UNIT 4: CONSERVATION AND AMENITY

CONTENTS

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1 LEARNING OBJECTIVES

- Be able to discuss the role of trees for erosion control and riparian management on farms.
- Be able to discuss the benefits of trees for biodiversity and landscape enhancement.
- Be able to discuss the potential uses of trees for environmental amelioration including effluent disposal and carbon assimilation.

2 INTRODUCTION

In this Module we will concentrate on those aspects of the use of trees on farms and in landscapes which are not so easy to value in dollar terms as timber and livestock production. The benefits of resource conservation and enhancement of amenity value are nevertheless real, and have assumed increasing importance in recent years.

Table 1 Environmental impacts of tree plantations.

BENEFITS	DRAWBACKS
Erosion control	
Water quality	Monoculture risks
Flood control	Wood preservatives
CO_2 sequestration	Water yields
Shelter and shade	Visual impact
Noise and dust limitation	
Control of pollutants	
Renewable resource	

There are many facets to the impact of trees on conservation and amenity interests. Table 1 illustrates a list of benefits and drawbacks. It was drawn up originally in relation to the effects of tree plantations, but, with one or two exceptions, could apply equally well to native forest.

Established forests intercept rainfall and can have an important ameliorating effect on flood incidence compared with pasture on bare ground. They are likely to reduce water run-off to streams ("water yield") by 30-50%; the extent to which this is seen as an advantage or a disadvantage depends upon the normal rainfall of the region. Along with a lower incidence of flood risk from afforested areas goes a general improvement in water quality as measured by dissolved nutrients, suspended solids and microbial organisms. These benefits are lost when an afforested area is cleared, and are only re-established after 5-10 years of tree recovery.

Tree cover provides a major benefit in erosion control, as will be seen in the next section. This is a direct consequence of both interception of rainfall by the forest canopy and the soil stabilising influence of tree roots. On the debit side, there is some suggestion that successive tree harvests may deplete soil nutrient status and soil structure, but the evidence is not conclusive.

The contributions of forested areas to the provision of shelter and shade and the control of noise and dust annoyance may be difficult to quantify but are nevertheless real, and the use of such areas for the controlled management of effluent disposal is now an active interest. Visual impact on the landscape is shown in the table as a negative aspect of (usually) single-species plantations, but a more broadly based table could also have indicated the potential visual benefits of mixed native woodland. There are also benefits in the value of trees as a renewable energy resource, which is roughly neutral in its impact on carbon dioxide balance and its contribution to global warming (in contrast to the serious consequences of the use of fossil energy resources). Even this list, however, omits reference to the wildlife and amenity advantages of forests and plantations.

Potential drawbacks which are usually specific to exotic tree plantations are the risk of pest and disease attack from a large area of monoculture, and the risks of soil pollution from wood preservatives. We need to remember, of course, that the use of pesticides on pasture may pose its own problems.

It is impossible to cover all impacts on conservation and amenity in this Unit. Rather, we have chosen to focus on the following aspects in order to illustrate the broad range of issues which may need to be considered when planning programmes of tree introduction or management:

Soil stability and sustainable land use

Trees and wildlife

Biomass production and effluent disposal

The three aspects are inter-linked. They all represent sectors of interest in terms of resource sustainability and environmental impacts, issues which assumed major importance in legislation associated with the Resource Management Act (1991) and which are exerting increasing influence on the planning and management of rural and urban environments.

EXERCISE

See if you can find out for yourself areas in the locality where questions of land stability or wildlife conservation have created concern, and look for sources of information on them. In many cases they are likely to have featured in press reports and analysis, and some may be written in to local or regional development plans.

Look in the local library for information on the Resource Management Act of 1991, and the ways in which it is being administered by regional authorities. To what extent can the legislation be seen to provide an opportunity for managed development? Write a checklist for yourself of examples of ways in which rural development might be either encouraged or inhibited by the use of the Act's provisions.

3 SOIL STABILITY AND SUSTAINABLE LAND USE

3.1 Introduction

New Zealand is a young country in geological terms. Many of its rock formations are relatively soft, and the steady uplift of land as a consequence of tectonic plate movement and volcanic activity has resulted in rapid erosion and many steep slopes. This is particularly the case in the North Island. Risks of erosion are exacerbated by the frequency of high-intensity rains like those which accompany tropical storms like cyclones "Bola" and "Hilda". These effects are further heightened where forest cover is removed and replaced by grassland.

There are several reasons for this. A tree canopy provides more protection to the soil surface than a close-grazed pasture because it intercepts and dissipates rainfall at high level. There is also usually more surface litter and more ground unevenness under trees than under pasture to limit the effects of surface water washing. When the ground becomes waterlogged the deeper penetration and more massive structure of tree roots provides better protection against earth movements (slips, landslides and earth flows) than does pasture. This is by no means a simple picture, because the risks of surface erosion or mass flow of soil are strongly influenced by variations in soil conditions, ground slope and the characteristics of the underlying rock. Nevertheless, trees can play an important part in helping to control soil erosion, and its consequences to silt loads and flow impedance in watercourses.

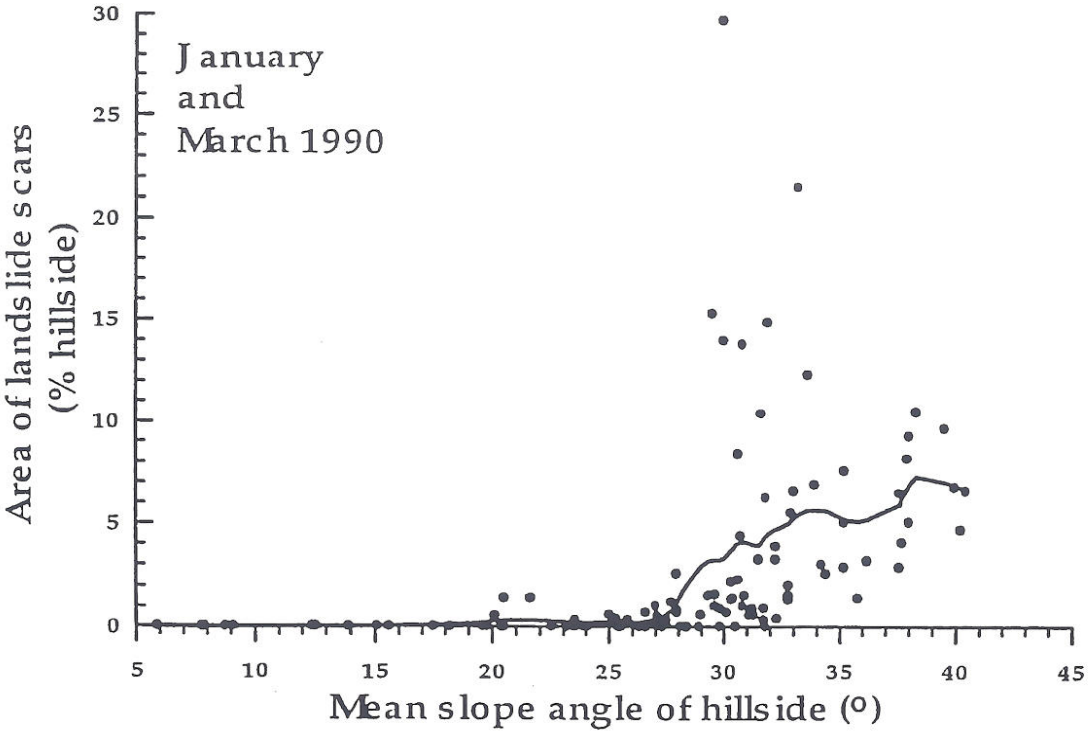
3.2 Field Studies

Recent studies in the Wanganui and Taranaki Regions, involving the Regional Councils and the Landcare Crown Research Institute, provide good examples of these effects and illustrate the potential implications of vegetation management to soil stability and resource sustainability. The results of one series of studies show a strong relationship between ground slope and the risks of soil slippage during heavy rainfall, and also show that vegetation cover can have a substantial influence on slippage risks. These results are shown in Box 1. Evidence from allied studies, shown in Box 2, illustrates the long-term consequences of soil slippage to land stability and pasture production.

Box 1. **Effects of land slope and vegetation cover on soil erosion.**

Studies of landslide scars following heavy rainfall events associated with cyclonic storms have shown a general relationship between hillside slope and the proportion of the land area affected by slippage. This is illustrated in Figure 1 which comes from Taranaki and relates to Cyclone "Hilda" in 1990. There is a substantial amount of "noise" in the data which reflects in part the difficulty of making objective measures of soil slippage, but the results indicate that risks of slippage increase progressively once slope angle increases beyond about 27°.

