of the current level of wood production from plantations and likely future changes in production levels. Despite the scarcity of forest plantation inventories there is still much information available in various forms, the reliability and timeliness of which varies across countries and regions. FAO has commissioned a study[6] that derives representative age-class structures on a country-by-country basis, consistent with published information. It should be emphasised that these age class structures have been developed using a significant amount of data manipulation, the intention being to obtain structures that are representative of the "shape" of national data. The derived global age-class classification for industrial plantations, by region, is illustrated in Figure 3.

Figure 3: Derived industrial forest plantation age-class structure by region 1995



Source: Brown (1999)

Two dominant trends are apparent in Figure 3. Firstly, the preponderance of Asian plantation forests compared with the other regions is clearly evident. This is particularly the case for forest plantations established in the past decade. Asian plantations constitute 40 percent of the global total and 57 percent of the forest plantations established since 1985.

A second conspicuous feature of Figure 3 is the very high proportion of plantations aged less than 15 years, particularly in developing countries. Overall, 54 percent of industrial plantation forests are less than 15 years of age, with 21 percent planted between 1990 and 1995. Only 2.2 percent of plantation forests are aged more than 50 years. A further 16 percent are between 30 and 50 years of age.

This is largely the result of an acceleration in the rate of new plantation forest establishment, but also reflects the harvesting of mature forest plantations in the older age-classes and a general shortening of rotation lengths in many countries. Forest plantations aged more than 50 years are almost exclusively in temperate and boreal

[5] An assumption that ignores, for example, the establishment of, for example, recreational forests in countries such as United Kingdom, Holland and Denmark, and protection forests in mountainous countries such as Switzerland and Austria.
[6] Brown (1999)

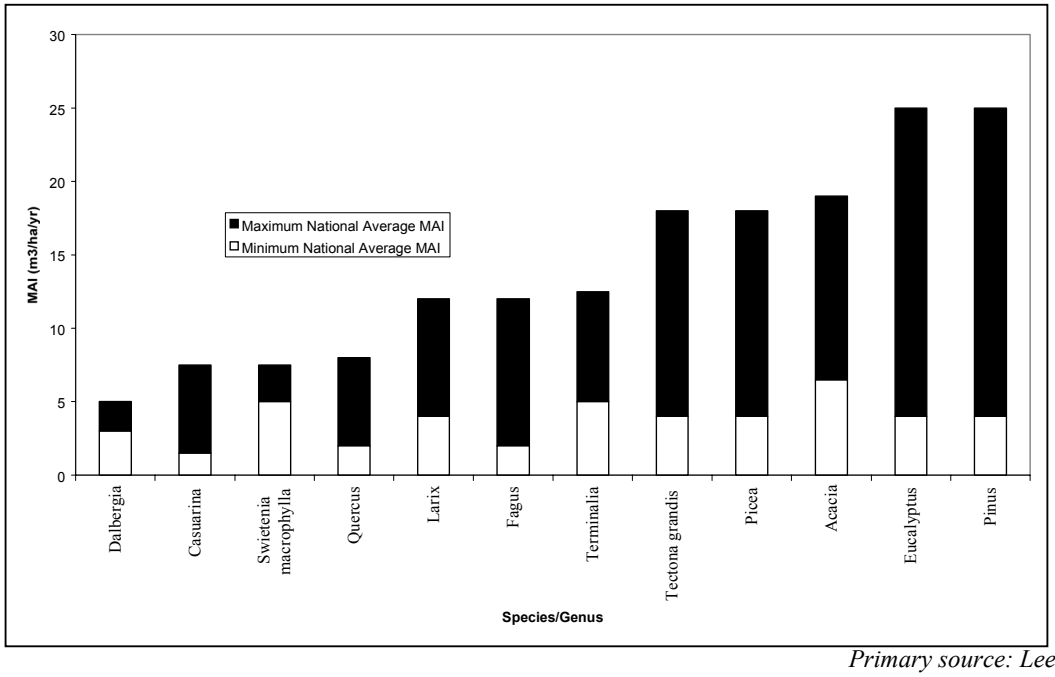
regions. Countries with significant areas of plantation forests established prior to 1946 include the Russian Federation, Ukraine, France, Portugal, Denmark, Ireland and South Africa.

