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Many countries in the southern hemisphere have become important producers of plantation-grown softwood timber for lumber and long-fiber pulp. About 90 % of these softwood plantations have been established with pines from the northern hemisphere. The total area of pine plantations in the southern hemisphere and tropics is almost 8 million ha and the annual increment 140 million m^3. Since a large proportion of the plantations is less than 10 years old, the annual cut is presently only 55-60 % of the increment. It is estimated to exceed 100 million m^3 by 2000 and reach 140-160 million m^3 by 2020. Compared to slow-grown boreal softwoods, fast-grown southern pine logs tend to produce inferior lumber, but tree breeding, pruning, product-oriented management and new processing technology will result in an improvement in the quality of both wood and end products. The paper examines the changing southern pine resource from the view point of the Finnish forestry sector.

Key words: Pine, plantation, southern hemisphere, tropics, wood resource

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1 Introduction

In 1990, the total area of the world's forests was estimated to be 3411 million ha. Wood consumption amounted to 3429 million m^3, of which 1295 m^3 or 38 % was coniferous wood (Forest resources... 1993).

Of the total area of closed forests in the world, 40 % is dominated by conifers and 60 % by broad-leaved trees (World Resources... 1988). The coniferous forests are concentrated in the boreal, temperate and some subtropical regions of the northern hemisphere in Europe, Asia and North America, where they form the primary raw material base for the world's forest industries. The share of coniferous species in the growing stock is 84 % in the Nordic countries, 75 % in Canada, 74 % in the former USSR and 57 % in the United States (The forest... 1992a).

A little over half of the wood consumption, 53 %, is used in the form of fuelwood and charcoal, accounting for 6 % of the total consumption of primary energy in the world. The rest is used for industrial purposes and construction. According to the latest FAO forecast, the consumption of fuelwood and charcoal is expected to increase by 31 % and the consumption of industrial roundwood 67 % between 1991 and 2010 (Forestry statistics... 1993).

The world's growing demand for industrial wood is increasingly met by forest plantations. This development towards man-made forests has made it possible for many *tropical and southern hemisphere regions to enter into the large-scale production of softwood timber* and establish softwood-based industries, traditionally a privilege of relatively few northern hemisphere countries. Fast growth, short rotation cycles and low costs have helped many of the new producer countries to become competitive in the world markets within a surprisingly short time. There is no doubt that *plantation-grown timber from the southern hemisphere and tropics will play a significant role in the future wood supply of the world.*

Fast-grown southern softwood differs in its properties from slow-grown northern softwood. However, the assumed superiority of the latter is no longer self-evident. Tree breeding, product-oriented forest management regimes and advances in science and processing technology will result in valuable, though different softwood products in southern latitudes. On the other hand, under very favorable growth conditions, inferior seed sources and management failures rapidly result in a loss of quality and value.

Of all the softwood plantations in the tropics and southern hemisphere, about 90 % have been established with various species of pine from the northern hemisphere. Although excellent plantation statistics are available in some countries, for example in New Zealand, the potential and nature of this increasing resource of exotic pine timber as a whole are not well documented. No reliable source of global data on southern softwood timber is available.

The shift towards plantations in southern latitudes affects the position of the traditional softwood producers such as Finland and other Nordic countries in international trade. Therefore, the southern hemisphere and tropical pine resource and projections of its quantitative and qualitative development are of importance to the long-term planning of forestry and forest industries in the northern producer countries. The ongoing development means increasing competition in the world markets of forest industry products. Simultaneously, it will also open up opportunities for Nordic know-how, since equalities in the crucial characteristics of southern and northern pine resources allow the application of basically similar harvesting and processing technology. *The purpose of the present study is to examine the changing southern pine resource essentially from the viewpoint of the Nordic forestry sector*, so as to increase understanding and appreciation of the resource in the traditional softwood producing countries.

Evans (1992) *defines the tropics as the broad belt extending to latitudes of 25-27°* on either side of the equator and accommodating some 40 % of the world's land surface. It is the climate that distinguishes the tropics from other parts of the world. The distinction is not so much in magnitude, such as intense heat, but in constancy and uniformity. Except in more subtropical regions, seasons only occur because of variations in rainfall, not because of variations in temperature, which characterise summers and winters in temperate regions. Industrial forest plantations occur in the tropics mainly in humid climates, where wet and dry seasons are well-defined and potential evapo-transpiration exceeds rainfall for 4-6 months of the year.

This review also deals with non-tropical forest plantations of the southern hemisphere. In fact, most of the southern hemisphere pine plantations are situated in the subtropical and temperate regions in Australia, Brazil, Chile, New Zealand and South Africa, and not in the tropics.

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Pentti Hakkila

2 Tree plantations in the southern hemisphere and tropics

2.1 The role of plantations in southern forestry

FAO estimates that 15.4 million ha of closed and open tropical forests were deforested annually between 1981 and 1990. The annual loss was greatest, 7.4 million ha, in Latin America. On average, *the pan-tropical deforestation rate for the decade was 0.8 % per year* (Forest resources... 1993, Singh 1993).

The reduction and degradation of the world's tropical forests continues and is even accelerating. Rather than originating from improper silviculture and harvesting practice, deforestation primarily stems from the uncontrolled collection of fuelwood, too intense shifting cultivation, overgrazing, accidental or deliberate forest fires, and the conversion of forest land into permanent agriculture, pasture fields and urban areas, distinctively as a consequence of the rapid growth of poor landless populations (Palo 1987, Palo et al. 1987). Although deforestation thus continues independently of forestry and forest industries, *the establishment of forest plantations has become a necessary measure for securing a sustainable supply of wood to the increasing population of the world*, and it has an important role to play in the overall strategy of controlling tropical deforestation.

The lack of forest cover in many tropical countries is not only causing an acute wood shortage but also serious soil erosion, liberation of carbon dioxide, loss of rich ecosystems and, perhaps most important of all, a threat to the survival of many forest-dwelling peoples. Forest plantations directly relieve some of these pressures and, especially when linked to agroforestry, can divert development away from the natural resource. On the other hand, it is important to note that plantations themselves are not immune from environmental concern (Evans 1992), and their role in reducing the pressure on natural forests is not as straightforward as often presumed. Neither plantation establishment programs nor legal measures can immediately change the dependence of a population on natural forests, since plantations and natural forests essentially yield different types of commodities and benefits. Furthermore, natural forests need protection and management for other than industrial purposes (Niskanen et al. 1994).

The planting objective varies from the production of industrial raw materials and fuelwood to the rehabilitation of bare land and erosion control. *Plantations are defined* as forest stands established artificially, either by afforestation on land which previously did not carry forest, or by reforestation on land which carried forest within the previous 50 years or within living memory, and involves the replacement of the previous crop by a new and essentially different crop. Plantation forests can also be called man-made forests. They can be classified according to their function as follows (Forest resources... 1993):

- *Industrial forest plantations* are established totally or partly for the production of wood for industry, mainly as saw logs, veneer logs, pulpwood and pit props.
- *Non-industrial forest plantations* are established mainly for the following objectives: production of fuelwood or charcoal; production of small-sized wood for domestic consumption; production of non-wood products; or soil protection.

Some agricultural tree crops may also become a source of timber due to advancement in processing technology and local scarcity of wood. For example, improved preservation and drying technology have greatly promoted the use of rubberwood (*Hevea brasiliensis*) for quality furniture and other products in south-eastern Asia (Salleh 1984). Of the major *non-forest plantations*, rubberwood occupies 7.2 million ha, coconut 4.2 million ha and oil palm 2.7 million ha. The majority of these crops are grown in Indonesia, Malaysia and Thailand (Pandey 1992).

Forest plantations in the southern hemisphere and tropics are generally monocultures of introduced species, forming often rectangular stands of trees of uniform size and geometric spacing. As such they are incapable of supporting the multi-purpose use and biodiversity characteristics of native forests. Nevertheless, due to their high productivity *plantations are actually one of the most efficient ways to reduce the pressure on native forests and combat environmental destruction, erosion and desertification.* This is partly because they are frequently established on barren land. A much higher proportion of the biomass is potentially recoverable for industrial purposes as compared to the natural tropical forests.

2.2 The area of southern plantations

Although the leading individual countries in terms of forest plantation area, i.e. China, Russia, USA, Japan and many European countries, lie north of the tropical regions of the world, large areas have also been put under forest trees in the southern hemisphere and tropics. Unfortunately, information on tropical forest plantations is based on diverse sources of data that relate to a variety of dates, differing definitions and assessment methods, and sometimes on outdated, inflated or even falsified reports. No clear distinction is made between reforestation immediately after final cutting, and the creation of new forests through afforestation on bare land. Areas that have failed as a result of bad maintenance or been destroyed by drought, cattle, fire or insects are only seldom deducted from the compiled statistics. Planting for land rehabilitation without wood production goal, or planting to produce a wood supply for energy purposes or forest industrial use, are not always separated in the statistics. Consequently, the area, species composition, age class structure, productivity, timber drain and purpose of establishment of *the southern plantations as a whole are poorly known.* The most recent information on the global plantation resource is provided by the FAO Forest Resources Assessment Project, which also estimates survival rates, on average 70 % of the planted stock in tropical plantations (Forest resources... 1993).

The reported area of forest plantations in the southern hemisphere and tropics is presented in Fig. 1. The statistics of FAO on developing countries for 1980 have been supplemented in the figure with the plantations of Australia, New Zealand and South Africa, which together are responsible for a substantial part of the pine plantations. In 1980, the total plantation area added up to over 16 million ha. It was equally distributed into non-industrial, industrial hardwood and industrial softwood plantations, but geographically there were significant differences in the distribution. In the Pacific Ocean region, plantations were established mainly for industrial softwoods, whereas the tropical Asian plantations were for non-industrial purposes or industrial hardwoods. *During the 1980s considerable developments took place*, noticeably in non-industrial plantations in the form of community forestry, agroforestry and land rehabilitation. The area expanded most rapidly in tropical Asia. India alone reported a total area of 18.9 million ha, 20-30 % of which may be industrial. Progress was slow in Africa.

According to Evans (1992), the area of forest plantations in the tropics and hotter subtropics was 42.7 million ha in 1990. According to Pandey (1992), *the total area of forest plantations in all of the southern hemisphere and tropics was 49.7 million ha in 1990. The area of industrial softwood plantations was 8.7 million ha* (Fig. 1). Of all southern hemisphere and tropical softwood plantations, 4.4 million ha were in Latin America, 1.7 million ha in the region of Oceania, 1.5 million ha in Asia and 1.3 million ha in Africa. Relatively, the share of industrial softwood plantations in the total planted area was radically reduced during the 1980s.

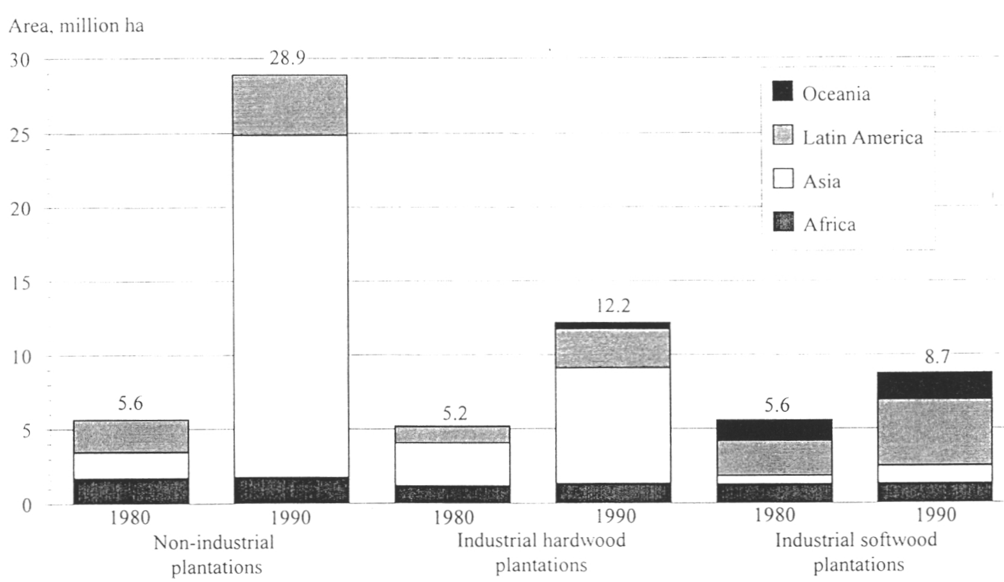


Fig. 1. Reported area of tree plantations in the southern hemisphere and tropics in 1980 and in 1990 (data from An interim... 1988 and Pandey 1992).

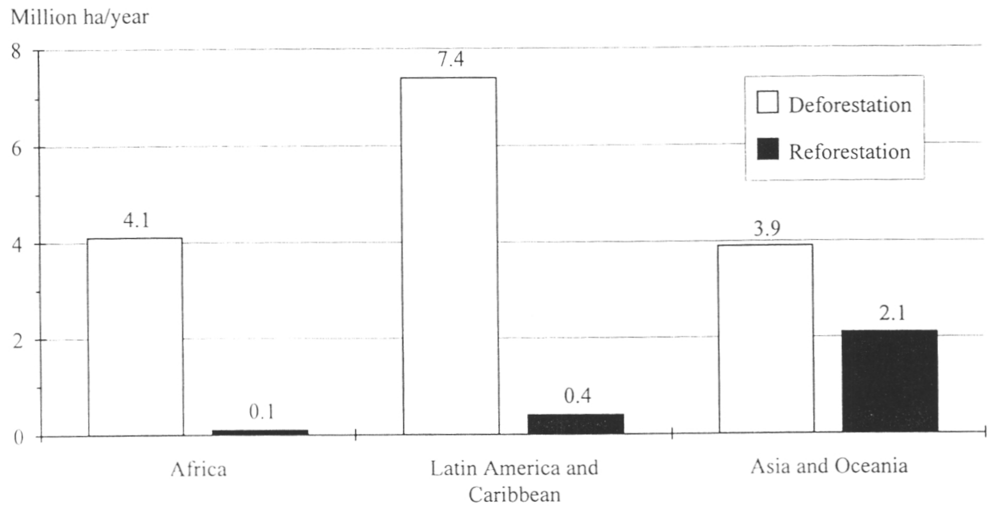


Fig. 2. Annual deforestation and successful reforestation rates of the period 1981-1990 by region. Assumed survival rate 70 % of the reported plantations (Forest resources... 1993).

In the developing countries, a large part of the forest plantations are thus non-industrial, either aimed at the production of fuelwood or small-sized poles for rural construction work, or established exclusively for land rehabilitation purposes. For example, the proportion of non-industrial plantations is 80 % in West Sahelian Africa and more than 50 % in East Africa, Insular Africa, and South-East Asia from Myanmar to Vietnam (An interim... 1988).

Although the plantation area increased rapidly in the 1980s, *the rate of establishment did not match deforestation*. The areas of deforestation and reforestation do not always coincide geographically, but are typically separated in both time and space. The creation of plantations could substitute only a fraction of the loss of natural forests (Fig. 2). Nevertheless, by supplying large quantities of timber of preferred species from relatively small and easily accessible areas of land, plantations help to slow down the rate of contraction in the natural forests. In relation to the production of industrial wood, *the significance of plantations is disproportionate to their area* (Mather 1990).

It is widely believed that growth rates are outstandingly high in the southern hemisphere and tropical plantations, but this is only so on sites with good soils and in favorable precipitation and temperature conditions. Many of the most productive southern plantations are at higher altitudes or latitudes. Furthermore, *high yields are dependent on good management*, and the unexpectedly poor yields experienced in some tropical plantation projects, half or less of the expected growth, can be directly related to management failure (Evans & Wood 1993). The principal factors for low yield are wrong site selection for a given species, wrong choice of the species on a given site and lack of tending. Many plantations suffer from poor stocking due to initial casualty of seedlings and their non-replacement, illegal felling and damage from grazing and fire (Forest resources... 1993). However, it is notable that those southern hemisphere plantations which have been established to produce timber for the forest industries are typically well-managed and fast-growing, and thus represent a much larger production potential than the area alone may suggest.

Sutton (1991) categorizes *a plantation as fast-growing if the mean annual increment exceeds 14 m^3/ha*. In 1990, the area of fast-growing industrial hardwood plantations, intended primarily for the production of short-fiber pulpwood, was 6.0 million ha. *The area of fast-growing southern softwood plantations was 7.7 million ha*, a half of it in South America. Table 1 shows the distribution of fast-growing industrial plantations by region and by management intention. About 40 % of the fast-growing southern softwood plantations are intended for non-sawlog objectives, whereas saw logs or veneer logs are the primary product in 60 % of the softwood plantations. Latin American softwood plantations are typically equally headed for the production of pulpwood and unpruned saw logs, whereas in New Zealand and Australia pruned or unpruned saw logs are usually the main potential product and the primary source of net incomes from forestry.

Only a small number of tree species is responsible for the production of industrial timber in the southern hemisphere and tropical plantations. Most of these species are *exotic, i.e. introduced from other countries*. In the early 1980s, eucalypts covered 37 % and teak 14 % of the total area of southern industrial plantations. Pines occupied 34 % of the total area, and other softwoods, such as *Araucaria angustifolia* from Brazil, *Araucaria cunninghamii* from Australia and New Guinea, *Cupressus lusitanica* from Mexico, and *Pseudotsuga menziesii* from North America in all 3 % of the total area (Evans 1987). In the southern hemisphere and tropics, softwood plantations are thus established mainly for various species of pine, which are the topic of the present paper.

Table 1. An estimation of the area of fast-growing industrial plantations by region and management intention in 1990. Fuelwood plantations are not included (Sutton 1991).

