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The Potential for Fast-Growing Commercial Forest Plantations to Supply High Value Roundwood

Ryde James and Alberto Del Lungo

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For further information please contact:

Mr. Jim Carle, Senior Forestry Officer (Plantations and Protection)
Forest Resources Development Service
Forest Resources Division
Forestry Department
FAO
Viale delle Terme di Caracalla
I-00100 Rome (Italy)
e-mail: Jim.Carle@fao.org

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Summary

Several previous studies of the world's forests resources have revealed a number of clear trends. The total area of forest continues to decrease at about 0.22% per year (FAO, 2003). In addition to the absolute loss of area, a considerable, but less well quantified area of forest continues to be degraded due to a number of factors. Counter-balancing that are large areas of well managed natural and semi-natural forests and, comparatively recently, an increase in the area of highly productive forest plantations.

The natural and semi-natural forests are mostly managed for multiple uses and benefits, including for industrial forest products. Forest plantations can be managed for multiple benefits too but many, on sites which allow fast growth, are managed primarily for industrial products. There is an increasing tendency to reserve natural and semi-natural forests for non- extracted benefits such as conservation of fauna and flora. Plantations are seen by many as having a role in providing wood which will substitute for wood from natural forests. Whether forest plantations can fully achieve this role is speculative and while in some countries their area continues to increase in others the expansion seems to have halted.

The area of forest plantations is expanding fastest in Asia where they appear to be designed to provide fibre on short rotations, for paper making. This appears to be the result of commercial decisions resulting from forecasts of increasing demand for fine writing and printing papers in that region.

However the role of forest plantations in providing high value structural timber or furniture timbers is less clear. Currently, these timbers are mostly produced in natural and semi-natural forests over long rotations. Even when forest plantations are established on forest sites which result in fast growth, rotation lengths necessary to produce high value logs may be commercially unattractive. The potential to provide this wood from forest plantations, and therefore to reduce production pressures on natural forests, is less well known.

In this paper we have used a simple formula to calculate the amount of high value structural timber produced by planted forests in the top 30 countries where planted forests are most relevant. The main source of data used for the analysis was the Planted Forest Data Base (PFDB) that provided information on: appropriate species, growth rate, sufficient area and favourable indications of plantation purpose; to estimate future potential to produce high value wood. Potential yields were calculated for a sub-set of 30 countries which together contained 90% of the world's plantation area and most common species. The formula that we used multiplies two different parameters: the stocked area managed for sawlogs by growth rate and an utilisation factor to give volume of saw or veneer logs. An inherent assumption of such a method is that the forest estate is "normal"; but in fact the plantation resource is known to be immature and this method will over-estimate the yields currently available.

The amount of high-quality wood potentially available for harvest from fast-growing commercial forest plantations[1] is about one quarter of that which was produced from all forest types in 2000.

Although the latest estimates report that planted forests in the world account for 187 millions of ha (Global Forest Resources Assessment 2000, FAO 2001), the area of planted forests considered in the present study is a restricted proportion of the total forest plantation area and refers to the sub-set being the most "commercial" from the point of view of investors.

While the data and the methods used can only provide a broad estimate of the potential for forest plantations to substitute for natural forests, never-the-less it is clear that the potential of the current resource is limited. This means that natural and semi-natural forests will remain important sources for forest products, that prices for this class of wood might rise as demand increases, that because there has been increased privatisation of forest plantations it cannot be assumed that increases in prices will result in increased establishment of forest plantations aimed at producing saw or veneer logs. This is because the private sector generally will not invest in new forest plantations for sawlogs. New plantation forests managed to produce sawlogs (over rotations of 20-40 years) have mostly been established by governments or with government assistance in the past.

It is recommended that further studies of the potential for plantation forests to provide high value wood be carried out as data sources improve. That governments, especially of the important 30 countries identified here, consider the implications of this study when formulating their own plantation policies. In the absence of government action, it is possible that private investment will be restricted to short rotation crops which are more “commercially” viable. Without further expansion, the ability of forest plantations to relieve the pressures on natural and semi-natural forests to provide increasing amounts of wood products will be limited.

Introduction

Throughout the world, the amount and use of all types of forests remains controversial. There is pressure on forests to produce increasing amounts of extractable products of all kinds and also pressure for them to be reserved for other uses such as maintenance of biodiversity and preservation of water and soil values. Forecasts of the amount of wood products which forests can produce are also subject to uncertainty. The most recent authoritative statement on the condition of the world’s forests (FAO, 2003), notes that the annual loss of world forest area has amounted to 0.22 percent – every year during the 1990’s. In addition to loss of area there is a less easily defined area of forest which has been degraded by over-exploitation or other causes. The same report noted that “there is a

[1] The term "fast-growing plantations", as used in this paper, refers to plantations which exhibit fast growth, are of commercial species and are being managed over a rotation length or have a declared purpose of management that indicates commercial intentions. Such plantations are a subset of the world's "industrial plantations"; as they are defined by the FAO

need to review the complementarity of products from different forests". The issue of what benefits society expects from forests and the changing nature of societal expectations has been noted for some time. For example in an earlier report (FAO, 1997) it was stated that while the forest resources of the world were generally in balance with expected demand for extracted forest products, "This presupposes forest policies which allow continued industrial exploitation while environmental and recreational needs are also met". By 1999 this had changed so that it was said "the area of natural forest which was currently available for wood production is diminishing because of deforestation and the designation of some forests as strict conservation areas" (FAO, 1999).

Counter-balancing this reduction in the area of natural forest has been an increase in the area of forest plantations. It has been suggested that this increased forest planting "can help compensate for an anticipated reduction in production from natural forests" (FAO, 1999) and in some countries (e.g. Brazil, Chile, New Zealand, and Zambia), production of industrial roundwood from forest plantations already exceeds that from their natural forests. Currently forest plantations make up only about 5% of all forest land (FAO, 2001), but although it is likely that this land is more productive than the natural forest in each country, it is not known how much this forest could substitute for areas of natural forest. However one commentator has stated that to provide for future world wood needs, "an additional 100 million hectares of managed plantation forests will be required" (Sutton, 1999). It seems clear that the role of forest plantations as source of wood products will continue to increase.

This raises the question of which of the industrial forest products, now obtained from natural forests, can be provided by forest plantations. Table one shows the world production – from all forests – of industrial wood over the last ten years. Over this time, total wood production, of all types, has increased by 6%. Production is still dominated by coniferous sawlogs which was 42% of all industrial wood production in 2002 and has grown a total of 11% since 1992. However the fastest growing category is non-coniferous pulpwood which grew 30% over the last ten years. The amount of wood extracted for "other" uses reduced appreciably and production of non-coniferous sawlogs also reduced over the ten period.

Table 1: World Production of Industrial Roundwood (million metric tonnes)

Product and wood type	1992	2002	Percent of 2002	Percent change, 1992 - 2002
Sawlog/veneer a) coniferous	599	666	42	+11
b) non-coniferous	305	282	18	-7
Pulpwood a) coniferous	252	289	18	+15
b) non-coniferous	152	196	12	+30
Other industrial a) coniferous	76	61	4	-20
b) non-coniferous	99	85	6	-14
Total World a) coniferous	927	1016	64	+10
b) non-coniferous	556	563	36	+1
All Industrial Wood	1483	1579	100	+6

FAO 2003: Online Statistical Database

The development of a globally significant area of forest plantations is a relatively new phenomenon and on a global basis the age-class structure is biased towards the younger age classes (Brown, 2000). "Estimates suggest that (in 1995) some 54% of all industrial forest plantations comprised trees younger than fifteen years", (FAO, 2001). It is difficult to interpret these data in terms of intended land use. For example as well as for production, it has been estimated that up to half the area of planted forest may have been intended for uses other than wood production, (Carle and Holmgren, 2003). Recent new planting has been concentrated in South Asia where there has been an increase in the planting of short-rotation non-coniferous species. This is almost certainly a response to the increased demand for non-coniferous pulp and the increased production of non-coniferous pulpwood shown in Table 1, but sawlogs are amongst the objectives of non-coniferous forest plantation establishment in some countries (FAO, 1999).

Silviculture of forest plantation crops

In silvicultural terms pulpwood is easier to produce than attempting to provide high value logs to be sawn, sliced or peeled. The forest plantations will also provide a better industrial feedstock than wood from a natural forest. For pulpwood crops, the main silvicultural requirements are: selecting a high quality site, good establishment practices using genetically improved stock and efficient logging and transport to mill or export port. While these conditions are not as easily achieved as this simple description may make them seem, they are more easily accomplished than growing high value sawlogs which requires – in addition to the all the previously mentioned conditions – silvicultural manipulation to enhance log size while restricting the defects associated with branches (i.e. knots).

In the natural forest, branches are either shed by a biological process (for a few genera such as *Eucalyptus*) or become suppressed and die, eventually rotting and falling off. The result, over many decades, can often be defect-free timber of high value for uses requiring both strength and good appearance. To achieve the same results within an economic time-frame in a plantation requires either pruning to remove the branches which would eventually form knots; or establishment at a high stocking density and delayed thinning to suppress branch size and lead to early branch death. In principle, the techniques can be applied to either coniferous or non-coniferous species. However coniferous are more frequently used for construction and high value requires that knot size be restricted; not necessarily that knots be eliminated entirely as with pruning. Both methods incur costs. For pruning, there is the direct cost of the operation and that of associated thinning to encourage the growth of defect wood. Manipulating stand density to reduce knot sizes requires the retention of high stocking rates, using high cost delayed thinning and that the rotation length be extended in order to obtain merchantable tree diameters.

The decision to grow high value wood in a plantation is different in kind from that of deciding to grow a pulpwood crop. Firstly the response time is longer. Pulpwood regimes may be as short as seven years and ten years is common. This means that forest planning has a planning cycle of about the same length as long term business planning. By contrast, the shortest rotation length in which high value wood may be grown is probably about 20 years for some species and as much as twice that for others. Therefore a decision to grow pulpwood can be made as a response to measurable market demand, but a decision to plant and manage a forest to supply high value wood will be made over a much longer time frame than projections of demand and response usually made in business.

Secondly, although conventional measures of profitability such as calculations of Net Present Value using discounted cash flow analysis can often show that it is profitable to grow wood for high value purposes; (see ABARE, 1999); these are not the criteria on which purely business decisions are usually made. Hence while purchase of forest plantations by the private sector has frequently been made (see FAO, 1999) establishment of forest plantations rarely occurs without Government assistance; especially for long term projects.