Volume increments

Forest plantation yield data, at a suitably aggregated level for global modelling, are both scarce and imprecise. While a vast body of literature assesses the yield of different species in research trials, the actual yield achieved on a commercial/operational scale are generally lower as the land is more variable, and the quality of establishment and silviculture is more difficult to control. Climate, altitude and geomorphology, matching of species to site, pests and diseases can all have marked effects on tree growth at local levels. And small variations in annual yields can have major implications for final harvest volumes. For example, if a plantation estate yields 7 cubic metres/hectare/annum it will produce 40 percent more wood than at 5 cubic metres per hectare. Thus, at a global level, any consistent bias in yield data can badly distort the results. Initiatives such as the Tree Growth Potential Information System (TROPIS)[7] and the Sistema de Manejo de Informacion sobre Recursos Arboreos (MIRA) [8]are making significant improvements to improving the availability and quality of data, as well as improving the efficiency of research efforts.

Tropical regions may offer greater potential for future productivity gains than temperate regions. For example, while eucalyptus species, in the field, rarely yield more than 25 cubic metres per hectare per annum at present, significant advances may well be achieved in the not too distant future. In Brazil, for instance, hybrids of *E. grandis* with *E. urophylla* have, on some sites, attained growth rates of 70 cubic metres per hectare per annum (Campinhos, 1994). The extent to which such results can translate to the field, and particularly, whether other problems (for example, wood quality, or susceptibility to disease or windthrow) may arise from focussing mainly on growth and yield attributes remain important question-marks.

Figure 4: Indicative national-scale forest plantation yields by species (MAI at harvest)



Primary source: Leech (1998)

Figure 4 illustrates comparative average yield data for temperate and boreal forest plantations. As shown, the highest yielding species are generally *Eucalyptus* and *Pinus* species, though these have a high degree of variability among various species and locations. At the other end of the scale are species adapted to very dry or very cold climates, which may produce only 1 cubic metre per hectare per year (at a national scale).

Rotation lengths

[7] Developed by CIFOR.
[8] Developed by CATIE.

Rotation lengths in industrial wood plantations are determined by a number of factors: rate of wood and fibre production; desired wood and fibre properties; and maximisation of site productivity. However, the over-riding factor determining rotation lengths is generally profitability. Growth rates and wood properties should form part of an investment equation that marries costs and prices to determine the optimal length of time that the plantation investment should be "held". In terms of profit maximisation, rotation lengths, for single forest plantation blocks[9], are easily varied within a moderate time-span to capitalise on market conditions. Harvesting can be brought forward, or deferred according to prevailing market prices.

In terms of modelling[10], changes to rotation lengths can have significant impacts on predicted wood yields, but they are likely to be less important source of error than, for example, errors in estimated Mean Annual Increment, which will be compounded through the span of the rotation.

Planting

The question as to what role forest plantations might play in meeting future wood demands is inextricably linked to past and current patterns in plantation establishment. Plantation production, through to 2010 is almost exclusively dependent on trees already in the ground. Beyond 2010, future rates of planting will be increasingly important in determining the level of forest plantation production. Rates of plantation establishment vary annually in most countries and are driven by a range of factors including government finances, general economic conditions, incentives offered to private sector interests, perceptions of forestry profitability, successes of previous planting programmes, and perceptions of future supply-demand imbalances.

Pandey (1997) reports 1995 annual rates of plantation establishment in tropical and subtropical countries to be slightly more than 4 million hectares per annum, of which 1.65 million hectares was in the tropics and 2.36 million hectares was in the subtropics. Some of this planting (an unknown but, perhaps, large proportion) is, however, replanting of harvested areas. The current annual rate of new plantation establishment in temperate and boreal countries is estimated to be around 750,000 hectares, although this estimate does not include significant areas of enrichment planting and seeding in semi-natural forests.

FOREST PLANTATION PRODUCTION

Current harvest from forest plantations

Current annual industrial roundwood production from forest plantations is estimated to be 331 million cubic metres, based on mature age-class production potential. Fuelwood production is estimated to be 86 million cubic metres (Brown, 1999).

Figure 5 shows an estimate of current industrial and non-industrial forest plantation harvests as a percentage of the total harvest of natural forest and plantation-grown industrial roundwood, fuelwood and total roundwood. A number of interesting features are evident from the graph. The "bottom-line" shows that current plantation production for industrial and fuelwood purposes could[11] be supplying around 12 percent of the world's total roundwood harvest. The harvest from forest plantations designated "industrial" constitutes, however, a far greater proportion of reported industrial roundwood production, than does the proportion of non-industrial plantation relative to fuelwood production. Industrial forest plantations are estimated to contribute 22 percent of global industrial roundwood production, compared with non-industrial plantations' 4 percent share of fuelwood production. It is important to note that these estimates are for over bark standing timber. Delivered mill-gate volumes of industrial roundwood may be significantly lower.

