オーストラリアと日本の育成林業の比較(生物生産学科)

A comparison of Plantation forestry in Australia and Japan

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Summary

Our earlier paper (Florence, Shinohara and Asato: NO. 40 Bulletin) established that Japan must depend, in the future, on expanding imports of plantation−grown wood, as well as greater domestic production of wood. This paper compares plantation programs in Australia and Japan in terms of species, plantation establishment technologies and stand management regimes, and illustrates the great cost advantage of growing wood in Australia and other Southern Hemisphere countries. Ways in which Japan might expand domestic wood production are discussed, and the earlier call for cooperative wood supply studies in Asia−Pacific countries is endorsed.

1. Introduction

The first of our papers (Florence, Shinohara and Asato 1993: this Bulletin) established that a decline in timber imports from traditional sources (the Pacific Coast of North America and Southeast Asia) could have serious consequence for Japan−a country dependent on imports for 70 percent of the wood consumed. Japan has a large plantation resource, but there are economic and social circumstances restricting the realization of its potential. As an era characterized by trade in products derived from the world's natural forests comes to an end, Japan will look, increasingly, to trade in plantation−grown wood. New Zealand and Chile are already servicing softwood markets in Japan and other North Asian countries. Our earlier paper questions whether Australia should also aim to service export softwood markets, and expand its plantation program accordingly. If this question is to be resolved, it will be important to know the extent to which Japan's domestic forestry sector might be revitalised. Thus this paper examines more critically the status of plantation forestry in Japan.

Japan's domestic forestry sector has been weakened during the past three decades by a combination of rising domestic costs and competition from unrestricted timber imports. Some of the initiatives which Japan might take to restore the strength of its domestic forestry sector are discussed in the earlier

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paper. The present paper is concerned with initiatives directly related to plantation management. Characteristics of plantation species, plantation establishment practices, stand management regimes and plantation costs in Australia and Japan are compared. This highlights reasons for the weak competitive position of Japan's plantation－grown timber, and suggests ways in which Japan might develop more cost－effective programs. Nevertheless, it is recognized there may be many social and environmental constraints to achieving such an objective.

2. Plantation Programs : an Historical Perspective

Japan

Japan's reforestation history goes back about 400 years, but systematic reforestation started only in the Meiji era (1868－1911). While natural regeneration systems have been used since this time, the most widespread and effective reforestation has involved planting.

Japan's National Forests were formalised when shogunate or feudal clan forests, and some of the hamlet forests, were transferred to national ownership at the beginning of the Meiji era. As in many other countries of the world, production forestry developed freely after the capitalist system replaced feudal land ownership. With the consequent decrease in the forest resource, successive governments embarked on the preservation of forest resources and the establishment of afforestation programs (Funakoshi 1988). The National Forest Law of 1897 provided the legal foundation for national forest management. Annual harvesting and plantation programs were started at this time; and twelve kinds of protection forests were established to guard against floods and to conserve forest values in other ways.

These initiatives were also directed to non－national forests. For example, policies were formulated to help afforest municipal forests which had been transferred from hamlet ownership. An important development for private land forestry came with the formation of forest cooperatives in 1907 and, in 1939, a legal obligation was imposed on the cooperatives to draw up silvicultural plans for each land owner.

The demand for timber during World War II was very great. As Japan was forced to supply its timber needs solely from its domestic resources, large areas of forest were heavily cut over. Afer the war, the restoration of denuded forests by planting became the main objective of forest policy. Beyond 1955, policy also focused on planting to expand the forest resource (Handa 1988). Forest planting reached a peak during the 1960s, but thereafter declined sharply as import competition began to weaken the competitive position of domestic forestry.

The plantation resource now constitutes the main production resource. The *natural* forests within the National Forest estate have lost the leading role they once played in controlling the domestic timber market (Handa 1988). Beyond 1969 the National Forests began to operate at a loss, forest employment was reduced, and environmental constraints began to affect the amount of timber which could be harvested. Where harvesting of natural forest continues, it is part of a wider multiple use management strategy. Thus continuing timber supply from the domestic forests will come primarily from the plantation forests within national, prefectural, municipal and private ownership.

There is some uncertainty about the way the plantations will be managed in the future. Opposition to clearfelling and expansion of man－made forests has tended to influence policies and strategies in Japan. Natural regeneration has been actively promoted as an alternative to planting, though this system has not been firmly established, and caution should be exercised against its excessive use (Handa 1988).

Australia

While Japan has a long history of forest planting, Australia does not. Since Australia was settled by Europeans in 1788, most of the nation's timber has come from the native hardwood (eucalypt) forests. Some 25 percent of the total timber consumed has been imported, mostly softwood for construction, or as pulp and paper.