Thirdly, the complexity of management is different between the two product objectives. While the principles are well known, accurate prescription and more particularly, accurate scheduling and application of treatments requires a level of expertise and infrastructure very much greater than that required to grow wood for reconstituted products. Last, the longer time period also magnifies the risk that the project will not be completely successful. For example the silviculture required to grow knot-free timber using radiata pine usually requires five silvicultural interventions: three pruning operations and two thinnings. Success implies that management has the expertise to schedule and apply all five treatments at close to the optimum times. While this expertise is presents in all of the three countries which grow large areas of radiata pine, (Australia, Chile, NZ) it is only carried out on a major scale in New Zealand where considerable investments have been made in research and research extension. The conditions which stimulate the establishment of crops aimed at producing pulpwood are different from those which lead to the establishment of longer rotation crops. It is therefore useful to have an assessment of the potential of forest plantations to provide high value wood, separately from the increasing tendency to grow forest plantations for pulpwood which has now been documented.

Stands in natural forests which can supply high value wood are often those – which by their maturity – are also most capable of supplying “unpriced products” such as natural beauty, water and soil protection and habitats for flora and fauna species which should be conserved. Natural forest stands tend to develop wood with features recognised as “high value” such as large log sizes yielding strong and/or decorative defect-free wood, over a very long time. If the wood supply from these stands were to be replaced by wood from forest plantations, then much of the controversy surrounding the use of forests could disappear.

Previous Estimates of Future Wood production

The FAO has been producing long term projections of future consumption, production and trade in forest products since 1947. More recently the two main kinds of projections,

projections of future demand and projections of future production have been harmonised so that on a world scale they are equal thus ensuring "data consistency and coherence of projections", (Zhu *et al*, 1998). This involved the development of a Global Forest Products Model and this model has been used to project both production and consumption for the years 2000, 2005 and 2010. The model assumed that demand for forest products in each country would change according to income but that supply would shift according to a given scenario. It also assumed that technology would change, thus influencing how wood was used (i.e. how much re-cycling would take place) and that capacity would increase or decrease with a level of new investment which depended on past production and profitability. Long run production was related to both market and political forces. The world was considered as four regions: Africa, Asia, America and Europe, but ultimately projections were given at country level. The model system was based on linear programming (optimisation) and solved the market equilibrium by maximising the value of the products, less the cost of production, subject to material balance and capacity constraints in each country, each year.

Production and consumption of world industrial roundwood was projected to increase from 1.5 billion cubic metres in 1994 (actual) to 1.9 billion cubic metres in 2010; a rise of 26% over 16 years. Sawnwood (and veneer logs) were projected to increase from 413 million cubic metres to 501 million cubic metres over 16 years; an increase of 21 %.

In 1999, the Australian Bureau of Agricultural and Resource Economics (ABARE, 1999) published results of a study it had commissioned from Jaakko Pöyry Consulting on the Global Outlook for Plantations. This study carried the projections of wood supply further up to 2040 and specifically considered the proportion of the world's wood which could come from plantation forests. On a whole of world basis their projections closely agreed with those of Zhu *et al* (1998). The estimates are summarised in Table 2.

Table 2: Projected Supply of Roundwood and Potential Contribution of Forest Plantation. (million cubic metres per year.)

	2000	**2020**	**2040**
World Supply (All Forests)	1,800	2,200	2,275
World Supply (Plantations)	624	969	1043
Percent by (Plantations)	35%	44%	46%

ABARE, 1999

A regional allocation of projected supply was also given which showed that over 40 years, growth was expected to be greatest in Africa (156%) and Asia (100%); although Africa started from a lower base. No estimate was made of the potential for production by different wood quality classes. Never-the-less the common theme of the increasing relative importance of forest plantations as a source of industrial wood was reinforced.

Another set of projections of future wood supply was given by Brown (2000). He analysed the status and growth rate of forest plantations throughout the world to determine which could potentially provide industrial roundwood. He concluded that the age class distribution was towards immature ages and that until at least 2010, potential production would increase irrespective of any future expansion of stocked area. Brown's calculations were based on an analysis of the potential of each region according to estimates of stocked area, age class distribution and likely levels of increment. He applied three scenarios for rates of future new planting to the current resource estimates and derived estimates of future production up to 2050. Values from his "most likely" scenario are given in Table 3 below.

Table 3. Projected World Supply of Roundwood from Forest Plantations (million cubic metres)

Year	All Wood	Industrial Wood
2000	546	415
2010	746	583
2020	911	724
2050	1,115	868

Brown, 2000

The figures for this scenario (number two) are comparable with those given ABARE (1999) but slightly less for each common year and are given down to region or country level in the publication.

Tomberlin and Buongiorno (2001) took Brown's (2000) estimates and, making the assumption that forest plantations will be harvested in preference to natural forest, they combined them with the estimates for production/consumption from the Forest Products Outlook Study by Zhu *et al* (1998). They adopted the same assumption as Zhu *et al* (that production will equal consumption) and used the future projections to derive natural forest production as a residual volume. They concluded that "the projected supply from forest plantations is insufficient to prevent a gradual increase in the harvest of natural timber". They were able to qualify this conclusion by region; concluding that China would be "the most successful of all countries in reducing harvests from natural forests".

They discuss their conclusions from the point of view of substitution of forest plantations for natural forests and the conversion of those forests to be primarily for conservation. As well as the shortfall in wood supplies, even under the favourable assumption that forest plantations will be felled in preference, Tomberlin and Buongiorno (2001) list other reasons why substitution will be restricted. They include: the unequal distribution of favourable conditions for plantation forest across countries, and the implication that the market will act rationally and some countries will specialise in timber production. They also note that much of the recent increase in forest plantations in Brazil, Chile and the USA is specifically for market pulp and that species grown for this purpose "are unlikely to substitute for logs from natural forests". They note that "the large logs required for boards and panels come mostly from older forests" and that the usefulness of plantation timber as a substitute for this wood is limited (Tomberlin and Buorngiorno, 2001). Finally they mention that some object to forest plantations citing a variety of environmental and social concerns and conclude that the effectiveness of forest plantations as a substitute for natural forests will be a function of public policy as well as timber availability.

The situation regarding the source of future supplies of industrial roundwood is subject to considerable uncertainty. For example Tomberlin and Buongiorno (2001) quoted only one of three scenarios explored by Brown (2000) in his work. Brown calculated the effects of these scenarios for both consumption and production of industrial roundwood. He noted that “until 2010, potential industrial roundwood production from industrial forest plantations increases by about the same amount (in volume terms) as projected total future consumption”. This implies that potential future plantations have the potential to meet the projected increase in demand for industrial roundwood (at the broad level) in the near term. Beyond 2010, the contribution that industrial forest plantations will make is dependent on the extent to which consumption continues to increase and on future levels of forest plantation expansion.

The scenarios calculated by Brown illustrate his point. If the scenario for the greatest increase in consumption is compared to the scenario for the greatest increase in production from industrial plantations, then the short term balance identified by Brown will continue after 2010. However other pairings of scenarios (eg highest rate of increase in consumption with lowest rate of increase in industrial roundwood production) would lead to the conclusion that consumption will outstrip supply in the long term. It is technically difficult to forecast the extent to which the area of fast-growing commercial plantations will increase in the future and this has been discussed in detail before by Whiteman et al 1999 and Whiteman and Brown 1999. In the latter paper the authors also mention the problem of estimating the non-biological factors which affect the level of production. These include: harvesting costs, product prices, non-financial forest management objectives and national forest policies. As well there are the effect of changes in industrial processing such as improvements in efficiency, the levels of recycling (eg waste paper recovery) and the use of non-wood materials as feedstocks for paper making.

The definition of "commercial" plantations used here implies that forest sites will need to be of at least average quality by world standards to support "fast-growth". Such sites will be subject to competition from other land uses such as agriculture. Restoration of degraded natural forest is a possible source of new land for such plantations. Reduction of consumption by the use of wood substitutes, recycling of processed wood or the use of technology to upgrade roundwood which may have been considered to be of low quality are other ways in which the difference between consumption and production could be reduced. Despite the uncertainty which must surround such projections, it seems safe to conclude that roundwood from fast-growing commercial plantations could replace much but not all of the wood currently obtained from natural forests and other types of planted forests. "

Definitions and Data Sources

The term "plantation forest" has been surprisingly difficult to define on an agreed, international basis. The way in which definitions have changed with time has been thoroughly documented in FAO Working Papers. Del Lungo (2001) describes the definitions for four FAO data-sets. This includes a chart which makes clear the relationship between the each of the databases from four major surveys; (in 1980, 1990, 1995, and 2000) and how these may be compared with each other. A paper which looks towards future harmonisation of definitions is that of Carle and Holmgren (2003) in which the intensity of intended management is related to the definition of forest type. Three overlapping types of forest are illustrated. Natural Forest is where the forest is based on natural regeneration alone, semi-natural forest where the process of regeneration is assisted by planting or seeding where necessary and intensively managed forest which is almost entirely planted. These three main types of forest overlap in practice and eight forest types have been defined in terms of their "naturalness". In many countries, the technique of planting is only one of many techniques employed to ensure that regeneration is successful, in forests which will otherwise be managed as natural forests. The managers of these forests do not wish to characterise them as "Plantations", a term they reserve for intensively managed forests with objectives similar to agriculture. This view is convenient for the present study. Forests which are natural or semi-natural comprise 95% (by area) of the world forestry resource. This study is concerned with the 5% which are unambiguously forest plantations.

It is the objective of the current investigation to provide an estimate of the extent to which commercially viable forest plantations might provide wood which could substitute for the high value wood currently obtained from natural forests.

Not withstanding the difficulty of defining plantations, much is known about the planted forests of the world. For example it is recognised (Carle *et al*, 2003) that the importance of wood supply from plantations is greater than that indicated by their share of stocked area and that this importance is increasing with time. It has also been noted that different countries have different strategies for forest plantation development and that past studies of plantation potential have "differed greatly from each other".

The Planted Forest Data Base

In carrying out this analysis, the primary source of qualitative data on the plantation forest resource was the Planted Forest Data Base (PFDB). The PFDB was designed to combine new incoming data, with the already existing information available at FAO head-quarters, into a better standardised and homogenised format. PFDB was also meant to supply FRA, and users, with additional data and references on planted forests. Both PFDB and FRA 2000 data-sets had the same breakdown of countries; adopted the same species definition ; used the same methodology in assessing data reliability and adopted the same definitions of gross and net area. Additional data contained in the PFDB are: mean annual increment (MAI), rotation length, purpose of planting, ownership category and rate of annual planting. Within each country the data were specified by species where relevant. Because the definition of forest plantations has been so problematic in the past and because FRA 2000 results have been endorsed by FAO member countries, the definitions of forest plantation and forest plantation area used in FRA 2000 were also adopted for the PFDB. However in PFDB the number of species was extended to more precisely quantify some which had been listed under broader categories in the FRA 2000 but which are recognised as important. Ownership was defined as being: Public, Private Corporate, Private Smallholder or Unknown. This divided the Private category used in FRA 2000 into two. Likewise the purposes of planting listed in the PFDB is a sub-division of those used in FRA 2000. Although it was attempted to divide "planting" into four categories: Afforestation, Re-afforestation, Both and Unknown; the data were generally not available. MAI and rotation lengths data were collected from original sources and quote exact figures for these parameters. Minimum and maximum increments were not calculated and figures given are those quoted directly from referenced sources.