Region	Softwoods				Hardwoods	Total
	Management intention					
	Pulp-wood	Unpruned saw logs	Pruned saw logs	Total softwood	Pulp-wood	
	Area, million ha					
Africa	0.4	0.1	0.5	1.0	0.9	1.9
Asia	0.4	-	-	0.4	0.25	0.65
Latin America	2.0	1.6	0.3	3.9	3.9	7.8
Europe	0.05	0.2	-	0.25	0.8	1.05
Oceania	0.2	0.7	1.2	2.1	0.1	2.2
Total	3.05	2.6	2.0	7.65	5.95	13.6

3 Pines as southern exotics

3.1 Conifers in the southern hemisphere and tropics

A number of coniferous tree species thrives naturally in the southern hemisphere. Genera such as *Araucaria*, *Podocarpus* and *Agathis* are well-known for their excellent wood properties, but they all occur in a limited area only, and are in very short supply. The most important native conifer in the southern hemisphere is probably *Araucaria angustifolia*, known as Parana pine in the international timber trade. Earlier, araucaria forests covered large areas in southern Brazil and neighboring countries, but the resource has been unsustainably exploited. With few exceptions, the remaining *native coniferous forests in the southern hemisphere and tropics have only local importance*, and they are not able to supply raw material for large-scale industrial activities. A part of them is unexploitable for conservation, physical or economical reasons. Therefore, softwood lumber, long-fiber pulp and most paper products have been traditionally imported to this part of the world mainly from North America and the Nordic countries.

Of all the genera of conifers, *the genus of pine is the richest in species*. Up to 90 different pine species have been identified. No other conifer, and among the deciduous trees only the genus of oak, is comparable to pine in terms of the extent of its range. Although pines are characteristic of boreal forests, the number of pine species is actually low in the north. It increases toward the south, and is greatest in the frontier district between the temperate and subtropical zones of the northern hemisphere, especially in Mexico, China and the Mediterranean region (Sarvas 1964). Mexico has the greatest number of pine species of any country in the world. Occurring between latitudes 12° and 32°N, the pines of Mexico and Central America might be thought to be tropical, but because of the predominantly mountainous topography, the climates range from humid tropical on the narrow

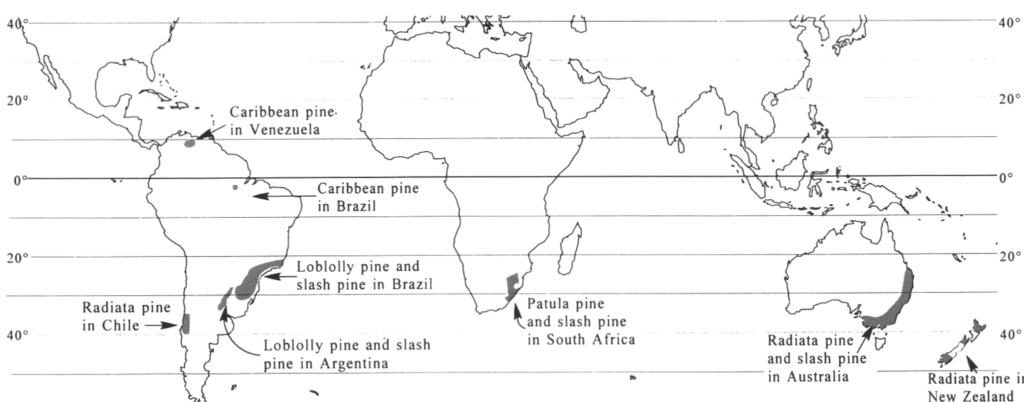


Fig. 3. Location of the major pine plantations in the southern hemisphere and tropics.

coastal plains of the south, to cold temperate on the mountains of the north, and to boreal on the high snow-capped peaks (Perry 1991). In a limited area in the Indonesian highlands, the world's southernmost pine species, *Pinus merkusii*, spreads out over the equator to the southern hemisphere.

About *90 % of all southern softwood plantations have been established for pines from the northern hemisphere* (Table 2, Fig. 3). Initially, the selection of a specific pine species for southern hemisphere plantations was based on its climatic and soil requirements and productivity, rather than the technical properties of wood. Of the major pine wood producers in the southern hemisphere, New Zealand, Australia and Chile grow primarily radiata pine (*Pinus radiata*) from California, whereas the large pine plantations in Brazil are based on the cultivation of slash pine (*Pinus elliottii*) and loblolly pine (*Pinus taeda*), two rather similar yellow pines from south-eastern USA. The Republic of South Africa, as well as several south-eastern African countries rely largely on patula pine (*Pinus patula*) from Mexico. Caribbean pine (*Pinus caribaea*) from the Caribbean region is grown in the tropics, for example in northern Brazil, Venezuela and Fiji. The wide variety of climates in China allows cultivation of several pine species, among them masson pine (*Pinus massoniana*), slash pine and loblolly pine in the south of the country. The area of plantations is rather modest for other species of pine grown in the southern hemisphere and tropics, such as *Pinus kesiya*, *Pinus merkusii*, *Pinus oocarpa* and *Pinus pinaster.*

Table 2. The major pine species cultivated in industrial plantations in the southern hemisphere and tropics.

Species	Common name	Native range	Location of major plantations
Pinus radiata	Radiata pine, Monterey pine	Californian coast in USA and Mexico	New-Zealand, Chile, Australia, Spain, South Africa
Pinus elliottii	Slash pine	South-eastern USA	USA, China, Brazil, South Africa, Australia, Argentina, Swaziland, Uruguay, Tanzania
Pinus taeda	Loblolly pine	South-eastern USA	USA, Brazil, China, South Africa, Argentina
Pinus caribaea	Caribbean pine	Bahama Islands, Cuba, Central America	Venezuela, Australia, Brazil, China, Mexico, Fiji, Tanzania, Philippines
Pinus patula	Patula pine, Mexican weeping pine,	Southern Mexico	South Africa, Swaziland, Malawi, Madagascar, Kenya
Pinus kesiya (P.Khasya, P.insularis)	Khasi pine	Continental south-eastern Asia, Philippines	Madagascar, Zambia, Malawi, Philippines
Pinus merkusii		South-eastern Asia	Indonesia
Pinus pinaster	Maritime pine	Western Mediterranean area	Portugal, Spain, Australia, South Africa
Pinus massoniana	Masson pine	China	China

3.2 Radiata pine as a plantation tree

Radiata pine is native to a very limited area of coastal California between 28° and 38°N where the average annual rainfall is 420-760 mm. Only five small relic populations exist: in Año Nuevo, Monterey and Cambria on the Californian mainland, and on Cedros and Guadalupe Islands in the Pacific off the west coast of Baja California. The total *area of the remaining native radiata pine forests is probably not more than 10 000 ha.* In the range of its natural distribution, it is a rare and technically inferior species without commercial value.

When cultivated in the southern hemisphere at suitable sites in a favorable climate, radiata pine grows amazingly well and *has become one of the most popular exotic forest trees.* It is multi-purpose timber which is used for the production of lumber, composite boards, pulp and paper (Kininmonth & Whitehouse 1991). Plantation-grown radiata pine has solved the problems caused by the shortage of native softwood timber in New Zealand, Australia, and Chile. All three countries are presently producers of long-fiber kraft pulp and pine lumber, once privileges of the northern forest industry countries. In the northern hemisphere, radiata pine plantations are successful in Spain. In November 1990, *the total area of radiata pine plantations was some 3.5 million ha* (Lavery 1990).

In terms of the technical properties, fast-grown radiata pine wood differs in many respects from slow-grown boreal Scots pine (*Pinus silvestris*) wood, particularly as a raw material of the mechanical forest industries. Compared with Scots pine in Finland, very high hectare yields are achieved with about a half of the number of trees planted per hectare, and by applying a rotation cycle which is at most only one third of that employed in the southern Finnish pine plantations. Due to a much longer growing season and wider spacing, the volume growth of an individual radiata pine tree is about ten times as fast as the growth of a Scots pine tree in Finland. While the width of an annual ring is in Finland typically about 2 mm, in radiata timber ring widths of up to 15 to 20 mm are not uncommon.

Radiata pine *wood is characterized by wide annual rings with a gradual transition from earlywood to latewood, a wide zone of juvenile wood around the pith, and thick branches.* Lower branches may die at an early age but persist below the live crown. The proportion of bark is 13 to 15 % of stem volume (Cown 1989).

Radiata pine is prone to malformation and does not shed dead branches easily. If planted at high densities and just left untreated, the stems will have a high proportion of malformation and the branches will still be large, dead and persistent (Fig. 4). Depending on genetic characteristics, radiata pine frequently has several whorl clusters per annual shoot. In spite of successful tree improvements, 70-80 mm or even over 100 mm thick knots occur in radiata pine saw logs. The maximum knot thickness allowed in saw logs in Finland is generally 50-70 mm for live knots and 30-50 mm for dead knots, depending on the diameter of the log.

If the trees are not pruned, branch diameter, the distance between branch clusters, the condition of the branch at the time it is embedded in the stem, and grain distortion about knots become critical factors affecting grade outturn in sawing and veneer production. On the other hand, pruning is a common silvicultural practice in New Zealand, where the production and export of high-valued clearwood logs is increasing rapidly.

The fast growth of radiata pine *per se* does not necessarily result in poor technical quality. On poorer sites, radiata pine can give rise to trees of better stem form and finer branching. *If selectively thinned for stem form, pruned and grown vigorously, genetically improved radiata pine will produce valuable defect-free butt logs* with even-textured clearwood which has many desirable features (Fig. 5).

Radiata pine is a medium-density softwood. In mature trees the average basic density is 420 kg/m^3 for the whole tree and 400 kg/m^3 for the sawn timber (Cown 1989). Compared with Scots pine of the same age, radiata pine seems to produce wood with a higher density. However, because of the shorter rotation cycle, radiata pine pulpwood and saw logs are actually lower in density than the corresponding timber assortments of Scots pine in southern Finland. For its density, clear radiata pine wood is high in shear strength parallel to the grain and side hardness, and the modulus of rupture is normal. The modulus of elasticity, maximum crushing stress

Fig. 4. If planted at high densities and left untreated, radiata pine stems will suffer malformation and the branches will be large, dead and persistent (courtesy of New Zealand Forest Research Institute Ltd).

parallel to the grain and possibly nail withdrawal resistance are low compared with the softwoods of the northern hemisphere (Walford 1991).

The wood density of radiata pine is characteristically rather uniform across the growth ring. It follows that little tearing-out occurs in planing or moulding, or in operations such as cross-cutting, boring and routing, when they are carried out on clear, mature outerwood. In a study by the New Zealand Forest Research Institute, number 1 clears from pruned trees and clear cuttings from between two branch whorls from unpruned trees had performance criteria justifying its consideration for demanding end-uses in the joinery and furniture sectors (Table 3). Because of its medium density, even texture, and low outerwood resin content, the wood is easy to peel and slice with minimum pre-treatment, whereas, for instance, southern yellow pine bolts are usually heated in steam or hot water to soften the knots and reduce the severity of knife checks (Cown 1989).

Compared with most wood, that of radiata pine is very permeable. This can be attributed to the presence of large interstices, which form as a consequence of the collapse of radial parenchyma, and to the lack of extractives. Because of its high permeability, radiata pine sapwood should be thoroughly sealed or treated with an appropriate preservative if exposed to conditions of high moisture content or dampness. Radiata pine is amenable to preservative treatment (Bamber & Burley 1983).

Fig. 5. If selectively thinned for stem form, pruned and grown vigorously, radiata pine will produce defect-free butt logs with a high proportion of valuable clearwood (courtesy of New Zealand Forest Research Institute Ltd.)

Table 3. Machining characteristics of New Zealand-grown radiata pine lumber compared with selected yellow pine and unsorted Finnish redwood (Scots pine) lumber (A prime... 1990).

	Machining operation							
Species	Plan-ing	Mould-ing	Rout-ing	Auger drill	Twist drill	Mort-ise	Cross-cutting	Turn-ing
Radiata pine (no. 1 clears)	*****	****	***	****	*****	*	****	***
Radiata pine (clear cuttings)	****	****	***	***	****	*	***	nt
Radiata pine (dressing grade)	**	**	***	***	****	*	****	nt
Yellow pine (select)	****	****	****	***	*****	*	***	**
Finnish redwood (unsorted)	****	****	****	*****	*****	**	***	**

Grade: ***** excellent, **** good, *** fair, ** poor, * very poor, nt = not tested

Because of the fast growth and relatively young age, radiata pine logs contain a large proportion of juvenile wood with inferior properties. Spiral grain reaches its maximum inclination of 5 degrees in about the third ring from the pith. It then gradually decreases in severity, and by about the fifteenth ring the grain is almost parallel with the tree axis. In this respect, radiata pine differs from many of the slow-grown commercial softwoods of the northern hemisphere, in which spiral grain is predominantly a feature of the outerwood of old trees (Bamber & Burley 1983, Harris 1991).

The critical pulping properties of radiata pine wood vary as a function of tree and wood age. Typically, the tracheid length is about 1.5 mm close to the pith and increases to 3.5-4 mm at the outer growth layers. The tracheid length then fluctuates about a mean value of a little over 4 mm length, and may still increase slightly with increasing cambial age. In the same way, the basic density of wood increases from the pith outwards, typical values being 320 kg/m^3 adjacent to the pith and 475 kg/m^3 at more than 30 growth layers from the pith (Harris & Cown 1991).

A summary of some basic wood properties of radiata pine by tree ages and timber assortments in New Zealand is presented in Table 4. For comparison, the average basic density of Scots pine in southern Finland is 400-405 kg/m^3 for pulpwood and 425-430 kg/m^3 for saw logs. In southern Finnish pulpwood, the content of acetone soluble extractives, i.e. resin, is 3.5 % (Hakkila 1968) or somewhat higher than in plantation-grown radiata pine pulpwood.

Wood with a considerable range of properties is thus available from different age classes and from within a single tree. In fact, use is made of this variable characteristic of radiata pine wood by some New Zealand pulp and paper mills by

Table 4. Basic density, tracheid length and resin content of radiata pine in New Zealand as a function of tree age and stem component (Harris & Cown 1991, Kininmonth 1991).

Stem component	Tree age, years	Density, kg/m³ Green	Basic	Tracheid length, mm	Resin content, %
Whole stem	12	1 025	325	2.5	3.3
	24	945	375	3.4	2.9
	34	955	415	3.4	1.9
	52	815	420	3.5	2.9
Saw logs (>25 cm)	24	940	390		
	34	945	420		
	52	810	430		
Lumber	24	810	365		
	34	820	395		
	52	620	400		
Slabwood	24	1 100	420	3.6	2.5
	34	1 100	450	3.8	1.6
	52	1 100	475	4.0	1.5
Top logs (<25 cm)	12	1 025	325	2.5	3.3
	24	950	355	3.0	3.0
	34	980	400	3.1	2.6
	52	920	410	3.2	2.0

directing chips from young thinnings and chips from sawmill slabs to the manufacture of specific products thereby assuring the best qualitative and economic results. Three pulp categories are recognized, corresponding to pulps made from chips of low, medium and high basic density. Each of these pulps has specific papermaking qualities. Manufacturers are able to control pulp uniformity and fiber quality through the segregation and monitoring of raw material from different sources in the wood yard (Cown 1989).

Radiata pine wood, unlike Scots pine wood in Finland, is also used *for mechanical pulping in the absence of spruce wood.* This is obviously facilitated by the more gradual transition from earlywood to latewood in the annual ring and the lower content of resin. In a recent study by Richardson et al. (1992) radiata pine top logs had a mean fiber length of 2.7 mm, and slabwood from radiata pine saw logs 3.2 mm. Radiata pine PRMP and TMP pulps had less shives and more long fibers than did mechanical spruce pulps from Europe under the same process conditions. It was suggested that by selecting the correct preheating conditions, refiner type, and screening and reject-refining strategies, radiata pine mechanical pulps could compete with spruce pulps in the international market place not only on the basis of processing cost but also on performance quality.

The radiata pine mechanical pulps generally have higher strength but lower brightness and opacity at a given freeness than corresponding pulps from northern spruce (Cown 1989). Thinnings are the best type of raw material for groundwood pulp production, although they have the disadvantages of low wood density and low through-put. But off-setting this there is the advantage of higher brightness as compared to mature radiata wood.

3.3 Yellow pine as a plantation tree

The subsection of southern yellow pines of genus *Pinus* is the most important timber source in the USA. Yellow pines primarily range south of latitude 40°N and east of the Great Plains in favorable climatic conditions with the average annual temperature between 10° and 25°C and an annual rainfall from 1250 to 1750 mm. Some of them also range northward of this region, but all have at least 50 % of their standing volume in the USA South. Owing to cutting restrictions for environmental reasons in the west of the country, *the relative importance of yellow pines in the USA is increasing*.

Eight yellow pine species grow natively in the USA. The principal species is loblolly pine (*Pinus taeda*), accounting for nearly half of the southern pine inventory. The second most abundant is shortleaf pine (*Pinus echinata*), followed by longleaf pine (*Pinus palustris*) and slash pine (*Pinus elliottii*). Three tropical yellow pine species occur in the Caribbean islands and Central America. The most important of them is Caribbean pine (*Pinus caribaea*).

In the early 1980s, loblolly pine was dominant in the USA on 11.7 million ha, occurring on a wide variety of soils. The best growth is in moderately acid soils having imperfect to poor surface drainage, a deep medium-textured surface layer, and a fine-textured subsoil. The climate over most of the loblolly pine range is humid warm-temperate with long, hot summers and mild winters. Mean annual precipitation varies from 1000 mm to 1500 mm (Baker & Balmer 1983).