Figure 1 **Relationship between mean slope angle of hillsides and the proportionate area of landslide scars produced by rainfall events with long average return periods. Running average is shown as a solid line.**



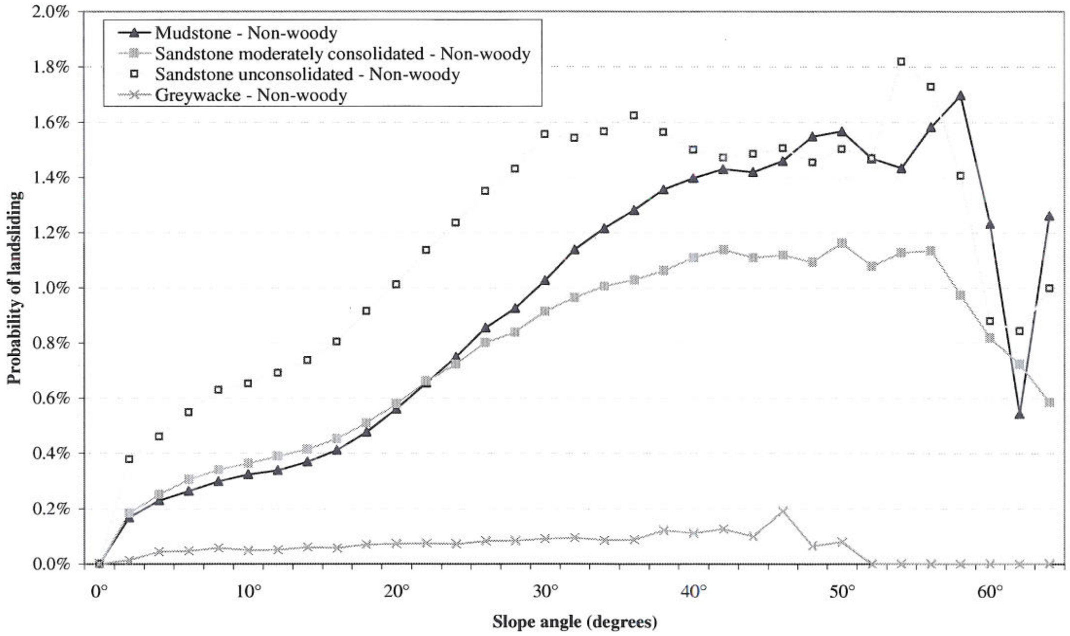
Source: De Rose, R.C. (1994) Proceedings International Symposium on Forest Hydrology.

A further source of variation in Figure 1 is the nature of the vegetation on particular areas of ground.

Box 1 continued

If the risk of landslides is considered with a single vegetation type, the risk of landslides on different slope angles is clearer. Figure 2 shows the risk of erosion on hill country in the Manawatu/Wanganui region during the 2004 storm in that region. This storm caused severe erosion and flooding in low lying areas.

Figure 2 **The probability of landslides on slopes of varying steepness comprising different parent material but with pasture cover. Probability is the proportion of land in an erosion scar.**



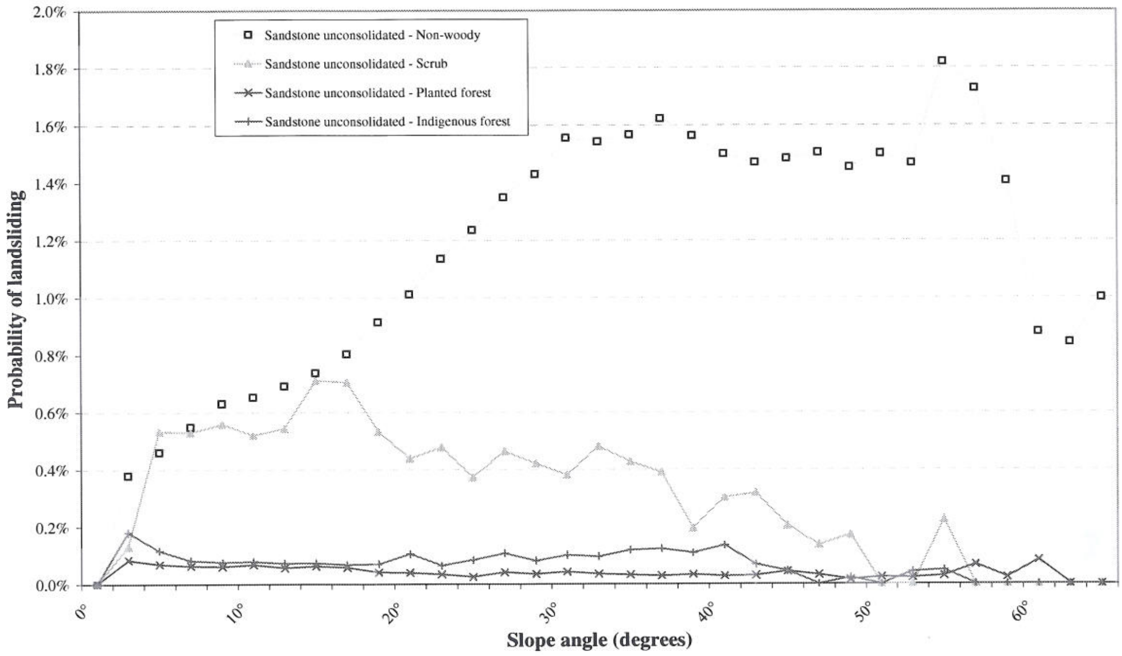
Source: Dymond, Ausseil, Shepherd and Buettner (2004). Validation of a region-wide model of landslide risk in the Manawatu/Wanganui region of New Zealand. Landcare Research, Palmerston North.

As is evident, the risk of landslides increases steadily with increasing slope angle. The risk is greatest with unconsolidated sandstone soils and least with greywacke, which is a hard rock. Much of the damage caused by the 2004 storm occurred in these unconsolidated sandstone soils. The local Regional Council (Horizons) has identified up to 400,000 ha of land with this soil type which needs to be retired from pastoral farming. Plantation forestry or native regeneration are the preferred options.

The influence of vegetation on landslide risk can clearly be seen in Figure 3. This also comes from the 2004 Manawaty storm. It demonstrates the benefits of woody vegetation (scrub or manuka, plantation forests and native forest) on erosion risk compared to pasture (non woody).

Box 1 continued

Figure 3 The probability of landslides on slopes of varying steepness on unconsolidated sandstone soils but with different vegetation. Probability is the proportion of land in an erosion scar.

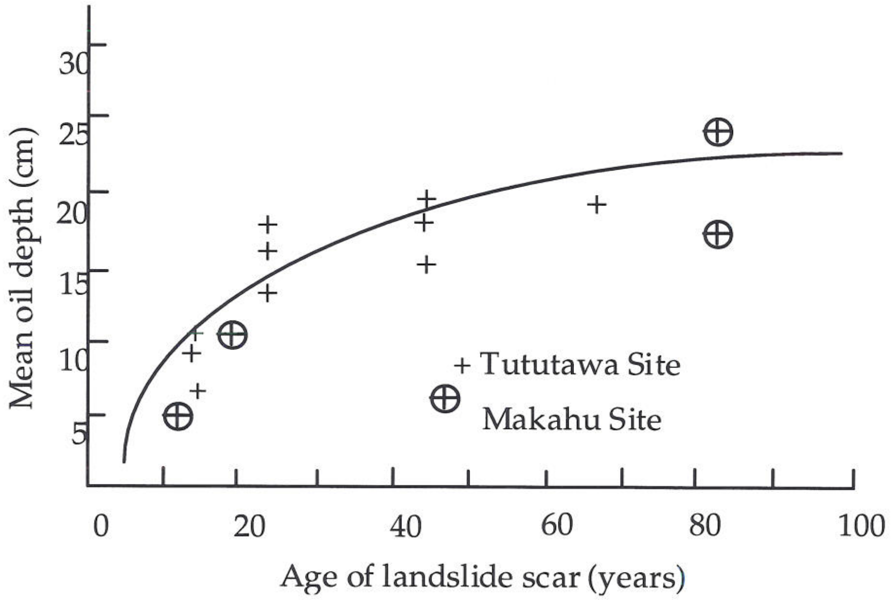


Source: Dymond, Ausseil, Shepherd and Buettner (2004). Validation of a region-wide model of landslide risk in the Manawatu/Wanganui region of New Zealand. Landcare Research, Palmerston North.

Box 2 Consequences of soil erosion to pasture production

Studies on a series of landslip scars of known age have shown that it may take up to 100 years to re-establish stable soil conditions on scar areas, with a progressive decline in the rate of recovery of soil depth with time (Figure 4). Pasture production on the affected areas may never recover fully to levels typical of unaffected areas (Figure 5), though it is in fact very difficult to define an objective base for comparison. The net effect of these two factors is a progressive decline in soil stability and pasture production in slip-prone areas, the rate of decline being dependent upon the frequency of rainstorms which precipitate slippage.

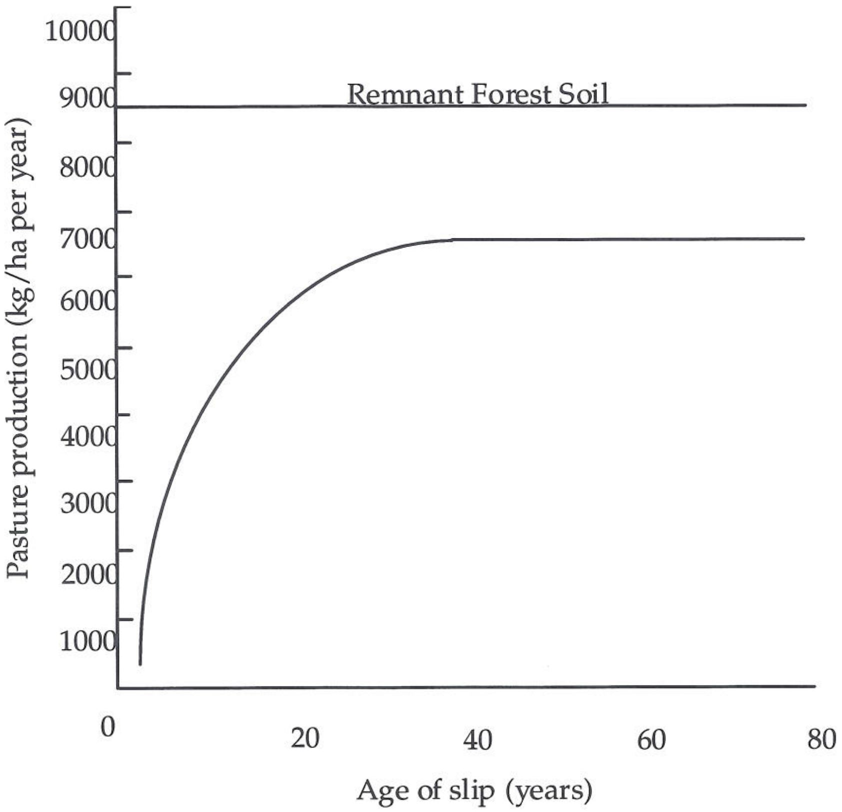
Figure 4: **Soil development on landslip scars: recovery of soil depth with time.**