The data from which the PFDB was developed came from many sources. The greatest number were collected from extensive searches under taken in the published literature as well as less formal sources such as conference proceedings and FAO working papers but also the same sources from which the FRA was developed were included. These references are incorporated into the database itself as well as an estimate of the reliability of each source.

The database is developed in "Microsoft Access" software which allows interrogation by properties and hence aids analysis of the dataset. A description of the PFDB is given in Carle *et al*, (2003) and in greater detail in Del Lungo (2003). The PFDB represents a considerable advance on earlier versions. As well as data on area it contains, for 520 species; 1759 observations on planting rates and 2885 observations on productivity. In terms of gross area the number of observations (2388) is 1.7 times that of the previous dataset, FRA 2000.

Preliminary analysis as shown that:

- Most countries with large plantation areas are in Asia;
- All countries which have large areas of plantation forest are expanding that resource;
- Throughout Africa, most countries with medium sized plantation resources are not currently expanding their resource;
- In many countries in which there is a decreasing forest plantation area there is also civil unrest. (Carle *et al*, 2003).

The authors further noted that development in plantation forestry throughout the world was becoming polarised; countries which already had substantial areas of planted forest were increasing their resource while the reverse was happening in those countries which had a small stocked area of plantations.

The new data set also has limitations and these have been outlined in Carle *et al* (2003) and discussed in greater detail in Del Lungo (2003). The problems mainly revolve around the non-reporting of information or reporting which did not conform to the definitions used in the database. For some applications these shortfalls could prove limiting, however the current PFDB represents a considerable improvement on previous data sets in that it has now become possible to link qualitative and quantitative information. As noted by Del Lungo (2003) further information is required before users can derive estimates of volume.

Methods of Investigation

The overall objective of attempting to derive the productive capacity of plantation forests to produce high value wood has already been stated. It is intended that this estimate be restricted to those forests which could produce the wood within generally accepted definitions of commercial profitability. For the purposes of this investigation "high value" has been defined as wood of sawlog or veneer log quality. Where data permits the sawlogs will be defined as being of greater than 20 centimetres small end diameter. It is acknowledged that logs of smaller diameter are sometimes sawn but it is contended that these are not really of "high value" and that logs of that size are often interchangeable with pulplogs. An exception is that for species of very high value, such as Teak, utilisation of logs down to lesser diameters were incorporated in to the calculations (see appendix 2).

The definition of "profitability" is problematic. There are few published references to profitability which could be applied to a national or even sub-national resource database. Instead a series of filters were applied to the PFDB database which were intended to act as surrogates for measures of profitability. First, using the ability to query the database we separated out the countries with the greatest area of forest plantation resources. It was known from earlier work (Carle *et al*, 2003) that expansion of the resource was only occurring in countries which already had large resources and we surmised that this also indicated that those forest plantations were also judged to be profitable. We then used a value of MAI greater than 14 cubic metres per hectare to discriminate between "fast" and slower growing forest plantations. This value has been used by Sutton (1984, 1991) and others for some time for this purpose. Lastly rotation lengths between 20 and 40 years were used to separate forest plantations which were aimed at providing saw and veneer logs from those where the product objective was pulpwood. Criteria used to judge profitability vary and many countries which grow forests which fall outside the criteria used here will be satisfied with their profitability. This will be especially so where measures of profitability include benefits in addition to the simple production of extractable, industrial forest products. The reason for restricting "profitability" to a narrower definition is to focus on the provision of wood products as an objective in itself, so that policy decisions which concern additional afforestation might be addressed from that perspective. It is recognised that in many countries, afforestation occurs for a variety of objectives and that in a great many cases these will include "unpriced" products; including those with environmental and social values. These are recognised as legitimate. However there has been a trend towards the privatisation of public forests throughout the world (FAO, 1999) and this has placed emphasis on managing forest plantations for commercial values. By focussing on profitability in a narrower sense it hoped to indicate the potential for fast-growing commercial forest plantations to release natural and semi-and natural forests, managed for mixed objectives from part of the task of providing commercial wood products.

Further automatic filtering of the data was not possible because the data were not sufficiently robust. However the process outlined was sufficient to identify countries which had resources relevant to this study. As a result of the automatic filtering the data base was successfully reduced to include only thirty countries and 17 species which covered 95% and finally 90% of the total world forest plantation area.

In order to determine which countries had a forest plantation resource which was potentially able to yield sawlogs, other criteria were applied. These were applied by careful inspection, country by country, of the database listed under each of the 30 countries previously identified as having substantial forest plantation resources. However, before any criteria were applied, the database was inspected for consistency. In particular we looked for consistency between national and sub-national sets of data and consistency between area by national total and total by species. We eliminated duplicate listings where these were found and gave preference in these cases to data from the most recent and/or most reliable sources. Lastly, for countries where the data reported in the PFDB were suspected as being deficient, data were compared with that listed in FRA 2000, the previously agreed international standard forest plantation database. In some cases, where the databases differed greatly, Total area was taken from the FRA 2000 database and a percentage allocation of species derived using the species breakdown from the PFDB. Such judgements are ultimately subjective but to eliminate this effect as much as possible, this stage was carried out by both authors acting together.

The criteria used for further discrimination were that the purpose of the forest plantation was listed as being for “industrial sawlogs” and that the forest plantation was to be managed over a rotation length of between 20 and 40 years. Due to gaps in the information recorded for each country it proved impossible to use these criteria in a totally automatic fashion. For example many of the records stated that the purpose of the resource was “Industrial unspecified” or “unknown” and some rotation lengths were stated to be less than 20 years but the purpose of the resource was listed as for sawlogs. This latter case was common where the listed MAI was high and obtaining a product of sawlog size in less than 20 years would have been possible. Although the intention of the filtering was to limit the database to that which was manageable in terms of subsequent calculations, some criteria were relaxed at the inspection stage. For examples species outside the list of the 17 most common were included if they were judged to be of local importance. In general this meant that the resource area within the country was substantial; “substantial” being defined as about 50,000 hectares, and they otherwise satisfied the criteria for a sawlog resource. As well, Teak (*Tectona grandis*) was always included where listed. The purpose of teak plantations is to provide a high value resource and the way in which it is managed (at low rates of stocking, often in conjunction with other crops) means that, on a per hectare basis the productivity was usually below the 14 cubic metres per hectare cut-off and an automatic application of this criterion would have excluded that species.

Volume Calculation

For all 30 countries in the final dataset, volume was calculated by species (or species group where applicable). The method was to use a simple arithmetic procedure explained by the formula below:

$$Vol\ HQ = GA * RF * PASP * MAI * SA$$

Where:
Vol HQ = is the volume of high value wood, (as defined in the present paper)
GA = gross planted area from the PFDB (ha)
RF = factor to reduce gross to net area = 90%
PASP = Proportion of wood allocated to sawlog production, empirically estimated (%)
MAI = Mean Annual Increment from PFDB (m3 * ha-1 * year-1)
SA = Sawlog Allocation, the proportion of wood of sawlog quality or better estimated through literature research (%) (see Appendix 2)

As an example, the first calculation was for *Eucalyptus grandis* in Argentina with the following parameters:
GA = 393 400 ha
RF =90% = 0.9.
PASP = 50% = 0.5, because only half of the volume was judged to be managed for sawlogs, (the remained being managed for pulpwood alone)
MAI = 20 $m^3 * ha^{-1} * year^{-1}$
SA = 38% = 0.38
Thus the formula was:

$$Vol\ HQ = 393{,}400 * 0.9 * 0.5 * 20 * 0.38 = 1{,}345{,}428\ m^3 * year^{-1}.$$

The figure for the MAI was obtained from the PFDB where growth rates are listed for each country by species. The reduction factor for sawlog proportion (SA) was obtained from the literature and a full explanation of the derivation of these factors is given in Appendix 2. Other factors however are matters of judgement and the effects of these on the volume estimates are discussed after the presentation of results.

Note that the volume obtained by this method is a volume that would be "potentially" available if the forest plantation resource from which it was drawn was a normal forest with equal areas in each age class. It has already been noted that the forest plantation resource of the world (in 1995) had an age class distribution biased towards the younger age classes (Brown, 2000). This will have a marked effect on the availability of future volumes and the forecasts made here are those which could be expected to occur in perhaps 5 to 10 years when the – now immature – age classes become available for harvest. In all types of forest production, logs of an intrinsically high value product quality can be used for a less demanding purpose; but not the reverse. That is sawlogs can be pulped but pulplogs cannot be sawn or peeled. The term potential also includes the possibility that in a real market the logs will be used for a lower quality purpose than their properties would permit.

Results

<u>Area of plantations</u>

Previous work (Del Lungo, 2003) had shown that the 30 countries with the greatest area of forest plantation accounted for 93% of total stocked area. Accordingly the database was arranged in order of plantation area and the "top 30" noted. The reference area first used was that listed for each country under the FRA 2000 database, because this is the agreed standard. However, because the area data in the PFDB are not necessarily the same for all countries as that in the FRA 2000 dataset and because the areas in the PFDB were those ones used in further analysis, the "Top 30" countries were also identified according to areas listed in the PFDB dataset. When the two datasets were compared there was much commonality between the two sets but in total 41 countries were listed at least once. These data were again filtered such that countries which did not have at least one species in their dataset with a recorded MAI of at least 14 cubic metres per hectare were not included. Fortuitously this reduced the dataset to 30 counties again. The most important plantation countries as derived from the FRA 2000 and PFDB datasets are compared in Table 4 below. It should be noted that the differences between the lists is mainly a reflection of the different definitions applied to forest plantations and the management intensity implied by that definition. In particular it should be noted that method used to derive the last column was intended to provide an indication of the financial profitability of forest plantations, in commercial terms. Only forest plantations from countries in the last column were included in subsequent calculations. In general it was noted that forest plantation areas for most individual countries were greater in the more recent PFDB than for the FRA 2000 but that the total area for the Top 41 was smaller. About half this difference can be explained by the differences between the area data for China and India in the two data sets.