Slash pine is dominant on 5.0 million ha. It occurs naturally in two varieties within 240 km of the Atlantic and Gulf coasts from South Carolina to Louisiana, and throughout most of Florida. Since it is susceptible to ice damage, it is usually found near the coast and in warm areas where ice storms are not common. The commercial range has been extended by planting to the north and west. Although slash pine adapts to a great variety of soil conditions, it grows best in deep, well-aerated soils that supply ample quantities of moisture during the growing season. The climate within the natural range of slash pine varies from tropical in the Florida Keys, to transitional between temperate and subtropical in the north (Shoulders & Parham 1983).

Koch (1972a) lists three reasons why the southern *yellow pines are pre-eminent as a source of raw material for the forest industry in the USA*:

1. Substantial volumes of timber are available and the resource is rapidly renewable. The trees can be grown economically on a rather short rotation in pure stands over a broad range of sites throughout the USA South. Technologies for regenerating and managing the stands are highly developed.
2. Geography favours the growth, utilization, and marketing of the species. Year-round woods operations are possible, labor and land costs are competitive, and nowhere is the growing region distant from primary markets.
3. *The wood itself has an unusual combination of desirable properties*. Its strength is outstanding. Its light colour and the strength of its fiber adapt it for pulping by both chemical and mechanical process. The self-pruning attribute permits clear lumber to be produced in quantity for millwork. It is a prime material for structural plywood. Further, the form of the stem favours its broad acceptance for poles and piling. The permeability of the wood facilitates drying and preservative treatment.

Young stands of yellow pines respond promptly to thinning or release. Precommercial thinning to 1200-1700 trees per ha before the stand age of five years is recommended in the USA. Commercial thinnings should be initiated by the age 20, but they are frequently neglected. Rotation lengths vary according to product objective. The optimum rotation is about 25 years for pulpwood and 30 years or more for saw log production. Loblolly and slash plantations can be established for fiber, but as the fiber rotation approaches, they can be thinned and grown another ten years for lumber production with no loss in yield.

In the growth conditions of the south-eastern USA, both loblolly pine and slash pine *produce wood of long 4 mm fibers, high basic density and excellent strength* (Koch 1972a). Slash pine has even denser and stronger wood than loblolly pine. The following table is based on data accumulated from defect-free samples of yellow pine wood by the USDA Forest Products Laboratory over a long period of years (Bentsen & Ethington 1972).

	Moisture content	Basic density, kg/m^3	Modulus of elasticity, MPa	Modulus of rupture, Mpa
Loblolly pine	Green	470	9 450	49,6
in the USA	12 %	470	12 070	86,9
Slash pine	Green	530	10 550	60,0
in the USA	12 %	530	13 650	112,4

Yellow pine accounts for over 26 million ha in the USA South. This wood source is evolving toward plantation dominance and smaller trees. Plantations, mainly loblolly pine, presently make up one third of the area, and by 2030 their share is expected to grow to two thirds of the resource (Fig. 6). Forest industry controls 63 %, private forest owners 32 % and the public owners 5 % of the plantations.

The long upward trend of the pine timber inventory of the USA South ended in the mid 1980s when it started to decline. It is projected to rise again, but not to regain 1985 levels until 2030. The decline is related to a reduction in the total area of timberland and the conversion of older natural stands to young plantations (Brown

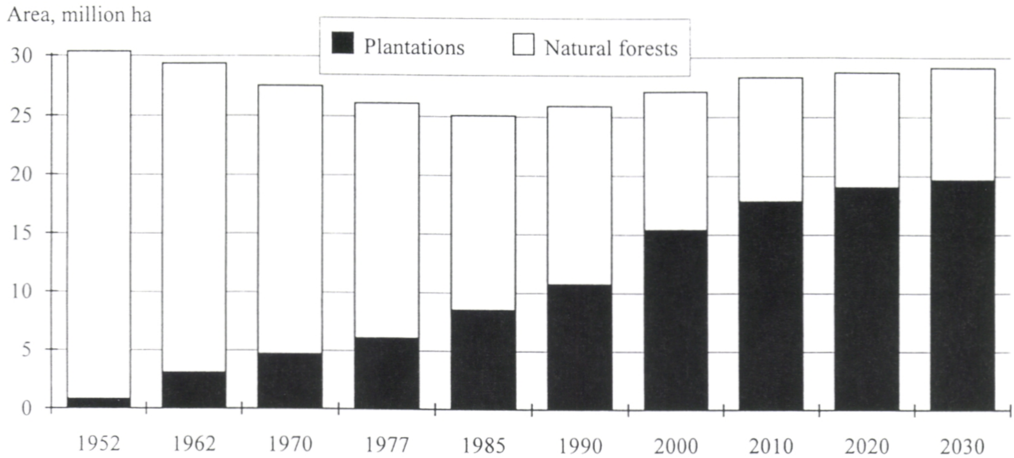


Fig 6. Trends and projections of the area of natural and planted yellow pine stands in the USA South (data from Brown & McWilliams 1990).

& McWilliams 1990). The area of successful regeneration does not match the area of final cuttings. However, substantial opportunities exist for increased production if private industrial landowners more intensively regenerate and manage their forest lands.

In the USA, the average yield for yellow pine plantations is 6-9 m^3/ha/a (Shoulders & Parham 1983). The total net annual increment of yellow pine wood in the USA is presently about 150 million m^3 (Hellström 1993). The annual increment of all the southern hemisphere and tropical pine plantations is slightly less. The annual cut of yellow pine timber in the USA is about 130 million m^3 and is expected to reach 160 million m^3 by 2020. The proportion of plantation-grown timber in the annual cut is increasing rapidly (Fig. 7).

The shift from natural pine stands to plantations has many implications for industrial manufacturing and product quality. For example, as fast-grown pine with its shorter rotation cycles consists of an increasing proportion of juvenile fibers, both pulp and paper properties are changed. The cost of manufacturing increases as digester packing, pulp yield and by-products decline. Paper made from chemical pulp with a high content of juvenile fiber has higher burst, higher tensile strength, higher fold endurance, higher sheet density and lower tear than paper with a high content of mature wood fiber. Juvenile wood has greater whiteness properties and, consequently, requires less bleaching. Uniformity of sheet formation and printing characteristics also improve due to more homogenous fiber source from young plantations. From the pulp and paper manufacturing point of view, the change in the raw material base thus provides both benefits and limitations. It is of great importance that the nature of changes is known and the processes adjusted accordingly (Thomas & Kellison 1990). It is obvious that the changes in technical properties of wood are even more radical when yellow pines are grown in the southern hemisphere and tropical plantations.

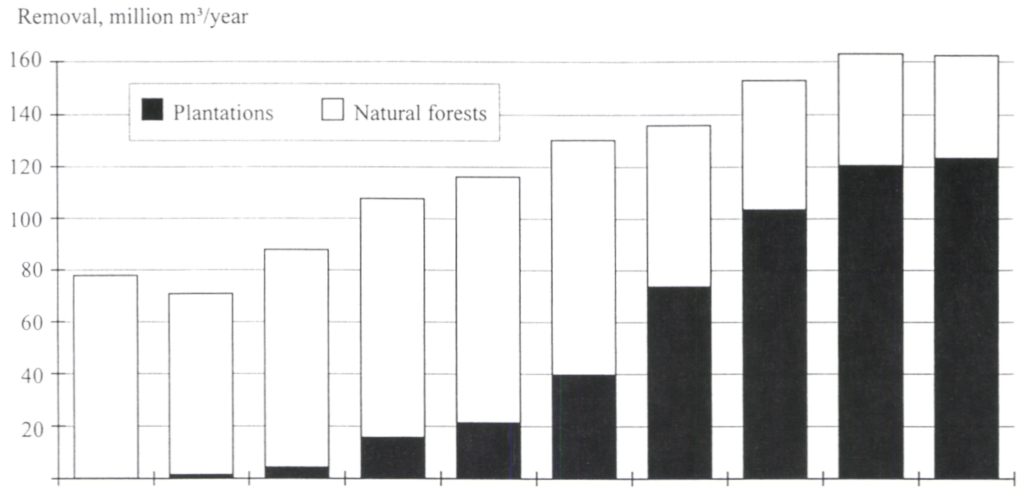


Fig. 7. Trends and projections of the average annual removals of yellow pine timber from natural and planted stands in the USA South (data from Brown & McWilliams 1990).

Product properties similarly change in the mechanical forest industries when naturally grown yellow pine is replaced by plantation-grown timber. Some changes in the properties of lumber and plywood are listed below (Oberg 1990):

Changes in lumber properties:

- Greater proportion of knotty wood
- Lower strength and stiffness for visually graded lumber
- Greater variability of strength and stiffness, except for machine-stress rated products
- Increased degrading if only conventional kiln-drying techniques are used
- Greater potential for warpage
- Better treatability using water-borne preservatives

Changes in plywood properties:

- Lower net recovery of veneer resulting from smaller block size
- Lower panel density resulting from lower basic density of wood
- Different grade of veneer from average block, including a lower proportion of clear grades
- Lower panel stiffness if juvenile wood is on face or back plies
- Greater linear expansion of panels resulting from higher content of juvenile wood

When grown and intensively managed *in widely-spaced exotic plantations outside their natural range, individual loblolly and slash pine trees grow considerably faster and their rotation period is shorter than in the USA*. The resulting timber has a larger proportion of juvenile wood, shorter tracheid length, lower basic density, lower mechanical strength, more knots, and a tendency to produce a malformed bole. For example, in stands 15, 30 and 45 years old on the Coastal Plain of South Carolina, the respective basic density of extracted resin-free loblolly pine wood is about 410, 460 and 480 kg/m^3 (Koch 1972b). In Brazilian plantations, the average basic density of unextracted loblolly pine and slash pine pulpwood was 390 kg/m^3 at the age of 10 years, and 445 kg/m^3 at the age of 15 years. In the latter study, the average tracheid length was 2.4 mm and 2.8 mm respectively, and the outer tracheid diameter 40 and 42 μm (Tomazelli et al. 1979).

Two thirds of the yellow pine plantations of the world are being established in the south-eastern United States inside the native range of the species. On an areal basis, the second largest grower of yellow pines is probably the Peoples' Republic of China, where the timber is intended exclusively for domestic consumption. The third largest producer is Brazil, where the main uses are in the sawmill industry for domestic markets and in the kraft pulp industry for domestic and export markets. Other major growers of yellow pine timber are Argentina, Venezuela, the Republic of South Africa, and Fiji (McDonald & Krugman 1986).

Outside their native range *in temperate and subtropical climates, loblolly pine and slash pine are the most successful of all yellow pines. Caribbean pine thrives in the hot tropical climate*, but plantation areas are modest compared to loblolly and slash pine.

4 Producer countries of exotic pine wood

The southern exotic pine resource is outlined countrywise in section 4. Southern countries not examined here are not likely to become internationally significant producers of softwood timber during the next 2 or 3 decades, although some of them are emerging as important producers of plantation-grown hardwood timber, intended mainly for the manufacturing of short-fiber pulp, but hardwood plantations are outside the topic of this paper.

4.1 Major producers of radiata pine wood in the southern hemisphere

Pine wood from New Zealand

Radiata pine was first introduced into New Zealand sometime between 1830 and 1850. By the early 1910s, it became evident that the indigenous timbers would last no longer than 40 years on their own, and a major programme of afforestation with exotics was launched in the 1920s. Radiata pine soon became the main species in the plantations and rapidly took *a fully dominating role in New Zealand's forestry and forest industry*. The primary role of the 6.2 million ha of closed natural forests is now to protect water and soil resources, to preserve distinctive scenic and natural values for recreational and tourist development, and to maintain biodiversity. Only about 4 % of the natural forests are allocated to or potentially available for commercial forestry.

Plantations extend throughout most of the latitudinal range of the country. The area of man-made forests was 1.31 million ha in April 1992. The majority of the plantations are in gentle terrain, but one third is located on steep slopes requiring the use of cable systems when harvesting (Fig. 8).

In 1992, as much as *1.18 million ha were under radiata pine* alone. In addition, 67 000 ha were under Douglas fir (*Pseudotsuga menziesii*) at higher altitudes, 39 000 ha under other softwoods such as ponderosa pine (*Pinus ponderosa*), Corsican pine (*Pinus nigra* var. *laricio*) and lodgepole pine (*Pinus contorta*), and 26 000 ha under hardwoods. About 70 % of the plantation area is in the North Island and 30 % in the South Island, the largest concentration being located in the Central North Island wood supply region (New Zealand... 1993).

Over half of the plantations were established by the State. However, a privatization programme was started in the late 1980s (Birchfield & Grant 1993). While retaining ownership of the land, *the State sold fixed term evergreen forestry rights* to a range of domestic and overseas companies. The evergreen period is generally

Fig. 8. A third of New Zealand's radiata pine plantations are on steep slopes requiring the use of cable systems in harvesting.

35 years, allowing any tree crop purchased or established by the rights' holder to reach maturity and be harvested. The rights are automatically extended annually by one year until notice of termination is given. Carter Holt Harvey Forests Ltd, Tasman Forestry Ltd, NZ Forestry Corporation Ltd and Rayonier NZ Ltd are the largest plantation holders.

The total standing volume of all plantations is 223 million m^3 excluding bark. *The current annual increment is 21.2 million m^3 per year*. The average standing volume is 187 m^3/ha, *the average current increment 17 m^3/ha/year*, and the area-weighted average age is 14 years (A national... 1992). Mean annual increments as high as 40 m^3/ha/year have been recorded.

Due to genetically improved material and more efficient management, rotation ages have declined from over 50 years in the old crop to just over 30 years now, and will decline further to just below 30 years before increasing slightly. In 1990 about 43 % of the total radiata pine estate was *genetically improved for better stem form and increased volume growth*. The initial spacing has been reduced to only 750-850 seedlings per hectare in plantations which are to be pruned, due to improvements in tree breeding (Goulding 1993). If the management schedule does not include pruning, the stand is usually established at a higher stocking and thinned later and less heavily in order to reduce branch thickness. *Four categories of management regimes* are recognized (A national... 1992):

	Proportion of the plantation area of radiata pine, %
Intensively tended with production thinning	20
Intensively tended without production thinning	38
Minimum tended with production thinning	7
Minimum tended without production thinning	35

Production thinning refers to the extraction of thinnings for commercial use. *Intensive tending* refers to pruning carried out prior to the age of 12 years, such that more than 50 % of the stems in the planned final crop stocking will contain a pruned butt log of not less than four meters in length. The management strategy incorporates timely pruning to enhance yields of clearwood with early heavy thinning to concentrate growth on the final crop trees (Kininmonth & Whiteside 1991). Volume productivity is thus sacrificed in favour of tree size to ensure an adequate amount of pruned clearwood. The role of intensively tended plantations is increasing, with a significantly higher proportion in the younger age classes (Fig. 9).

The first commercial thinning at the age of 12 years yields pulpwood rich in juvenile wood. The technical properties of pulpwood from early thinnings differ from pulpwood from top logs from larger trees and slabs from sawn goods. While radiata pine is the only timber species available for the New Zealand forest industries in great quantities, *this variation in radiata pine properties can be used by pulp mills to produce different pulp and paper grades* (Kibblewhite & Bawden 1990, 1991).

Fig. 9. A young radiata pine plantation in New Zealand just after the first pruning.

In 1992, the total removal from plantation forests was 14.2 million m^3. The majority of timber, 11.8 million m^3, was harvested from clear-cut areas with a high average yield of 590 m^3/ha. Thinning cuttings produced 1.6 million m^3. The removal comprised the following timber assortments (New Zealand... 1993):

	Removal from plantations in 1992, million m^3
Saw logs	4.9
Veneer logs	0.2
Small logs and pulpwood	4.7
Export logs	3.6
Export chips	0.8
Total removal	14.2

With the resource characterized by predominantly young crops, almost two thirds being 15 years of age or less, the allowable cut will increase substantially over the coming decade. Since the local demand will not grow in the near future, *the amount of radiata pine wood available for exports will increase considerably*. At present about two thirds of the harvest is sold to domestic industries and one third is exported in the form of logs or chips, but in the next 15 to 20 years the ratios may be reversed.

The "old crop" plantation timber from the 1920s and 1930s is now exhausted and these early plantations have been re-established. New planting started to increase in the mid 1960s, but declined rapidly in the late 1980s. In 1991 only 37 000 ha were planted, consisting of 22 000 ha of replanting and 15 000 ha of new planting. The trend was then reversed again after changes to the forestry taxation regime, so that in 1992 over 40 000 ha of new areas were planted, the restocking of clear-cut sites excluded (Valentine 1993).

Even if no new areas are planted for trees, the wood supply from New Zealand's plantation forests is forecast to *rise rapidly from the current level of 14 million m^3 per year to 23-24 million m^3 per year by 2005* (Fig. 10). Radiata pine makes up approximately 80 % of the wood supply forecast in 1992 and is expected to increase to 90 % by 2000. The primary assumptions for the scenario are that the rotation length is 30 years, and that all areas are replanted in the year following clear-cutting. An alternative early-cut scenario, based on a shorter rotation cycle of 25 years, would allow for an even sharper rise in the 1990s, but in the long run the annual sustainable cut would then be about 1.5 million m^3 lower. It is important to note that shorter rotation cycles would produce timber with poorer technical properties: smaller diameters, a smaller proportion of clearwood, a higher proportion of juvenile wood, a lower basic density of wood, and lumber of lower strength.