It was becoming apparent in the early 1900s that the native forests would not sustain indefinitely the rate of harvesting, and all six State forestry agencies began to examine prospects for developing a new resource based on exotic softwood species. At first, planting was on a small scale. The States expanded softwood planting and research following World War II, and programs were further expanded from 1965 when the central (Commonwealth) government began to support them financially. Presently there are about one milion ha of plantations, a resource which, in conjunction with the native hardwood forests will meet most of the domestic demand for wood. A case has been put in our earlier paper for further expansion of planting to help improve the economies of scale for the softwood industries, and to provide a surplus for export.

3. The Plantation Species

Japan's 10 million ha of plantations are based on many species (Table 1), though dominated by Japanese cedar, *Cryptomeria japonica*, (44.3% of area) and Japanese cypress, *Chamaecyparis obtusa*, (43 %). The discussion will focus on these species.

Table 1 Areas of man-made forest by species in Japan (as at March 1986)
Unit = 1000ha

	Area	%Total area
I Coniferous Species		
Cryptomeria japonica	4,509	44.3
Chamaecyparis obtusa	2,337	23.0
Pinus sp	1,091	10.7
Larix kaempferi	1,091	10.7
Abies and Picea sp	883	8.7
Others	81	0.8
Total	9,992	98.2
II Broadleaved Species		
Quercus acutissima	54	0.5
Quercus sp	2	–
Others	123	1.3
Total	179	1.8
Total	10,171	100

Both Japanese cedar and Japanese cypress are outstanding plantation species—tall boled, fine—branched trees with regular compact crowns. Japanese cedar can be planted on a wide range of sites, it grows relatively fast, suffers comparatively little damage from insects and diseases, and produces wood of excellent quality. The environmental range of Japanese cypress is not as great, and it is slower growing on good sites. However, it is able to cope better with dry sites, and its wood commands substantially higher prices than the Japanese cedar.

Both Japanese cedar and Japanese cypress can be characterized as relatively 'tolerant' species, that is, a high stocking density and a dense tree canopy can be maintained in plantations. Japanese cypress is particularly shade tolerant; the stand may be so dark that the vegetation of the forest floor disappears entirely, leaving the soil prone to erosion when planted on steep slopes. Both species are able, like most tolerant conifers, to maintain good volume production at higher stocking densities, and to a greater age than the more intolerant conifers. Thus there is a tendency to manage the stands conservatively, and with relatively long rotations.

The Australian plantation species include radiata pine (*Pinus radiata*) in the more temperate regions of the continent with a winter dominant rainfall and a dry summer. Radiata pine makes up 67 percent of the total plantation resource. Slash pine (*P. elliottii*), Caribbean pine (*P. caribaea*) and their hybrid are planted in the subtropics with a summer dominant rainfall. There is a limited planting (46, 000 ha) of the native conifer, hoop pine (*Araucaria cunninghamii*), on more fertile soils of the subtropics which once carried rainforests.