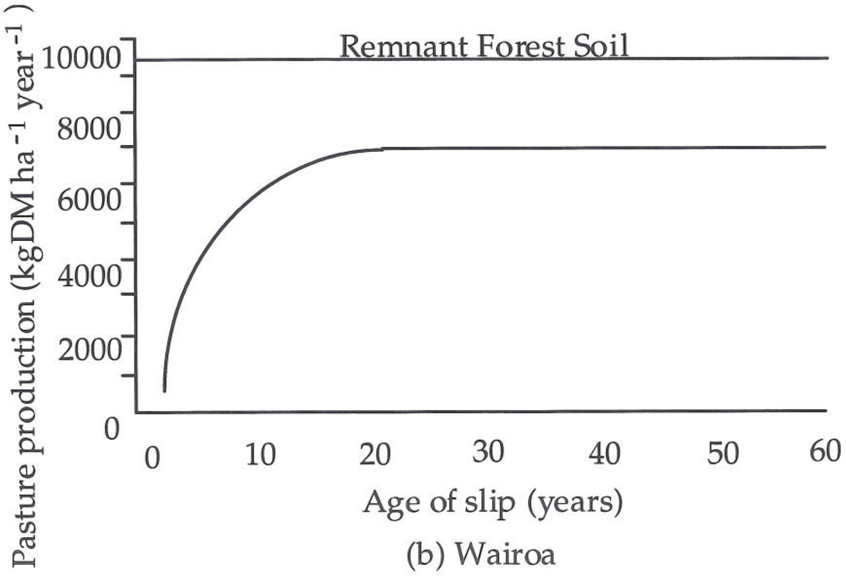
Source : N.A. Trustrum and R.C. de Rose (1988) Geomorphology, 1: 143-160.

Box 2 continued

Figure 5: **Pasture production on landslip scars of different age, relative to production on uneroded sites.**



(a) Wairarapa



(b) Wairoa

Source: N.A. Trustrum, P.M. Blaschke, R.C. de Rose, A.W. West (1990) Transactions 19th International Soil Science Congress, Kyoto, Japan. Section 1, 125-130.

The evidence from studies like these has been used to define categories of slippage risk in relation to soil and rock characteristics, ground slope, and vegetation cover. It has also been used to prescribe appropriate planting and management regimes to provide some protection in high-risk areas. The protection cannot of course be guaranteed, but risk factors should be reduced where control measures are properly carried out. Recommendations are summarised in Box 3.

The use of trees for control of soil stability may range from the spaced-planting of poplar or willow to limit soil flows and gully erosion, to the virtual retirement of the most susceptible land and the replacement of pasture by exotic forest or by a succession through regenerating scrub to native forest. Even this protection is likely to be inadequate until trees are at least six years old, and have had a chance to develop strong roots. From this point of view there are clear advantages to mixed-age forest or coppicing procedures (see Section 3) to maintain on-going protection, rather than a clear-felling policy which will create intermittent hazard.

The planting of prepared poplar or willow poles on wet hill faces is a long-established practice. It can be a particularly effective way of establishing tree cover quickly because of the ready rooting characteristics of these species, though establishment may be inhibited by drought or damage by livestock. Detailed information on choice of tree species and establishment procedures for land resource protection is given in the series of handbooks "Plant Materials Handbook for Soil Conservation". (See Course Administration Guide for details).

Box 3 Soil slope, erosion risk and management effects.

The results shown in Boxes 1 and 2 can be re-cast to illustrate land management implications in terms of erosion risk and vegetation effects. These are illustrated in Tables 1 and 2. The results in Table 1 came from a study in the Makahu locality of Taranaki.

Table 1 **Soil slope class, pasture production and erosion risk.**

Mean slope angle of hillsides (°)	Total hillside area (ha)	Uneroded herbage production (kgDM ha^{-1} yr^{-1})	Area of landslides (% of hillsides) 1990	Net annual herbage production after landsliding (kgDM ha^{-1} yr^{-1})	
				1990	100 yrs
6 – 23	28	14,000	0	14,000	14,000
24 – 27	30	10,000	2	9,850	9,850
28 – 32	34	8,800	8	8,250	8,250
33 – 37	21	7,300	12	6,700	6,460
38 – 42	7	6,000	23	5,100	4,850

Data from Landcare

Pasture production declines, and the extent of landslide damage increases markedly, as hill slopes increase. The table also shows the long-term nature of depression in pasture production following a slip.

Table 2 **Effects of vegetation cover on risks of soil erosion.**

Compared with open grassland, incidence of soil slippage will be:

(a) reduced 10% by sporadically spaced trees

(b) reduced by up to 60% where a well-planned programme of spaced planting is implemented

(c) reduced by up to 90% under close-spaced afforestation, reversion to closed scrub, or indigenous forest.

3.3 The Prevention of Soil Erosion

Soil erosion can be seen in many forms, however the most widespread, visible and damaging form in NZ is slipping/slumping on hill country. Other forms include stream/river bank erosion, wavelap erosion of the coastline and wind erosion of cultivated paddocks.

3.3.1 Slope stabilisation

Planting trees on hillslopes improves stability by:

a. Binding action of roots on soil. This keeps soil together and helps anchor unstable soil to more stable material lower in the soil profile. The effectiveness of root systems in preventing soil erosion is dependent on their spread and depth, the tensile strength of roots and the density of fibrous roots.

b. Reduction of soil moisture. Trees reduce soil moisture by intercepting and evaporating rainfall, preventing it entering the soil and also through evapotranspiration. Reducing soil moisture increases the shear strength along slip surfaces. Most soil erosion occurs in the winter months when a combination of high rainfall and low water evapotranspiration result in wet soils. The ability of trees to reduce soil moisture at this time is minimal, particularly deciduous trees such as poplars and willows.

The factor providing the greatest benefits for preventing soil erosion is the effect of tree roots on soil shear strength i.e. binding of soil.

A severe form of soil erosion in steep hillcountry is gully erosion. Gully erosion is characterised by very heavy sediment removal and high water velocities, particularly in the stream channel, resulting in undercutting of the slope (which causes more soil movement). In these situations spaced planting of trees is usually not sufficient to control erosion. Retirement from grazing and oversowing with herbage species may be necessary to help reduce sediment runoff. In addition debris dams may also be required to provide sufficient stability in the stream channel for trees to establish.

Areas to be permanently retired from grazing may be planted in *Pinus radiata* for wood production. The best species for streambed planting is willow (*Salix sp.*) because of its ability to thrive in wet areas and form a protective root mat over the channel.

On erosion prone hill country, poplar is the preferred species for slope stabilisation. Poplars are easy to establish, even in the presence of grazing animals (not cattle), quick to grow, have extensive root systems, and can be utilised as a source of fodder during feed deficits (as can willows). Willows are occasionally used and Eucalypts rarely.

Poplars and willows are easily established from large poles without the need to retire land from grazing. They are tolerant of wet soil conditions. Both species have poor resistance to drought which is a frequent occurrence on much of NZ's eroding hill country (East Coast, Hawkes Bay, Wairarapa). In these areas poplars may be useful on the lower slopes and gully areas only. Willows have lower drought tolerance than poplars so are not suited to these regions. On the upper slopes it is necessary to use drought tolerant species, the most promising of which are the Eucalypts. They are more difficult to establish but can produce very rapid growth. However it is necessary to remove stock during the establishment period.

Poplars are usually established by planting 'poles' 2-3m in length enclosed in plastic sleeves to protect them from stock. Most of the important breeds planted in NZ are hybrids. These hybrids are bred for superior growth rate, resistance to poplar rust disease, resistance to possum browsing and improved form characteristics such as narrow crown. Narrow crowns are desirable due to less shading and increased resistance to wind damage.

Once planted, cattle must be excluded for a period of 2 years. Cattle rubbing loosens poles, eventually killing them. In regions with large areas of erodible land, Regional Councils provide a subsidy which partially compensates farmers for the cost of establishing poplars. Ratepayers provide these subsidies because of the 'downstream' benefits of erosion control (i.e. better water quality in streams and rivers, less flood damage). The cost of planted poles is about $8.00 each and planting each ha of erodible land $400. This is a significant cost considering the lack of profitability of farms on this land and the long payback periods of such investments.

Planting densities will vary with the degree of slope instability. Areas which are actively moving (flows, slumps and slips) should be planted at densities ranging from 400/ha at the toe down to 40/ha at the head of the erosion. On areas not actively moving 25 stems/ha is sufficient. However for hill country with a high erosion potential 50 stems/ha is recommended.

EXERCISE

For land steeper than 25°, calculate the length of the payback period if $400/ha is invested in poplars for erosion control. Use the information on degree of protection and the loss in productivity resulting from slip erosion provided earlier in UNIT 4. You may want to use your own income data but if not, assume $35/stock unit. The payback period is the length of time required to recover the initial investment (including interest costs) from income resulting from the investment.

3.3.2 Streambank erosion control

Trees planted in the water channel are used to provide protection against the effects of floods, particularly on the outside of bends which are more vulnerable to flood damage. Often large trees are anchored by wire cables in these situations and poles planted behind this protective shield. Eventually a long thicket of vegetation establishes along the channel which reduces flood velocity as well as helping to bind soil.

Several species are suitable for this, but willows are by far the most important particularly for planting in water channels. Poplars may be used to protect drier stopbank areas.

Willows can also be used to help 'train' streams and rivers to follow a new course, usually in association with retards. Retards are light channel excavations (usually done with a bulldozer) which help encourage flow down a desired course.

