The following two papers were part of a symposium on "Nutritional aspects of exotic forestry in New Zealand."

SOME ASPECTS OF GROWING EXOTIC FORESTS IN NEW ZEALAND

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INTRODUCTION

New Zealand's exotic forests cover 1,200,000 acres, or nearly 2% of the total land area of the country and are being extended by about 33,000 acres annually. The creation of this estate over a period of 70 years has led to the successful establishment of various wood-processing industries, which at present utilise 150,000,000 cu. ft. of logs each year. These industries are supplying a high proportion of the sawn timber, timber products, and pulp and paper needed by the home market and are becoming increasingly important earners of overseas exchange. The management and exploitation of exotic forests has become an accepted primary industry in New Zealand and can contribute significantly to our future prosperity. A full understanding of the composition of these forests and their management problems is therefore extremely valuable.

THE ENVIRONMENT

New Zealand is a mountainous country extending over 13 degrees of latitude. Exotic forests have been planted between sea level and the 2,500 foot contour in many parts of both North and South Islands; in some localities they have been planted even higher. Extensive plantations are found in nearly all districts and in a wide range of climates.

Climatological data are available from many forest stations and provide reasonably comprehensive records of local conditions. For example, mean annual temperatures vary between 46°F. in forests in central Otago and 58°F. in forests in Northland and Coromandel Peninsula. Ground frosts occur on 170 days per year in central Otago but on only 11 days in parts of Northland. Again, central Otago, with an average annual rainfall of 24 inches, is one of the driest areas in the country. Some Canterbury and Marlborough forests also lie in low rainfall areas; conversely, forests on the west coast of the South Island may experience over 100 inches of rain annually.

Approximately three-quarters of the exotic forest estate is in the North Island and is particularly concentrated on the central volcanic plateau in the Rotorua–Taupo district. The volcanic ash soils of this region are very suitable for growing exotic trees but afforestation has been attempted, very successfully in many instances, on a wide range of other soils. Extensive plantings have been made on weathered clays near Auckland, on sand dunes along the North Island's west coast, on gravel plains in Canterbury, on yellow-grey earths in Otago and Southland and on the Moutere gravel hills of Nelson.

SPECIES AND PROVENANCE

Early plantings were largely experimental and followed the British woodland pattern of mixed stands and forests of many species. Ponderosa pine (*Pinus ponderosa*), strobus pine (*P. strobus*), redwoods (*Sequoia sempervirens* and *Sequoiadendron giganteum*), Douglas fir (*Pseudotsuga menziesii*), European larch (*Larix decidua*) and pedunculate oak (*Quercus robor*) were among those most commonly used. A trend towards pure stands developed in the early 1900s, favouring ponderosa pine and Corsican pine (*P. nigra laricio*). Radiata pine (*P. radiata*) became popular shortly before the 1914–18 war because of its rapid rate of growth in farm shelterbelts and its apparent usefulness as a general purpose building timber. It was almost the only species used by afforestation companies during the Depression and formed a high proportion of the State's programme during the same period. Radiata pine is still the most widely planted and important tree in exotic forests.

In spite of the wide range of soils and climates under which exotic forests have been established, the same few major species have been planted on different sites in almost all districts throughout the country. Radiata pine, for example, has been planted, and is still being planted, throughout New Zealand. Often it has been used on unsuitable sites where, subjected to severe climatic damage and attack by various pathogens, it has produced understocked, low-quality stands with a high incidence of stem malformation and below-average volume increment. But even inferior stands of this nature may yield a higher usable volume of wood than stands of any other available species. Thus there is a tendency to plant radiata pine beyond the areas best suited for its silviculture because it yields, or appears to yield, a higher financial return than hardier species.

Forests north of latitude 38° S. contain comparatively large areas of slash pine (*P. elliottii*), loblolly pine (*P. taeda*), longleaf pine (*P. palustris*) and other similar species from the south-east of North America. Radiata pine still predominates, however, but species such as Douglas fir and larch, which are common in more southerly districts, have little place in northern forests.