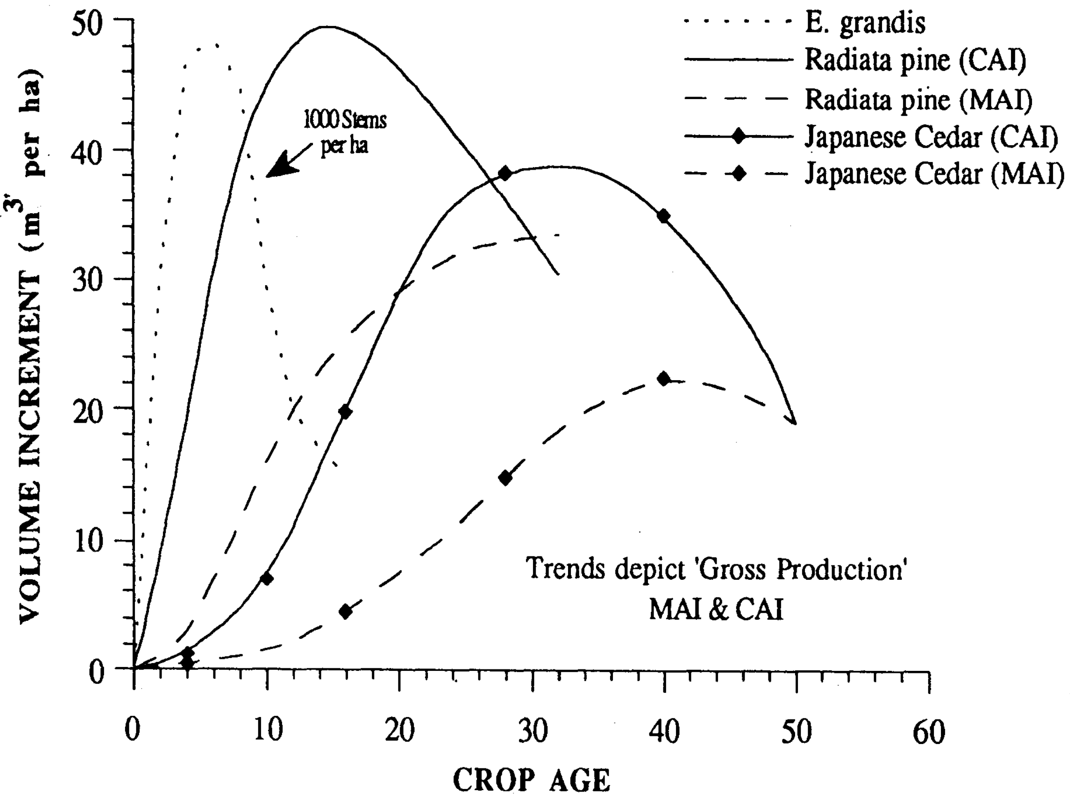

Fig 1. Current and mean annual increment curves (CAI, MAI) for *Pinus radiata* in Australia, and *Cryptomeria japonica* in Japan. The curves for E. grandis are from a high quality plantation in South Africa.

The *Pinus* species can be characterized as 'intolerant', while hoop pine is more like the Japanese conifers in its silvical characteristics. The intolerant pines have the potential for fast early growth, relatively early peaks in annual volume production (CAI), and a rapid decline in CAI thereafter. There may be a strong segregation into canopy classes on good sites as the stands develop (particularly in radiata pine), and rapid self－thinning as the 'intermediate' and 'suppressed' trees succumb to competition and die. Because of this, seedlings are often planted at relatively wide spacings, and the stands are thinned early and heavily. Under these conditions, the diameter growth rate of the larger trees of the stand can be very rapid.

The differences between Japanese and Australian plantation species can be expressed by plotting within the one Figure their CAI/MAI curves (Fig. 1). A fast－growing eucalypt (*Eucalyptus grandis*) is also included to illustrate the relatively extreme performance of a fast－growing hardwood.

4. The Plantation Establishment Phase

Australian plantations are, by world standards, fast－growing, though handicapped by periodic and sometimes prolonged droughts, and their relegation to lands and soils which are often too poor for sustained agriculture. Differences between Australia and Japan in plantation establishment technology will reflect, to a large extent, the poor condition of Australian soils. They will also reflect the high proportion of Australian planting land which is flat to undulating, and hence accessible to large machines which facilitate soil amelioration treatments, and later, mechanized harvesting.

There is now much attention directed in Australia to achieving near full site growth potential during the early rapid growth phase (Fig. 1). The steeper the stand volume growth curve during this phase, the greater will be the total stand volume production at the end of the rotation. Maximum early growth rate is achieved by:

(i) cultivating the site in the most appropriate way in order to facilitate rapid exploration of the soil by tree roots, and their access to soil air, water and nutrients.

(ii) controling competition for site resources by weed species, normally with herbicides, and

(iii) adding fertilizer to ensure the growth potential created by physical soil amelioration is achieved.

Site preparation

Many Australian plantation soils have characteristics which restrict the rapid proliferation of tree roots. These include a strong texture contrast between A and B horizons ('podzolic soils'), and a heavy－textured and poorly－structured B horizon which limits soil aeration and impedes soil drainage.

Depending on the soil condition, the site might be ploughed once or twice to improve soil tilth, deeply ripped to improve tree stability and root access to soil resources at depth, or ripped and mounded where soil aeration and drainage are likely to limit seedling growth. Some quite sophisticated site and soil classifications have been developed to help the forester determine the most appropriate form of site amelioration (e.g., Foster and Constantini, 1991, a, b, c).

Japan's 'Brown Forest Soils' have an organically enriched A－horizon with a crumb structure, and a deep B－horizon. These soils might not be expected to restrict root and seedling growth. Thus any additional 'intensive' site preparation may be unnecessary, or it might not generate sufficient extra growth to justify the cost or erosion risk. In the past, brush and logging debris was simply burned or removed manually from the site in order to facilitate the planting of the new crop. However, in order to conserve nutrients, the practice of burning debris has been discontinued, and it is now retained in windrows or scattered over the planting site (Forestry Agency 1981a, b).

Cultivation or light ripping of soils in Japan may be warranted where physical site conditions are less favorable, and machinery can be used. For example, this could be particularly advantageous on some of the red and yellow podzolic soils of the Ryukyu Islands where the A−horizon may be thin and the B−horizon a poorly structured heavy clay. However, given the small and dispersed areas now planted, and the steep slopes, this could be difficult to implement. Nevertheless, it would be useful to know just what effect physical soil amelioration might have on the growth, form and stability of the more commonly planted native species on the Islands.

Weed control

Under conditions of fertile soils, high rainfall and warm summers, the growth of coppice and successional vegetation in Japan is rapid and luxuriant. The planted seedling is sensitive to competition from grass, shrubs and vines, and this must be reduced periodically to ensure the survival and growth of the seedlings. Depending on site history and environmental influences, a weed control operation may be carried out once or twice a year for up to 6 to 7 years (Forestry Agency, 1981, a and b).