These resource-based forecasts are conservative, since they recognize only 92 % of the existing national plantation area and assume no new planting at all. If, in

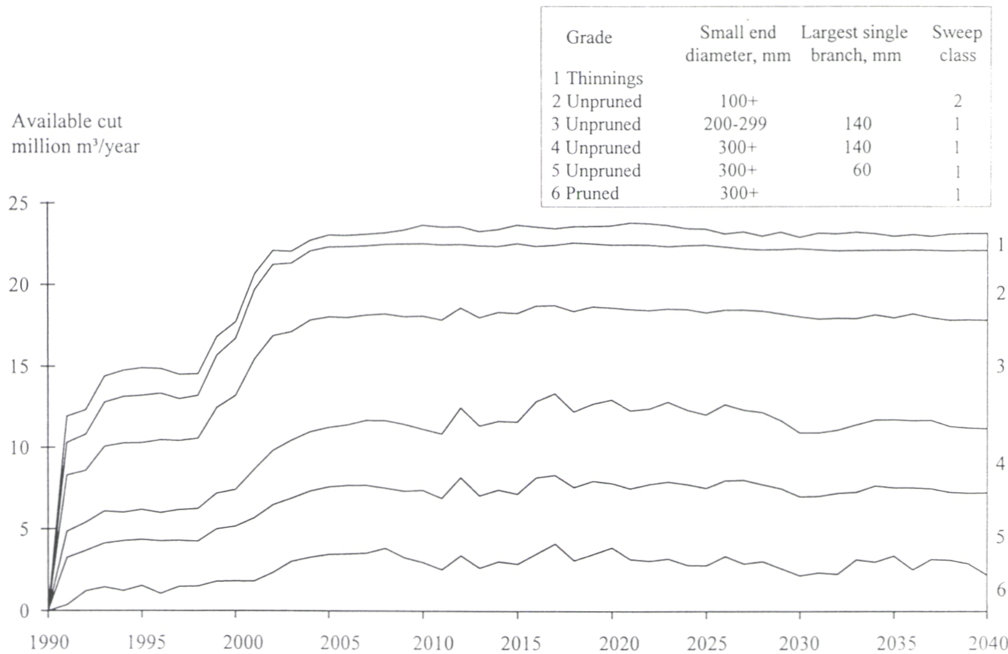


Fig. 10. The potential sustainable wood supply by log grades from New Zealand's plantation forests by 2040. Assumptions: the clear-cut age is 30 years; all areas are replanted in the year following clear-cut; no new plantation areas are established (Turland et al. 1993).

addition to re-establishing clear-cut areas, 50 000 ha of new plantations are constantly established annually, the sustainable annual cut can be raised to 16 million m^3 in 2000, 29 million m^3 in 2010, and 58 million m^3 in 2040 (Fig. 11).

According to the base-cut scenario, almost all timber will be harvested from clear-fellings, so that *the annual cut from production thinnings will gradually decrease* from the current level of 1.6 million m^3 to only 1 million m^3. On the other hand, *the amount of high grade saw logs will increase*. While only 350 000 m^3 of pruned clearwood logs were harvested in 1991, *the annual forecast for clearwood is 1.8 million m^3 by 2000 and 3.4 million m^3 by 2005* (Turland et al. 1993). Although pruning generally greatly improves the quality and value of radiata pine saw logs, pruned logs of the same size and similar external appearance can differ in potential clearwood yields by up to 100 %. Contributing factors include differences in site productivity, seed stock, establishment and early growth, and the number and timing of silvicultural operations (Park 1994).

The release of marginal farmland in New Zealand would theoretically permit even 100 000 ha of new planting annually over the next 30 years. Achieving such a target would leave New Zealand with a planted forest estate in excess of 4 million ha with a sustainable annual yield of 65-70 million m^3. However, given the current rate of new planting, such a target seems to be in the outer levels of optimism (Valentine 1993).

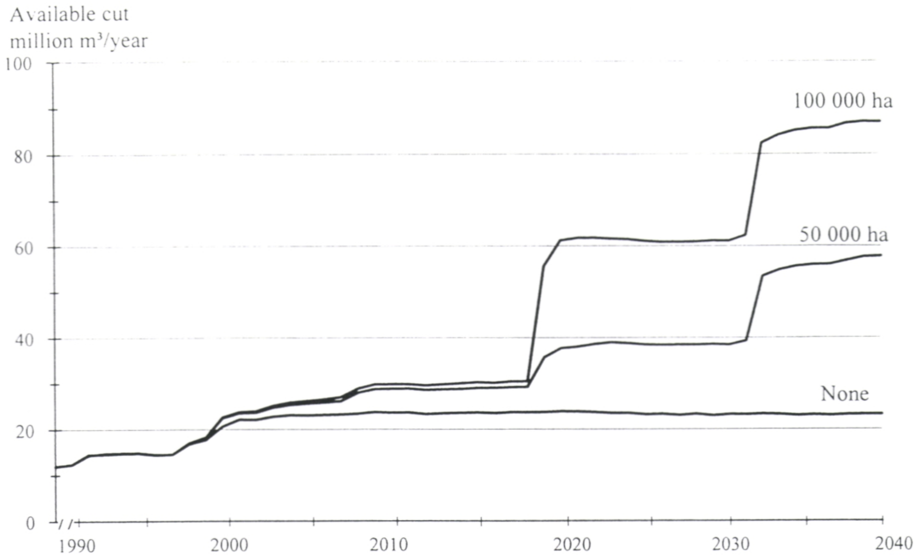


Fig. 11. The potential sustainable wood supply from New Zealand's plantation forests by 2040. Assumptions: rotation age is 30 years; all cut-over areas are replanted in the year following clear-cut; the area of new plantings is alternatively none, 50 000 ha per year or 100 000 ha per year (Turland et al. 1993).

In 1992, the production of the New Zealand forest industries was as follows. Practically all plywood and 87 % of lumber was manufactured from radiata pine. A half of the pulp was exported (New Zealand... 1993):

	Production in 1992
Lumber, 1000 m^3	2301
Veneer and plywood, 1000 m^3	83
Particle board, 1000 m^3	155
Fiberboard, 1000 m^3	514
Mechanical pulp, 1000 (air dry) tonnes	669
Chemical pulp, 1000 tonnes	674
Newsprint, 1000 tonnes	356
Printing and writing paper, 1000 tonnes	20
Other paper and paperboard, 1000 tonnes	404

The domestic consumption of wood is expected to rise only little. It follows that most of the future increase in wood supply will be available for export. The destinations of the New Zealand forest products export are presently primarily Australia, Japan, Korea and Taiwan. While the supplies of Southeast Asian native hardwoods and North American Douglas fir logs are dwindling in the international markets, Japanese companies have become interested in importing radiata pine logs from New Zealand for the production of lumber, plywood and laminated beams and joists. Consequently, the price of radiata saw logs has increased considerably in a short time. In fall 1993, the stumpage price for unpruned radiata pine saw logs was about US \$ 70 per m^3, and that of pruned logs as high as US \$

120 per m³ (Goulding 1993), whereas the stumpage price of Scots pine saw logs in Finland was only US $ 40 per m³. This great difference in stumpage prices made it profitable for the first time in 1993 for Finnish producers of Scots pine and Norway spruce saw logs to penetrate the Japanese and South-Korean markets.

Pine wood from Australia

The forest area in Australia is 41 million ha, but only 7 million ha of the native forests are designated for wood production. Most of the native forests under commercial exploitation are dominated by eucalypts. Since the native forests are important also from the conservation point of view, a relatively small proportion of them is presently managed for the growth of timber. Selective cutting in Queensland's tropical rainforests was stopped in 1989, and the remaining old-growth forests are conserved.

In consequence of conservation measures in Australia's native hardwood forests, plantations are of utmost importance for the country's forest industries. In March 1988, the total area of forest tree plantations was 938 000 ha and that of pine plantations alone 815 000 ha. Two thirds of the area was on public land and one third on private land. The most important producers of pine timber in Australia are, in order of importance, the following states: New South Wales, Victoria, Queensland, South Australia, Western Australia and Tasmania. In South Australia and New South Wales plantations have particularly suffered from wild fires during the last few years, and there is also some concern about the damage caused by woodwasp (*Sirex noctilio*). Soil depletion after three consecutive crops of fast-growing trees is also cause for concern. On the other hand, genetically improved seedlings and new management regimes result in higher growth and better quality.

Radiata pine is the prevailing species in the Australian forest plantations, although in Queensland the main species are slash pine, Caribbean pine and araucarias. Maritime pine is popular in Western Australia. For the entire sub-continent, the species distribution at the end of the 1980s was as follows (Australian forest... 1990):

	Plantation area, ha in 1988
Radiata pine	648 000
Slash pine	89 000
Caribbean pine	46 000
Maritime pine	32 000
Araucaria spp.	46 000
Other conifers	29 000
Eucalypts	42 000
Other hardwoods	6 000
Total	938 000

The area of pine plantations presently exceeds 900 000 ha. Old plantations are being replanted after the final cut, whereas the rate of afforestation on cleared or partially cleared marginal farmland has been decreasing. There is a physical limit to the land that is suitable for continued pine planting, and economic, environmental and social factors further reduce the amount of such land potentially available for plantation forestry (Nimmo 1988).

As in New Zealand, spacing has been widened because of the high cost of early thinning and improved stem form resulting from tree breeding, but pruning for the production of clearwood is not as common. Stem defects such as multiple leaders, forks, sinuosity, butt sweep and heavy branching are most prevalent in former pasture sites, deformities being directly correlated with soil mineral nitrogen concentrations (Birk 1991).

Commercial thinnings are started at the age of around 15 years, and they may be repeated several times. The Nordic fully mechanized log-length system, based on one-grip harvesters and forwarders, is used increasingly for harvesting.

The rotation age is typically 30-40 years, which is longer than in the radiata pine plantations in Chile and New Zealand. Leech (1993) suggests that the rotation length should be actually somewhere near 45 years. The analysis is then based on the whole forest estate and not on a single stand, and consideration is given to economics, wood availability over time and expected future market requirements.

In 1987, more than a half of the plantation area was less than 15 years of age. While the Australian plantation resource has not yet reached a dynamic state of maturity in equilibrium, its maturity is, nevertheless, relatively greater than that in other radiata pine producing countries. This resource maturity is relevant not only to volume production, but also to quality outturns from industry as cambial age-related quality considerations come into play. Of particular relevance in the Australian domestic market is, that outturns of structural lumber from the sawmill industry will be markedly superior where the resource base allows a high proportion of log input to be from stands beyond 30 years of age (Lavery 1990).

In 1990, the Australian forest industries consumed about 4 million m^3 of pine saw logs and 3 million m^3 of pine pulpwood. The use of eucalypt timber was about 5 million m^3 for both purposes (FAO Yearbook... 1991). The annual production of pulp is about 1 million tonnes, which is used exclusively for domestic consumption. Australia imports softwood-based pulp and paper products, yet is exporting increasing quantities of pine chips. Expansion of the domestic pulp and paper industry is a major development challenge. Australia has the potential to capitalize on the growing Asian markets of forest products, but a precondition is the expansion of pine and eucalypt plantations (Florence 1993).

The average annual growth rate in the Australian radiata pine plantations *is in the order of 18* m^3/ha. However, due to variations in climate, soil and altitude, there are great differences between sites and regions. A projection of the available cut of

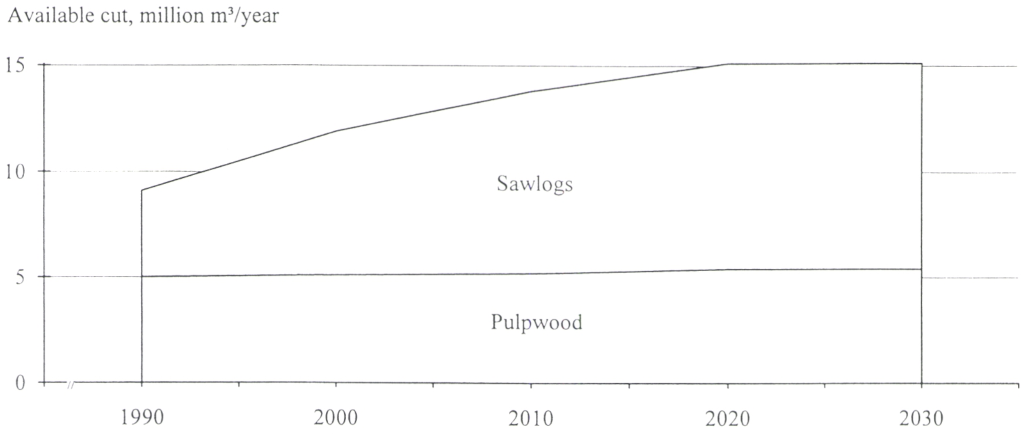


Fig. 12. Projection of the available cut of pine in Australia by the year 2030 (data from Australian forest... 1989).

pine timber is presented in Fig. 12. *The availability of softwood saw logs is estimated to increase from 4.1 million m³ in 1990 to 9.7 million m³ in 2030.* The dependence on imported softwood lumber from overseas is thus decreasing. At the same time, the available cut of hardwood saw logs is expected to decline. *The availability of pulpwood is estimated to remain rather constant, at 5 million m³/year* for softwood (Australian forest... 1989).

Pine wood from Chile

Although Chile has 7.6 million ha of productive native forests, its forestry and forest industries are based on plantations (Fig. 13). The planted area was 1.57 million ha in December 1992 and it is expected to expand to 1.9 million ha by the year 2000. From 20 to 50 % of the plantations are located on slopes steeper than 35 %, thus requiring cable systems for harvesting of timber (Eeronheimo 1994).

The predominant species is *radiata pine, with a total area of 1.31 million ha* and growing stock of 170 million m³ in 1992. The area under planted eucalypt was 172 000 ha, but this species is of increasing importance, and presently its area is growing annually by 30 000 ha. In addition, 11 000 ha are under Douglas fir and another 100 000 ha under other species, mainly slow growing, drought-resistant hardwoods in the semi-arid regions of the country (Cerda et al. 1992).

The first commercial plantations in Chile were established in the early 1900s. Stimulated by government incentives, a dramatic increase has taken place since the mid 1970s. Between 1975 and 1991, about 82 000 ha annually were put under radiata pine (Cerda et al. 1992), one fourth of which consisted of replanting, and the rest was new plantation establishments. As a result, *in terms of area, Chile has become the largest owner of radiata pine plantations,* ahead of New Zealand, Australia, Spain and South Africa. However, as much as 56 % of the Chilean plantations are younger than 10 years of age. Compared to New Zealand and Australia, *the proportion of stands approaching maturity is still small.* Therefore, despite the larger area, the amount of timber currently available from the plantations is less than in New Zealand, but it is increasing rapidly. The plantation subsidies will end in 1994, and thereafter the landowners must carry out both afforestation in barren areas and reforestation in clear-cut areas at their own cost, which will probably slow down the rate of stand establishment.

Plantation forests in Chile are presently under private ownership, Celulosa Arauco y Constitución S.A., CMPC and Inforsa having the largest areas of pine. Private small owners with 50-150 ha holdings control about one third of the plantations. Since suitable land is still readily available from marginal agricultural use and cattle grazing, possibilities to expand the area of plantations are great (Fig. 14).

Radiata plantations are *located in the central part of the country*, mainly in the administration regions VII-IX, between the 35° and 40°S latitude, where temperature, humidity, rainfall and light conditions are favorable. The average annual temperature is 12-15°C and the annual rainfall 1000-3000 mm. The optimum area occurs in the coastal mountains between Constitución and Valdivia. *The average annual increment in all plantations is just over 20* m^3/ha.

The usual goal of forest management is the integrated production of saw logs and pulpwood. The emphasis is on pulpwood production on poorer sites, and on saw log production on more fertile sites. The target *rotation cycle is typically 24 years*. There are signs that requirements for the immediate export cashflow, generated more from the pulping sector than the solid wood sector, may see rotation lengths compromised in the short term. There is a real danger that the appetite of the wood usage system may dominate the wood-growing system to the detriment of the combined sector: rotations of 20 to 22 years may become the norm. This would be many years short of the peak in mean annual increment and, especially, in the net revenue for individual stands, and in turn may result at a national level in a substantial compromise of production capability (Lavery 1990).

If the emphasis is on saw log production, the planting density should be 1000-1300 seedlings per ha, while thinnings and pruning to 5-8 m in height are essential features of the management regime. If pulpwood is the only product, the planting spacing can be 1600 seedlings per ha and the rotation age only 18 years. Pruning and thinning do not then belong to the management regime, which results in higher natural mortality and uneven stem size (Hakkila & Mery 1992). Presently, the use of pine wood is evenly distributed between sawmilling and pulping.

Large knots and malformations lower the yield and quality of lumber. The bucking practice of stems to saw logs is not well developed, reducing the yield further and adding to the quality problems. Sawmills frequently apply only one single saw log length, whereas in the Nordic countries up to ten alternative log lengths are usually available by adapting the bucking selection in accordance with the stem form and location of defects in an individual tree.

Fig. 13. An unthinned mature radiata pine stand ready for clear-cutting in Chile.

Fig. 14. Marginal agricultural land is readily available for radiata pine plantations in Chile.

Due to the fast growth, high proportion of juvenile wood and knottiness in unpruned radiata pine stems, the Chilean radiata pine lumber is considered inferior to boreal softwood lumber in the international markets. For example, because of its wide annual rings, it does not meet the quality requirements of structural lumber in Japan and, consequently, it is used to a large extent for low-grade products such as pallets and boxes.

Genetically improved material, more efficient forest management including pruning and selection for stem form in thinnings, and stricter quality control in timber procurement and sawmilling, are expected to result in better saw log and lumber quality in the future. An intensive management regime, involving pruning in conjunction with early precommercial thinning, was adopted by the major companies during the 1980s. Consequently, valuable *clearwood from pruned butt logs will become available in large amounts around 2010.* As the quality improves, Chilean pine logs and lumber will become more competitive in the international markets. If saw log prices then rise, small and medium-sized sawmills, who have to buy the logs from private forest owners, will suffer more severely than large enterprises who obtain their raw material from their own forests.