---

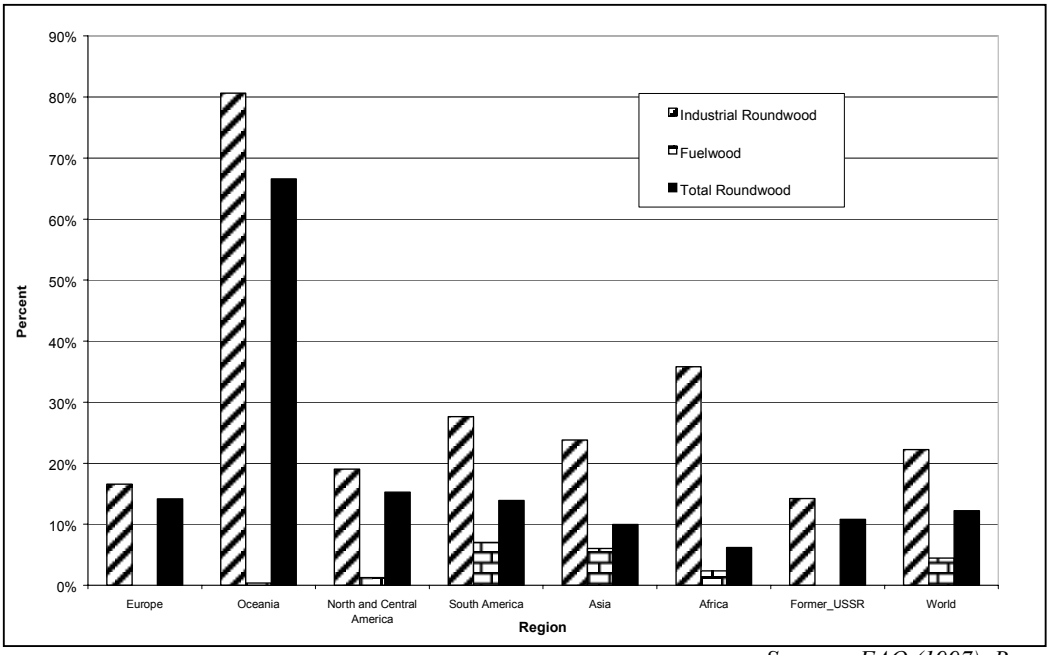
[9] Profit maximising strategies will vary according to the size and age-class structure of a plantation estate, and long-run objectives of an investor. For example, a forest corporation owning multiple plantations of varying age-classes will have different cash-flow requirements and strategies to a single age-class, sole stand plantation owner.

[10] The modelling in Brown (1999) allows for harvesting to be distributed around an average rotation length and thus mimics some of the uncertainty between planned and actual rotation.

[11] That is, the global plantation age-class structure under the assumed national harvesting profiles would suggest that 417 million cubic metres of plantation-grown roundwood had reached maturity (i.e. its assumed rotation age) in 1995.

Forest plantation production for industrial roundwood is particularly important in the Oceania region, where 80 percent of industrial roundwood is plantation-grown. Africa (35 percent), South America (27 percent) and Asia (23 percent) also have above average proportions of industrial roundwood produced in plantation forests. Production from forest plantations in a handful of countries in each of these regions – Australia, New Zealand, Chile, China, Japan and South Africa – is sufficiently large to put these regions ahead of the global average.

Figure 5: Estimated forest plantation wood supplies as percent of total roundwood harvest – 1995



Sources: FAO (1997), Brown (1999)

Future forest plantation harvest scenarios[12]

Comprehensive modelling of production, consumption and trade in forest products has been carried out as a core component of the Global Forest Products Outlook Study (GFPOS)[13] using the Global Forest Products Model (GFPM), a price endogenous linear programming system. Three scenarios for future wood supply from forest plantations have been modelled as part of the subsidiary GFPOS Thematic Study on Plantations, but independently of the GFPM analysis. The three forest plantation scenarios are:

Scenario 1 provides a baseline forecast, by assuming that forest plantations are not expanded beyond their current area and that all areas are replanted after harvesting.