Weeding in Japan is normally done manually using scythes or portable brush cutters with small gasoline engines. The treatment may be applied to the whole of the forest area, or by strip−weeding along rows of planted trees, or by spotweeding with spots extending about 1m from each planted tree. Continuing weed control is essential as weed growth redevelops after cutting, and vines and lianes climb up and around planted trees. Weeding ceases when planted trees have an average height 1.5 times that of surrounding weeds. A large amount of labour is required for weeding, representing one of the major components of the total cost of plantation silviculture to the thinning stage (e.g. Komaki 1991). During the 1960s an average of 80 to 100 man days per ha were spent on weeding within the one stand during the rotation (Kyushu University Forest papers), but by 1986 this had been reduced to 60 days. It still represents a very substantial cost and one which must be further reduced if plantation forestry is to be more profitable.

Herbicides have been applied by machine in some areas of Japan but, by and large, this is not common. At one time the Forestry Agency appears to have been optimistic about the use of herbicides, referring in 1981 to 'low toxicity' chemicals, biological weed control, the application of small doses, and the matching of herbicides with the ecological characteristics of weeds and planted trees. The Agency also refers to the success of pre−emergent weedicides (applied to surface soil) in suppressing grass and inhibiting the emergence of new grass culms for several years; and to the great effectiveness of combinations of propionic and chlorophenoxyacetic acids in inhibiting vines. Despite initial successes, the use of herbicides declined, largely on environmental grounds. The herbicides in use at the time were regarded as being injurious to human health, both directly and through pollution of water supplies. The labour force, perhaps in response to world−wide concern about the impacts of chemicals based on the chlorophenoxyacetic acids (2, 4−D, 2, 4, 5−T), have preferred to use manual weed control in plantations.

Since the early 1980s considerable development has taken place in other countries in the control of plantation weeds, and new herbicides and application techniques are still emerging. Combinations of 'knock – down' herbicides (which act by inhibiting photosynthesis) and pre – emergent herbicides (inhibiting seed germination or shoot development) are now widely used throughout the world for the control of grass, ferns, and broadleaved species in a wide range of situations. A typical example is the combination of 'glyphosate' and 'atrazine'. The use of the pre – emergent herbicide, atrazine, alone or in combination with other chemicals can confer an additional benefit which is similar in nature to the application of a nitrogenous fertilizer – an important bonus for Australian soils.

Combinations of site cultivation and herbicide application can be particularly effective in weed control. In South Australia, the sandy soils are first cultivated with a heavy disc plough up to a year ahead of planting. This uproots and destroys woody rootstocks. Repeat ploughings prior to planting result in much of the perennial weed competition being replaced by grasses and annual broadleaved weeds. These weeds are relatively easily controlled by overspraying the planting lines to achieve almost complete weed control for a year after planting.

While Australian site preparation treatments will not be appropriate on most sites in Japan, they highlight, at least, the need for continuing research into modern herbicides in order to reduce the high cost of manual weed control. This research might be concerned with determining the effectiveness of individual herbicides or combinations of herbicides, the rate and frequency of application, their effect on the successional process, the sensitivity of planted seedlings, the residual effects in soils, and so on.

The Australian weed control circumstances which most resemble those in Japan relate to the planting of *Araucaria cunninghamii* following the clearfelling of rainforest on relatively fertile soils in the subtropics. A weed – reduced plant zone is required for successful establishment of *A. cunninghamii*, but this must achieve an appropriate balance between early seedling growth and the amount of bare soil exposed to heavy summer rains. Grasses and cereals are sown between the planted rows to minimise immediate soil erosion, and to control the composition and structure of the inter – row vegetation for continuing weed management. *A. cunninghamii* seedlings are planted at a spacing of 5m × 2. 4m (833 per ha). Constantini (1989) found that a 2m vegetated inter – row on the contour is needed to ensure soil loss is kept to tolerable levels on some of the steeper forest sites. Thus a 3m plant zone band, maintained with herbicides, is a good compromise between production, soil conservation and economic objectives. It might be worthwhile to carry out similar studies in Japan.

Use of Fertilizers

Many softwood programs in Australia have been based on infertile soils which did not support native eucalypt forest of commercial quality. While *Pinus* species are generally well – adapted to infertile soils, they may develop poorly or fail altogether on older and more weathered soils, or on deeply leached siliceous sands. Consequently there has been a long history of fertilizer research in Australian forestry.

Initially, fertilizers were used sparingly, and only on those sites where commercial wood production was impossible without them. While use of fertilizers has increased only slowly to the present time, there is now convincing evidence that substantial gains in productivity are possible on a wide range of sites where fertilizer application is combined with site cultivation and weed control (Flinn and Turner 1990).