The data were not of sufficient quality to carry out all of this filtering entirely automatically. For example, Venezuela and Vietnam would have been eliminated because the values for listed MAI in the PFDB were less than 14 cubic metres per hectare per annum. Both were retained upon inspection of the results. However the elimination from the list, of all other counties was logical when their climatic conditions were considered. Results have been presented in alphabetical order to facilitate comparisons between the different sources of data. When comparing the different countries by stocked area the order changes according to the database used; and this is clearly an artificial result. However, of the Important 30 countries, Brazil, United States, China, Indonesia, India and Thailand are consistently at the head of the lists when arranged by stocked area, each with about four million hectares or more of forest plantation area. At the other end of the Important 30, Cuba, Turkey, Kenya, Bulgaria, and Madagascar have less than two hundreds thousands hectares or less of planted forest (Table 1, Appendix 1).
It was originally intended to further reduce this database by restricting consideration of production to only the few most important species, by area. Data were inspected by country and Unspecified was removed as a "species" type. A total of 95 species were present in the forest plantations of the newly defined "Important 30" countries; although in this case the term species includes taxa such as *Pinus spp*, *Populus spp*. and

Eucalyptus spp. By arranging the database in order of stocked area by species and analysing the result it was found that 90% of the stocked area in the Important 30 countries was planted in just seventeen species. Results of this analysis are given in table 5 below. The data used for volume calculations were however not restricted to these species alone as inspection of the data by individual countries showed that some species, represented by minor areas, were of local importance.

Table 4. The Thirty Countries with Largest Areas of Forest Plantations; listed by data-sets[2].

Top 30 FRA 2000[3] *(source Del Lungo 2003)*	Top 30 PFDB[4]	"Top 41"	Final important 30[5] (PFDB >14m ^{3} /ha)
Algeria	Algeria	Algeria	
Argentina	Argentina	Argentina	Argentina
Australia	Australia	Australia	Australia
Brazil	Brazil	Brazil	Brazil
Bulgaria		Bulgaria	Bulgaria
Chile	Chile	Chile	Chile
China	China	China	China
	Cuba	Cuba	Cuba
	Ethiopia	Ethiopia	Ethiopia
France		France	
India	India	India	India
Indonesia	Indonesia	Indonesia	Indonesia
Iran		Iran	
Japan	Japan	Japan	
	Kenya	Kenya	Kenya
	Korea (DPR)	Korea (DPR)	
	Korea (Rep)	Korea (Rep)	
	Madagascar	Madagascar	Madagascar
Malaysia	Malaysia	Malaysia	Malaysia
	Morocco	Morocco	Morocco
Myanmar	Myanmar	Myanmar	Myanmar
New Zealand	New Zealand	New Zealand	New Zealand
Nigeria		Nigeria	Nigeria
	Norway		
Pakistan	Pakistan	Pakistan	Pakistan
	Peru	Peru	Peru
Philippines		Philippines	Philippines
Portugal		Portugal	Portugal
Russia		Russia	
	Rwanda	Rwanda	
South Africa	South Africa	South Africa	South Africa
Spain		Spain	Spain
Sudan	Sudan	Sudan	Sudan
Thailand	Thailand	Thailand	Thailand
	Tunisia	Tunisia	
Turkey		Turkey	Turkey
Ukraine		Ukraine	
United Kingdom		United Kingdom	
United States		United States	United States
	Uruguay	Uruguay	Uruguay
Venezuela	Venezuela	Venezuela	Venezuela
Vietnam	Vietnam	Vietnam	Vietnam

[2] *Notes: China refers to the Peoples Republic of China, Iran refers to the Islamic Republic of Iran, Korea (DPR) refers to the Democratic Peoples Republic of Korea and Korea (Rep) refers to the Republic of Korea.*
[3] Top 30 countries with the greatest area of forest plantation derived from FRA 2000 estimates
[4] Top 30 countries with the greatest area of forest plantation derived from PFDB estimates
[5] Final important 30 countries after comparison analysis of both FRA and PFDB Top 30 countries and further filtering

Table 5 Forest Plantation Species in Order of Importance by Stocked Area

Species (or genera)	Gross Area (World) (000 ha)	Cumulative Area (%)
Pinus spp.	**12 186**	**21**
Hevea brasiliensis	**10 196**	**39**
Eucalyptus spp.	**7 886**	**52**
Populus spp.	**6 395**	**63**
Tectona grandis	**3 921**	**70**
Pinus radiata	**3 799**	**77**
Eucalyptus grandis	**2 148**	**81**
Pinus merkusii	**902**	**82**
Pinus taeda	**887**	**84**
Acacia nilotica	**802**	**85**
Eucalyptus globulus	**614**	**86**
Acacia auriculiformis	**590**	**87**
Eucalyptus saligna	**509**	**88**
Pinus elliotii	**450**	**89**
Pinus Caribaea var hondurensis	**414**	**90**
Gmelina arborea	**326**	**90**

Problems with data have been discussed elsewhere (Carle and Holmgren, 2003, Carle *et al*, 2003). These have mostly been concerned with definitions of area. It should be noted that definition of species is also a problem; especially when it comes to assigning growth and productivity to a taxonomic unit.

Potential Volumes

Potential volumes are given for each country in table 6, by coniferous and non-coniferous species.

Table 6. Potential Availability of High value Wood from Forest Plantations, by Type, (coniferous/ non-coniferous) (volumes of roundwood, 000 cubic metres per annum)

Country	Coniferous	Non-coniferous	Total
Argentina	2 994	1 345	**4 339**
Australia	8 142	431	**8 573**
Brazil	13 018	3 019	**16 036**
Bulgaria		295	**295**
Chile	16 870	163	**17 033**
China	156	27 258	**27 414**
Cuba	723	105	**828**
Ethiopia	1 010	392	**1 402**
India	1 042	12 647	**13 690**
Indonesia	10 318	10 095	**20 413**
Kenya	1 298	41	**1 338**
Madagascar		5	**5**
Malaysia	55	2 050	**2 105**
Morocco	549	222	**772**
Myanmar	118	2 188	**2 306**
New Zealand	18 378	65	**18 443**
Nigeria	55	3 011	**3 065**
Pakistan	214	1 496	**1 710**
Peru		476	**476**
Philippines	124	4 105	**4 229**
Portugal		486	**486**
South Africa	8 287	2 185	**10 472**
Spain	9 661	686	**10 346**
Sudan		130	**130**
Thailand	930	6 781	**7 711**
Turkey	31	1 614	**1 646**
United states	77 393	393	**77 785**
Uruguay	297	1 493	**1 790**
Venezuela	1 864	373	**2 237**
Vietnam	823	870	**1 693**
World total	**174 348**	**84 419**	**258 767**

Note: Totals do not add exactly because of rounding

Some of the main points from the table are: The United States of America is forecast to be the largest producer of wood from forest plantations at 77 million cubic metres per

annum. This is much greater than any other nation; for example the country with the next largest potential production is the Peoples Republic of China with less than half the level of production forecast for the USA. Other large producers are Brazil, Chile, India, Indonesia, New Zealand, South Africa and Spain; all of which are forecast to have the potential to produce more than 10 million cubic metres of high value wood per annum. Most countries produce either conifers or non-coniferous but not large quantities of both. The only exception to this is Indonesia which is forecast to be potentially able to produce about 10 million cubic metres per annum of both wood types.
A more detailed breakdown of production is given in Appendix 2 where potential supply is forecast by species for each country. This shows that nearly 8 million cubic metres per year of Rubberwood (*Hevea* brasiliensis) could potentially be produced. Rubberwood is a comparatively new species as far as wood production is concerned. Its potential for timber production is described in Balsiger *et al* (2000) and although its contribution to overall world wood supplies has been discussed (ABARE 1999, Carle *et al* 2003), estimates of production in terms of roundwood volume were not provided.

<u>Comparison with current production</u>

The latest data for Forest Production are given in the FAO On-line database. Actual production of high value (i.e. saw and veneer logs) wood from all forest types is compared to predicted potential supplies from forest plantations.

Table 7. Comparison of Predicted Production of high value Wood from Forest Plantations with Actual Production from all Forests, 2000 (million cubic metres, roundwood)

Saw and Veneer Logs	Actual Production all Forests Year 2000	Potential Production Forests Plantation	Potential as Percent of 2000 Actual
Conifers	666	174	26%
Non-conifers	282	85	30%
Total	948	259	27%

Essentially this table summarises the whole study. The fast-growing forest plantations of the world have the potential to supply about one quarter of the high value saw and veneer logs currently obtained and used on the world market. This is less than the overall proportion of wood which can be supplied from forest plantations. The forecasts published by ABARE (1999) predicted that forest plantations could supply about 35% of all industrial wood in 2000, rising to 46% by 2040. Assuming that both sets of predictions are approximately correct, the difference probably results from two causes. Additional wood will come from forest plantations which are managed on longer rotations for multiple uses and from forest plantations designed to supply pulpwood on short rotations. This may be a response to forecast of increasing demand for paper products in the Asian region.

Comparison with previous estimates is difficult because of the different bases for the calculations. An attempt is made in table 8 below where estimates of total forest plantation production which were previously made by Brown (2000) and ABARE (1999) are compared. For the purpose of the this comparison, the component of total wood production that is of "high value" has been estimated by multiplying total wood volumes by 0.6, the proportion of saw and veneer logs which was produced from all forest sources in 2000.

Table 8. Comparisons of estimates of "High value" Wood with Estimates of Total Forest Plantation Production (Volumes in million cubic metres, roundwood)

Year	All Industrial Wood	"High value" component	Current Estimate
2000	415[1]	249	
	624[2]	374	259
2010	583[1]	349	
2020	724[1]	434	
	969[2]	581	

[1]Brown (2000)
[2]ABARE (1999)

Because these estimates have been derived using completely different methodologies, they can only be compared in the broadest sense. The current estimate, that about 259 million cubic metres of high value wood could be produced from the current world estate of fast growing forest plantations, is however not inconsistent with previous estimates of production from forest plantations. It reflects a specialised component of production and is less that the previous estimates but is of the same order of magnitude.

Discussion

Accuracy of current estimates

While care has been taken to calculate volumes using values judged to be reasonable and based on data wherever possible, it is emphasised that many of the values were poorly defined in the databases and that the final choice of values relied a great deal on the judgements of the authors. The multiplicative nature of the calculation poses its own problems as errors in one or more of the values used are increased by the process of calculation.