Willows planted for channel protection lose their effectiveness as they mature. Stem numbers decrease, become rigid and act as a barrier to water flow particularly if they catch debris. To prevent this trees need to be lopped and layered. This involves partially cutting through the stems/trunk so that they fall but are still attached to the stump. Direction of fall should be downstream. There are two reasons for this. One is that leaving them attached to the trunk anchors them during a flood and the second that this insures access to nutrients until the felled branches develop new roots. This treatment promotes the growth of a large number of small stems which provide protection to the channel but minimal resistance to water flow.

3.3.3 Wind erosion

Wind erosion is not a widespread problem in NZ but it can be severe in some regions. It is usually associated with soil cultivation for cash or forage crops. A combination of light soil texture, low soil moisture, cultivation and strong wind can result in complete loss of topsoil. These predisposing factors are frequently found in eastern regions of both islands, particularly during a 'norwester'.

The southwest coast of the North Island suffers from sand being blown inland off the beaches during high winds. This results in highly productive land being buried under sand dunes. Much of this dune country has been stabilised with *Pinus radiata* forestry.

Shelterbelts are commonly used to help minimise the risk of soil erosion through a reduction in wind velocity. The principles of shelterbelt design are detailed in the section covering shelterbelts and timberbelts in UNIT 2.

4 TREES AND WILDLIFE

4.1 Introduction

We often assume that increases in forest area or in the number and variety of tree species enhance the richness of wildlife. Within limits this generalisation is likely to be acceptable, but relationships between tree and wildlife populations tend to be quite complex. This is an important issue for forest and landscape management, amenity plantings and the development and enhancement of refuge and riparian areas on farms. However, we cannot possibly deal with more than a small facet of the topic. To illustrate the point, we have chosen to focus on birds as a relatively high-profile indicator of wildlife activity, and to illustrate two examples of their associations with trees: (a) New Zealand data on the relationship between forest area and the numbers of resident bird species, and (b) bird populations in native forests and exotic conifer plantations in New Zealand and elsewhere in the World.

4.2 Forest area and bird species richness

Figure 5 illustrates the relationship between the number of native forest bird species and percentage forest cover in New Zealand, based partly on the geological and historical records and partly on forward projection from the current forest cover of about 25%. It shows an accelerating trend of species loss which can only be halted by retention of residual forest areas.

This figure, though somewhat speculative, also indicates that species variety has historically been smaller on the offshore islands than on the mainland. The implications in Figure 5 are supported by the firm evidence in Figure 6 which shows clearly the decline in species diversity with reduction in the area of either genuine islands (Figure 6(a)) or of virtual forest "islands" (6 (b)).

Figure 5. **Relationship between number of forest bird species and percentage forest cover in New Zealand, based on fossil records, recent historical record and future projections.**

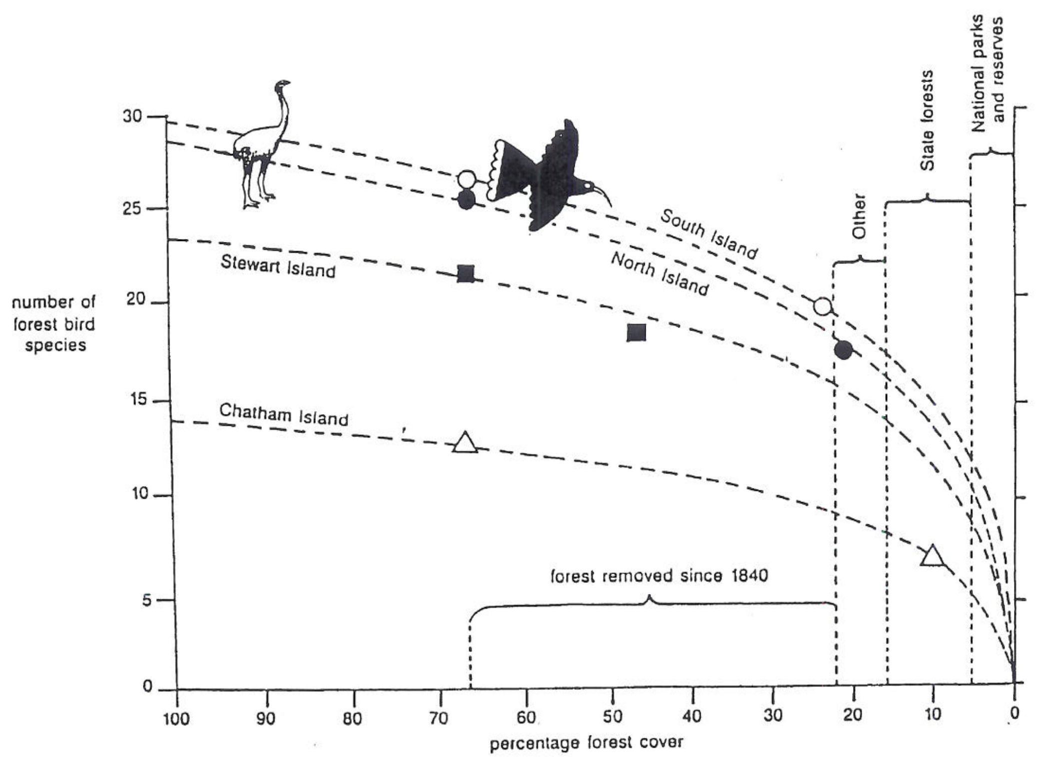


Fig. 168. As native forests disappear, so do the native birds they support. Projections based on fossil and subfossil birds, and our recent history of extinctions show the likely scale of future losses. These curves based upon almost universally accepted principles of biogeography probably also apply to native invertebrates and other forest animals. Our remaining forest remnants lie between many native forest animals and extinction.

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Source : **R. Brockie (1992). A Living New Zealand Forest. Publ. David Bateman.**

Figure 6: **Relationship between numbers of native bird species and island area, illustrating the results for sea islands and "islands" of native bush.**

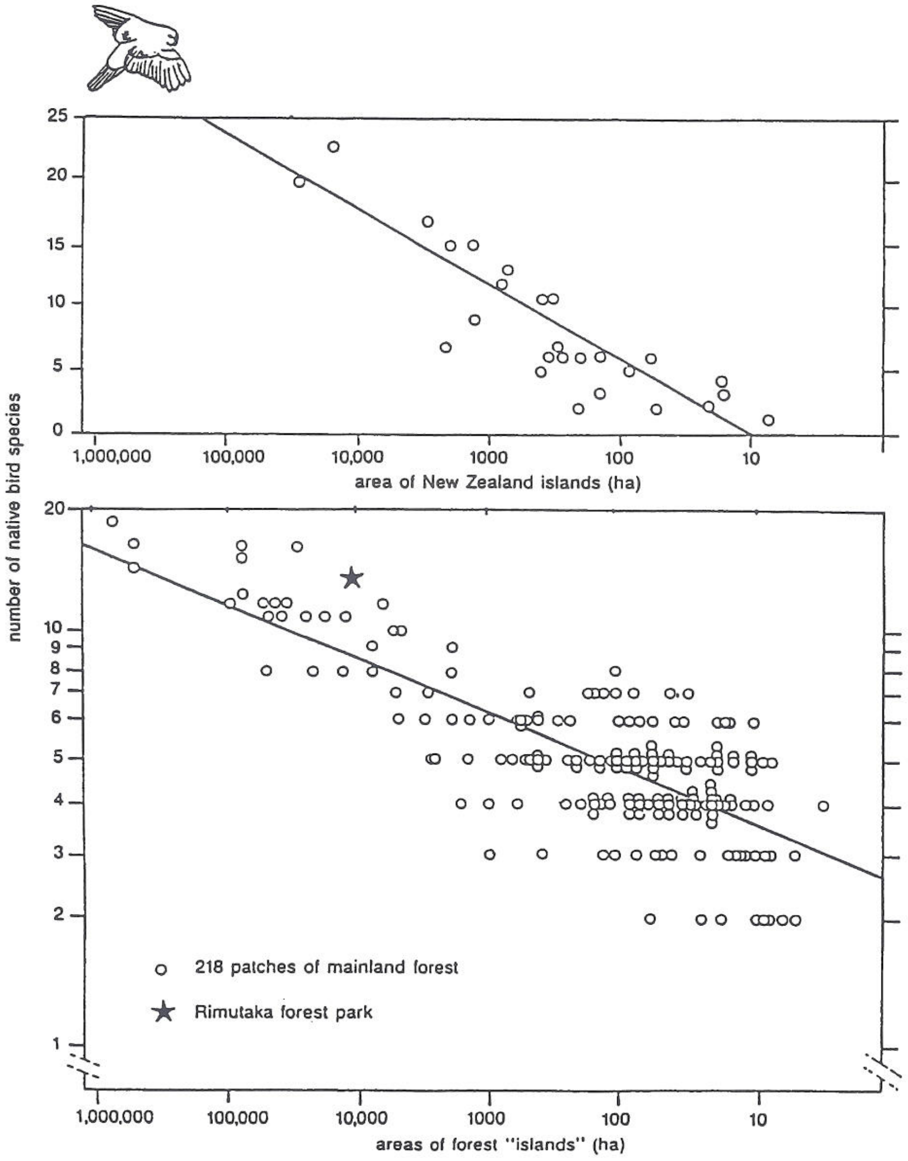

Fig. 139. ***Above*** Number of bird species on 26 New Zealand islands, showing that smaller islands usually support fewer species. ***Below*** Number of native bird species in 219 'virtual islands' or areas of native New Zealand forest. The largest areas support the greatest diversity of native birds. As areas of forest become smaller, they support a narrower range of birds.

Source : R. Brockie (1992). A Living New Zealand Forest. Publ. David Bateman.

The horizontal axes on both parts of Figure 6 are set out on a logarithmic scale from right to left, and the vertical axis in Figure 6(b) is also logarithmic. This use of a logarithmic scale tends to condense the data (and in this case produces convenient linear relationships). Converted into linear scales (*try it*) they result in similar relationships to those shown in Figure 5.