Scenario 2 assumes that new planting will increase the forest plantation area at a constant rate of 1.2 million ha per annum in total (equal to 1% of the current area of forest plantations).

Scenario 3 assumes that the annual rate of new planting estimated in 1995 (4.71 million ha in total) is maintained until the year 2010, after which it is reduced by 940,000 ha at the start of each of the following decades (i.e. until it declines to zero in 2050).

The implications of these Scenarios in terms of plantation establishment by region and for major countries are shown in Table 2.

[12] Note the assumptions behind the modelling and a more detailed discussion are found in Brown (1999).
[13] Results are published in Shushuai et al (1998).

Table 2: Industrial forest plantation areas under new planting scenarios (million hectares)

Country	Area 1995	Area 2050 Scenario 1	Area 2050 Scenario 2	Area 2050 Scenario 3
North and Central America	**18.9**	**18.9**	**29.3**	**43.2**
United States	*18.4*	*18.4*	*28.5*	*41.2*
South America	**5.4**	**5.4**	**8.4**	**13.6**
Asia	**41.8**	**41.8**	**64.8**	**119.5**
China	*17.5*	*17.5*	*27.1*	*68.3*
India	*4.1*	*4.1*	*6.4*	*11.7*
Japan	*10.7*	*10.7*	*16.6*	*12.4*
Oceania	**2.7**	**2.7**	**4.2**	**5.7**
Africa	**3.6**	**3.6**	**5.6**	**8.9**
Europe	**8.7**	**8.7**	**13.5**	**15.3**
Former-USSR	**22.2**	**22.2**	**34.4**	**28.0**
Russian Federation	*17.1*	*17.1*	*26.5*	*21.1*
WORLD	**103.3**	**103.3**	**160.2**	**234.2**

Source: Brown (1999)

Scenario 2 is notable for requiring only relatively modest, and seemingly plausible, increases in plantation areas. For example, the 27.1 million hectares proposed for China in 2050 under Scenario 2 is markedly less than the 40.35 million hectares currently planned in China to 2050. Scenario 2 implies a 55 percent increase in current plantation forest areas. Plantation development is, however, unlikely to be uniform across countries. Countries such as Chile and New Zealand have, for example, achieved isolated increases in forest plantation areas of 5-10 percent in a single year. Other countries have gone for extended periods with little or no forest plantation establishment. South Africa, for example, is not encouraging further afforestation, with a preference to maximise water yields from catchments. Conversely, Australia has targeted the development of a 3 million-hectare plantation estate (a trebling of the current) by 2020. The impacts of subsidies and other incentives could play a major role in distorting competitive advantage in forest plantation establishment away from current patterns.

The areas implicit in Scenario 3 also seem to be generally achievable in physical terms. Institutional and policy constraints may, however, play a highly significant role in limiting planting below the indicated levels. Two notable cases are China and the United States, both of which would be required to maintain rates of plantation establishment higher (or for longer) than seems likely at present. Some of this "excess" planting could, however, be spread across other countries without markedly affecting the results of Scenario 3.

Several issues are likely to be of substantial importance in determining actual rates of plantation establishment. Perhaps most important will be the suite of government policies that impact on plantation establishment. A key change over the past 30 years has been national policy shifts away from centralised government planting programmes, with governments taking less direct means of encouraging tree planting. A variety of incentive policies, privatisation, management devolution and government promotions, have contributed to this change in a variety of countries. An important future trend, in at least some countries, may be a form of "private sector devolution" whereby forestry companies take a lesser role in plantation establishment, and outgrower-type schemes assume much greater importance.

Future forest plantation wood production

Future wood production from industrial plantations under each of the three scenarios is compared with a forecast of industrial roundwood consumption derived using the GFPM until 2010 and long-term trend analysis, beyond to 2050 in Figure 6.

Several points of interest can be noted from the graph.