Areas of uncertainty include: the reduction from gross to net stocked area. In all forests some area within the forest estate is occupied by roads, firebreaks and other non-stocked land that is part of the estate. This area may have been included in the gross area. In any forest compartment there are gaps due to poor survival and unplantable areas such as swampy ground, areas too steep to be planted or reserved for conservation purposes or stream-side reserves to protect environmental values. While such reductions occur in all forested countries the amount of reduction varies widely. If full or partial planting failures occur they may or may not be reflected in the gross figures. All this means that there are uncertainties associated with forest area – which are in addition to the already noted difficulties in defining a forest plantation. The accuracy of the area data may vary with the source country, but in the absence of any other information the authors have largely accepted the data at face value, except where comparison of successive datasets has revealed inconsistency. These estimates have included volumes from Rubberwood (*Hevea brasiliensis*). The importance of this species has been noted before, (ABARE, 1999; Carle *et al*, 2003), but apparently not included in estimates of wood production because it was little used for sawn timber. Its potential as a furniture timber has now been recognised (Balsiger *et a*l, 2000) and use of this wood is likely to increase in the future. However the extent of to which it will be used is a matter of conjecture. The utilisation of this species is comparatively recent, (beginning in the 1980's) but although its future extent is unknown its the potential should be acknowledged as being high since Rubberwood is the second largest forest plantation species (by area) in the world. In the current project it has been assumed that in Indonesia, Malaysia and Thailand half the current area of Rubberwood will be used for timber purposes but in all other countries with substantial area, timber will be extracted from only one tenth of the area. Clearly this represents a judgement on behalf of the authors.

Of all the countries with fast growing forest plantations, one, the United States of America has been estimated to be capable of producing more much more forest plantation grown wood than any other. The estimates produced here indicate a potential productive capacity for high value wood equivalent to 30% of the estimate for the world. This is based on a forest plantation area of just over seven million hectares – a figure which has been checked and confirmed by official USDA Forest Service data (USDA-FS, 2003). However no increment data are provided for pines in the United States so the value applied here, 20m^3/ha/ann, was the average MAI reported for the species *Pinus elliotii* and *P. Taeda*, from 42 and 30 observations respectively from around the world. The MAI for *P. elliotii* in South Africa, a country with comparable technology and identical latitude to the southern USA is listed as 22 cubic metres per hectare per year. The sensitivity of estimates to each element of the volume calculation has already been noted. If the value of the increment for Pinus spp. in the USA was reduced from 20 to 15 m^3/ha/ann, the predicted volume of conifer wood would reduce from 174 to 155 million cubic metres and the estimated production of wood at world level would reduce by 7%. It can be concluded that estimates of production are sensitive to assumptions about increment; particularly that applied to the growth of pines in the USA. The figure used was adopted because of the evidence in the database. The authors have no rationale basis for over-riding this substantial evidence. Likewise some five million hectares of forest plantations in Brazil are recorded as "unspecified" and it was not possible to estimate a yield for this area.

Interpretation of “Potential”

The word potential has been used to describe the yields estimated here. There are different reasons for this.

Wood of high value can be used for purposes which are intrinsically less demanding. For example it is possible to reduce a valuable veneer log to pulp (but not to produce veneer from a log of only pulpwood quality). The methods used here were designed to determine volumes available for their highest possible use – based on their physical properties. How wood is actually used is a decision for the market and since wood cannot be used for a purpose higher than its properties would permit, any market led decision can only move the wood in one direction. Thus the volume estimates produced here can be regarded as upper estimates.

The second caveat to the word potential is that in order to derive volumes for the “important 30” countries – in the absence of better resource data – volumes were calculated using MAI, a parameter which is strictly only valid when applied to a given site, rotation length, and utilisation specification. Its use in calculations such as this implies that the forest estate is in the normal (or standard) state. Previous work (Brown, 2000) has shown that currently most of the world forest plantation estate is likely to be immature and therefore a normal yield will not be obtained for perhaps another 5-10 years. The potential rate of production represents an overestimate of yield and more realistically provides an estimate which should be expected in about 2010. Comparing the estimated yield of high value wood with total production from all forest sources, for the year 2000 probably exaggerates the contribution which could be made from fast-growing forest plantations. It should also be noted that the yield estimate is static. That is, it assumes that the forest plantation estate is of fixed size and will be managed without addition or subtraction to its area. However many countries are actively expanding the area of their forest plantations so that yields will increase with time as the new areas mature.

Finally, the area of plantations which are capable of providing high value wood could also be increased by the conversion of stands which were originally intended to provide pulpwood over a short rotation. This is not without silvicultural problems as the choice of best species may not be the same for both products and the silviculture required to affect the change may be expensive and expose the stand to the risk of damage from delayed operations, wind and disease. However under favourable circumstances it provides a real option.

Despite the qualifications described above, defining an area of planted forests on which to base the calculations of potential yield has also defined a forest resource which can be considered to be both commercially viable and also likely to be managed in a sustainable manner because of its value. The total area of this type of forest on a world basis is about 60 million hectares (total gross area, Table 1, Appendix 1) and includes forest managed under both short and long rotations. Additional area will come from species and countries eliminated in the data-filtering process employed here. Never-the-less at 32%,this area is a minor component of the 187 million hectares which is the total area of world plantations (FAO, 2003). Many of the plantations excluded from consideration here are being managed in a sustainable manner and many will also be profitable if this was considered in a broader sense than simple commercial profitably. However, since both commercial viability and sustainability are desirable ideals. It is suggested that investors consider methods similar to those used in this work to indicate which plantation investment opportunities might also qualify under both criteria.

Other Sources of High value Wood

This study has had the object of providing estimates of the availability of high value wood from fast-growing forest plantations. In this case, fast-growing has been used as a surrogate to indicate commercial viability. This narrow-sense definition of profitability has been used to identify a forest type which might increase in response to commercial investment, either by the private sector, through government action, or both. High value wood can be produced from natural forests, semi-natural forests in which planting is used as a tool of regeneration and slower growing forest plantations. These forests may also be profitable in a broader sense where benefits from environmental protection, social and conservation values are included. On a world scale there will be changes in the area of all types of forest, the general tendency, noted over at least the last decade, has been for the total area to decrease. Where this has occurred in forest plantations it has been linked to economic problems and political and civil unrest (Carle *et al*, 2003). Many forests, particularly in Europe, Scandinavia and North America, are semi-natural forests or forest plantations which have been managed on a sustainable basis for a long time, centuries in some cases. Their principal feature is their stability and high standard of management and it is expected that these forests will continue to supply wood of all types for the foreseeable future. However while these forests will be maintained, it is unlikely that major increases in area will occur.

The dichotomy between nations in the rate at which they are expanding their forest plantation area has already been noted (Carle *et al*, 2003). It is suggested that the possibilities for substantial increases in plantation forest lie very largely – if not exclusively - with those countries where trees can be described as “fast-growing”. Most commentators on world forest production levels have forecast continued increases in the level of yield from forest plantations, and for the share of the world’s wood which will be derived from forest plantations to also increase. Whether this expansion will also include forest plantations which will be managed with a silviculture and over a rotation length appropriate to the production of high value wood is problematical. The role of governments in the establishment of forest plantations has been noted by others (e.g. ABARE, 1999, p6). These authors note that large scale establishment of forest plantations has, in the past, largely been an activity of governments in many parts of the world. They list Australia, Chile, New Zealand and the United Kingdom as examples where governments have either carried out afforestation directly or encouraged it through a variety of financial incentives. It should also be noted that where the private sector has purchased such forests, they have been unwilling to carry out large scale expansion of the resource; except where government incentives remained. When comparing the forecast rate of future production from forest plantations and expected increases in wood demand, Zhu *et al* (1998) concluded that demand for wood would increase faster than the potential supply from forest plantations. If forest plantations are unable to supply the extra wood – particularly high value wood - where will supplies come from? A potential source is through the application of technology aimed at improving low quality wood. This may be using simple steps such as cutting out defects caused by knots from sawn timber then finger jointing and gluing the defect-free wood together again; to completely reducing the wood to fibres then re-constituting it to form a defect-free building component. Products such as laminated veneer lumber and oriented strand board are other examples of how technology can be used to supply a high value product from wood that is intrinsically of low quality. The silviculture required to produce the raw material for such processes is similar to that used to produce pulpwood and much simpler than that required to produce high value wood in the forest. This approach has been publicly advocated by at least one prominent forest forest plantation owner (Dyck, 1999) and alternative views also put, (Sutton, 1999; Henry, 1999; O'Neill, 1999). Another alternative is that non-wood materials will substitute for wood products – usually with the implication that greater amounts of energy from non-renewable sources will be required and/or more greenhouse-gas emissions will ensue.

Policy Implications

In carrying out the calculations for this study it has been necessary to make a number of assumptions regarding the data (area, growth rates and purpose of forests) such that the volumes derived can only be regarded as indicating the broad order-of-magnitude of the volume potentially available. It is suggested that the current forest plantation estate of fast growing forest plantations can – without further expansion – supply only about one quarter of the high value wood currently consumed throughout the world. There are growth, silvicultural and financial reasons why forest plantations capable of supplying high value wood will not expand fast enough to supply the demand expected for this type of product in the future. This is especially true of the forest plantations established by the private sector in market economies – which tend to be concentrated on supplying short rotation pulpwood crops.

The implications are: that current sources of supply, such as the natural and semi-natural forests of the world will continue for some time to be the major source of high value roundwood. The value of this roundwood should remain high leading to continued or improved high value management where the forests are located in countries with technical expertise and good governance; but increase the chance of over-exploitation where administrative controls are poor. If supply becomes constrained then prices will tend to rise and this may also affect decisions about whether forests should continue to be harvested or be reserved for other purposes. It may also stimulate the development of fast-growing commercial plantations or other alternative sources of supply. Because of the long term nature of forest plantations managed for the production of high value wood, it is unlikely that these market changes will, of themselves, result in a response within a time span which could contribute extra wood and thus stabilise prices. Although calculations of the profitability of planted forests have demonstrated their theoretical financial viability -and this has been confirmed in practice by the sales of Government owned forests in many countries – establishment of new, long rotation, planted forests without Government involvement or assistance is rarely observed. It appears that commercial profits alone are insufficient to stimulate investment in long-rotation planted forests by the private sector. Although in can be argued that it is not appropriate for governments to take a role in a commercial enterprise such as plantation forestry; others have noted that "governments can become involved in forest plantation developments to overcome perceived markets impediments created by the nature of plantation investments" (ABARE, 1999). There are reasons why Governments may wish to reconsider their lack of involvement in the extension of the plantation estate in their nation. Failure to provide an alternative source of high value wood may result in the degradation of natural or semi-natural forests which currently provide the bulk of the non-wood benefits of forests such as: protection of soil and water values, habitat for wildlife and conservation of endangered species, sequestration of carbon and social benefits for all people. Natural and semi-natural forests also provide most of the high value wood.