There has been much discussion lately about the importance of tree "corridors" – shelter belts, riparian strips, hedge lines or simply tree infill – in linking established blocks of refuge forest and so enhancing habitat and species numbers. However, though the amenity effects of such developments can be quite high, the benefits to bird populations are not always so obvious.

4.3 Bird populations in native and exotic forests

The best way to deal with this topic is to let you read the results of a careful investigation for yourself, and draw your own conclusions. The paper reproduced here is the outcome of a detailed study of populations of native and introduced bird species in exotic conifer plantations and in native Nothofagus forest, and includes some interesting and revealing comparisons with the results of studies elsewhere in the World. We suggest that you read it carefully, and evaluate the author's conclusions critically. Do not be put off by the technical terms used; they are all explained in the text.

For those of you who do not have experience of statistical analysis of data, the terms "significant effects" or "significant differences" indicate effects that are probably true, or genuine, rather than being simply due to chance variations in the observation.

The results of this investigation are interesting, because they show clearly the risks of drawing general conclusions about biological parameters like bird behaviour and distribution which are essentially variable in nature. The "true" patterns were only apparent when population distribution of native and introduced bird species were examined separately, and even then the authors could show that individual species had their own distribution characteristics based on feeding and shelter preferences.

EXERCISE

Can you make your own comparison locally of bird species diversity in mature, exotic and/or mixed woodland? Do your conclusions match up with those of the authors? Do you have bird species in your area which were not represented in the survey featured here, and how do their behaviour patterns compare? Do your observations bear out the effects of woodland area or species variety as in Section (a), and could you make allowance for this in your comparisons of species diversity? Can you name the species of tree and bird involved? Good hunting!

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EFFECTS OF PLANTATION FORESTRY ON BIRDS IN NEW ZEALAND

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SUMMARY

(1) The relative densities of birds were compared, vegetation profiles measured and bird food resources assessed in seven exotic conifer plantations and five areas of native *Nothofagus* forest in New Zealand.

(2) Of sixteen native bird species, seven were most abundant in native forest and two in conifer plantations. In contrast, none of the ten introduced birds preferred native forest, but at least seven were commonest in plantations.

(3) There was no significant relationship between overall bird species richness (BSR) and foliage height diversity (FHD). However, when introduced and native birds were considered separately, the BSR of introduced species was negatively correlated with FHD whereas BSR of native birds was positively correlated with FHD. Several introduced passerines preferred structurally simple plantations, but there were always more native bird species in native forest than in plantations.

(4) The distribution of birds between areas was largely explained by the differing availability of food such as fruit and honeydew, but for some species vegetation structure or the presence of tree-holes for nesting may be important factors.

(5) The native birds which suffer most from replacement of native forest with conifer plantations are frugivores, nectar-feeders and hole-nesters. Conservation of these species in large exotic forests is best achieved by retaining areas of native forest within conifer plantations.

INTRODUCTION

The establishment of extensive conifer plantations in New Zealand has caused concern and debate over the effects on native birdlife (Jackson 1971: Heinekamp & Ramsay 1973; Bull 1981), especially where these plantations have replaced mature or regenerating native forest. Despite this, the only quantitative work on the avifauna of New Zealand plantations is the study by Gibb (1961), and the bird populations of conifer plantations and native forest have not been directly compared.

The New Zealand avifauna has suffered numerous extinctions and introductions since human settlement (Diamond & Veitch 1981). The land and freshwater birds of the North and South Islands now include only fifty-four of the *c.* 100 species which were present 1000 years ago, but thirty introduced species and six Australian colonists have become established since *c.* 1850 (Kinsky 1970). Along with these avifaunal changes, there has been extensive deforestation, so that only about 22% of the original forest cover now remains (Mills & Williams 1979), most of it in the high country.

Native deforestation continues in New Zealand, but since *c.* 1930 it has been counterbalanced to some extent by the extensive planting of exotic conifers. Conifer plantations now cover about 1 million ha and continue to expand at a current rate of *c.* 40 000 ha p.a. (Kirkland 1981), so that by 2000 New Zealand could have 1·5 million ha of plantations, and eventually perhaps 2·3 million ha, or 8·7% of the total land area (New

Zealand Forest Service 1980). *Pinus radiata* is the most widely planted species, covering 83% of the exotic forest area in 1978, compared with 7% for *Pseudotsuga menziesii* and 10% for all other species (Levack 1979). The *P. radiata* plantations are grown for both timber and pulp and are generally managed on short rotations of 30 years or less.

Our study assessed the effects of plantation forestry on New Zealand birdlife, by comparing the bird populations, vegetation and food resources in a series of conifer plantations and native forest in the same region.

STUDY AREAS

The study was conducted in the Rai-Whangamoa and Golden Downs State Forests to the east and southwest of Nelson (41° 18′S, 173° 17′E) in the South Island of New Zealand. Study areas consisted of seven conifer plantations of varying age and type and five areas of native *Nothofagus*/podocarp forest (Table 1). The conifer plantations included three *Pinus radiata* stands adjacent to native forest, at Rai-Whangamoa, and three *P. radiata* stands away from native forest. at Golden Downs. There was also a study area in an old *Pseudotsuga menziesii* stand at Golden Downs. The native forest study areas were extensive blocks adjacent to the first three plantations at Rai-Whangamoa and two remnant patches (23 and 150 ha) at Golden Downs, surrounded by conifer plantations.

We laid out marked transects in each study area, with numbered stations at linear intervals of 100 m. The transects at Rai-Whangamoa ran from pine plantations into adjacent native forest and had twenty stations each, ten of them in plantation and ten in

TABLE 1. Summary of study area characteristics

(i) Conifer plantations

Name	Location*	Species†	Age (years)	Silviculture	Altitude (m)	Area of block (ha)	Distance from native forest (km)
Inwoods Pine	GD	Pr	6–8	Thinned, pruned	460	80	4
Olivers Pine	GD	Pr	15–17	Thinned, pruned	490	400	1·5
Hiwipango Pine	GD	Pr	30–32	Untended	350	60	3
Douglas Fir	GD	Pm	46–48	Thinned	350	200	5
Graham Pine	RW	Pr	10–12	Untended	410	80	Adjacent
Tinline Pine	RW	Pr	17–19	Thinned, pruned	320	80	Adjacent
Camp Pine	RW	Pr	29–31	Thinned	280	50	Adjacent

(ii) Native forest

Name	Location*	Major canopy species†	Altitude (m)	Area of block (ha)	Surrounding or adjacent habitat
Winns Bush	GD	Nf, Nt, Nm, Ns, Pf	380	23	Plantations, 15–17 years.
Spooners Bush	GD	Nt, Nm, Ns, Dc	400	150	Plantations, 6–40 years.
Graham Bush	RW	Nt, Wr, Pf, Nm	420	*c.* 10 000	Graham Pine
Tinline Bush	RW	Nt, Wr, Dc	340	*c.* 10 000	Tinline Pine
Camp Bush	RW	Nt, Wr, Bt, Dc	300	*c.* 3000	Camp Pine

* Locations: RW = Rai-Whangamoa State Forest, GD = Golden Downs State Forest
† Species names: Bt = Beilschmiedia tawa
Dc = Dacrydium cupressinum
Nf = Nothofagus fusca
Nm = Nothofagus menziesii
Ns = Nothofagus solandri
Nt = Nothofagus truncata
Pf = Podocarpus ferrugineus
Pm = Pseudotsuga menziesii
Pr = Pinus radiata
Wr = Weinmannia racemosa

native forest. The transects at Golden Downs each sampled only one habitat type and had ten stations. All stations were at least 200 m from the edge of the habitat type concerned, apart from those straddling the boundary between plantation and native forest on the Rai-Whangamoa transects and some of the stations in the smallest native forest patch at Golden Downs.

METHODS

Vegetation analysis

The structure and composition of the vegetation in each study area was measured by point-height intercept (PHI) analysis (Park 1973) in summer 1979–80 and 1980–81. Ten random points were located at distances of up to 11 m around each of the numbered stations on the study transects, so there were 100 points per study area. At each point a vertical sight line was projected through the vegetation above 2 m, using a gimbal-mounted sighting device. All live or dead vegetation intercepting this line was identified and the height of each intercept was measured using a 'Ranging' rangefinder. Intercepts up to 20 m above ground were recorded in 1 m intervals and those above 20 m in 2 m intervals. Intercepts below 2 m were measured with a graduated vertical pole.

Park (1973) recommended that PHI analysis should not be used in forests having a mean canopy height of over 15 m, because dense undergrowth can mask higher intercepts and make accurate determinations difficult above this height. Most of our study areas had canopies over 15 m high, but undergrowth above 2 m was rarely dense and it was usually possible to cut away or push aside vegetation which blocked the line of sight.

Fruit and nectar availability

In all study areas we examined plants within 5 m of each station once each month from May 1978 to April 1979. All plants bearing fleshy fruits or nectar flowers which were likely sources of food for birds were scored on a scale of 1–4. A score of 1 was given if the amount of fruit or flower present was judged to be 25% or less of the plant's maximum capacity (based on previous experience of each species) with scores of 2 for 25–50%, 3 for 50–75% and 4 for 75–100% of the possible maximum. Fruit and flowers were recorded separately and the height of each fruiting or flowering plant was noted. Multiplying the fruiting or flowering score by the height of the plant gave a crude index of the value of that plant as a potential food source. We then summed these values over all stations to calculate combined seasonal indices of fruiting and flowering for each study area.