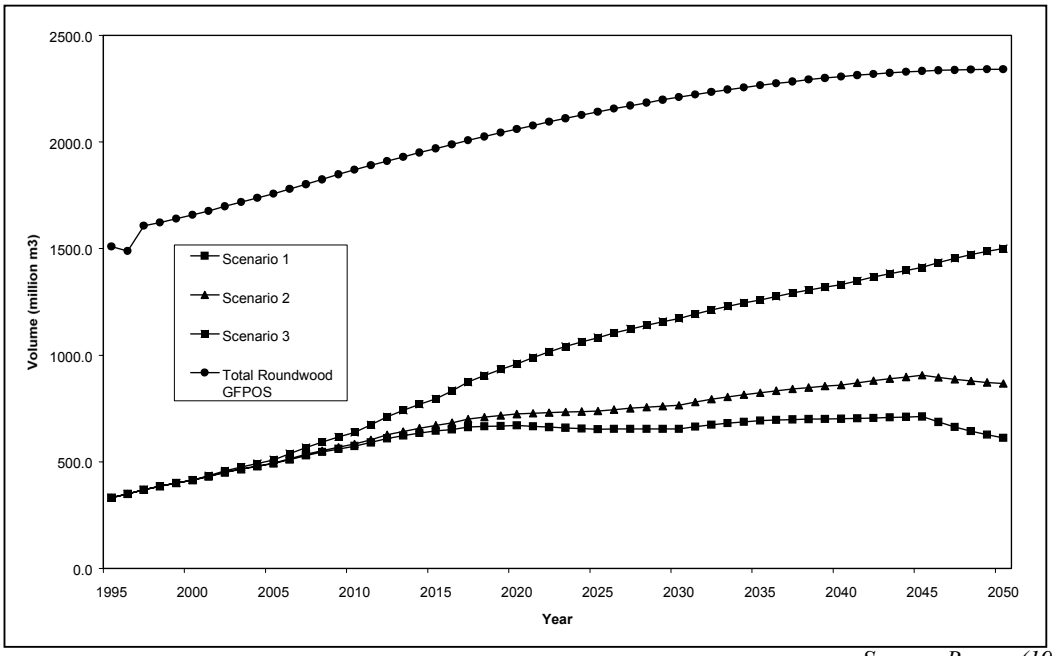
1. There is little difference between the three forest plantation scenarios until 2010. This is because trees already in the ground will determine production over the next decade.
2. The heavy weighting towards the youngest age-classes in the global distribution means that even Scenario 1 (zero new planting) shows a significant increase in wood production from forest plantations. Scenario 1 shows an increase in production from 331 million cubic metres to 712 million cubic metres. Note, however, this growth in plantation production would be insufficient to keep pace with the forecast growth in

roundwood consumption, and additional new sources of wood or fibre would need to be found to supply additional new demand.

3. Scenario 2 increases at approximately the same rate as projected new demand for roundwood. Scenario 2 shows an increase in plantation wood production to 906 million cubic metres. Note, however, that current levels of harvesting in natural forests, recycling, etc. would need to be maintained if no other new fibre sources are found, or efficiency is not significantly improved.

4. Only Scenario 3, with its relatively large landuse implications, would enable forest plantations to substitute for wood production from natural forests. Scenario 3 expands plantation production to 1.5 billion cubic metres, approximately equal to current levels of global industrial roundwood consumption. Under Scenario 3, the industrial forest plantation share of industrial roundwood production is estimated to increase from the current 22 percent, to 64 percent in 2050.

Figure 6: Comparison of projections for industrial roundwood production with three plantation scenarios



Source: Brown (1999)

The long-term production forecast from forest plantations is very sensitive to the assumptions made about future forest plantation establishment rates. Consequently, much is likely to be determined by the future availability of land for new planting and perceptions of supply-demand balances for wood and fibre. In general, it should be expected that plantations will supply a high proportion of feedstock to fibre based industries and for the production of utility sawntimber (particularly, outside Europe). High quality hardwood timbers, especially, are likely to continue to be sourced from natural forests, although plantation grown teak can be expected to become increasingly important.

PRIORITY AREAS FOR FOREST PLANTATION RESEARCH

The analysis to this point highlights a need for continued focus on forest plantation research. If future supply shortfalls are to be avoided, or harvesting in natural forests be reduced, then forest plantation areas are likely to need significant expansion or plantations will need to come significantly more productive. The following offers a brief suite of potentially rewarding research topics.

Data deficiencies: Problems relating to incomplete, inaccurate and obsolete plantation inventory data have already been highlighted. Currently, data weaknesses have significant implications for the accuracy and reliability of production modelling and forecasting. In turn, doubts over the reliability of modelling create uncertainty in public policy setting and for the private sector.

Silviculture and management: Silviculture and management have considerable room for improvement in many countries, particularly in terms of mortality and general neglect. Broader dissemination of best practice

techniques for various species and continuing site-specific experimental trials could lead to extensive improvements in productivity.