The removal of radiata pine was 10.7 million m^3 in 1990 and 14.0 million m^3 in 1992. *The allowable cut is expected to rise steeply to 22 million m^3 in 2000* and further to 37 million m^3 in 2018 (Fig. 15). Some concern is aroused by the *Rhyacionia buoliana* butterfly, a recent invader which causes alarming damage in the southern range of the Chilean radiata pine plantations by destroying new shoots of young saplings.

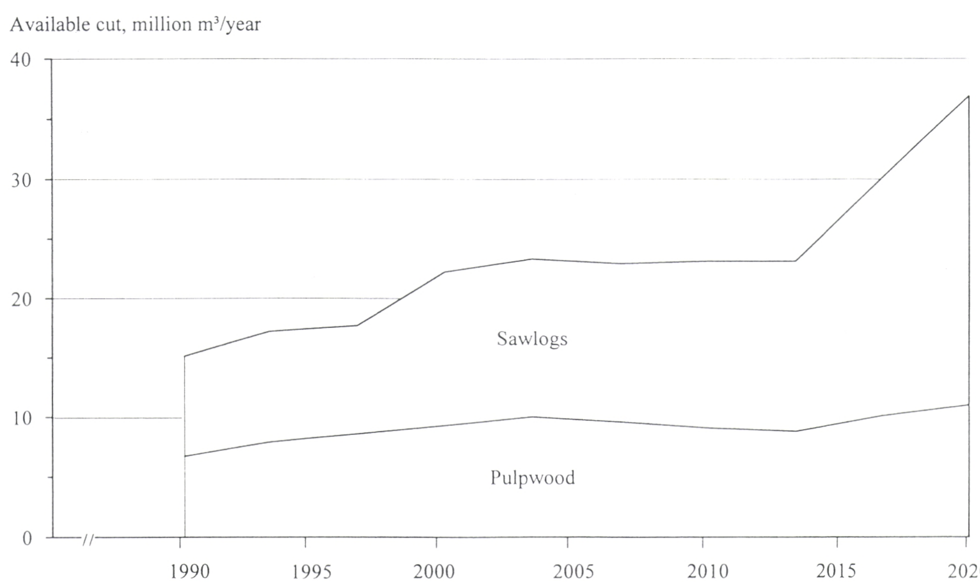


Fig. 15. Projection of the allowable cut of radiata pine in Chile by the year 2018 (data from Cerda et al. 1992).

As shown by the figures below, the radiata pine timber is mainly consumed by the domestic forest industry. In addition, round logs and chips are exported (Estadísticas forestales... 1991 and 1993):

	Consumption of Chilean radiata pine, million m^3 per year under bark	
	in 1990	in 1992
Used in Chile for:		
Mechanical pulp	0.41	0.50
Chemical pulp	2.02	5.72
Lumber	6.00	5.42
Composite boards	0.46	0.48
Other products	0.17	0.25
Exported in the form of:		
Saw logs	1.03	1.03
Pulpwood, solid	0.23	0.16
Pulpwood, chips	0.39	0.45
Total	10.72	14.01

Chile's pulp industry is presently very competitive, due to cheap and skilled labor, a stable economy with a statute of guarantees for foreign investors, and good and cheap plantation-grown raw material. In the international markets Chile is better known for its market pulp than its paper. However, the Chilean exporters of kraft pulp were seriously hit during the early 1990s, when the prices of market pulp fell as a result of the world recession. Newsprint is the only paper grade exported in any significant quantity from Chile.

The production capacity of pulp, primarily bleached pine sulfate, was 1.9 million tonnes and the actual production 1.5 million tonnes in 1992. The paper production capacity is 600 000 tonnes a year (Estadísticas Forestales... 1993). The largest producers of pine pulp are Celulosa Arauco y Constitución S.A. (annual capacity 800 000 tonnes of bleached and unbleached kraft pulp), CMPC (unbleached and bleached kraft pulp 310 000 tonnes, mechanical pulp 30 000 tonnes), CELPAC (bleached kraft pulp 315 000 tonnes), and Inforsa (sulfite pulp 24 000 tonnes and mechanical pulp 86 000 tonnes). A greenfield mill of Celulosa Licantén S.A. with a capacity of 70 000 tonnes of bleached long-fiber kraft pulp a year is coming on stream in 1994. Other proposed projects have been put on hold.

4.2 Major producers of yellow pine wood in the southern hemisphere

Pine wood from Brazil

In the mid-1960s, the area of man-made forests in Brazil was some 500 000 ha, or not more than 0.1 % of the total forest area of 456 million ha. Whilst the destruction of native forests continued and the demand for wood increased, the government deemed it necessary to ensure future timber supply through afforestation and intensive management of the plantations. To make the country self-sufficient and eventually a major exporter of pulp and paper products, land use and taxation policies were aimed at promoting the establishment of plantations.

The new forestry philosophy and sizeable federal subsidies led private companies to expand the afforestation area annually by over 400 000 ha in the late 1970s and the early 1980s. As a result, Brazil presently has a highly competitive pulp and paper industry which enjoys a cheap and high-quality wood supply based on fast-growing pine and eucalypt plantations. But the fiscal incentives were stopped in 1987, and *the establishment of new plantations has declined* since then.

At the end of 1989, the area of approved plantation projects covered 6.7 million ha, but one fourth of the recorded plantation area does not meet the quality required for an industrial plantation (Fast growing... 1987). Nevertheless, although these man-made forests presently only occupy some 1.5 % of the total forest area in Brazil, the forestry sector of the country has largely evolved around them. In 1989, the harvest of plantation timber was altogether 88.2 million m^3.

The area of pine plantations was 2.04 million ha in 1989. This is more than in any other country where pines are not native. The area of eucalypt plantations was 3.91 million ha and that of other species 0.76 million ha. *The most popular coniferous species belong to the yellow pine group*: slash pine and loblolly pine in the

Fig. 16. A company-owned yellow pine plantation in southern Brazil.

southern and south-eastern regions of the country, and Caribbean pine (*Pinus caribaea* var. *caribaea* and *Pinus caribaea* var. *hondurensis*) in the north-eastern tropical regions. Small areas have also been planted for *Pinus oocarpa* and other tropical pines. Another noteworthy conifer is the native *Araucaria angustifolia*.

Plantations of slash pine, loblolly pine and eucalypts are particularly concentrated in the states of São Paulo, Paraná, Espirito Santo, and Santa Catarina. Caribbean pine and some *Pinus oocarpa* are grown in the tropical regions, where the only major pulp mill is Compania Florestal Monte Dourado, i.e. the Jari Project in the state of Pará. Large energy plantations of eucalypt, aimed at providing charcoal to the pig-iron industry, are located mainly in the state of Minas Gerais.

The majority of the plantations are owned by forest industry and independent reforestation companies (Fig. 16). The pulp and paper industry alone owns 0.55 million ha of pine plantations, 0.83 million ha of eucalypt plantations and 0.03 million ha of plantations of other species such as *Araucaria*, *Gmelina* and *Acacia* (O sector... 1993). Little effort has been directed toward forest extension work with small farmers.

The spacing and rotation cycle of yellow pine vary depending on external conditions, production intension and company policy. Whereas one company plants 1600 trees per hectare and follows a 17-year rotation cycle, another company may plant 2500 trees per hectare and apply a 25- or 30-year cycle. *The average annual increment of pine is about 25 m^3/ha*, varying from 10 to 20 m^3/ha in the central and northern regions to 20 to 40 m^3/ha in the southern and coastal regions, which is probably more than in any other pine wood producing country. The use of genetically improved seedlings is expected to result in a further growth increase, perhaps shorter rotations and wider spacing.

Although a large part of *the 31 million m^3 annual cut of pine* is used for the manufacturing of lumber and plywood for domestic consumption, the quality of logs is not given sufficient attention. Stem characteristics, such as taper, sweep, tilting, crookedness, and branchiness, have been of minor significance in the tree improvement and management programmes compared to the volume productivity. If the initial spacing is wide and the stand is not pruned, especially on the edges of a plantation, branches become thick, although generally not as thick as in radiata pine plantations in some other countries.

The management aim for pine is commonly the production of fiber following which thinning cuttings are not necessarily applied to accelerate diameter growth, and the practice of pruning is rare. However, in most cases pine stands are thinned at short intervals of only a few years, i.e. up to three or four times during the rotation cycle. A typical management regime is as follows (Carneiro 1994):

	Stand age, years	Proportion of trees removed, %	Volume, m^3/tree	Removal, m^3/ha
First thinning	8-9	50	0.025	25-30
Second thinning	12-13	40	0.140	50-60
Third thinning	16-17	40	0.340	80-90
Final cut	25-30	100	0.760	250-300

Pulp production in Brazil was initially based on native long-fiber araucaria wood, but gradually a shift to plantation-grown long-fiber pine took place. Later, eucalypts have gradually overtaken softwoods as the most important tree crop from the plantations. Currently, less than 30 % of all pulp in Brazil is made from pine.

Brazil is the leading producer and exporter of bleached eucalypt pulp in the world. In addition, in 1992 *long-fiber pine pulp* accounted for 1.26 million tonnes or 26 % of all pulp production, and *was mainly consumed in the unbleached form for the manufacture of wrapping papers*. The major producers of pine pulp were Divisão Paraná Celulose e Papel of KFPC (244 000 tonnes), Igáras Papéis e Embalagens LTDA (237 000 tonnes), Rigesa Celulose (147 000 tonnes), Compania Florestal Monte Dourado (116 000 tonnes) and Papel e Celulose Catarinense S.A. (104 000 tonnes) (O sector...1993). The continent's first producer of lightweight-coated papers based on chemi-thermomechanical pulp is Inpacel's new plant in Paraná. The annual capacity is 150 000 tonnes for CTMP and 180 000 tonnes for LWC. The plant currently uses only pine wood, but intends to switch part of its raw material base to eucalypt by 1998 (Inpacel leads... 1993).

The Brazilian *pulp and paper industry is very competitive* in the international markets. Since *the cost of wood at the mill is lower* than in many other countries, the emphasis is in products such as market kraft pulp and packaging papers where wood plays a major role in the final cost (Klabin enjoys... 1993). The projected increase in the production of pulp will centre mainly on short-fiber eucalypt pulp, and is to be used in the expanding domestic market. Heavy investment requirements and foreseen shortages of raw material have slowed down development plans.

The challenge Brazil faces in the production of solid wood products such as lumber, plywood and particle board is far different to that of pulpwood production. Apart from the native hardwood logs in the northern tropical regions of Brazil, the only noteworthy wood source for lumber and plywood is plantation-grown pine. Since plantation management has not been well conducted by the sawmill and veneer industries, *the quality of pine wood is inadequate for the production of high-grade export lumber and plywood.* New management practices need to be implemented, and the industry should revise the roundwood specifications to promote more complete utilization of timber and better control of waste (Murakami 1987).

During the fiscal incentives programme that lasted from 1967 to 1987, pine plantations were established in Brazil at an impressive rate, reaching up to 158 000 ha per year during the peak period. Consequently, large areas of plantations established in the 1970's will reach their maturity in the early 1990s. However, the rate of establishment has been reduced dramatically, and *if the area planted with pine is not soon increased significantly, after two decades Brazil will face a shortage of pine wood for lumber and pulp*. If the wood supply from plantations starts to decline, the pressure on native forests will increase correspondingly. One solution could then be to import softwood lumber from neighboring countries such as Chile. Another alternative that seems viable is to use eucalypt logs for the production of lumber, especially lower density species such as *E. grandis*, *E. pilularis* and *E. urophylla* (de Freitas 1993).

There is no national projection of the future availability of pine wood in Brazil. *The supply after 2010 will be completely dependent on stand establishment activity during the late 1990s*, and this activity on its part will be affected heavily by the government's policy, especially by the incentives offered to the forest owners. For example, in Paraná 27 000 ha of pine plantations were established annually during the first half of the 1980s, but after the cancellation of the fiscal incentives programme, the rate of establishment collapsed to the insignificant level of 3300 ha a year during 1987-1992. Ramos (1993) estimates that, in addition to replanting the clear-cut areas, 20 000 - 30 000 ha of new planting areas are required annually in Paraná alone to satisfy the local forest industry's demand for pine wood in the future. Unfortunately, large areas of land are no longer available for forest plantations in the southern regions of Brazil, and the price of land is increasing. Consequently, the trend is for new plantations to be extablished in the north-eastern regions, especially Bahia State.

Pine wood from Venezuela

The area of commercial native forests in Venezuela is 17 million ha. Large-scale experimental planting of pine was started by the Ministry of Agriculture in 1967. In 1993, *the area of industrial plantations was 453 000 ha* and the area of plantations established for environmental protection 15 000 ha. The annual rate of new planting is approximately 30 000 ha. As much as 98 % of the industrial plantations are occupied by *the Honduran variety of Caribbean pine* (*Pinus caribaea* var. *hondurensis*) from Central America. The remaining 2 % or the area has been planted for eucalypts (Balaguer 1993).

Almost all plantations lie near the eastern extremity of the great central plain, Llanos, between 8° and 9°N. The sandy soil is poor in nutrients and organic matter, and the predominant vegetation type is savanna. The climate is hot with alternating wet and dry seasons.

The planting density is 1200 trees per ha. The mortality is typically 20 %, much of which is attributed to ants. The problem can be reduced in subsequent rotations by a practice of leaving the cut-over areas barren for three years, until the ants have migrated out of the area. The target rotation age is 15 years for pulpwood and 20 years for saw logs. The expected mean *annual increment is presently 10-13 m³/ha*, but the tree breeding programme is aimed at raising the increment to 15 m³/ha.

The management system of pine plantations is based heavily on clear-cutting. Pruning and thinnings are not practised. Almost no understory occurs in the plantations, and operation conditions are favorable except that logging trucks can have difficulties in the deep sand.

Since Caribbean pine is a poor self-pruner, *the timber is suitable primarily for kraft pulp, particle boards and export chips* (Fahnestock et al. 1987). However, practically no exports are taking place at this time, and domestic markets cannot consume the available volume of pine wood. In 1993 the total production capacity of long- and short-fiber pulp was 234 000 tonnes but the actual production only 112 000 tonnes (World trends...1994).

Most of the industrial plantations belong to the government. The state-owned CVG-Proforea controls 78 %, and the state-owned Conare 5 % while private pulp and paper companies own the remaining 17 % of the plantation area. Since the average age of plantations is low, *the available cut is increasing rapidly*. CVG-Proforea estimates that the available annual cut from its plantations will grow from 1.1 million m³ in 1992 to 5.7 million m³ in 2017. Fig. 17 is based on an assumption that the relative increase will be similar in the remaining 22 % of the plantations. Then the total available cut will amount to 7.4 million m³ in 2017. However, totally new industrial enterprises may appear.

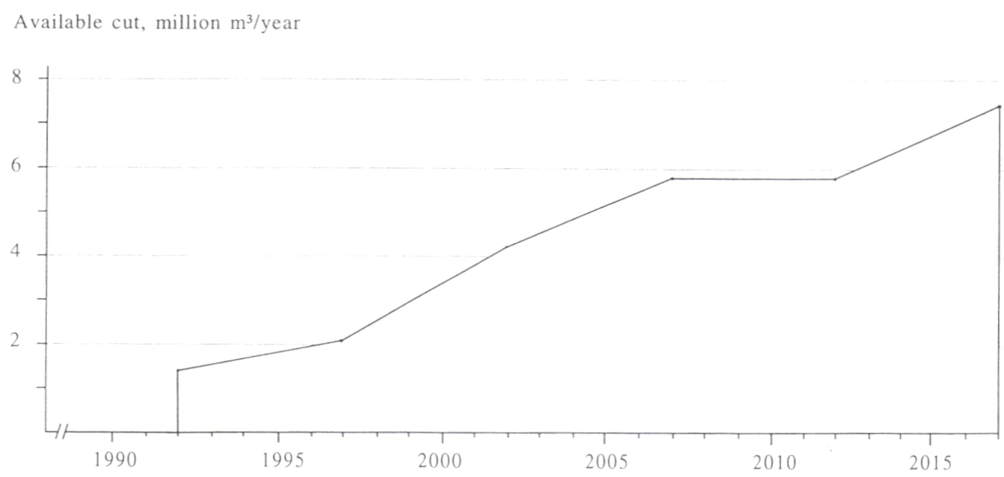


Fig. 17. Projection of the available cut of Caribbean pine in Venezuela by the year 2017 (adjusted from data from Balaguer 1993).

Pine wood from Argentina

In Argentina, the total area of forests is 36 million ha and the area of productive forests 15 million ha. The rate of deforestation is high.

The potential for plantation forestry is great. Growth conditions are favorable, suitable land is abundantly available at a low cost, and the infrastructure is generally sufficient. Nevertheless, the forest sector has suffered from the difficult economic situation of the country, and the atmosphere has not been as alluring as in neighboring Brazil and Chile for long-term investments in plantation forestry.

The rate of plantation establishment, currently about 25 000 ha per year, is expected to increase. In 1990, the total area of plantations was about 800 000 ha, including *391 000 ha of slash and loblolly pine*, 236 000 ha of eucalypts and 155 000 ha of *Salix alba* and other willows (Pandey 1992). The pine plantations are located between 27° and 34°S, mainly in the provinces of Misiones, Corrientes and Córdoba.

The typical initial planting density for pine is 2200 seedlings per ha. The rotation age is 15-30 years and *the mean annual increment 25* m^3/ha (Pandey 1992).

A large number of small sawmills and veneer and board mills use plantation-grown pine wood, but *the majority of pine wood is used for the production of pulp* by the local paper mills. Alto Paraná S.A., Celulosa Argentina S.A. and Papel Misionero S.A. in Misiones are the major users of long-fiber pine wood. In addition, Celulosa Puerto Piray is building a new pine pulp mill. *Araucaria angustifolia* wood is used for the production of long-fiber pulp as well.