Honeydew sampling

The scale insect *Ultracoelostoma assimile* (Maskell) inhabits the trunks and branches of *Nothofagus* trees in the South Island of New Zealand (Crozier 1981) and excretes honeydew which is consumed by nectar-feeding birds. The number of trees bearing honeydew was counted in a 10 × 10 m square plot laid out immediately to the northeast of each station along the native forest study transects in March 1982. More detailed observations on seasonal variations in honeydew quantity and quality were carried out from August 1978 to July 1979 in the Graham Bush, Spooners Bush and Winns Bush areas as part of a separate study (Gaze & Clout 1983).

Frass collection

The amount of falling invertebrate frass was used as an index of active invertebrate biomass (Tinbergen 1960) in the Graham Pine, Graham Bush, Tinline Pine, Tinline Bush, Hiwipango Pine and Spooners Bush study areas. Ten conical metal trays, as described by Beveridge (1965), were randomly placed in two groups of five in each of these areas. Each tray was suspended 1 m above the ground from metal stakes and collected the debris falling onto an area of 0·28 m^2. The trays were emptied once every month from July 1978 to October 1979. After overnight oven-drying at 60 °C, invertebrate frass was carefully shaken, brushed and sieved from the litter and its volume was measured to the nearest 0·01 cm^3.

Bird counts

The main focus of our study was to compare the relative abundance of bird species between areas. For this, we used the 5-min bird count (Dawson & Bull 1975), in which all birds seen or heard within an estimated 200 m radius of a point are counted over a 5-min period. This yields an index of density for each species, which can be expressed as number of individuals per 5-min count. Since species differ in detectability, each one is effectively measured on a separate scale and the counts of different species may not be added together or used in species-diversity calculations (Dawson 1981).

Our sampling was designed to minimize biases in bird counts, caused by differences between observers, weather, time of day and season. For 24 months from November 1977, two 5-min counts per month were made at every station in each study area by different observers on different days. Field work was done on fine days whenever possible. Twenty counts (each at a different station) were made per observer per day. Ten of these were in the morning, starting at 09.30 h (New Zealand Standard Time) and ten in the afternoon, starting at 13.00 h. Each observer either counted two of the ten-station transects at Golden Downs or one of the twenty-station transects at Rai-Whangamoa in a day. Bird counts were conducted at alternate stations whilst passing along a transect in one direction and at the other stations as the observer returned. Since stations were 100 m apart, the counts were effectively made at 200 m intervals. At Golden Downs each area was counted in the morning on one day by one observer and in the afternoon of another day in that month by the other observer. We then swapped morning and afternoon counts in the following month. On the twenty-station transects at Rai-Whangamoa we alternated in starting our counts at the native forest and plantation ends of the transects, to avoid always counting the more distant native forest sections in the late morning and early afternoon.

Analysis of bird counts

During the study we conducted 480 bird counts in each study area, for a total of 5760 counts.

In the main analysis we compared the abundance of each bird species between study areas by using the means and variability of 5-min counts for the species concerned. Since in general the numbers of birds counted per 5 min do not fall symmetrically around their means (Dawson & Bull 1975), all counts were subjected to a square-root transformation to stabilize the variance. Means and variances of these transformed data were then used in subsequent statistical testing. Analysis of variance was used to look for significant differences between areas in the counts for each species, and *t*-tests were used to examine differences between pairs of means. The transformed data used in statistical testing are listed in Appendix I.

For some mobile species, seasonal patterns were also analysed, using χ^2 tests on contingency tables of total numbers counted in each season. Differences in the number of birds counted in different seasons can result not only from real changes in abundance, but also from seasonal differences in detectability caused by changes in bird behaviour. Our analysis therefore determined the overall (i.e. expected) seasonal pattern for all areas and examined departures from this in the observed seasonal patterns of different study areas. The total counts in each area for the species concerned were divided into spring (September–November), summer (December–February), autumn (March–May) and winter (June–August) and compared using contingency tables.

For the sake of readability, we do not quote the results of all statistical tests in the text, but whenever differences in bird abundance are stated to exist they are significant at least at the 5% probability level.

Nomenclature

Names of plants mentioned in the text follow Allan (1961) and Moore & Edgar (1970) for native species and Healy (1969) for adventive species. Names of bird species follow Kinsky (1970).

RESULTS

Structure and composition of the vegetation

Point-height intercept (PHI) profiles of vegetation of the seven conifer plantations (Fig. 1) clearly showed the increase in stature with age of stand, and the changes in canopy density and understorey development associated with thinning and pruning. In the youngest, thinned stand (Inwoods Pine) there was an understorey of bracken (*Pteridium aquilinum*) with fruiting shrubs (*Coprosma robusta*, *Rubus fruticosus* and *Leycesteria formosa*) and open, grassy areas. In other young stands (Olivers Pine, Graham Pine and Tinline Pine) the understorey was mainly bracken with some fruiting shrubs, including *Aristotelia serrata* in the latter two areas. The old stands of Hiwipango Pine and Douglas Fir had dense canopies and little understorey, apart from patches of shrubs (including *Fuchsia excorticata*) in gaps. Most of the plant material in the lowest height interval in these stands was dead leaf litter. In contrast, the thinned old stand of Camp Pine had a well-developed understorey of fruiting species (including *Carpodetus serratus* and *Coprosma* spp.) with some kamahi (*Weinmannia racemosa*).

All five native forest areas were beech (*Nothofagus*)/podocarp forest with *Nothofagus truncata* as a major canopy species and an understorey of ferns and fruiting shrubs. PHI profiles (Fig. 2) revealed that the Graham Bush, Tinline Bush and Camp Bush areas had a marked subcanopy of kamahi, whereas the remnant patches of Spooners Bush and Winns Bush had little kamahi and a much higher proportion of beech. Spooners Bush and Winns Bush contained *N. solandri* (unlike the other areas), and Winns Bush was the only area with a large amount of *N. fusca* in its canopy. The occurrence of fruit-producing canopy trees also varied between areas. The predominant podocarp was *Dacrydium cupressinum* at Tinline Bush, Camp Bush and Spooners Bush, but *Podocarpus ferrugineus* at Graham Bush and Winns Bush. Camp Bush was the only area containing *Beilschmiedia tawa*.

All of the native forest areas had had a few large trees (mainly podocarps) removed 50–100 years ago, but were nevertheless essentially intact. The small patch of Winns Bush had suffered wind damage in the recent past, resulting in some canopy gaps and fallen debris.

Distribution of bird food resources between study areas

Fruit, nectar and invertebrates all varied in abundance between areas. Seasonal fruiting scores (Table 2) show that native forest areas provided more fruit than conifer plantations.

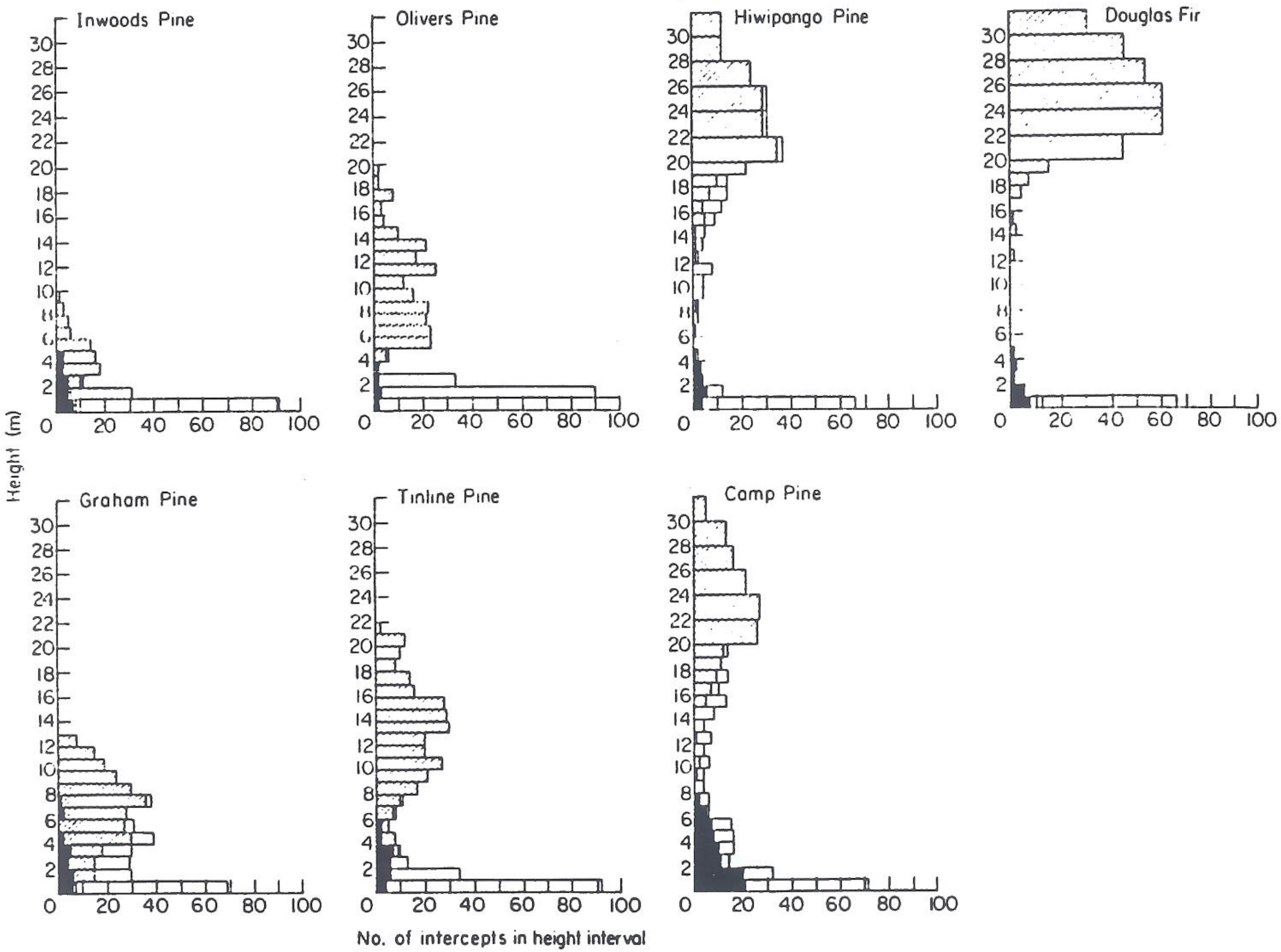

FIG. 1. Vertical profiles of vegetation in seven conifer plantations, as revealed by point-height intercept analysis. (■), fruiting trees and shrubs; (▨), exotic conifers; (□), all other vegetation and dead material.