Species-site matching: Significant improvements in productivity could also be achieved through greater attention to matching species, provenances and clones to sites. Often successful plantings of a particular species or provenance are merely extended across a range of sites, where varying the species selected or testing other provenances could improve harvests. At the same time, a primary driver of species selection should be intended end-use. The species that grows best may not necessarily yield the highest financial returns or have a recognised use or market.

Genetics: The broad field of genetics offers substantial opportunities for improving forest plantation productivity, though activities such as genetic modification (small scale in forestry) are fraught with controversy. Much work may be required to secure acceptable levels of risk to the environment and allay public fears over controversial activities.

Tree-breeding: There is considerable potential for increasing wood yields though tree-breeding and other fields of biotechnology, though effectively translating the results of laboratory or small-scale research plots to the field is doubtless a major challenge. In view of this, it is distressing that still today, seed for planting in the tropics is generally procured or purchased from the most readily available sources, due to lack of information on consequences and potential losses, due to lack of knowledge of within species diversity and its adaptation to varying environmental conditions, and due to unavailability of quality seed, stemming from institutional weaknesses and lack of technical knowhow in seed collection and handling in many countries which possess these valuable genetic resources (Palmberg 1989). Even more disturbing is the fact that countries, at times, will embark on tree breeding programmes based on haphazardly introduced genetic materials, sometimes of unknown origin and genetic base. Such action can only lead to disillusion and economic losses. Amidst excitement over potential improvements in yields and uniformity of products, sight must not be lost of the dangers posed to forest plantations by climatic variation, abiotic factors, pests and diseases.

Issues of wood quality: Plantation grown timbers are often perceived as being inferior to natural forest timbers, particularly in high value applications or for applications where strength or elasticity are important. In some instances this may be more a marketing issue. From a research perspective, many of these issues may be overcome by applying (or developing new) wood engineering techniques. For example, the development of laminated veneer lumber enables plantation grown timber to be used in high load bearing applications where ordinary sawn beams are insufficient.

Wood utilisation: Much small dimension roundwood is produced in forest plantations, as thinnings, top-logs, or due to economics of short rotations. Much of this timber is used for low value purposes such as posts and poles, low quality sawn timber or pulp. Recovery rates for solid wood processing of small logs tend to be low, and often the wood or fibre is of low quality. In many areas utilisation could be improved by better distribution, or by introducing new processing techniques or technology.

Tree-growing in low forest cover countries: Far greater attention needs to be applied to experimental trials in low forest countries, particularly those where there is a weak "forest culture". Considerable strengthening of research into social, policy and legislative issues, as well as strengthening technology transfer and information dissemination may be required in a number of countries.

Revitalising degraded land: Plantation forests are often proposed as a means of rehabilitating or utilising degraded lands. Further attention needs to be given to species-site matching in this regard, as well as more study of the economic and/or environmental efficacy of such rehabilitative efforts. The need for Environmental Impact Assessments to be carried out prior to implementing afforestation projects on "wastelands" should be noted.

Forest plantation sustainability: Considerable controversy continues over the long run sustainability of forest plantations. While most research indicates that plantations meet "narrow sense" definitions of sustainability (notably maintaining productivity across multiple rotations), considerable further work is required to demonstrate that plantations meet broader sustainability criteria. These will be a key consideration if extensive increases in plantation forest areas are to be achieved. Activities that, for example, promote greater biodiversity in plantations may provide fruitful areas for research. Similarly, attention to multifunctional uses of forest plantations can enhance their social and environmental values.

Policy-related: On-going study and research across a broad spectrum of topics will be required to support national plantation policy development. Diverse issues such as land availability, effectiveness of incentive policies, appropriate ownership structures, social impacts of plantation establishment, and mechanisms for carbon offset schemes require study or monitoring.

CONCLUSIONS

The analysis suggests a central conclusion that the role of plantation forests in meeting future wood and fibre demands will increase during the next 30 years, irrespective of future rates of plantation establishment. Forest plantation wood supplies for the next decade are already largely determined by trees in the ground and, in many countries, a considerable increase in areas of plantation forests reaching harvestable age is expected. Thus, by 2010, the annual yield of plantation grown industrial roundwood is estimated to increase from the current 331 million cubic metres to around 600 million cubic metres. Production of plantation-grown fuelwood is expected to double from the current 8 million cubic metres.