The annual cut is about 5 million m^3 from all plantations and 3.5 million m^3 from native forests. The total consumption of wood in the Argentine pulp industries is 3.6 million m^3 per year (Lackman 1993). In 1992, the production of pine pulp was 350 000 tonnes. The total production of pulp was 630 000 tonnes and that of paper and board 1.0 million tonnes, but the installed capacity was about 40 % higher (World trends... 1993).

Owing to long transport distances from Misiones, the home province of the largest pine plantations, very little pine wood is exported. Instead, eucalypt pulpwood has been exported especially to Spain, but even to Finland.

Pine wood from the Republic of South Africa

Although the Republic of South Africa has only 164 000 ha of closed native forests, the country has been able to create a modern forest industry based on plantation-grown timber. The first plantations of fast growing exotics were established in the 1870s to produce fuelwood for the railroads. After World War One, the state took the initiative to develop forestry, and the area of plantations started to grow.

In 1992, the total area of plantations was 1.30 million ha or 1.1 % of the country's total surface area. In addition, Transkei had 66 000 ha of forest plantations. More than a half of the area, *667 000 ha, is under pines* and the rest primarily under eucalypts and wattle. The largest concentrations of plantations are located in Natal and eastern and south-eastern Transvaal. About 57 % of the plantation area is owned privately and the remaining 43 % publicly (South African... 1993).

The choice of pine species in South Africa depends mainly on the local rainfall: patula pine, loblolly pine and slash pine in the summer rainfall area with dry winters; maritime pine, radiata pine, slash pine and loblolly pine in the whole-year rainfall area; and maritime pine, radiata pine and *Pinus canariensis* in the winter rainfall area (Warkotsch 1988). The species distribution is as follows:

	Area, ha
Patula pine	287 000
Slash pine	153 000
Loblolly pine	87 000
Radiata pine	67 000
Maritime pine	40 000
Other softwoods	33 000
Softwoods, total	667 000
Eucalypts	519 000
Other hardwoods	114 000
Hardwoods, total	633 000
Total plantation area	1 300 000

Although the Republic of South Africa is one of the major producers of slash and loblolly pine timber in the southern hemisphere, *patula pine is the primary softwood species*. This species which has its natural range within latitudes 13°-24°N in southern Mexico, is the most successful exotic softwood in Africa. It thrives in frost-free areas where the annual rainfall is at least 750 mm, falling mostly in the summer, as well as in areas subject to two-peak rainfall distribution with most of the rain coming in the cooler season. It also grows on sites located within the high-elevation mist belts. It reaches 20-30 m and occasionally over 40 m in height. It has a rather good stem form with up to 50 % of the stem clear of branches. Although the wood is lower in density and strength than that of many temperate conifers, it is suitable for construction (Gillespie 1992).

The area of plantations is increasing at about 30 000 ha annually. To satisfy the anticipated rise in demand, the rate of planting should be increased still further from the present level. Some unused marginal land is potentially available on privately owned farms, and rising prices for wood have caused much land that was

Fig. 18. Clear-cutting a 30-year-old pine plantation in South-Africa.

Fig. 19. A pruned young pine stand in South Africa.

previously planted with maize and sugar to be turned into forest plantations. In Kwa-Zulu and Transkei forest industry companies encourage small farmers to grow timber, providing them with free seedlings and technical advice. Nevertheless, due to lack of water *suitable land is limited*, and the industry has already fallen behind in planting new areas. Therefore, the increasing demand for timber in the future will also require the use of improved genetic material and intensified management, although the standard of management is already high.

The ultimate use of the final crop determines the management regime. Regarding pine plantations, the main product may be either saw logs, veneer logs, small saw logs on marginal sites, or pulpwood. *Normally, the aim is saw log production* with a planting density recommendation of 1370 trees/ha. The regime is then composed of a first thinning at the age of 8 years to 650 trees/ha, two later thinnings and ultimately clear-cutting at the age of 30 years. The thinnings yield raw material mainly for kraft pulp. After the thinning operations, all remaining trees are pruned gradually in four stages to the height of 7 m (Figs. 18 and 19). In the case of pulpwood production, the initial planting density is 1740 trees/ha with the rotation length only 15-20 years. No thinning or pruning is then carried out.

Patula pine has the highest annual yield, 12-31 m^3/ha depending on the site. The yield is 6-21 m^3/ha for slash pine, 4-26 m^3/ha for radiata pine, but only 2-9 m^3/ha for maritime pine (Wessels et al. 1983). The weighted *mean annual increment of pine in South Africa is 14.8* m^3*/ha* (South African... 1993).

In 1992, the total removal was 14.3 million m^3, including 7.9 million m^3 of pine wood (Forest owners... 1993). The forecasted supply from all plantations for the year 2000 is 17.7 million m^3 but the demand will be 21.4 million m^3. For pine, *the supply in 2000 will be 9.7 million* m^3 *and the demand 11.7 million* m^3, thus leaving an annual deficit of 2.0 million m^3. Of the deficit of pine timber, 1.2 million m^3 will be for saw logs and 0.8 million m^3 for pulpwood (Warkotsch 1988).

In 1992, the total production of pulp was 2.3 million tonnes, including 460 000 tonnes of mechanical pulp, and that of paper and board 1.8 million tonnes. Almost 0.6 million tonnes of pulp, mainly dissolving pulp, and 0.5 million tonnes of paper and board was exported (World trends... 1993). The major forest industry companies are Sappi and Mondi. Both companies own extensive plantations.

The forestry and forest products industry is one of the fastest growing sectors of the South African economy. The country is virtually self-sufficient in forest products, and has become an exporter of pulp, newsprint, boards, pine lumber, wood chips and furniture. It is *the world's largest producer of dissolving pulp*, the production capacity of which is being expanded to 0.6 million tonnes per annum.

4.3 Other producers of pine wood in the southern hemisphere

More than 90 % of the southern hemisphere and tropical pine plantations lie in the countries discussed in sub-sections 4.1 and 4.2. The establishment of new industrial softwood plantations continues to take place mainly in these same countries. Elsewhere, environmental rehabilitation, fuelwood production, community forestry, agroforestry, and industrial hardwood plantations are given priority over industrial softwood plantations, i.e. in many countries the emphasis of plantation establishment has changed from softwood fiber to hardwood fiber, or from industrial raw material to fuelwood and protection.

Economic and political stability and a favorable investment climate are required for implementing large-scale long-term industrial investments. Unfortunately, many countries with good plantation development potential lack these prerequisites. Furthermore, domestic markets are often too limited to allow new pulp and kraftliner mills to take full advantage of economies of scale. The dependence on exports often increases distribution costs significantly, when establishing large-scale mills (Fast growing... 1987). Consequently, *no country new to plantation forestry is expected to launch an extensive softwood production programme* during the next ten years.

Countries which have not been discussed above are now examined. None possess very large areas of pine plantations, nor is the area of softwood plantations substantially expanding in any of these countries.

Pine wood from Indonesia

Indonesia has one of the largest forest areas in the world, 144 million ha, consisting largely of mixed tropical hardwoods. Of the total area of forests, 64 million ha are categorized as production forests. The recorded area of plantations was 8.5 million ha in 1990. The annual rate of new plantation establishment is about 0.5 million ha. However, a large majority of the plantations have been established for land rehabilitation purposes without substantial timber production objectives. The area of industrial timber plantations was 1.43 million ha in 1990.

Industrial plantation forestry has a long tradition in Indonesia. The first teak (*Tectona grandis*) plantations were established in Java in 1880, and teak presently covers 0.88 million ha. The first pine plantations were established in the 1940s with *Pinus merkusii*, a native but rather rare highland tree in Indonesia (Fig. 20). In addition, small areas of softwood plantations have been established with Caribbean pine. *The area of natural and man-made pine forests is presently 0.72 million ha.*

The state-owned forestry enterprise Perun Perhutani in Java administers 283 000 ha of pine plantations, mostly located in mountainous terrain, where the use of

Fig. 20. A mature *Pinus merkusii* plantation in the highlands of Sumatra in Indonesia.

tractors and trucks is difficult and the plantations are consequently underexploited. The plantations were initially established for resin tapping, and wood is only of secondary importance mainly being used for chopsticks. Due to the high population density, *it is not possible to further expand the pine plantation area in Java*.

Sumatra also has substantial pine plantations. They are usually established with 1700 seedlings per hectare and grown under a rotation cycle of 30 years. *The annual increment is estimated to be 15 m^3/ha*. Although the average stem volume at the phase of final cut is 0.5-1.0 m^3 and the trees are rather good self-pruners, *in Sumatra practically all pine wood is used for pulp*. The largest concentration is in the Lake Toba area, where 115 000 ha of pine forests are used for the production of kraft pulp by P.T. Inti Indorayon Utama. Another important pine plantation concentration occurs in Aceh, where the timber is used by P.T. Kertas Kraft for the raw material of kraft pulp and for the production of kraft liner and sack paper (Hakkila 1994).

The Government's Timber Estate Development Program aims at reaching a massive 4.4 million ha area of industrial plantations by 1999, consisting of 1.3 million ha of pulpwood plantations and 3.1 million ha of veneer and saw log plantations. Quite obviously the ambitious program cannot be realized in its entirety, but it is clear that large areas of new plantings will be established for fast-growing hardwoods such as eucalypts and *Acacia mangium* in the 1990s. During the past few years, *the establishment of pine forests has stagnated*, or even declined, and the same trend is expected to continue as it seems to be more profitable to invest in the cultivation of fast-growing short-rotation hardwoods. Unless proper emphasis is given to pine plantations in the future, the present trend will result in imbalances in the supply of short fiber and long fiber for the expanding pulp and paper industry.

Indonesia's annual production capacity is presently 1.9 million tonnes for pulp and 3.6 million tonnes for paper and board. Current construction plans suggest that pulp capacity will have risen to over 3 million tonnes, and paper and board capacity to 5 million tonnes per year by 2000 (World trends... 1994). However, in this incomparable development projection the role of pine is negligible.

Pine wood from south-eastern Africa

In many African countries plantation management was depressed during the 1980s. The reason for the downturn was not so much that expectations were not fulfilled in terms of productivity, but more due to the logistics of marketing the wood and products cheaply, efficiently and reliably. Many countries with major plantation developments do not have a sufficiently large or well-developed economy to absorb the industrial products and to take advantage of the economies of scale, and must therefore look to exports. Exporting, especially from land-locked nations, is difficult owing to poor communications, economic and political instability in the region, factors of topography, climate etc. All these aspects tend to work against a successful industrial project, hence their attraction to the investor has diminished (Evans 1986). Consequently, the Republic of South Africa alone is responsible for a lion's share of the forest industry products in all Africa, for example 80 % of pulp and 70 % of paper and board.

Countries such as Ethiopia, Nigeria, Sudan and Angola possess considerable areas of hardwood plantations but very little softwood plantations. *In addition to the Republic of South Africa, substantial softwood plantations are found only in south-eastern African countries.* The plantations were mainly established after the Second World War. These other producer countries of pine wood in Africa are listed below in order of plantation area.

In Madagascar, the first commercial pine plantations were established at the beginning of the 1970s. Man-made forests, mainly eucalypts and pines, currently cover an area of 260 000 ha. *The primary pine species are khasi pine (Pinus kesiya) with a plantation area of 80 000 ha and patula pine with 40 000 ha.* The former is best suited to 500-1000 m elevation sites in the interior of the island, whereas the latter is better adapted to cool conditions of higher elevations.

Large pine plantations were initially financed by the World Bank to provide wood on a 15-year rotation to a proposed pulp mill. However, *the annual increment has been poorer than expected, only 5-6 m^3/ha*, on account of nutritional problems on infertile sites, drought and incorrect choice of species. Consequently, the pulp mill has not been built. Both the management and the eventual utilization of this pine resource are problematic (Armitage & Burley 1980, Burley et al. 1989).

Swaziland has 100 000 ha of industrial forest plantations. *Pine covers 77 000 ha, the main species being patula and slash pines*, with a small proportion of loblolly. The plantations are mainly owned by two timber companies, one producing lumber and the other unbleached pulp.

The Usutu forest consists of 52 000 ha of pine plantations in the high veldt grassland of Swaziland. It is on land which has not supported forest in historic times. Most part of the area was afforested between 1951 and 1957, creating the largest single area of man-made forest in Africa. Silvicultural practice is based on *a short 12-year rotation* and no thinning. In the early 1990s, half the plantation area was on its third rotation without any indication of reduction in the soil productivity. *The mean annual increment of timber is 15-25 m^3/ha* (Evans 1988).

The plantation supplies the raw material for Sappi's Usutu pulp mill situated in the middle of the forest area. The annual production capacity of the mill is 185 000 tonnes of unbleached kraft pulp for overseas export, requiring more than 900 000 tonnes of green timber. In 1992 the operating rate of the mill was 97 % (World trends... 1993), and a 50 % increase in the capacity is being considered.

Zimbabwe has around 105 000 ha of privately and state-owned industrial plantations of pines, eucalypts and acacias, mainly located in the highlands of Manicaland province in the eastern part of the country. *Patula, slash and loblolly pine plantations cover 74 000 ha*, mainly in the eastern highlands. There are also 15 000 ha of non-industrial eucalypt plantations (Pandey 1992).

The rotation cycle of pine plantations is 30 years for saw log production but only 12 years for pulpwood production. *Saw timber is the primary management objective* so that pruning and thinnings are an essential part of the regime. *The average annual increment is about 15 m^3/ha* (Fast growing... 1987). Only a small part of the increment is utilized, and currently rather small areas are put under pine.

Zimbabwe has a relatively well-developed forest industry. In the late 1980s, it produced annually some 65 000 m^3 of structural lumber, 54 000 m^3 of case and boxwood, 15 000 m^3 of treated poles and fence posts, 42 000 tonnes of semichemical and mechanical pulp, and 87 000 tonnes of paper and board. The country is almost self-sufficient in newsprint and lumber, although the sawmilling capacity is underutilized (Radford 1987, World trends... 1993).

In ***Malawi***, plantations were created from the early 1950s, mainly to provide softwood for lumber and eucalypt for poles and fuel. In 1963, steps were taken to establish the Viphya pine plantation which was intended to produce raw material for an export pulp mill. However, the long distance to the exporting port and failure to secure financing led, in the 1970s, to the demise of the mill project and the consequent overproduction of pulpwood-sized pine timber. In the late 1980s, the total area of forest plantations was 96 000 ha. State-owned *pine plantations covered 66 000 ha* at altitudes between 1100 and 1700 m above sea level, *the major species being patula pine and khasi pine* (Burley et al. 1989).

The annual increment of pine varies between 12 and 27 m^3/ha with *an average of 17.6 m^3/ha* (Pandey 1992). Pulpwood stands are managed under a 16-year rotation, whereas saw log production follows a 30-year rotation schedule. The annual allowable cut is estimated to be 800 000 m^3 for pine pulpwood and 200 000 m^3 for saw logs. The pine plantations will reach their maximum yields in the early 1990s (Fast growing... 1987).

Kenya has 2.3 million ha under native forests, about 10 % of which are coniferous, composed mainly of podocarps. In addition, there are *168 000 ha of state-owned industrial plantations. Cupressus lusitanica* accounts for over 40 %, *patula pine nearly 30 % and radiata pine about 10 % of the plantations*. The majority of industrial plantations is located in the highlands 1800-2700 m above sea level, west and east of the Rift Valley.

World Bank missions have been *concerned at the quality of plantation management* in Kenya. As in several other South-East African countries, *Cupressus lusitanica* has been heavily attacked by pathogens, and many stands have begun to die. Radiata pine plantations also have suffered damage. Consequently, softwood plantations are established at present mainly with patula pine. The area of industrial plantations is not increasing, and the government gives a higher priority to environmental rehabilitation and fuelwood plantations.

The annual increment of patula pine and radiata pine varies between 10-30 m^3/ha under a rotation cycle of 25-35 years. The total annual allowable cut of plantation-grown timber is estimated as 1.5-2 million m^3, but the actual cut is not more than a half of it. The plantations supply annually 400 000 m^3 logs to sawmills and plywood mills. The production of unbleached and bleached kraft pulp and mechanical pulp was 112 000 tonnes in 1993 (World trends... 1994). The total production capacity of pulp in Kenya is 150 000 tonnes. Panafrican Paper Mills is the major producer with plantation-grown softwood and wastepaper as the primary raw materials.

In ***Zambia***, plantings were started on a commercial scale during the 1960s with the aim of producing raw material for both sawmills and a planned pulp mill. Since the pulp mill has not been established, there is little market for small-sized wood. However, the process of establishing Pamodzi Pulp Mill Ltd, an integrated mill producing thermomechanical pulp, newsprint and printing and writing papers, is underway (World trends... 1993).

At the beginning of 1985, *the area of pine plantations was about 40 000 ha* and the area of all forest plantations 50 000 ha. *Khasi pine alone covers 28 000 ha*. As regards the industrial plantations of this species, Zambia is probably second only to Madagascar. *Pinus oocarpa* is another pine species grown in Zambia, covering presently about 12 000 ha. The pine plantations are located in Copperbelt province at an elevation of 1200 m.

The initial planting density of khasi pine is typically 1300 seedlings per hectare, with a recommendation for three consequent thinnings by the age of 18 years. The target rotation period is 25 years. However, due to a lack of demand for small-sized wood, most thinnings have been delayed or totally omitted. At present, *the mean annual increment is 16* m^3/ha under bark (Saramäki 1992). The annual available cut of pine timber is 270 000 m^3 for saw logs and 480 000 m^3 for pulpwood (Saramäki 1987).