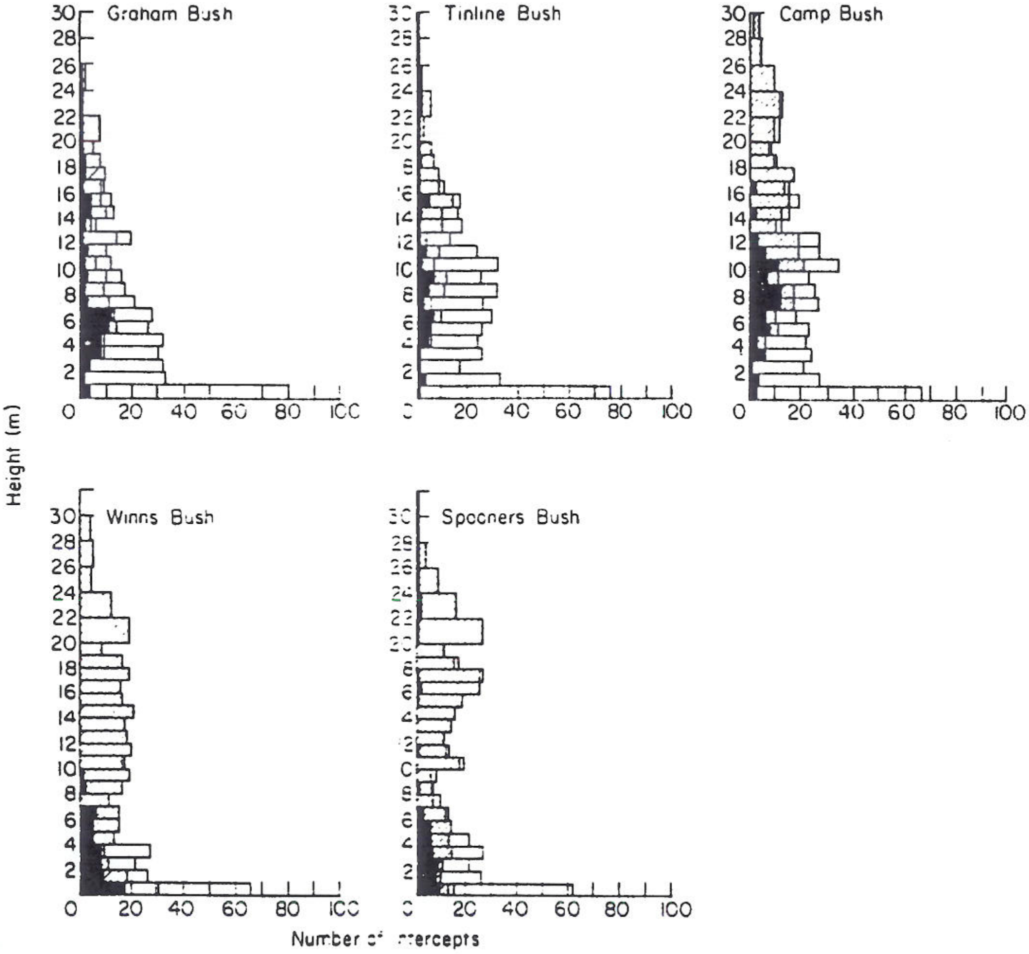

FIG. 2. Vertical profiles of vegetation in five native forest areas, as revealed by point-height intercept analysis. (■), fruiting trees and shrubs; (▨), beech; (□) all other vegetation and dead material.

Apart from the old thinned stand at Camp Pine (which had a relatively diverse understorey), the conifer plantations held very little fruit in winter and spring. In contrast, all of the native forest areas except Winns Bush had some fruit in every season. In conifer plantations the main fruiting plants were the introduced *Leycesteria formosa* and *Rubus fruticosus* and seral native species such as *Fuchsia excorticata*, *Coprosma robusta* and *Aristotelia serrata*. Native forest commonly had the latter two species and many other fruiting plants such as *Coprosma australis*, *Carpodetus serratus*, *Cyathodes fasciculata*, *Hedycarya arborea*, *Pseudopanax crassifolium*, *Pseudowintera axillaris*, *Ripogonum scandens* and the large podocarps. *Dacrydium cupressinum* and *Podocarpus ferrugineus*.

Floral nectar was scarce and seasonal in all areas, occurring mainly from November to January (Table 2). However, Graham Bush had some winter-flowering *Neopanax arboreum* and the Douglas Fir area had patches of *Fuchsia excorticata*, which flowered from September to December.

Beech honeydew, secreted by scale insects on the trunks and branches of *Nothofagus* trees, was available only in native forest areas. The Spooners Bush and Winns Bush areas had more honeydew-bearing trees per 100 m^2 than the other three native forest areas (F =

TABLE 2. Seasonal indices of nectar and fruit availability in each study area, May 1978–April 1979. See METHODS for details

		Inwoods Pine	Olivers Pine	Hiwipango Pine	Douglas Fir	Graham Pine	Tinline Pine	Camp Pine	Winns Bush	Spooners Bush	Graham Bush	Tinline Bush	Camp Bush
Spring	Nectar	3·0	—	9·6	21·6	14·1	17·7	4·8	24·6	32·1	55·5	14·7	12·6
(September–November)	Fruit	13·5	8·4	12·0	0·9	—	15·9	33·6	—	27·0	60·6	49·5	26·0
Summer	Nectar	23·1	—	3·5	3·6	—	—	—	—	6·0	30·0	15·3	13·2
(December–February)	Fruit	101·4	8·4	51·9	15·6	23·1	39·0	73·2	149·7	142·2	98·4	163·5	82·5
Autumn	Nectar	0·5	—	—	—	—	—	—	—	—	0·5	—	—
(March–May)	Fruit	63·3	18·0	26·1	—	0·6	12·0	70·2	93·0	87·9	204·3	170·4	145·8
Winter	Nectar	—	—	—	—	—	—	—	—	—	8·5	—	—
(June–August)	Fruit	2·4	7·5	3·9	—	—	11·4	42·6	6·0	20·1	112·5	81·0	46·2

TABLE 3. Occurrence of beech honeydew in native forest study areas, showing the mean number (± S.E.) of *Nothofagus* trees bearing honeydew per 100 m² plot (n = 10 plots per area)

Study area	Trees per 100 m² with honeydew
Winns Bush	1·1 ± 0·6
Spooners Bush	1·5 ± 0·4
Graham Bush	0·1 ± 0·1
Tinline Bush	0·2 ± 0·2
Camp Bush	0·7 ± 0·2

TABLE 4. Mean monthly volume (cm³ per 0·28 m²) of invertebrate frass falling into debris trays in six study areas ($n = 10$ trays per area).

	1978										1979					
	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.
Hiwipango Pine	0·17	0·19	0·11	0·11	0·34	0·49	0·51	0·34	0·99	1·37	0·64	0·37	0·35	0·16	0·27	0·81
Graham Pine	0·22	0·28	0·18	0·30	0·22	0·43	0·68	1·42	0·78	0·72	0·78	0·75	1·01	0·27	0·44	0·77
Tinline Pine	0·05	0·04	0·09	0·22	0·33	0·24	0·24	0·32	0·21	0·15	0·42	0·14	0·19	0·03	0·15	0·24
Spooners Bush	0·18	0·36	0·22	0·13	0·36	0·26	0·39	0·52	0·61	0·23	0·26	0·17	0·24	0·07	0·11	0·17
Graham Bush	0·34	0·54	0·15	0·10	0·19	0·19	0·36	0·80	0·69	0·50	0·22	0·26	0·31	0·12	0·10	0·17
Tinline Bush	0·42	0·39	0·17	0·19	0·17	0·34	0·19	0·25	0·29	0·26	0·20	0·07	0·34	0·05	0·10	0·13

10·24, $P < 0.01$) (Table 3). This is partly because Spooners and Winns Bush had a higher overall proportion of *Nothofagus* than the other areas and partly because they contained *N. solandri*, which is a particularly good source of beech honeydew.

Invertebrate abundance, assessed from frass falling into debris trays, was higher overall in conifer plantations than in native forest ($F = 7.95$, $P < 0.05$) for the six areas sampled (Table 4). However, there was no significant difference ($F = 1.10$, $P > 0.05$) between plantations and native forest in the monthly pattern of frassfall. The presence of fresh frass every month suggests that invertebrates were active throughout the year in all of the areas sampled. Without data on the composition of the invertebrate community these findings cannot be assessed in relation to the (poorly known) dietary preferences of the various insectivorous birds. They do however indicate that pine plantations are relatively good sources of general invertebrate prey.

Distribution of native birds between study areas

We recorded twenty native bird species, but three of these (kea*, parakeet sp. and black-backed gull) were classified as vagrant because they did not occur more than twice in any area and one nocturnal species (morepork owl) was disregarded because all counts were made in daylight. Most of the sixteen remaining species contrasted greatly in their abundance between study areas (Table 5 and Appendix I).