Nursery stock for the establishment of new exotic forests is usually raised from seed collected within New Zealand, but some seed is imported from carefully selected localities within the natural range of the species needed. Many species have an extensive natural distribution and have formed races adapted to local climates and environments. Seed collected from distinct localities within the natural range of a species gives rise, in exotic forests, to stands markedly different in growth rate and tree form. In New Zealand the effects of provenance are well illustrated by ponderosa pine, which occurs in North America from central British Columbia in the north to central Mexico in the south, and from the Pacific coast in the west to the state of Nebraska in the east. (Three major provenance groups have been planted in New Zealand.) Trees from the Coast Ranges of Washington, Oregon and northern California produce two or three times the volume of timber obtained from provenances of the same age from the interior of British Columbia. But British Columbia races of ponderosa pine are superior to the variety *scopulorum* from the eastern side of the continental divide in Colorado and Wyoming. Similar differences are readily apparent between the so-called blue and green strains of muricata pine (*P. muricata*) and green and yellow strains of lodgepole pine (*P. contorta*), and between Corsican, Austrian and other races of *P. nigra*.

FORMER LAND USE

Uses to which land is put before it becomes available for afforestation may have a marked effect on forest management and tree growth. Radiata pine plantations in the Moutere district of Nelson, for example, were sometimes planted in abandoned apple and pear orchards. Repeated cultivation between the rows of fruit trees to prevent the formation of a grass sward caused soil erosion and loss of nutrients. Forest growth on these sites is often poor and trees frequently show nutritional disorders.

Much exotic forest land was formerly occupied by hill farms. These farms were originally cleared from indigenous forest by early settlers, but pastures deteriorated and reverted to indigenous scrub or were colonised by introduced weeds. The composition and condition of these induced plant communities influence costs of land clearing and techniques used during the establishment phases of afforestation and may affect tree survival and growth rates.

GROWTH RATES

Variations in climate, soil, topography, provenance and former land use preclude the presentation of a national summary of growth rates in exotic forests which has any practical meaning.

Comparative figures from Golden Downs Forest, in Nelson Province, for three commonly planted coniferous species possibly will suffice for the purposes of this paper. Golden Downs represents fairly average geographic and climatic conditions for New Zealand and is a forest with which the writer is presently familiar.

	Actual at 40 Years		Projected at 60 Years	
	M.T.H.	Average T.S. Vol./ac.	M.T.H.	Average T.S. Vol./ac.
Species	(ft.)	(cu. ft.)	(ft.)	(cu. ft.)
Radiata pine	130	13,700	150	16,600
Douglas fir	101	12,800	130	16,700
Corsican pine	71	9,200	90	13,500

(M.T.H.=mean top height, the average height of the 100 tallest trees per acre. T.S. volume=total stem volume, the inside bark volume of a tree from stump height to the growing tip.)

Indigenous forest at Golden Downs, which is predominately beech (*Nothofagus*) forest with scattered podocarp species, growing on sites identical with those now supporting exotic forest, carries an average usable volume of approximately 2,900 cu. ft. per acre. This volume is attained in not less than 100 to 150 years. Radiata pine on the other hand will yield 10,000 cu. ft. of sawlogs in 40 years.

MANAGEMENT PROBLEMS

Coniferous trees from many parts of the world form the major component of the exotic forest community, but other introduced plants and introduced animals, as well as representatives of the indigenous flora and fauna, have become firmly established members of it. These artificially-created forests can be managed to produce continuous supplies of wood, but successful management has problems, some of which are discussed below.

Destructive animals

Exotic forests are inhabited by a variety of mammals, originally introduced into New Zealand for hunting or to provide meat and skins. Hares, rabbits, goats, Australian opossums and several species of deer browse young trees or strip bark from branches and younger parts of the main stem. This may cause malformed growth and result in death of the tree. Shooting, poisoning and trapping are used to control the animal populations to prevent severe damage to the forest.

Clear-felling of mature exotic forests creates favourable habitat for mice and several species of birds. These creatures eat large quantities of pine seed and the birds destroy newly germinated tree seedlings. The stocking of natural regeneration may be reduced to so low a level that reseeding, replanting or enrichment planting is necessary, particularly in winter-felled areas.