It is recommended that further studies of the potential for forest plantation to supply high value wood be carried out as data sources improve. It will be important to incorporate age class structure and future planting rates into these projections if possible. The conclusions of this study and the policy implications outlined above are important and governments, especially those identified as being in the important 30 forest plantation countries, should consider them when developing their own policies for plantation forestry.

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Appendix 1.:

Table 1. Values used in Yield Calculations

Country	Species	Gross area	Net area	PASP	MAI	SA
		(ha)		(%)	(m^3*ha^{-1}*$year^{-1}$)	(%)
Argentina	Eucalyptus grandis	393.400	354.060	0,50	20	0,38
	Eucalyptus spp.	68.600	61.740	0,00	0	0,38
	Pinus spp.	308.000	277.200	1,00	18	0,60
	Total	**770.000**	**693.000**			
			0			
Australia	Eucalyptus dunnii	7.374	6.637	1,00	15	0,38
	Eucalyptus grandis	26.430	23.787	1,00	20	0,38
	Eucalyptus nitens	28.123	25.311	0,50	15	0,38
	Eucalyptus regnans	12.276	11.048	0,50	15	0,38
	Eucalyptus spp.	21.160	19.044	1,00	15	0,38
	Araucaria sp	46.588	41.929	1,00	7	0,60
	Pinus caribaea var. hond.	57.857	52.071	1,00	15	0,60
	Pinus elliotii	78.758	70.882	1,00	9	0,60
	Pinus pinaster	39.614	35.653	1,00	7	0,60
	Pinus radiata	716.543	644.889	1,00	18	0,60
	Total	**1.034.723**	**931.251**			
Brazil	Unspecified	4.862.130	4.375.917	0,00		
	Eucalyptus grandis	1.631.234	1.468.111	0,10	25	0,38
	Eucalyptus saligna	504.200	453.780	0,10	22	0,38
	Eucalyptus urophylla	266.929	240.236	0,10	25	0,38
	Eucalyptus viminalis	59.318	53.386	0,10	16	0,38
	Gmelina arb	60.000	54.000	1,00	20	0,80
	Hevea brasiliensis	59.000	53.100	0,10	7	0,32
	Tectona grandis	10.000	9.000	1,00	15	0,80
	Pinus caribaea var. carib.	273.938	246.544	1,00	15	0,60
	Pinus elliotii	237.413	213.672	1,00	15	0,60
	Pinus oocarpa	273.938	246.544	1,00	14	0,60
	Pinus taeda	840.075	756.068	1,00	15	0,60
	Total	**9.078.175**	**8.170.358**			
Bulgaria	Populus spp.	25.645	23.081	1,00	16	0,80
	Total	**25.645**	**23.081**			
Chile	Eucalyptus spp.	317.212	285.491	0,10	15	0,38
	Pinus radiata	1.420.015	1.278.014	1,00	22	0,60
	Total	**1.737.227**	**1.563.504**			
China	Eucalyptus spp.	52.000	46.800	0,00	14	
	Hevea brasiliensis	39.000	35.100	0,10	7	0,32
	Populus spp.	6.280.000	5.652.000	0,50	12	0,80
	Tectona grandis	15.200	13.680	1,00	11	0,80
	Pinus spp.	26.300	23.670	1,00	11	0,60
	Total	**6.412.500**	**5.771.250**			

Country	Species	Gross area	Net area	PASP	MAI	SA
		(ha)		**(%)**	**(m^3*ha^{-1}*$year^{-1}$)**	**(%)**
Cuba	Eucalyptus spp.	40.500	36.450	0,50	15	0,38
	Tectona grandis	200	180	1,00	9	0,80
	Pinus caribaea var. carib.	133.800	120.420	1,00	10	0,60
	Total	**174.500**	**157.050**			
Ethiopia	Eucalyptus spp.	181.500	163.350	0,50	15	0,32
	Cupressus lusitanica	90.750	81.675	1,00	20	0,60
	Pinus spp.	2.750	2.475	1,00	20	0,60
	Total	**275.000**	**247.500**			
India	Acacia nilotica	801.610	721.449	0,50	5	0,50
	Bombax ceiba	37.970	34.173	1,00	9	0,80
	Dalbergia sissoo	266.580	239.922	1,00	5	0,80
	Eucalyptus spp.	1.360.910	1.224.819	0,25	15	0,38
	Gmelina arborea	148.010	133.209	1,00	10	0,80
	Hevea brasiliensis	563.000	506.700	0,10	7	0,32
	Populus spp.	40.000	36.000	1,00	20	0,80
	Shorea robusta	250.280	225.252	1,00	5	0,80
	Tectona grandis	1.330.090	1.197.081	1,00	6	0,80
	Pinus kesiya	127.120	114.408	1,00	15	0,60
	Pinus patula	1.500	1.350	1,00	15	0,60
	Total	**4.927.070**	**4.434.363**			
Indonesia	Dalbergia latifolia	28.461	25.615	1,00	16	0,67
	Hevea brasiliensis	3.372.000	3.034.800	0,50	7	0,32
	Shorea spp.	28.801	25.921	1,00	6	0,67
	Swietenia macrophylla	116.282	104.654	1,00	15	0,67
	Tectona grandis	1.218.771	1.096.894	1,00	6	0,80
	Agathis spp.	143.669	129.302	1,00	20	0,60
	Pinus merkusii	901.910	811.719	1,00	18	0,60
	Total	**5.809.894**	**5.228.905**			
Kenya	Eucalyptus spp.	15.886	14.297	0,50	15	0,38
	Cupressus spp.	73.732	66.359	1,00	20	0,60
	Pinus spp.	51.575	46.418	1,00	18	0,60
	Total	**141.193**	**127.074**			
Madagascar	Eucalyptus grandis	968	871	1,00	15	0,38
	Total	**968**	**871**			
Malaysia	Acacia mangium	3.714	3.343	0,25	24	0,38
	Acacia mangium	55.595	50.036	0,25	24	0,38
	Acacia mangium	64.630	58.167	0,25	24	0,38
	Eucalyptus deglupta	5.728	5.155	1,00	27	0,38
	Eucalyptus spp.	786	707	0,50	15	0,38
	Gmelina arborea	215	194	1,00	28	0,80
	Gmelina arborea	10.142	9.128	1,00	28	0,80
	Gmelina arborea	515	464	1,00	28	0,80
	Hevea brasiliensis	1.430.700	1.287.630	0,50	7	0,32

Country	Species	Gross area	Net area	PASP	MAI	SA
		(ha)		(%)	(m^3*ha^{-1}*$year^{-1}$)	(%)
	Paraserianthes falcataria	176	158	0,25	20	0,38
	Paraserianthes falcataria	12.049	10.844	0,25	20	0,38
	Paraserianthes falcataria	1.530	1.377	0,25	20	0,38
	Shorea spp.	4.811	4.330	1,00	6	0,67
	Swietenia macrophylla	134	121	1,00	15	0,67
	Tectona grandis	1.704	1.534	1,00	12	0,80
	Tectona grandis	2.621	2.359	1,00	12	0,80
	Pinus caribaea	695	626	1,00	20	0,60
	Pinus spp.	5.875	5.288	1,00	15	0,60
	Total	**1.601.620**	**1.441.458**			
Morocco	Eucalyptus camaldulensis	106.548	95.893	1,00	5	0,38
	Eucalyptus cladocalyx	6.147	5.532	1,00	5	0,38
	Eucalyptus gomphocephala	79.911	71.920	0,00		
	Eucalyptus grandis	2.050	1.845	1,00	15	0,38
	Eucalyptus occidentalis	2.050	1.845	0,00		
	Eucalyptus sideroxylon	6.147	5.532	1,00	5	0,38
	Populus spp.	2.000	1.800	0,50	12	0,80
	Cedrus atlantica	4.211	3.790	0,00		
	Cupressus spp.	1.755	1.580	1,00	15	0,60
	Pinus brutia	20.946	18.851	0,00		
	Pinus caneriensis	5.372	4.835	1,00	5	0,60
	Pinus pinaster	187.531	168.778	1,00	5	0,60
	Pinus pinea	1.610	1.449	0,00		
	Pinus radiata	2.913	2.622	1,00	10	0,60
	Total	**429.191**	**386.272**			
Myanmar	Eucalyptus spp.	63.030	56.727	1,00	12	0,38
	Hevea brasiliensis	48.000	43.200	0,10	7	0,32
	Pterocarpus macrocarpus	15.286	13.757	0,00		
	Tectona grandis	266.649	239.984	1,00	10	0,80
	Xylia kerri	50.780	45.702	0,00		
	Pinus spp	14.575	13.118	1,00	15	0,60
	Total	**458.320**	**412.488**			
New Zealand	Eucalyptus spp.	12.659	11.393	1,00	15	0,38
	Populus spp.	50	45	0,00		
	Pinus radiata	1.607.726	1.446.953	1,00	20	0,60
	Pinus spp.	88.458	79.612	1,00	5	0,60
	Pseudotsuga menziesii	102.573	92.316	1,00	14	0,60
	Total	**1.811.466**	**1.630.319**			
Nigeria	Eucalyptus spp.	40.500	36.450	0,50	15	0,38
	Gmelina arborea	193.700	174.330	1,00	16	0,80
	Hevea brasiliensis	225.000	202.500	0,10	7	0,32
	Swietenia macrophylla	1.900	1.710	1,00	15	0,67
	Tectona grandis	73.500	66.150	1,00	10	0,80
	Terminalia spp.	8.300	7.470	1,00	14	0,80
	Pinus spp.	10.100	9.090	1,00	10	0,60
	Total	**553.000**	**497.700**			