The primary use of wood is in sawmilling. Therefore, the trees should be pruned in two stages to the height of 7 m. It would be feasible to increase the proportion of saw logs, and extend the rotation beyond the present recommendation (Saramäki 1992). However, when khasi pine is grown in hot, humid tropical lowland sites, defects such as sinuosity, crookedness, multiple stems, forking, butt sweep, nodal swelling, and whorls of heavy, persistent branches commonly occur (Armitage & Burley 1980). New plantations are mainly established with *Pinus oocarpa* due to its superior technical quality.

Tanzania has 1.4 million ha under closed native forests and 42.9 million ha under open woodlands. The area of industrial plantations is about 80 000 ha, half of which are located in the Sao Hills (Pandey 1992). The major species in these state-owned plantations are patula pine and *Cupressus lusitanica* in the highlands at elevations of over 1500 m above sea level, and teak and eucalypts in the lowlands. *Patula pine occupies an area of 30 000 ha* and *Cupressus lusitanica* 13 000 ha. The planted species also include Caribbean pine, slash pine and loblolly pine.

The rate of planting for industrial purposes declined during the 1980s to a very modest level. The emphasis was shifted to community forestry and hardwood plantations for the production of fuelwood.

The allowable cut from the plantations is 1 million m^3 per annum, but the present rate of harvesting is only 470 000 m^3. The lack of markets for small-sized timber constrains full utilization of the plantations (Intermediate technology... 1988). The largest user of pine wood is the 60 000 t/a Mufindi kraft pulp and paper mill. The operating rate of the present capacity is low, so that the production of pulp was only 36 000 tonnes in 1993 (World trends... 1994).

5 Discussion

A shift towards plantations

According to the findings of the UN-ECE/FAO 1990 Forest Resource Assessment, the total area of exploitable pine forests in the world is at least 200 million ha (The forest... 1992b). Since pines are native species in most of the northern forest industry countries, there the differences between managed native pine stands and pine plantations are not very marked. Therefore, native forests and plantations are not separated in the statistics, and data on northern pine plantations are vague. Pandey (1992) presents the following orienting estimates of the area of pine plantations in selected northern hemisphere countries in 1990:

- In the former USSR the total area of plantations was 23.8 million ha, including 12.4 million ha of pine, mainly Scots pine.
- In China the total area of plantations was 36.0 million ha and the area of industrial plantations alone 18.7 million ha. The most popular species in the plantations is China fir (*Cunninghamia lanceolata*), but extensive areas of various species of pine have also been planted, including 3.4 million ha of masson pine (*Pinus massoniana*), 1.2 million ha of *Pinus tabulaeformis*, and other pines such as *Pinus mongolica*, *Pinus koraiensis*, *Pinus elliottii*, *Pinus taeda*, etc.
- In the USA the area of forest plantations is not available. The planted area of loblolly pine and other yellow pines in the USA South alone is over 8 million ha. Several other pine species are planted in various parts of the country, although the areas are considerably smaller.
- In Japan the area of forest plantations was 10.7 million ha, native sugi (*Cryptomeria japonica*) and hinoki (*Chamaecyparis obtusa*) being the major plantation species. Japanese red pine (*Pinus densiflora)* and Japanese black pine (*Pinus thunbergii*) are the next in importance, with a total plantation area of 1.0 million ha.
- In Canada the total area of planted forests was only 5.0 million ha. The most common plantation species are white spruce (*Picea glauca*) and black spruce (*Picea mariana*), followed by jack pine (*Pinus banksiana*) with a plantation area of 0.6 million ha, and lodgepole pine (*Pinus contorta*).

The world's timber requirements are increasingly met by forest plantations as old-growth forests have gradually been exploited and regenerated. The location of timber sources is no longer confined to traditional forest industry countries, but can now include any country with favorable biological and geographical features. Southern regions that earlier were not able to produce softwood timber have become important actors in world trade.

Against the plantation acreages mentioned above, the area of the tropical and southern hemisphere forest plantations may seem modest. However, assuming an annual average yield of 15 m^3/ha, the estimated total plantation area of 43 million ha in the tropics would produce over 600 million m^3 of wood, an amount equal to 15 % of the world's estimated requirement in 1995. By the year 2000, the area is expected to amount to 60 million ha producing some 900 million m^3 of wood annually (Evans 1992). Since management failures and wild fires are common, especially in non-industrial plantations, these projections may be over-optimistic. On the other hand, the estimates given by Evans do not include non-tropical plantations in the southern hemisphere.

The strong economic performance of industrial plantations in the southern hemisphere, compared to northern hemisphere forestry, is not so much a result of large areas, but rather of high production potentials, short rotation cycles, and low costs of establishment and management. The ongoing rapid expansion of plantation acreages, combined with high productivities, means that an increasing proportion of the world's industrial wood requirements will be supplied from this source. During the coming decades plantation-grown wood will be more and more needed to replace timber from the native forests of the U.S. West, distant forests of Siberia, tropical rainforests, etc.

A relative shift towards lower latitudes for major timber production areas is taking place as southern plantations expand. This is particularly noticeable with respect to short-rotation hardwoods but also for pine. For example, in the mid- 1980s, industrial plantations comprised only 1 % of the forest area in Latin America, but they supplied one third of the continent's industrial wood. By the year 2000, plantations will account for about half of the continent's production. These southern latitudes generally have an advantage, not only in terms of growth rates, but ultimately also of costs (Mather 1990).

Available cut from southern hemisphere pine plantations

The total area of pine plantations in the southern hemisphere and tropics is approaching 8 million ha, tropical China excluded. The area is still modest compared to the pine forests in the northern forest industry countries. Finland alone has 12.7 million ha of natural and planted Scots pine-dominated forests (Yearbook of... 1993). Nonetheless, the relative importance of these southern and tropical pine plantations as producers of industrial raw material is far more significant than indicated by their area. The growth and technical quality of southern pine timber can be improved by means of tree breeding much more effectively than is possible in Nordic forestry, e.g. due to early flowering and seed production, short rotation cycles, lack of severe winter climate, and wide adaptability of the pine species under consideration. *The average annual increment of southern pine plantations is close to 20 m^3/ha, amounting to a total annual net increment of about 140 million m^3*. In Finland the annual increment of pine wood is 32 million m^3 (Yearbook of... 1993).

From the view point of international trade, seven producer countries of plantation-grown pine wood are especially important: New Zealand, Chile and Australia for the production of radiata pine timber; Brazil, Argentina and Venezuela for the production of yellow pine timber; and South Africa for the production of a mixture of several pine species. Most of the production is located south of the tropical zone of the world. Since the proportion of young plantations is great, the drain from the plantations is presently far less than the increment. As the plantations mature, the allowable cut will increase rapidly.

In 1992, *the drain of plantation-grown pine timber in these seven countries was estimated as 79 million m³* of which Brazil produced 40 %, New Zealand 18 % and Chile 16 %. New Zealand and Chile were the major exporters of pine wood in the southern hemisphere.

End use	Drain of exotic pine wood in seven major producer countries, million m^3 in 1992
Lumber, plywood	41.0
Pulp, particle board, fiberboard	31.7
Export of saw logs	4.6
Export of pulpwood and chips	1.8
Total drain	79.1

In South America, *Chile will have an increasing surplus of radiata pine timber available for exports* in the form of saw logs, veneer logs, round pulpwood, and chips. Clearwood from pruned logs will come to the markets in large quantities only around 2010. Argentina, Venezuela and Uruguay are countries where the production of pine timber is increasing, while the local consumption is small, but the plantations are still young. *In Brazil, the declining trend in the establishment of pine plantations and an increase in domestic demand are expected to restrict the export* of long-fiber pulp and paper products in the future. But Brazil remains a big question mark. The past plantation development programme shows that with government incentives, production can be stimulated effectively and rapidly. On the other hand, without the government's financial support the opposite trend is also possible.

In Asia, Indonesia has one of the most ambitious forestation programmes in the world, but in this programme fast-growing hardwoods are in the fore and the role of pine is very marginal. In other tropical countries of Asia, pine plantations are of little importance.

Concerning Africa, pine plantations are limited to the southern and south-eastern parts of the continent, while some of the West-African countries own successful hardwood plantations. The Republic of South Africa is responsible for the bulk of the African pine plantations but is short of suitable land for large-scale new plantations. In other African countries, the rate of pine plantation establishment has declined and standard of management has deteriorated during the last ten years. Therefore, although the domestic consumption is increasing, *substantial changes are not expected in the production of softwood timber in Africa.*

In New Zealand and Australia, the forestry and forest industries are heavily based on pine plantations. *The production of high-quality saw logs and veneer logs is a common goal*, and rather strict requirements for tree breeding and management practices in the form of longer rotation cycles, repeated thinnings for quality, and pruning have been set. The increase in the available cut will largely be in saw logs. *New Zealand is considerably increasing the export of round wood, primarily to Asian countries*, and has perhaps a higher potential to expand the area of fast-growing pine plantations than any other country in the world.

Fast-growing hardwoods are increasingly important in some of the countries under consideration. Therefore, the establishment of pine plantations is, in those countries, mainly restricted to replanting after clear-cutting. Based on the present rate of establishment, the long-term increase in the area of pine plantations in the southern hemisphere and tropics does not seem to be as rapid as during the past two decades. Nonetheless, *New Zealand, Chile and Venezuela are examples of countries where the pine plantation area and timber projections continue to grow rapidly*, whereas in Australia and South Africa the expansion of pine plantations is slow, and in Brazil the area may even be declining.

Since a large proportion of the southern hemisphere pine plantations is less than 10 years old and not yet mature for timber harvesting, *the actual cut is only 55-60 % of the increment*. As young plantations mature, *the annual available cut is estimated to increase to over 100 million m³ by 2000*, to reach 110-130 million m³ by 2010 and 140-160 million m³ by 2020 (Fig. 21).

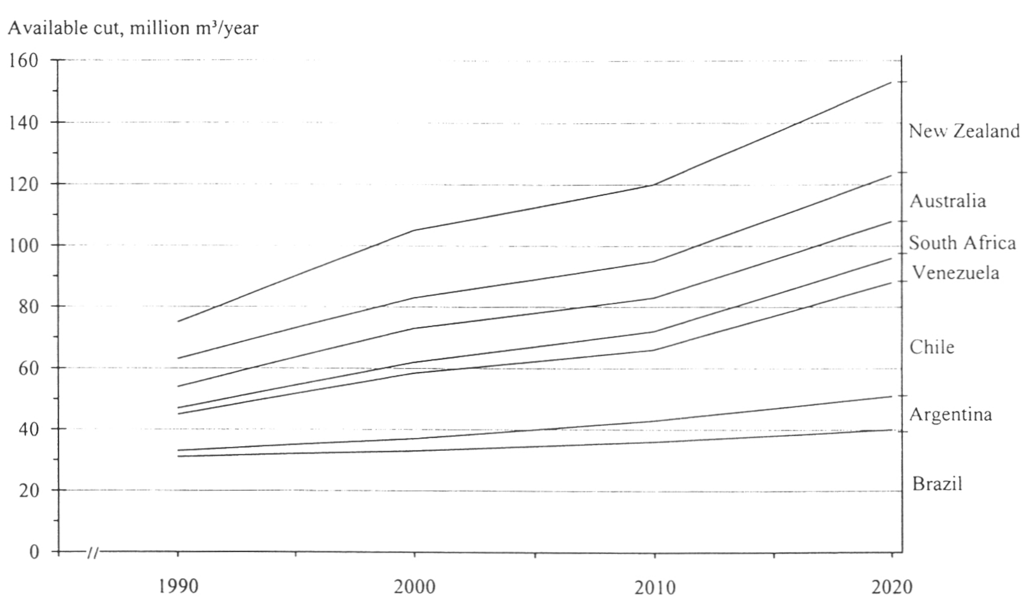


Fig. 21. Projection of the total available cut of plantation-grown pine timber in seven leading producer countries in the southern hemisphere and tropics by 2020.

The following figures show that the present surplus production of coniferous wood in Europe still significantly exceeds the annual cut from southern hemisphere pine plantations. The forests of the former Soviet Union are not included in the European figures (Kuusela 1994):

	Finland	Europe
	m^3 under bark in 1990	
Net annual increment of softwood in exploitable forests	54.3	379.5
Annual fellings of softwood, including residual wood	44.7	265.4
Balance of softwood timber	9.6	114.1

Improving the quality of pine wood

In the southern hemisphere and tropics, *plantation densities are low* compared to European softwood plantations, especially those in Central Europe. Wide spacing of trees allows free development of the crown and branches, concentrating the high areal yield of timber on a relatively small number of individual stems.

Due to the large proportion of juvenile wood, thick dead and live knots and frequent defects in the stem form, *the quality of saw logs from unthinned and unpruned plantations is inferior to that of slow-grown boreal softwoods. However, if thinnings are carried out by selecting for stem form, and trees are high-pruned, the resulting saw logs and veneer logs can be of high quality in end uses such as joinery and furniture manufacturing.* As a raw material for kraft pulp, plantation-grown exotic pine wood does not differ greatly from the Nordic pine wood, and in the absence of spruce wood it can be used as a raw material for mechanical pulp as well.

In many countries, the *genetic improvement of forest trees* has until now been aimed mainly at increased growth and fiber production, rather than at a higher quality of saw logs. In some cases, especially in New Zealand and Australia, tree breeding has improved branching habits and reduced the malformation of stems to such an extent that it has become possible to compromise over the planting densities, so as to reduce the cost of establishment and accelerate the early diameter growth of the final crop trees.

About 2 million ha of fast-growing southern hemisphere pine plantations, i.e. one fourth of the total area planted for pine, *are managed under an intensive regime in which the high-pruning of the butt logs of the final crop trees plays a key role.* Almost one third of the annual increment of the final crop trees in the pruned stands, 4-5 m^3/ha, can be attributed to valuable clearwood production. *In the long run, the annual production of clearwood logs in the southern pine plantations may* *approach 10 million m³*, i.e. roughly one hundredth of the world's saw log harvest. However, since pines in the southern hemisphere require 15-25 years to mature after pruning, only modest amounts of clearwood will come onto the market during this decade. As Sutton (1991) points out, even with conservation and environmental pressures, there is little possibility to replace the 134 million m^3 annual consumption of quality hardwood logs from native tropical forests with premium pine logs from southern hemisphere plantations.

Concerning the prospects of the Finnish forestry sector, this clearwood supply is significant. In Finland, the pruning of Scots pine was started on a practical scale in the late 1970s, and since then about 200 000 ha of young Scots pine stands have been pruned to 4-5.5 m height (Yearbook of... 1993). The annual production of narrow-ringed clearwood logs from these plantations will be 300 000 m^3/a at most, and the pruned stands will require up to 40-50 years to reach maturity. It is also important to note that *the ongoing shift from naturally regenerated forests to plantations tends to change the wood quality in the Nordic forests*, especially the quality of Scots pine timber, and not necessarily in a better direction.

An opportunity for Nordic technology

Excluding the climate and infrastructure, *the physical operating environment in southern hemisphere and tropical forest plantations is rather similar to those of the Nordic countries*. Although southern pine logs tend to have more defects, they do not differ greatly from Scots pine and Norway spruce logs from the processing point of view of the lumber and plywood industries. It follows that *Nordic small-log technology is commonly adaptable to southern hemisphere plantation timber*. Resulting mainly from inferior stem form, and in some countries from less strict bucking rules and practice, southern logs are typically branchier and more crooked with a heavy sweep. Defects in stem form together with rapid taper have an adverse effect on the raw material consumption and quality of the end product. The Nordic bucking practice and techniques for debarking and automatic measurement of the diameter, length, taper, eccentricity and sweep in a log, and the use of techniques such as curve sawing, could help to handle the southern pine log supply more efficiently, so as to improve the yield and quality of end products.

Increasing emphasis is being placed on a planned utilization of wood, and on the environmental role of forestry. *Nordic logging technology, based on the log-length system and the use of load-carrying forwarders, offers a wide range of machine options and system alternatives for efficient and environmentally friendly harvesting in southern forest plantations in gentle terrain* (Hakkila et al. 1992, Hakkila 1994). The Nordic logging machines and work methods naturally need to be adapted to local climate, specific tree characteristics and the professional skills of the staff and workers, but the technical and organizational changes required can be solved. Where socio-economic conditions and infrastructure allow, for example in Australia, New Zealand and Chile, even the most advanced fully mechanized logging schedules, including *equipment such as one-grip harvesters, can prove to be both successful and competitive* (Hakkila & Mery 1992).

Since the annual available cut of plantation-grown pine wood alone in the seven major producer countries is expected to increase by the year 2000 by approximately 20 million m^3, possibilities will open up for the application of new technology. Increasing timber production and the need to holistically improve the efficiency of operations in the industrial plantations of Argentina, Australia, Brazil, Chile, Indonesia, New Zealand, South Africa, Venezuela and other countries means *a challenge and an opportunity for Nordic timber procurement and processing technology*. To serve the producers and consumers of plantation-grown timber in the best possible way, full attention must be paid to their specific conditions, changing goal-setting and training when Nordic small-log technology is transferred to the southern hemisphere and tropics.

References

Armitage, F.B. & Burley, J. 1980. Pinus kesiya. University of Oxford, Commonwealth Forestry Institute. Tropical Forestry Papers 9. 199 p.

Australian forest resources. 1989. Present areas and estimates of future availability of wood. Forest Resources Committee for the Standing Committee of the Australian Forestry Council. Canberra. 77 p.

Australian forest resources 1988. 1990. Australian Bureau of Agricultural and Resource Economics. 30 p.

Baker, J.B. & Balmer, W.E. 1983. Loblolly pine. In: Burns, R.M. (Ed.). Silvicultural systems for the major forest types of the United States. Agriculture Handbook 445: 148-152.

Balaguer, T. 1993. Evaluación de la situación actual de los recursos forestales de Venezuela. Santiago. Manuscript. 43 p.