Phosphorus is almost invariably the primary limiting nutrient in Australian soils. There may be relatively little 'available' phosphorus in older soils, much of that which is present being immobilized in aluminium and iron clay complexes. Where a phosphorus deficiency is corrected, a strong additional response may be obtained to nitrogen. Other macro and micro – nutrients may be needed in specific situations, for example, the infertile dune sands in the southeast of South Australia. Site treatment in this case involves no less than five applications of a 'complete fertilizer' during the early rapid growth phase—two are 'spot' applications made close to the tree, two are made by tractor and spreader, and one is made aerially, all before canopy closure some 60 months after planting.

The costs of establishing plantations

Plantation costs in Japan greatly exceed those in Australia. Japanese costs (Komaki 1991) are summarized in our earlier paper. These show direct silvicultural costs (site preparation, planting, weed control, non—merchantable thinning, pruning) to be around 1.2 million yen per ha. A further 0.66 million yen per ha are incurred in 'social costs' (workers compensation and other insurances, control of operations, miscellaneous costs). Australian costs vary with site conditions and intensity of site amelioration. In New South Wales these are generally around 200,000 yen per ha for direct costs, and 100,000 yen for 'overhead' costs. It is only to be expected, then, that given rapid growth rates and short rotations, plantation grown timber imported from the southern hemisphare will be highly competitive with that grown in Japan.

5. Stand Management Regimes

Plantation management regimes in Australia and other southern hemisphere countries, notably New Zealand, differ appreciably from those in Japan. Inevitably, our comments on plantation management in Japan are greatly influenced by the management objectives and strategies in Australia.

A general appreciation of plantation management in Australia is found in Shepherd (1986), and Shepherd *et al* (1990).

Plantation management in Australia

Initially, stand management regimes in Australia were relatively conservative, with high stockings designed to ensure maximum site production, small branches and knot size, and sufficient stems from which to select good quality trees for the final crop. A typical conservative regime would be one with an initial stocking of 2250 stems per ha, a series of thinnings at 6—year intervals commencing at age 13 to 15, and the clearfelling of a final crop of 370 to 500 stems per ha at age 40 to 50. This might not be regarded as 'conservative' by European and Japanese standards. The problem with the conservative regime was that it required a 50—year rotation to produce boles of desired diameter. Moreover, it paid little attention to the financial viability of the enterprise, particularly the effect of rotation length on the rate of return on the plantation investment.

A change in the philosophy and practice of radiata pine management emerged in New Zealand in the late 1960s. Financial analyses were showing that the relatively conservative regime was not economically viable at sensible rates of interest on invested capital. Consequently it was recommended that silvicultural regimes incorporate relatively low stockings throughout the life of the stand, active pruning programs to maintain wood quality, and much shorter rotations. An example of a radical New Zealand regime is given in Table 2 (Shepherd 1986). The adoption of regimes like this meant that plantation managers were prepared to sacrifice volume production in order to achieve fast growth of the valuable final crop trees, shorter rotations, and greater return on capital.

The New Zealand research was to influence Australian plantation practice—although thinning regimes have remained essentially more 'conservative' than those in New Zealand. Plantation regimes in Victoria are now based on an 'optimum approach' to plantation management, not simply the minimum input needed to avoid plantation failure or achieve target areas. In Western Australia, the adoption of a low initial stocking and early and heavy thinning reflects, as well, the severe soil moisture deficits usually experienced in the late summer (McKinnell, 1981). Stands which are maintained at lower stockings from an early age will be less susceptible to drought deaths and damage from strong winds. In New South Wales plantations, the main driving force for thinning regimes has been the need to obtain substantial quantities of smallwood for pulp and particleboard manufacture. This is achieved through a relatively severe first thinning, with residual stands being maintained subsequently at low stocking densities. One of the more conservative regimes, that used in the southeast of South Australia to service a complex of sawlog, particleboard and pulp industries (Lewis *et al* 1976), and the Western Australian regime are illustrated in Table 2.

The adoption of wider initial spacings, non-commercial thinning and more rigid prunning prescriptions, places some pressure on financial resources, and creates inflexibilities in the timing of

Table 2 Examples of stand management regimes in New Zealand and Australia

A stand management regime for Radiata pine developed in New Zealand	
Initial planting stocking	1500 stems per ha
Pruning	At ages 4/5, 6 and 8/9, progressively to 5.8m, and with a reduction in numbers pruned from 750 to 220 stems per ha
Non-commercial thinning	At age 8/9 to 360 stems per ha, and at age 11/12 to 200 stems
Clearfell	Age 25/26 when stems of 50cm dbh can be harvested
Thinning regime for Radiata pine in the southeast of South Australia (moderate to good site quality)	
Initial planting stocking	1600 stems per ha
1st commercial thinning	At age 12 to 800 stems per ha
2nd commercial thinning	At age 17 to 550 stems per ha
3rd commercial thinning	At age 23 to 400 stems per ha
4th commercial thinning	At age 30 to 300 stems per ha
Clearfell	At 40 years
Thinning and pruning regime for Radiata pine in the Southwest of Western Australia	
Initial planting stocking	1100 stems per ha
Non-commercial thinning	At age 5 to 750 stems per ha
pruning	To 2.1m at age 5 and 4.5m at age 7
Pulpwood thinning	To 250 stems per ha at age 11
Clearfell	Age 30

some operations. Non−commercial thinning and low and high prunning must be carried out at specified times if maximum economic advantage is to be gained. Neither of these operations has been successfully mechanized and hence remains labour intensive.