Beyond 2010, plantation production forecasts are increasingly dependent on assumptions of new planting rates, and on assumptions of improvements in annual increments. There is scope, depending on policy decisions and markets, for forest plantations to play a dominant role in industrial wood and fibre supplies. A more likely scenario is probably that the proportion of forest plantation-grown wood will increase, but natural forests will continue to supply a modest majority of industrial roundwood.

The question of where future plantation forest development is most likely to occur remains unclear. At present, many governments remain active in plantation forest establishment, either directly, through state planting programmes, or indirectly, by providing incentives to the private sector. In some instances plantations realising non-market values can justify incentives. In other cases the incentives are merely maintaining wood supply capacity. In any event, under these circumstances, competitive and comparative advantages are not clearly emerging.

The most significant forest plantation increases in the immediate future will be in countries where specific public planting programmes are in force, most notably China and India. In Europe, plantation establishment is likely to be mainly dictated by the life span of incentive policies. Europe is largely self-sufficient in terms of wood-fibre volumes and development of a larger than present plantation-based export trade seems a relatively unlikely development.

South America and Oceania are likely to continue to expand forest plantation areas under the perception that real competitive advantage in plantation growing is held in these regions. The extent to which forest plantations increase in these regions is likely to be dictated by the extent to which this perception is sustained. If plantation revenues are unsatisfactory then afforestation rates in these regions are likely to slow.

Plantation profitability in the southern countries is likely to be determined by conditions in North American and Asian markets and by wood and fibre supplies from forests in these regions. Similarly, if the current trend toward increasing regulation of natural forests increases then forest plantation establishment in both North America and Asia is also likely to accelerate. Of key interest will be natural forest wood supply trends in the US Pacific-Northwest, Canada, Indonesia and Malaysia.

Plantation forest establishment in the former-USSR and Africa seems unlikely to accelerate in the immediate future. In the former-USSR countries, economic difficulties are likely to mean plantation investment will be of relatively low priority, particularly given the extensive natural forest resource in several of these countries. In Africa, the absence of strong infrastructure is likely to remain a significant competitive disadvantage for many countries. It is difficult to see true competitive advantage in plantation investment emerging in many countries, even those that have important industries based on natural forests.

REFERENCES

Ball, J. and Pandey, D. 1998, The role of industrial plantations in future global fibre supplies. *Unasylva*, Vol. 49, No. 193. Food and Agriculture Organization of the United Nations, Rome, 7pp.

Brown, C. 1999, Global Forest Products Outlook Study: Thematic Study on Plantations. Working Paper No. GFPOS/WP/03. Food and Agriculture Organization of the United Nations, Rome, 129 pp.

Campinhos, E. 1994. Sustainable management of plantation forest in the tropics and subtropics. *in* Readings in Sustainable Forest Management, Forestry Paper No. 122. FAO. Rome.

FAO 1995, Forest Resources Assessment 1990, Global Synthesis. FAO Forestry Paper 124. Food and Agriculture Organization of the United Nations, Rome, 46pp.

FAO 1997, FAO Yearbook: Forest Products 1995. Food and Agriculture Organization of the United Nations, Rome, 442 pp.

Leech, J. 1998 (unpublished), Indicative estimates of hardwood volumes for the project "hardwood plantations in the tropics and subtropics". Project: GCP/INT/628/UK. Available from Forest Resources Division, Food and Agriculture Organization of the United Nations, Rome, 40pp.

Palmberg, C. 1989, Research needs in forest tree breeding and improvement in developing countries. Agroforestry Systems *9*:29-35.

Pandey, D. 1997 (unpublished), Hardwood Plantations in the Tropics and Subtropics: Tropical Forest Plantation Areas 1995. Project: GCP/INT/628/UK. Food and Agriculture Organization of the United Nations, Rome, 64 pp.

Shushuai, Z., Tomberlin, D. and Buongiorno, J. 1998, Global forest products consumption, production, trade and prices: Global Forest Products Model projections to 2010. Working Paper No. GFPOS/WP/01. Food and Agriculture Organization of the United Nations, Rome, 333 pp.

UN/ECE-FAO 1998, Preliminary results of the Temperate and Boreal Forest Resources Assessment 2000 (data presented to the Third Ministerial Conference on the Protection of Forests in Europe Lisbon, 2-4 June 1998). UN-ECE/FAO, Geneva, 25pp.