Country	Species	Gross area	Net area	PASP	MAI	SA
		(ha)		(%)	($m^3*ha^{-1}*year^{-1}$)	(%)
Pakistan	Dalbergia sissoo	196.000	176.400	1,00	10	0,67
	Eucalyptus spp.	245.000	220.500	0,25	15	0,38
	Pinus spp.	49.000	44.100	0,25	5	0,60
	Total	**490.000**	**441.000**			
Peru	Eucalyptus spp.	278.250	250.425	0,50	10	0,38
	Total	**278.250**	**250.425**			
Philipines	Eucalyptus deglupta	191.000	171.900	0,50	18	0,38
	Gmelina arborea	107.000	96.300	1,00	34	0,80
	Hevea brasiliensis	98.000	88.200	0,10	7	0,32
	Paraserianthes falcataria	133.000	119.700	0,50	20	0,38
	Swietenia macrophylla	25.000	22.500	1,00	10	0,67
	Tectona grandis	37.800	34.020	1,00	10	0,80
	Pinus caribaea var. hond.	23.000	20.700	1,00	10	0,60
	Total	**614.800**	**553.320**			
Portugal	Eucalyptus Globulus	237.000	213.300	0,50	12	0,38
	Total	**237.000**	**213.300**			
South Africa	Acacia mearnsii	112.029	100.826	0,25	15	0,38
	Eucalyptus grandis	441.394	397.255	0,50	18	0,38
	Eucalyptus spp.	156.570	140.913	0,75	17	0,38
	Pinus canariensis	5.306	4.775	0,50	10	0,60
	Pinus elliotii	197.826	178.043	1,00	20	0,60
	Pinus patula	396.625	356.963	1,00	20	0,60
	Pinus pinaster	52.469	47.222	1,00	10	0,60
	Pinus radiata	76.072	68.465	1,00	20	0,60
	Pinus taeda	69.220	62.298	1,00	20	0,60
	Total	**1.507.511**	**1.356.760**			
Spain	Eucalyptus spp.	390.277	351.249	0,25	15	0,38
	Populus spp.	102.830	92.547	0,25	10	0,80
	Pinus spp	1.485.000	1.336.500	1,00	12	0,60
	Pseudotsuga menziesii	5.000	4.500	1,00	14	0,60
	Total	**1.983.107**	**1.784.796**			
Sudan	Acacia senegal	281.102	252.992	0,10	10	0,38
	Eucalyptus spp.	7.560	6.804	0,10	10	0,38
	Tectona grandis	10.700	9.630	1,00	4	0,80
	Pinus spp.	100	90	1,00	10	0,60
	Total	**299.462**	**269.516**			
Thailand	Eucalyptus spp.	443.000	398.700	0,25	15	0,38
	Hevea brasiliensis	1.980.100	1.782.090	0,50	7	0,32
	Swietenia macrophylla	623	561	1,00	10	0,67
	Tectona grandis	836.000	752.400	1,00	7	0,80
	Pinus spp.	689.000	620.100	0,25	10	0,60
	Total	**3.948.723**	**3.553.851**			

Country	Species	Gross area	Net area	PASP	MAI	SA
		(ha)		**(%)**	**(m^3*ha^{-1}*$year^{-1}$)**	**(%)**
Turkey	Eucalyptus spp.	5.600	5.040	0,25	15	0,38
	Populus nigra	68.000	61.200	0,25	9	0,80
	Popupulus X euramericana	77.000	69.300	1,00	27	0,80
	Pinus spp.	8.300	7.470	0,50	14	0,60
	Total	**158.900**	**143.010**			
United States	Eucalyptus spp.	110.000	99.000	0,50	18	0,38
	Populus spp.	30.000	27.000	0,25	10	0,80
	Pinus spp	7.166.000	6.449.400	1,00	20	0,60
	Total	**7.306.000**	**6.575.400**			
Uruguay	Eucalyptus grandis	386.477	347.829	0,50	20	0,38
	Eucalyptus spp.	111.123	100.011	0,25	18	0,38
	Pinus spp.	25.000	22.500	1,00	22	0,60
	Total	**522.600**	**470.340**			
Venezuela	Gmelina arbore	25.900	23.310	1,00	20	0,80
	Pinus caribaea var. hond.	690.400	621.360	0,50	10	0,60
	Total	**716.300**	**644.670**			
Viet Nam	Eucalyptus spp.	451.500	406.350	0,50	10	0,38
	Hevea brasiliensis	380.000	342.000	0,10	7	0,32
	Tectona grandis	4.200	3.780	1,00	7	0,80
	Pinus kesiya	253.900	228.510	0,50	12	0,60
	Total	**1.089.600**	**980.640**			

Table 2. Results of Volume Calculations; by Country and Species

Country	Species	NON-CONIFEROUS	CONIFEROUS	TOTAL
		(m^3)	**(m^3)**	**(m^3)**
Argentina	Eucalyptus grandis	1.345.428		
	Eucalyptus spp.	0		
	Pinus spp		2.993.760	
	Total	**1.345.428**	**2.993.760**	**4.339.188**
Australia	Eucalyptus dunnii	37.829		
	Eucalyptus grandis	180.781		
	Eucalyptus nitens	72.135		
	Eucalyptus regnans	31.488		
	Eucalyptus spp.	108.551		
	Araucaria sp		176.103	
	Pinus caribaea var. hond.		468.642	
	Pinus elliotii		382.764	
	Pinus pinaster		149.741	
	Pinus radiata		6.964.798	
	Total	**430.784**	**8.142.047**	**8.572.831**
Brazil	Unspecified	0		
	Eucalyptus grandis	1.394.705		
	Eucalyptus saligna	379.360		
	Eucalyptus urophylla	228.224		
	Eucalyptus viminalis	32.459		
	Gmelina arb	864.000		
	Hevea brasiliensis	11.894		
	Tectona grandis	108.000		
	Pinus caribaea var. carib.		2.218.898	
	Pinus elliotii		1.923.045	
	Pinus oocarpa		2.070.971	
	Pinus taeda		6.804.608	
	Total	**3.018.643**	**13.017.522**	**16.036.165**
Bulgaria	Populus spp.	295.430		295.430
	Total	**295.430**		**295.430**
Chile	Eucalyptus spp.	162.730		
	Pinus radiata		16.869.778	
	Total	**162.730**	**16.869.778**	**17.032.508**
China	Eucalyptus spp.	0		
	Hevea brasiliensis	7.862		
	Populus spp.	27.129.600		
	Tectona grandis	120.384		
	Pinus spp.		156.222	
	Total	**27.257.846**	**156.222**	**27.414.068**
Cuba	Eucalyptus spp.	103.883		
	Tectona grandis	1.296		
	Pinus caribaea var. carib.		722.520	
	Total	**105.179**	**722.520**	**827.699**

Country	Species	NON-CONIFEROUS	CONIFEROUS	TOTAL
		(m^3)	(m^3)	(m^3)
Ethiopia	Eucalyptus spp.	392.040		
	Cupressus lusitanica		980.100	
	Pinus spp.		29.700	
	Total	**392.040**	**1.009.800**	**1.401.840**
India	Acacia nilotica	901.811		
	Bombax ceiba	246.046		
	Dalbergia sissoo	959.688		
	Eucalyptus spp.	1.745.367		
	Gmelina arborea	1.065.672		
	Hevea brasiliensis	113.501		
	Populus spp.	576.000		
	Shorea robusta	901.008		
	Tectona grandis	5.745.989		
	Pinus kesiya		1.029.672	
	Pinus patula		12.150	
	Total	**12.647.122**	**1.041.822**	**13.688.944**
Indonesia	Dalbergia latifolia	274.592		
	Hevea brasiliensis	3.398.976		
	Shorea spp.	104.202		
	Swietenia macrophylla	1.051.771		
	Tectona grandis	5.265.091		
	Agathis spp.		1.551.625	
	Pinus merkusii		8.766.565	
	Total	**10.094.631**	**10.318.190**	**20.412.822**
Kenya	Eucalyptus spp.	40.748		
	Cupressus spp.		796.306	
	Pinus spp.		501.309	
	Total	**40.748**	**1.297.615**	**1.338.362**
Madagascar	Eucalyptus grandis	4.966		4.966
	Total	**4.966**		**4.966**
Malaysia	Acacia mangium	7.621		
	Acacia mangium	114.081		
	Acacia mangium	132.621		
	Eucalyptus deglupta	52.892		
	Eucalyptus spp.	2.016		
	Gmelina arborea	4.334		
	Gmelina arborea	204.463		
	Gmelina arborea	10.382		
	Hevea brasiliensis	1.442.146		
	Paraserianthes falcataria	301		
	Paraserianthes falcataria	20.604		
	Paraserianthes falcataria	2.616		
	Shorea spp.	17.406		
	Swietenia macrophylla	1.212		

Country	Species	NON-CONIFEROUS	CONIFEROUS	TOTAL
		(m^3)	(m^3)	(m^3)
	Tectona grandis	14.723		
	Tectona grandis	22.645		
	Pinus caribaea		7.506	
	Pinus spp.		47.588	
	Total	**2.050.064**	**55.094**	**2.105.157**
Morocco	Eucalyptus camaldulensis	182.197		
	Eucalyptus cladocalyx	10.511		
	Eucalyptus gomphocephala	0		
	Eucalyptus grandis	10.517		
	Eucalyptus occidentalis	0		
	Eucalyptus sideroxylon	10.511		
	Populus spp.	8.640		
	Cedrus atlantica		0	
	Cupressus spp.		14.216	
	Pinus brutia		0	
	Pinus caneriensis		13.054	
	Pinus pinaster		506.334	
	Pinus pinea		0	
	Pinus radiata		15.730	
	Total	**222.376**	**549.333**	**771.710**
Myanmar	Eucalyptus spp.	258.675		
	Hevea brasiliensis	9.677		
	Pterocarpus macrocarpus	0		
	Tectona grandis	1.919.873		
	Xylia kerri	0		
	Pinus spp.		118.058	
	Total	**2.188.225**	**118.058**	**2.306.282**
New Zealand	Eucalyptus spp.	64.941		
	Populus spp.	0		
	Pinus radiata		17.363.441	
	Pinus spp.		238.837	
	Pseudotsuga menziesii		775.452	
	Total	**64.941**	**18.377.729**	**18.442.670**
Nigeria	Eucalyptus spp.	103.883		
	Gmelina arborea	2.231.424		
	Hevea brasiliensis	45.360		
	Swietenia macrophylla	17.186		
	Tectona grandis	529.200		
	Terminalia spp.	83.664		
	Pinus spp.		54.540	
	Total	**3.010.716**	**54.540**	**3.065.256**
Pakistan	Dalbergia sissoo	1.181.880		
	Eucalyptus spp.	314.213		
	Pinus spp.		214.118	
	Total	**1.496.093**	**214.118**	**1.710.211**