Plantation management in Japan

Thinning regimes The management of plantations in Japan has been typically conservative (in the European tradition), motivated largely by the twin objectives of achieving near−maximum site volume production, and the production of high quality timber. High initial stocking densities have also helped achieve early site control, and reduce weeding costs.

At the present time, thinning programs are affected by the economically depressed condition of the domestic timber industry. Thinning may not be carried out at all, it may be delayed, or stands may be thinned to waste. Up to 50 percent of all thinning may now involve thinning to waste. The rotation length for the final crop might also be extended where timber prices are unsatisfactory to the grower, for example, up to 80 years or more.

Before the current economic conditions developed, there were some differences in the way the plantations were managed. Ando and Fujimori (1981) and Fujimori (1988), have described four 'typical systems' of stand density control. Under the most conservative (the 'Yoshina System') 6000 to 10000 seedlings per ha were planted to achieve rapid site control and to produce high quality timber. The stands were thinned non−commercially at 7 and 12 years of age, and subsequently thinned commercially, 4 to 8 times at intevals of 5 to 10 years. Despite this intense thinning activity there would still be around 1000 stems per ha at final harvest (age 60) when the average tree diameter would be only 28cm dbh. However, given the changing economic circumstances, the Yoshina System is no longer appropriate ; the demand for thinnings has decreased substantially and, with a labour shortage, it is difficult to maintain the old system practices (Forestry Agency 1981a).

At the other extreme, the 'Obi system' represents a 'more radical' approach to stand management. Initially, 1500 seedlings per ha were planted. Commercial thinning was carried out twice from about 30 years at intervals of 10 years, and the forest was clearfelled at 50 years. In this case the development of the individual tree was regarded as more important than total stand volume production. However, the resulting 'fast−grown' timber was regarded by some as 'soft', and had wide growth rings and many knots. Because of a declining market for lower grade timber under import competition, there has been a shift towards more highly stocked stands in the Obi district.

Conservative stand management regimes have often been based on the perception that maximum volume production will be achieved only at high stockings−particularly within forests of the more tolerant species. This perception has been challenged in many countries, including Japan. Aiba (1975) found that where Japanese cedar is thinned while annual volume production is still rising, diameter growth of the residual stems will be stimulated; and where carried out relatively early, there may be a greater total yield of stem volume (final cut plus thinnings) at the end of the rotation. Where thinning and fertilization are combined, total volume production may be further enhanced, for example, a 48 percent increase in stem volume per tree, and a 19 percent increase per unit of ground area (Ito 1986). There will also be other advantages of early and relatively heavy thinning−a shorter rotation to achieve boles of specified diameter, the avoidance of waste through tree mortality, and greater resistance to wind damage.

Quantitative models expressing relationships between individual tree and stand parameters have also been developed to help establish, in a systematic and quantitative way, the most appropriate thinning regime for a particular set of circumstances (Ando 1968, Aiba 1977, Fujimore *et al* 1984). However, there still does not appear to have been much emphasis placed on the 'financial factor' in formulating stand management regimes—though this may be changing (Ejiri 1990, 1991, Akao 1991, Tanaka 1991). Ejiri (1991) examined the influence of site quality, planting stocking, rotation length and the log pricing system on the internal rate of return (IRR) on investment capital for thinned and unthinned stands of Japanese cedar. Where the discount rate is greater than 3 percent, the main thinnings will be most effective, financially, where carried out within the range 20 to 40 years, and where the number of trees remaining until clearfelling is less than 20 percent of the planted trees (i. e., a moderately heavy thinning regime). Fig 2 shows the IRR is consistently greater at the lower (3000 stems per ha) than at the higher (9000 stems per ha) planting stocking. Moreover, as the rotation becomes longer the IRR increases until it attains a maximum value, beyond which it either remains more or less constant or declines gently—as in the thinned forest, or declines more rapidly—as in the unthinned forest. A peak in IRR may occur around 40 years of age on high quality sites, and later on low quality sites.

It follows that wider initial spacing and reasonably early and moderately heavy thinning may be justified in financial terms. The extension of the rotation to, say, 70 years also appears to be justified where there are advantages in growing larger diameter logs. Compared with radiata pine, this reflects, undoubtedly, the greater capacity of Japanese cedar to maintain higher levels of wood volume production to a greater age.