Bamber, R.K. & Burley, J. 1983. The wood properties of radiata pine. Commonwealth Agricultural Bureaux. 84 p.

Bentsen, B.A. & Ethington, R.L. 1972. Properties of major southern pines: Part II: Structural properties and specific gravity. USDA Forest Service Research Paper FPL 177.

Birchfield, R. J. & Grant, J.F. 1993. Out of the woods. The restructuring and sale of New Zealand's state forests. GP Publications. 250 p.

Birk, E. M. 1991. Stem and branch form of 20-year-old radiata pine in relation to previous land use. Australian Forestry 54 (1&2):30-39.

Brown, M.J. & McWilliams, W.H. 1990. Pine stands across the South - Trends and projections. In: Saucier, J.R. & Cubbage, F.W. (eds). Proceedings of southern plantation wood quality workshop. Athens, Georgia. US Department of Agriculture, Forest Service. Southern Forest Experiment Station, General Technical Report SE-63:1-15.

Burley, J., Armitage, F.B., Barnes, R.D., Gibson, G.L., Hardcastle, P.D., Huguet, L., Plumptre, R.A. & Wood, P.J. 1989. Forestry research in eastern and southern Africa. Oxford Forestry Institute. Tropical Forestry Papers 19. 58 p. + annexes.

Carneiro, J.G. 1994. Speech given at the Finnish Forest Research Institute, Vantaa, Finland, on the 26th of May, 1994.

Cerda, I., Olavarria, J. & Abalos, M. 1992. El sector forestal en Chile: logros y desafios. Instituto Forestal. Informe Technico 129. 166 p.

Cown, D.J. 1989. Wood characteristics of New Zealand radiata pine and Douglas fir: Suitability and processing. New Zealand Forestry Corporation Ltd, Wellington. 85 p.

Eeronheimo, O. 1994. Suomalaisen korjuuteknologian soveltuvuus Chilen radiatamäntyviljelmille. Mimeograph. 8 p.

Estadísticas forestales 1990.1993. INFOR. Boletin Estadístico 21. 101 p.

Evans, J. 1986. Plantation forestry in the tropics - trends and prospects. International Tree Crops Journal 48(1): 3-15.

- 1987. Site and species selection - changing perspectives. Forest Ecology and Management 21: 299-310.

- 1988. The Usutu forest: twenty years later. Unasylva 40(1):19-29.

- 1992. Plantation forestry in the tropics. 2nd edition. Charendon Press. Oxford. 403 p.

- & Wood, P.J. 1993. The place of plantations in tropical forestry. Tropical Forest Update 3(5): 3-5.

Fahnestock, S.E., Tarbes, J. & Yegres, L. 1987. The pines of Venezuela. Journal of Forestry 85(11): 42-44.

FAO yearbook of forest products 1990. 1991. FAO. Rome. 283 p.
Fast growing plantations. 1987. Impact on the International Market Pulp, Linerboard and Woodfree Paper Business. Jaakko Pöyry Oy. Helsinki. 169 p.
Florence, R. G. 1993. Forestry in transition in Australia. The Commonwealth Forestry Review 72(4):321-337.
Forest owners association. 1993. 23rd annual report. 12 p.
Forest resources assessment 1990. 1993. Tropical countries. FAO For. Paper 112. 59 p.
The forest resources of the temperate zones. 1992a. Main findings of the UN-ECE/FAO 1990 forest resource assessment. United Nations. ECE/TIM 60. 32 p.
- 1992b. The UN-ECE/FAO 1990 forest resource assessment. Volume 1. General forest resource information. United Nations. ECE/TIM 62. 348 p.
Forestry statistics today for tomorrow. 1993. FAO. Rome. 46 p.
de Freitas, A. R. 1993. Os avancos technólogìcos no processamento e uso de productos florestais: Produção de madeira serrada de eucalipto. VII Congresso Florestal Brasileìro/I Congresso Florestal PanAmericano. Curitiba. 6 p.
Gillespie, A.J.R. 1992. Patula pine Schiede and Deppe. Patula pine. SO-ITF-SM 54. 5 p.
Hakkila, P. 1968. Geographical variation of some properties of pine and spruce pulpwood in Finland. Communicationes Instituti Forestalis Fenniae 66.8. 60 p.
- 1994. The development of small-log harvesting in Indonesia. Enso Forest Development Ltd. Imatra. 72 p.
- , Malinovski, J. & Sirén, M. 1992. Feasibility of logging mechanization in Brazilian forest plantations. The Finnish Forest Research Institute. Research Papers 404. 68 p.
- & Mery, G. 1992. Puun korjuu ja käyttö Chilessä. (Explotación y uso de la madera en Chile). The Finnish Forest Research Institute. Research Papers 428. 59 p.
Harris, J.M. 1991. Radiata pine in New Zealand. In: Kininmonth, J.A. & Whitehouse, L.J. (eds.). Properties and uses of New Zealand radiata pine. New Zealand Ministry of Forestry, Forest Research Institute. Volume 1(1): 1-7.
- & Cown, D.J. 1991. Basic wood properties. In: Kininmonth, J.A. & Whitehouse, L.J. (eds.). Properties and uses of New Zealand radiata pine. New Zealand Ministry of Forestry, Forest Research Institute. Volume 1(6): 1-28.
Hellström, E. 1993. Puuntuotantoa ilman metsälakeja Yhdysvaltain etelävaltioissa. In: Palo, M. & Hellström, E. (eds). Metsäpolitiikka valinkauhassa. Metsäntutkimuslaitoksen tiedonantoja 471. 467 p.
Inpacel leads in CTMP-based papers. 1993. Pulp & Paper International 9(35): 49-51.
An interim report on the state of forest resources in the developing countries. 1988. FAO. Forestry Department. FO:MISC/88/7. 53 p.
Intermediate technology in forest harvesting. 1988. Agricultural tractor with winch. FAO Project GCP/INT/427/FIN. 43 p.
Kibblewhite, R.P. & Bawden, A.D. 1990. Blends of extreme high and low coarseness radiata pine kraft pulps - fibre and handsheet properties. Appita 43(3): 199-207.
- & Bawden, A.D. 1991. Radiata pine thinnings and toplog kraft pulp qualities. Appita 44(4): 247-251.
Kininmonth, J.A. 1991. Water-wood relations. In: Kininmonth, J.A. & Whitehouse, L.J. (eds.). Properties and uses of New Zealand radiata pine. New Zealand Ministry of Forestry, Forest Research Institute. Volume 1(7): 1-23.
- & Whiteside, I.D. 1991. Log quality. In: Kininmonth, J.A. & Whitehouse, L.J. (eds.). Properties and uses of New Zealand radiata pine. New Zealand Ministry of Forestry, Forest Research Institute. Volume 1(5): 1-21.
- & Whitehouse, L.J. (eds.) 1991. Properties and uses of New Zealand radiata pine. Volume 1: Wood properties. New Zealand Ministry of Forestry, Forest Research Institute. Volume 1. 216 p.

Klabin enjoys lead role among Latins. 1993. Pulp and Paper International 11(35): 39-43.
Koch, P. 1972a. Utilization of the southern pines. The raw material. U.S. Department of Agriculture Forest Service, Agriculture Handbook 420(1): 1-734.
- 1972b. Utilization of the southern pines. Processing. U.S. Department of Agriculture Forest Service, Agriculture Handbook 420(2): 735-1663.
Kuusela, K. 1994. Forest resources in Europe. European Forest Institute. Research Report 1. 154 p.
Lackman, K. 1993. Yhteiskonttori Argentiinaan. Raportti kenttätutkimuksesta Argentiinassa suomalaisen vientiteollisuuden näkökulmasta. Helsinki. Mimeograph. 75 p.
Lavery, P.B. 1990. Radiata plantation statistics NEFD and notes on Chilean, Australian and other resource descriptions. New Zealand Forestry, November 1990. p. 24-29.
Leech, J. W. 1993. Determination of rotation length for radiata pine plantations. Australian Forestry 56(3):195-200.
Mather, A.S. 1990. Global forest resources. Timber Press, Portland, Oregon. 341 p.
McDonald, S.E. & Krugman, S. 1986. Worldwide planting of southern pines. Journal of Forestry 84(6): 21-24.
Murakami, E. 1987. The future trends for the forest industry in Brazil. Proceeding of the symposium on the co-operation of forestry between Finland and Brazil. Metsäntutkimuslaitoksen tiedonantoja 273: 101-115.
A national exotic forest description as at 1 April, 1992. 1992. Ministry of Forestry. Wellington, New Zealand. 54 p.
New Zealand forestry statistics 1993. 1993. Ministry of Forestry. Wellington, New Zealand. 126 p.
Nimmo, B. 1988. Planting radiata pine in New South Wales. Forest and Timber Vol. 24: 20-25.
Niskanen, A., Luukkonen, O. & Saastamoinen, O. 1994. Evaluation of the profitability of fast-growing tropical trees. Acta Forestalia Fennica 241. 38 p.
Oberg, J.C. 1990. Impacts on lumber and panel products. In: Saucier, J.R. & Cubbage, F.W. (eds). Proceedings of southern plantation wood quality workshop. Athens, Georgia. US Department of Agriculture, Forest Service. Southern Forest Experimental Station, General Technical Report SE-63:17-32.
Palo, M. 1987. Deforestation perspectives for the tropics: a provisional theory with pilot applications. In : Kallio, M., Dyckstra, D. P. & Binkley, C.S. (eds.). The global forest sector: an analytical perspective. John Wiley, New York. pp. 57-90.
- , Mery, G. & Salmi, J. 1987. Deforestation in the tropics: Scenarios based on quantitative analyses. In: Palo, M. and Salmi, J. Deforestation or development in the third world? Metsäntutkimuslaitoksen tiedonantoja 272: 53-106.
Pandey, D. 1992. Assessment of tropical forest plantation resources. Swedish University of Agricultural Sciences. Unpublished manuscript.
Park, J. 1994. Evaluating pruned sawlog quality and assessing sawmill recoveries in New Zealand. Forest Products Journal 44(4): 43-52.
Perry, J.P. 1991. The pines of Mexico and Central America. Timber Press, Portland, Oregon. 231 p.
A prime performer. 1990. Timber Trade Journal. March 1990. 16-17 p.
Radford, K. 1987. The timber industry in Zimbabwe. In: Appropriate wood harvesting in plantation forests. FAO Forestry Paper 78: 1-10.
Ramos, A. A. 1993. Perspectivas qualitativas e econômicas da produção florestal em sucessivas rotacões. 1° Congresso Florestal Panamericano. Curitiba, Paranà. 45 p.
Richardson, J.D., Corson, S.R. & Foster, R.S. 1992. Comparison of Scandinavian spruce and radiata pine as raw material for high yield pulping. Appita 45(1): 33-37.
Salleh, M.N. 1984. Heveawood - timber of the future. Planter Vol 60: 370-381.

Saramäki, J. 1987. The amount, growth and development of exotic plantations in the Copperbelt. Summary. Mimeograph. 1 p.

- 1992. A growth and yield prediction model of Pinus kesiya (Royle ex Gordon) in Zambia. (Pinus kesiyan kasvun ja tuotoksen ennustemalli Sambiassa). Acta Forestalia Fennica 230. 68 p.

Sarvas, R. 1964. Havupuut. Werner Söderström. Porvoo. 518 p.

O sector de papel e celulose em 1992. 1993. Associação Nacional dos Fabricantes de Papel e Celulose. São Paulo. Mimeograph. 7 p.

Shoulders, E. & Parham, G. 1983. Slash pine. In: Burns, R.M. (Ed.). Silvicultural systems for the major forest types of the United States. Agriculture Handbook 445: 162-166.

Singh, K.D. 1993. The 1990 tropical forest resources assessment. Unasylva 44(3): 10-19.

South African forestry facts. 1993. Promotion committee, Forestry Council. 12 p.

Sutton, W. 1991. Are we too concerned about wood production? New Zealand Forestry 36(3): 25-27, 30.

Thomas, R.J. & Kellison, R.C. 1990. Impact of changin raw material on paper manufacturing and properties. In: Saucier, J.R. & Cubbage, F.W. (eds). Proceeding of southern plantation wood quality workshop. Athens, Georgia. US Department of Agriculture, Forest Service. Southern Forest Experiment Station, General Technical Report SE-63:33-46.

Tomazelli, I., Villela, F. & Almeida, E. 1979. Estudos da densidade básica e dimensões de traqueóides de povoamentos de Pinus elliottii, Pinus taeda e Araucaria angustifolia. Projeto Braskraft 2 - Technologia relatorio final. Curitiba. 70 p.

Turland, J., Wakelin, S. & Lane, P. 1993. National exotic forest description. 1992 national and regional wood supply forecasts. Ministry of Forestry, Wellington, New Zealand. 147 p.

Valentine, J. 1993. Private forest development: experiences from New Zealand. Commonwealth Forestry Review. Vol. 72(2): 92-94.

Walford, G.B. 1991. Mechanical properties. In: Kininmonth, J.A. & Whitehouse, L.J. (eds.). Properties and uses of New Zealand radiata pine. New Zealand Ministry of Forestry, Forest Research Institute. Volume 1(8): 1-21.

Warkotsch, W. 1988. Harvesting of pine and eucalypt in South Africa. South African Forestry Journal 147. p. 37-52.

Wessels, N.O., Malan, E.J.P., Hinze, W.H.F. & Maree, H.B. 1983. Silviculture of pines. In: Forestry handbook. The South African Institute of Forestry, Pretoria. p. 63-72.

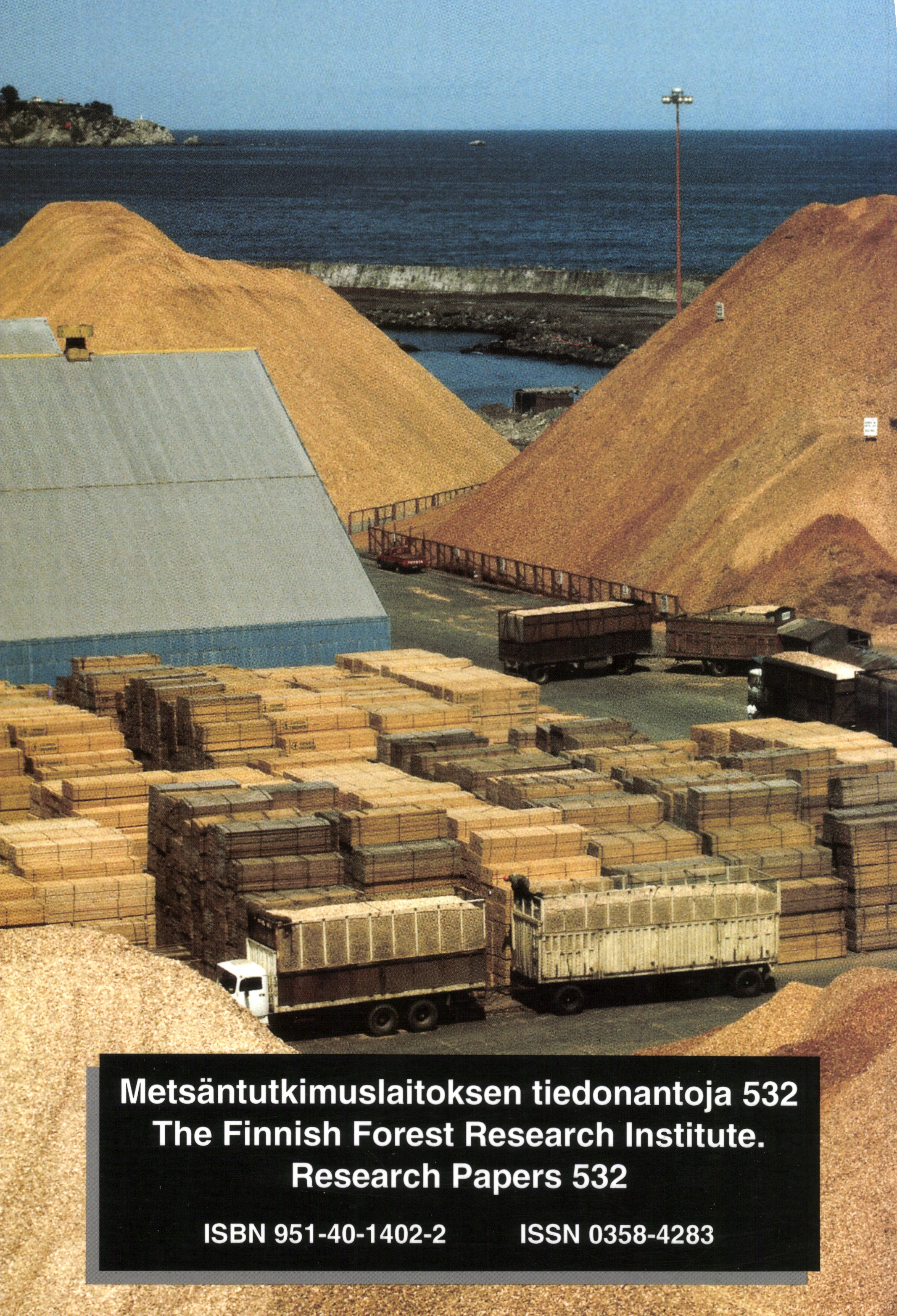
World Resources 1988-1989. 1988. A report by the World Resources Institute and the International Institute for Environment and Development in collaboration with UNEP. Basic Book, New York, 372 p.

World trends and trade. 1993. Pulp & Paper International 7(35): 23-89.

World trends and trade: Annual review. 1994. Pulp & Paper International 7(36):17-100.

Yearbook of forest statistics 1992. 1993. The Finnish Forest Research Institute. 317 p.

Goulding, C. 1993. Oral communication.



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