Country	Species	NON-CONIFEROUS	CONIFEROUS	TOTAL
		(m^3)	**(m^3)**	**(m^3)**
Peru	Eucalyptus spp.	475.808		475.808
	Total	**475.808**		**475.808**
Philipines	Eucalyptus deglupta	587.898		
	Gmelina arborea	2.619.360		
	Hevea brasiliensis	19.757		
	Paraserianthes falcataria	454.860		
	Swietenia macrophylla	150.750		
	Tectona grandis	272.160		
	Pinus caribaea var. hond.		124.200	
	Total	**4.104.785**	**124.200**	**4.228.985**
Portugal	Eucalyptus Globulus	486.324		486.324
	Total	**486.324**		**486.324**
South Africa	Acacia mearnsii	143.677		
	Eucalyptus grandis	1.358.611		
	Eucalyptus spp.	682.723		
	Pinus canariensis		14.326	
	Pinus elliotii		2.136.521	
	Pinus patula		4.283.550	
	Pinus pinaster		283.333	
	Pinus radiata		821.578	
	Pinus taeda		747.576	
	Total	**2.185.011**	**8.286.883**	**10.471.895**
Spain	Eucalyptus spp.	500.530		
	Populus spp.	185.094		
	Pinus spp.		9.622.800	
	Pseudotsuga menziesii		37.800	
	Total	**685.624**	**9.660.600**	**10.346.224**
Sudan	Acacia senegal	96.137		
	Eucalyptus spp.	2.586		
	Tectona grandis	30.816		
	Pinus spp.		540	
	Total	**129.538**	**540**	**130.078**
Thailand	Eucalyptus spp.	568.148		
	Hevea brasiliensis	1.995.941		
	Swietenia macrophylla	3.757		
	Tectona grandis	4.213.440		
	Pinus spp.		930.150	
	Total	**6.781.285**	**930.150**	**7.711.435**
Turkey	Eucalyptus spp.	7.182		
	Populus nigra	110.160		
	Popupulus X euramericana	1.496.880		
	Pinus spp.		31.374	
	Total	**1.614.222**	**31.374**	**1.645.596**

Country	Species	NON-CONIFEROUS	CONIFEROUS	TOTAL
		(m^3)	(m^3)	(m^3)
United States	Eucalyptus spp.	338.580		
	Populus spp.	54.000		
	Pinus spp.		77.392.800	
	Total	**392.580**	**77.392.800**	**77.785.380**
Uruguay	Eucalyptus grandis	1.321.751		
	Eucalyptus spp.	171.018		
	Pinus spp.		297.000	
	Total	**1.492.770**	**297.000**	**1.789.770**
Venezuela	Gmelina arbore	372.960		
	Pinus caribaea var. hond.		1.864.080	
	Total	**372.960**	**1.864.080**	**2.237.040**
Viet Nam	Eucalyptus spp.	772.065		
	Hevea brasiliensis	76.608		
	Tectona grandis	21.168		
	Pinus kesiya		822.636	
	Total	**869.841**	**822.636**	**1.692.477**
WORLD		**84.418.708**	**174.348.411**	**258.767.119**

Appendix 2. Derivation of Yield Allocation to Quality Classes

This appendix contains details of the values used to reduce total wood volumes to saw/veneer volumes. The volumes derived by multiplying net area by MAI were treated as mechantable volumes from which allowance had to be made to derive the high value component. This proportion varied by species group and was obtained from a search of relevant literature.

Pinus spp.

The best information for pines was that available for *Pinus radiata*, from Australian and New Zealand sources. Three main sources were used:

Turner, B.J. and James, R.N. 1997: Forecasting of Wood Flows from Australian Plantations – a report to the 1997 National Plantation Inventory. Bureau of Resource Sciences, Canberra.

Lewis, N. B., Keeves, A. and Leech, J.W. 1976: Yield Regulation in South Australian *Pinus radiata* Plantations. Woods and Forests Department. South Australia.

Ministry of Agriculture and Forestry, 2002: A national Exotic Forest Description. MAF, Wellington. New Zealand.

The first reference contains broad scale yield tables used to calculate future wood flows, by region, in Australia. The second reference is a set of much more detailed yield tables and the third gives details of primary use of radiata pine in New Zealand, by product category.
As MAI values are applied to the total stand, the high value proportion, (logs over 20 cm small end diameter inside bark) were derived for the whole rotation, including yield from thinning. For this calculation it was assumed that thinnings provided either no sawlogs at all or logs which were low quality; thus thinnings were assumed to provide pulpwood only. Values obtained from the Turner & James tables indicate that over a whole rotation, the yield of sawlogs is between 40% and 71% of total production. When the examples are compared it is clear that the high value was obtained from a region in which there was no market for small wood, hence the high proportion of sawlogs. Likewise the value of 40% was obtained from forests adjacent to a pulpmill. If the highest and lowest values are considered to be untypical then an "average" value of about 50% is obtained.
The South Australian yield tables are much more detailed and permit allowance to be made more precisely for log diameter. Taking an average site quality and a rotation length of 36 years as typical a proportion of 59% of volume in sawlogs greater than 20 cm sed was obtained. The description of the exotic forest estate in NZ contains a number of data which indicate proportional breakdowns of the total National yield by quality classes. The clearest indication is that given of wood use by primary and secondary wood flows. This indicates that wood from the forest is used: 61% for sawlogs and 39% for small wood uses. The forests of both countries are similar but not managed in the same way; more yield being extracted in the process of thinning in Australia than in New

Zealand where non-commercial (or to waste) thinnings are more frequently applied. In view of the close agreement between sources, and because such a figure can only be a broad indicator only, a value of 60% was adopted. Because the forests of Chile are so similar this value was applied there as well. It was also used as a default value for other pines where no better data were available.

Non-coniferous species

Eucalyptus spp.

Tables for the Eucalypts do not exist at the same level as for the pines. Experience with plantations of eucalypts is limited in Australia and elsewhere, while there is greater experience, most plantations are for pulpwood alone. The value used in the calculation of volumes is derived from just one source, but this is considered to be knowledgeable and relevant to the present study as it provides an estimate of yields in industrial terms. The reference is:
Heathcote, R. 2002: Case study on long rotation eucalypt plantations in New South Wales (Australia). Working Paper FP/22, FAO, Rome.
This reference quotes yield estimates which indicate the proportion of high value saw and veneer logs is 38% of total extracted yield. The reason why this proportion is much less than that quoted for other species is because of the high percentage of defective wood found in eucalypts. These defects include: end splits, spiral grain and internal rot including the absence of central wood (“pipe”). While some of these defects do not mean that wood is totally lost they do mean that the proportion of high value wood is much reduced. This value is used for all eucalypt crops because the low percentage in high value logs is judged to be a characteristic of the species which will apply outside Australia as well as within it.

Teak (*Tectona grandis*)

This high value species was always included where it occurred as part of each countries’ plantation resource. This is because of the high value of its logs and because rates of increment per hectare do not indicate the rate of individual tree growth because of the common practice of managing plantations of the species at low stocking rates, in conjunction with other crops.

Wood, H. 1992: Teak in Asia. Technical document GCP/RAS/134/ASB FORSPA Publications 4. FAO, Rome.

Provides information of regions where at least some of the Teak can be considered to be fast growing; (defined as growth in diameter >1 cm per ann.). These include: Bangladesh, China, India, Sri Lanka, and Côte d’Ivoire. This is a wide geographical spread leading to the conclusion that no country could be readily excluded.

Reference to sawlog proportions from the whole rotation length was found in:

Dalmacio, M.V. and Ahmed, I. 1989: Growth and Yield in Sylhet and Silvicultural Implications. Report FAO-FO—BGD/85/085. FAO, Rome

This reference indicates that Teak is utilised up to a 10cm top for sawlogs and that a reduction factor of 20% should be used, for waste and small wood uses. Accordingly the proportion of sawlogs assumed in this work was 80%. This value is much higher than for the eucalypts but it is thought to be reasonable in view of the high utilisation standards set for such a high value species in countries where costs of production are low. This value was used as the default value for similar species where wood value is high.

Gmelina arborea

This species is similar to Teak in that the wood is regarded as valuable and utilisation percentages are therefore high. A value which confirmed that this species was similar to Teak was found in:

FAO, 1982: A provisional yield table for Gmelina arborea plantations in Sibri River Forest Reserve, Ghana. Project Report 18. GHA/74/013. FAO, Takoradi Ghana.

The value was 83% of volume present to a 12 cm top, the utilisation limit. The value applied in deriving volumes was that of Teak, 80%.

Mahogany (*Swietenia macrophylla*)

The yield data for this species is said to be extremely variable, largely due to variation in the way that volume is defined, i.e. to what utilisation limit, and whether or not thinnings are included. A value of 67% of production in sawlogs was derived from the "most reliable" tables quoted in:
Mayhew, J.E. and Newton, A.C. 1998: The Silviculture of Mahogany. CABI Publishing, Oxford.
This value was applied to Mahogany wherever it was grown as other information was not available and because of the comments regarding the assessment of variation found by Mayhew and Newton.

Populus spp.

This species group also has a large range in the quoted rate of growth, however product assortment was found to be addressed in one paper and values for a tree of 50 cm DBH was selected as the general case. This gave a value of 80% in saw and veneer logs; the same as that for Teak. The reference is :
Birler, A.S. 1990: A Study of Yields from "I-214" Poplar Plantations. Ministry of Agriculture, Forestry and Rural affairs, Turkey – FAO, Rome Report TCP/RAB/8854.

Rubberwood, (*Hevea brasiliensis*)

Fortunately this species has been described very well in a recent study and this gave some perspective was given to allowed yield estimates to be made. The species is different from other plantation species in that it is used for timber as a residue after its main use, for rubber latex, has been finished. Because it is not managed as a timber tree, the usable bole is short and growth is low. The utilisation factor is also low as most of the growth goes into the crown and this is encouraged to increase latex yields.

MAI was set at 7 m^3/ha/ann.
Utilisation factor was set at 32%
Three countries produce 90% of the world's Rubberwood. They are Indonesia, Malaysia and Thailand. All other countries which grow the species have the potential to produce more. Whether they will is difficult to assess. In calculating volume, it has been estimated that Rubberwood will be harvested off half the area of rubber plantations in Indonesia, Malaysia and Thailand. In all other counties the value was set at one tenth of the area. It is emphasised that these values are estimates only; but also that the use of this species for the production of timber is so recent that a more reliable estimate is not available.

The reference is:
Balsiger, J., Bahdon, J. and Whiteman, A. 2000: The Utilisation, Processing and Demand for Rubberwood as a Source of Wood Supply. Working Paper No APFSOS/WP/50. FAO. Rome.

Other species were ascribed default values or discounted heavily because information from the literature had indicated that the species yielded only pulp. Species described as being grown almost entirely for pulp are: *Acacia auriculiformis*, *Ac. Mangium*, *Ac. Mearnsii* and *Ac. Nilotica*; *Dalbergia sisso*; *Pinus halepensis*, and *P. roxburgii.*

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