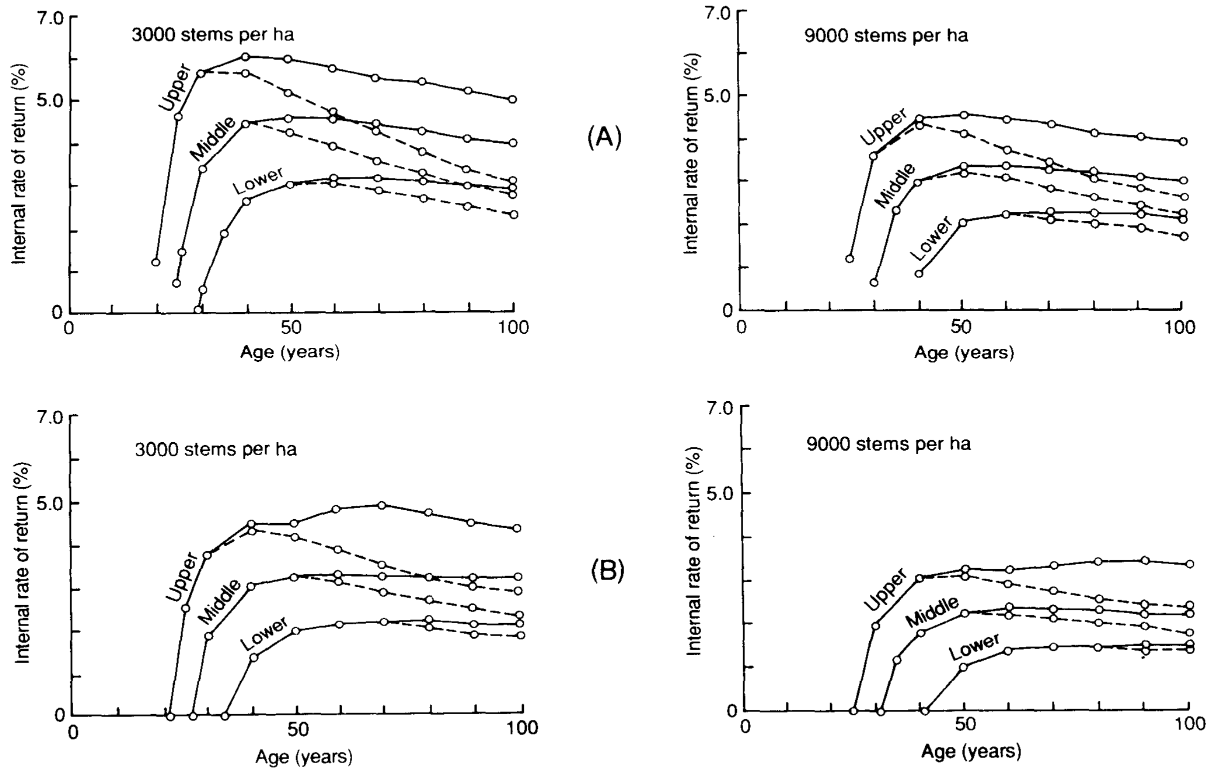

Fig 2. Internal rate of return for *Cryptomeria japonica* plantations, for various rotations (ages), site classes (Upper, Middle, Lower), stockings at planting (NO = 3000, 9000 stems per ha) and pricing systems (A, B)

○—○—○ Thinned stands

○···○···○ Unthinned stands

(from Ejiri 1991)

Profitability of plantation programs The restoration of plantation forestry as a vital component of Japan's timber economy may depend on many initiatives taken during the next 2 to 3 decades. These must be largely concerned with the restoration of profitability to domestic forestry. It might reasonably be anticipated that timber prices will rise as imports decline, contributing to a greater return on capital invested in the domestic plantations. However, this in itself may not be enough; greater emphasis may need to be placed on (i) reducing the costs of plantation operations (ii) formulating more profitable stand management regimes and (iii) restructuring industry to utilize more effectively the products of these regimes.

The impending decline in timber imports from traditional sources could mean an increase in demand for 'general purpose' construction timber, that is, timber of specified strength, but not necessarily with the attributes associated with, say, the Yoshina system of stand management. This implies a change in the product objectives of Japanese forestry which, in turn, will permit a change to a more profitable form of plantation management. An optimum regime will be one which provides a balance between timber quality and the financial return to the grower. This could require not only changes in the way the plantations are managed, but also the integration of forest and industry planning to provide adequate processing facilities for the thinnings and sawlogs as the forest develops. It may no longer be realistic to base management on a market for thinnings with the aim of providing trees 16 to 22 cm dbh which will yield one or two highly priced logs for house pillars (Ando and Fujimori 1981). Rather, new regimes are required with the objective of producing construction timber. Such regimes might have (i) a moderate initial stocking to achieve early site control, small branches and knots, and the minimum acceptable wood quality standards (ii) a heavy thinning as soon as commercially feasible to service *large-volume* smallwood industries (pulp, paper, particleboard, fibreboard) (iii) a further thinning to maintain strong diameter growth on wide-spaced trees, and (iv) a final harvest of, say, 200 to 300 stems per ha at 45 years providing good quality construction timber.