Weed growth

Land being converted to exotic forest frequently carries a dense cover of indigenous or exotic scrub or a mixture of the two. This must be at least partially removed before planting takes place. Fire alone may be adequate, but the addition of hand felling, bulldozing or chemical desiccation is needed in logged indigenous forest, in scrub hardwood forests and in broadleaved shrub vegetation on shaded faces. Discing or bulldozing after burning may be economically justified even in xerophytic scrub associations which readily carry fire; the additional operation creates a cleaner planting site and reduces the density and vigour of regrowth.

The growth of newly-planted trees may be checked or completely suppressed by regrowth of grass, bracken (*Pteridium aquilinum* var. *esculentum*) and shrubs such as gorse (*Ulex europaeus*) and tutu (*Coriaria arborea*). They are controlled by manual release cutting or selective weed sprays.

A dense understorey of woody plants and ferns may become established after thinning of the tree crop or as the forest becomes older. This understorey is severely damaged by logging when the forest is clear-felled, but regrowth may be sufficiently vigorous to suppress and cause the failure of natural regeneration of the trees.

Insects

The exotic forests have been colonised by indigenous insects and insects introduced from overseas. Although many cause damage very few present a serious threat to the existence of these artificial communities. This does not mean that the forests are resistant to attack; further accidental introduction of defoliating insects, for example, could be particularly dangerous.

Insect epidemics on an economically significant scale generally occur only when other factors predispose the trees to an attack. Thus *Hylastes ater*, which is normally a harmless insect in tree stumps and logging debris, causes severe mortality in young natural regeneration of radiata pine and among nursery stock planted into recently-logged areas on sites subject to unseasonal frosts. Shelterwood felling instead of clear-felling may alleviate the frost problem and promote healthier regeneration; alternatively, radiata pine may be replaced by a less frost-tender species.

Gross overcrowding in untended stands of radiata pine and a series of dry seasons preceded the heavy and widespread mortality caused 15 to 20 years ago by *Sirex noctilio* and its symbiotic fungus. The establishment of several insect parasites and greater attention to silvicultural thinning treatments now keep the *Sirex* population reasonably static.

The most spectacular attack by an indigenous insect occurred in 1952 when 8,000 acres of radiata pine in Canterbury were severely or completely defoliated by *Selidosema suavis*. Aerial spraying with DDT was used to control the outbreak in the worst-affected parts of the forest, while predators and parasites achieved natural control in unsprayed areas.

Fungi

Until the discovery of *Dothistroma pini* in the central North Island in 1964, few fungal diseases had caused any serious losses in exotic forests. The fungus associated with the wood wasp, *Sirex noctilio*, and the wound pathogen, *Diplodia pinea*, are possible exceptions, but both need predisposing conditions before they cause serious damage. *Diplodia* usually infects tissue which has been injured by frost, wind, pruning tools and other agencies, and causes cankers,die-back and seedling mortality. *Diplodia* is responsible for much of the multiple-leader type of malformation which is apparent in most forests and, with the bark beetle *Hylastes ater*, is responsible for seedling losses in natural regeneration on frosty sites. The fungus also causes the blue sap-stain in pine timber.

Some fungi present in exotic forests cause sporadic and scattered mortality but not enough to give concern. *Armillaria mellea*, for example, which is saprophytic on woody material in the soil, attacks exotic forest trees planted in logged indigenous forest and affects natural regeneration in second-rotation exotic stands, but is not a serious problem for the forester. The full economic significance of some diseases has yet to be determined. The effects of the root rot caused by *Phytophthora cinnamoni* in soils with impeded drainage is readily apparent, but more research is needed to determine the extent to which the fungus aggravates nutritional disorders of trees in infertile soils.

Dothistroma pini has been discovered in most parts of New Zealand but, so far, not on the east coast of the South Island. Distribution has been aided unknowingly by movements of infected nursery stock to previously disease-free localities. The behaviour of the fungus in New Zealand and its total effect on exotic forests are not fully known but are the subjects of a vigorous research programme. Meanwhile, extensive areas of exotic forest are being sprayed annually with copper compounds to prevent serious loss of growth.