It is not meant to imply that the foregoing regime would be the most appropriate in any given circumstances. Rather, it highlights the need to fully evaluate a wide range of stand management options in order to determine that which best balances the competing objectives of volume production, individual tree growth, wood quality, investment profitability and other factors bearing on the management decision.

The future forest-industry relationship may be more difficult to solve. Plantation profitability in Japan may be restored only where it is possible to develop appropriate sets of industries, and to plan and manage the forest resource and industries in an integrated way. At present there is little integration of industries in Japan, for example, timber production and pulp and paper production are completely separated (Murashima, 1988). In contrast, forest industries in the U. S. A. and Canada, and the plantation programs in Australia, are characterized by large industries which integrate vertically the whole process of forest management, pulp and paper production, sawnwood and plywood production, and so on. Handa (1988) recognizes that the horizontal and vertical integration of the various timber enterprises in Japan is needed to reduce the cost of timber by increasing '... the total amount of the various forest products through the intensified and diversified use of woodland'. He believes that once the system is developed, the stability of both the market and employment will be realized, and the regional economy will operate adequately.

6. Discussion

Differences between plantation forestry in Australia and Japan can be expressed through differences in:

(i) the 'tolerance' and growth characteristics of the species planted,

(ii) the topography of the planting land – permitting efficient mechanization of operations in Australia – but limiting use of machines in Japan,

(iii) the intensity of site preparation; the more intense operations in Australia reflect the poorer soils of that country, the responsiveness of fast – growing species to soil improvement, and the attempt to achieve maximum growth during the early establishment phase,

(iv) attitudes to the use of herbicides which are now widely used for weed control in Australia (and in many other countries),

(v) the philosophies underpinning stand management decisions, notably the strong weight given to the financial return on investment in determining stand management regimes in Australia (leading to wider spacings, heavier thinnings and shorter rotations),

(vi) the extent to which there is an integration of management and industrial development planning in order to ensure the effective utilization of all materials produced by the plantations; and

(vii) the far greater costs of establishing and maintaining plantations in Japan.

It cannot be argued, of course, that it will be possible for Japan to restore its domestic forestry sector simply by adopting new plantation establishment methodologies, implementing more radical stand management regimes, and developing large – scale integrated industries. The extent to which this can be done will be limited by a range of social, economic and environmental circumstances.

Many of Japan's forests are an integral part of a mountainous landscape with great visual appeal. Some are close to major population centres. Understandably, there may be a reluctance to accept an intensive working of these forests – involving more obvious clearfelling of stands, widespread use of herbicides, greater use of heavier harvesting machinery on steep slopes, increased risk of soil erosion and sedimentation of streams, expanded log traffic on mountain roads, the establishment of new and environmentally polluting industries, and so on. In any case, given the pattern of small area private ownership of forests in Japan, it seems unlikely a consensus on integrated resource management planning and industrial development would readily be achieved in many areas.

Nevertheless, it is clearly in Japan's interests to strengthen timber production to the greatest extent possible. This might be approached, for example, by categorizing all wood – growing regions and forests in terms of their environmental attributes and, where appropriate, evaluating prospects for more economic plantation management and industry re – structuring. It might be possible in this way to identify regions where the focus of future wood production can be on the lower – priced end of the market, for example, house framing, particleboard, pulp and paper. It would be necessary in these regions to implement more cost – efficient management regimes and to develop an appropriate range of industries to utilize fully all the products of those regimes. Elsewhere, the forests might service the market for higher quality timbers – largely through the continuation of present management regimes. Given the appreciation of fine – quality timbers in Japan, it should be possible to sustain a high – priced market in this way.

It will be important for many reasons to know how much of Japan's future wood demand might come from the domestic resource, and what market sectors it will service. This (and similar information for other wood—importing countries of the Pacific rim) would help sawlog—exporting countries develop appropriate plantation policies and strategies. This paper reinforces the call in our earlier paper for wider dialogue, and cooperative policy and management studies within the Asia—Pacific region.

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オーストラリアと日本の育成林業の比較

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要　　約

最初の論文（フローレンス，篠原，安里。学術報告第40号）では日本が将来，国産材の生産増大に加えて人工林材の輸入拡大に頼るに違いないことを明らかにした。この論文はオーストラリアと日本の人工造林事業を樹種，人工造林技術，人工林経営方式の面から比較し，そしてオーストラリア及びその他の南半球の国々における人工造林が費用面で非常に有利であることを明らかにしている。日本では国産材生産の拡大方法について検討されている。アジア・太平洋の国々の木材供給に関する共同研究の必要性が以前から求められている。