The presence of fungi complicates forest management, but the absence of certain fungi may also cause problems for the forester. Mycorrhizal fungi are usually introduced into new areas of exotic forest by inoculating the nursery soil in which planting stock is raised. Duff from a healthy, well-established forest is spread over the nursery seed-sowing area and incorporated into the soil. There have been numerous instances when lack of suitable mycorrhizal fungi has led to severe chlorosis and complete growth checks in young Douglas fir plantations.

Nutritional disorders

Continued development of land for farming and continued expansion of exotic forests will increase competition for land and force both industries to use less attractive sites. Exotic forests will be established in logged indigenous forests to a greater extent than they are now and will be planted at higher elevations, on steeper slopes and on comparatively infertile soils. Growth disorders caused by shortage of plant nutrients may become a major problem. Nutrient deficiencies are already being encountered in several exotic forests and in one locality, at least, there are indications of a significant decrease in growth rates in some second-rotation radiata pine stands.

On deeply-weathered clays in the Auckland area, radiata pine is often slow-growing and unhealthy. Tufts of short, pale-green needles are borne at the ends of short, fine branches; die-back is common, and stem cones are numerous. Moderate dressings of phosphatic fertilisers induce an almost immediate improvement in tree health and vigour and allow the economic production of wood on these otherwise infertile sites. Concurrently with better tree growth, the activity of earthworms is increased and the physical condition of the soil much improved.

The surface layers of some pumice soils are low in magnesium. Until such time as roots are able to reach greater depths, trees become short of this element during the flush of spring growth. The previous year's needles show distinct needle-tip chlorosis. These symptoms are more pronounced under dry conditions.

Radiata pine growing on coastal sands on the west coast of North Island frequently loses vigour and shows symptoms of nitrogen deficiency in the crown. The condition is alleviated by thinning and further improvement attained by dressing with nitrogenous fertilisers. There are indications that additional nitrogen is supplied by an understorey of yellow lupin (*Lupinus arboreus*). This plant is used with marram grass (*Ammophila arenaria*) to stabilise the dunes before afforestation. Although suppressed and killed by closure of the pine canopy, its seed remains viable for many years and germinates to form an understorey as soon as the forest is thinned.

Radiata pine and maritime pine (*P. pinaster*) growing on some granite soils in Waimea County are grossly malformed by repeated die-back of terminal and lateral shoots caused by boron deficiency. Normal growth is quickly restored by small quantities of boron compounds applied to the soil or directly to affected trees as a foliar spray. In the same locality radiata pine growth rates may be increased two to three times if additional nitrogen and phosphorus are made available after boron deficiency is corrected. Boron is also critically short in many Moutere gravel soils in Waimea County.

A number of second-rotation radiata pine stands, established on Mapua and Rosedale soils by natural regeneration after clear-felling, are less vigorous than first-rotation stands which grew on the same sites. Typically, the drop in productivity appears to be equivalent to the normal volume increment for a 5- to 7-year period. For a mean annual increment of 300 cu. ft. per acre per annum and a forest rotation of 35 years, the loss in volume is about 1,500 to 2,000 cu. ft. per acre or 15 to 20%. The growth pattern may be one of partial stagnation during the early life of the crop, followed by height and basal area development equivalent to that in the first-rotation stand; or growth rates may continue below those previously attained. Analysis of the needles shows low levels for most of the major plant nutrients — particularly nitrogen — and applications of nitrogenous fertilisers promote spectacular, but only temporary, improvement in vigour. Combined dressings of nitrogen and magnesium or nitrogen and phosphorus sometimes give even better results. Attempts are being made to increase the availability of nitrogen by introducing leguminous plants at various stages in the life of the crop. The technique gives some promise of success provided additional phosphorus boron, molybdenum, and sulphur are added to the soil. The availability of nitrogen and the uptake of nutrients depend on several factors, including the decomposition of roots of the previous crop, soil acidity and the activities of mycorrhizal and root-rotting fungi. These inter-related factors are being studied as part of overall investigations into the complex problem of nitrogen in second rotation stands of radiata pine.