The distributions of bellbirds and tuis between areas correspond with the general availability of honeydew and fruit, which are important foods of both species (Gaze & Clout 1983). Native forest areas provided fruit (Table 2) and beech honeydew (Table 3) in all seasons and they supported more† bellbirds and tuis than the conifer plantations, which had less fruit and no honeydew. Tui abundance (number per count) was positively correlated with the density of trees bearing honeydew (Table 3) in the five native forest areas ($r = 0.949$, $P < 0.05$). There was no significant correlation for bellbirds ($r = 0.735$, $P > 0.05$), but like tuis they were most abundant in the native forest patches of Winns Bush and Spooners Bush, where honeydew was most plentiful. The clear preference of bellbirds and tuis for native forest is illustrated in their distribution across native forest/plantation boundaries (Fig. 3). Both species were as common in plantations up to 5 km from native forest as in those adjacent to it.

New Zealand pigeons occurred in all native forest areas, but were absent from most plantations (Table 5). They are frugivores and especially favour the large fruits of native trees such as *Podocarpus ferrugineus*. *Beilschmiedia tawa* and *Hedycarya arborea* which do not occur in conifer plantations. The only plantations where New Zealand pigeons were recorded more than once were adjacent to native forest (Fig. 3) and in both areas the birds were feeding on fruiting shrubs (*Aristotelia serrata* and *Coprosma parviflora*).

The insectivorous, hole-nesting rifleman was the only bird species which we found to be absolutely restricted to native forest (Table 5). Their absence from our study plantations was probably due to a lack of suitable nest-holes in relatively young trees, rather than unsuitable foraging conditions, because riflemen occur in older (>30 years) pine stands elsewhere in New Zealand (Bull 1981). Within native forest, we found that riflemen were commonest at Spooners Bush (150 ha). although absent from similar habitat at Winns Bush (23 ha) only 5 km away.

Tomtits are also small insectivores. but unlike riflemen they require only a partially

* Scientific names of bird species are given in Appendix II.

† All stated differences are significant at $P < 0.05$.

TABLE 5. Mean number per 5-min count† of (a) native and (b) introduced bird species in each study area (n = 480 counts per area). Plantation ages are shown in parentheses

(a)	Inwoods Pine (6–8 year)	Olivers Pine (15–17 year)	Hiwipango Pine (30–32 year)	Douglas Fir (46–48 year)	Graham Pine (10–12 year)	Tinline Pine (17–19 year)	Camp Pine (29–31 year)	Winns Bush	Spooners Bush	Graham Bush	Tinline Bush	Camp Bush
Bellbird	0·25	0·50	0·50	0·64	0·48	0·54	0·31	5·96	3·50	1·43	2·14	1·61
Tui	*	0·06	0·12	0·08	0·04	0·12	0·03	0·60	0·75	0·13	0·34	0·25
N.Z. pigeon	—	*	—	—	*	0·04	0·04	0·15	0·27	0·09	0·30	0·31
Rifleman	—	—	—	—	—	—	—	—	0·40	0·18	0·07	0·09
Tomtit	*	0·08	0·02	0·09	0·21	0·21	0·11	0·54	0·51	0·48	0·63	0·49
N.Z. robin	—	*	0·54	0·86	—	0·01	—	—	*	*	—	—
Brown creeper	—	*	1·14	2·49	*	—	*	—	—	*	—	0·03
Grey warbler	0·44	0·92	0·77	0·78	0·78	0·91	1·14	0·53	1·02	0·89	1·07	1·25
Fantail	0·30	0·41	0·79	0·38	0·45	0·53	0·27	0·19	0·50	0·34	0·32	0·28
Silvereye	1·98	1·34	0·51	0·98	1·96	1·60	1·02	1·19	2·42	2·48	1·82	2·60
Shining cuckoo	*	0·02	*	0·01	*	*	*	0·03	0·03	0·01	0·03	*
N.Z. kingfisher	—	—	*	*	*	—	0·02	0·03	—	0·01	*	0·02
Australasian harrier	0·01	0·01	*	*	—	0·02	*	*	0·01	*	0·01	—
Weka	—	—	—	—	0·01	*	*	—	—	*	0·02	0·01
N.Z. pipit	0·02	—	—	—	—	—	—	—	—	—	—	—
Paradise shelduck	—	—	—	*	—	—	—	0·02	—	—	—	—
(b)												
Hedge sparrow	0·85	0·42	0·06	0·07	0·10	0·30	0·23	0·13	0·02	0·02	0·02	0·03
Redpoll	1·49	0·72	0·09	0·05	0·58	0·18	0·04	0·23	0·04	0·01	0·10	0·09
Californian quail	0·04	0·01	0·02	0·02	0·01	0·01	*	—	—	—	—	*
Song thrush	0·23	0·04	0·23	0·33	0·09	0·11	0·11	0·11	0·07	0·09	0·04	0·10
Blackbird	0·32	0·16	0·29	0·31	0·17	0·25	0·29	0·38	0·26	0·20	0·25	0·36
Chaffinch	2·02	1·10	1·99	1·24	0·59	1·07	1·48	1·52	0·97	0·26	0·43	0·63
Goldfinch	0·42	0·66	0·53	0·33	0·17	0·50	0·44	0·56	0·94	0·04	0·08	0·40
Greenfinch	0·06	0·04	0·07	0·01	*	0·08	0·07	0·13	0·11	0·01	0·01	*
Skylark	0·15	—	—	—	—	—	—	—	—	—	—	—
Starling	0·01	—	—	*	—	—	—	*	*	—	—	*

* Vagrant, recorded on <3 of 24 months.

† Means and standard errors of square root transformed counts are given in Appendix 1.

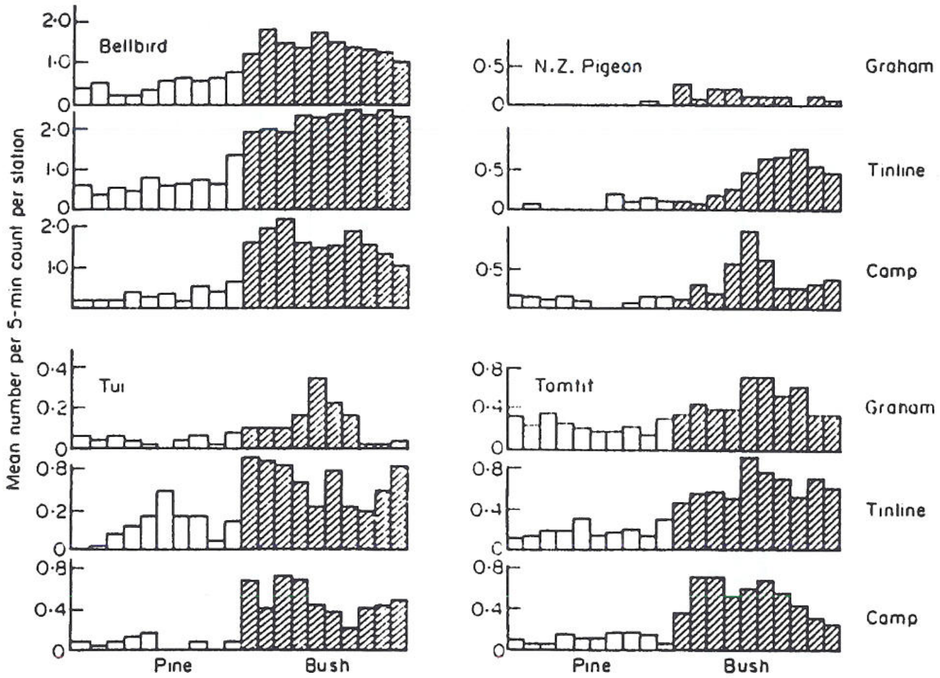

FIG. 3. Distribution of bellbird, tui, New Zealand pigeon and tomtit across plantation–native forest boundaries in the Rai-Whangamoa study areas. Shading denotes native forest. Stations were spaced at 100 m intervals.

enclosed cavity for nesting and will sometimes build in branch forks (Gibb 1961). They occurred in all study areas (Table 5), but clearly preferred native forest (Fig. 3). Only two solitary males were recorded in the Inwoods Pine area, which suggests that such young plantations are unsuitable as breeding habitat for this species.

New Zealand robins and brown creepers are insectivores which we found to have very similar patterns of occurrence. They were both common in the relatively dense, old conifer stands at Hiwipango Pine and Douglas Fir, but rare or absent elsewhere, including our native forest study areas (Table 5). Both species inhabit various types of native forest, with brown creepers being especially abundant in high-altitude *Nothofagus* forest and *Leptospermum* stands which have simple, monospecific canopies. Such canopies are also typical of conifer plantations, where the dense, even canopies inhabited by brown creepers produce extensive areas of bare leaf litter which are favoured by ground-feeding New Zealand robins.

None of the remaining native species was consistently more abundant in either native forest or conifer plantations (Table 5). However, when only the paired study areas of Graham Bush/Pine, Tinline Bush/Pine and Camp Bush/Pine were considered, for a direct comparison of native forest and plantations, the numbers of grey warblers ($F = 49{\cdot}42$, $P < 0{\cdot}001$) and silvereyes ($F = 32{\cdot}96$, $P < 0{\cdot}001$) were both greater in native forest.

The insectivorous grey warbler and fantail and the more mobile, omnivorous silvereye were present in every study area. Among exotic forest areas, grey warblers were least abundant in the young Inwoods Pine plantation and fantails most abundant in the old stand of Hiwipango Pine. Silvereyes showed a clear preference for the young pine stands and were least abundant at Hiwipango Pine. The small remnant of native forest at Winns Bush supported fewer grey warblers and silvereyes than any other native forest area and fewer fantails than any except Camp Bush (Table 5).

The migratory shining cuckoo and New Zealand kingfisher were present only in spring and summer, when cuckoos occurred in all areas but kingfishers only in some. Australasian harriers were occasionally seen flying over most areas, but wekas occurred only in our Rai-Whangamoa study areas. New Zealand pipits were present only at Inwoods Pine and paradise shelduck occurred on the margin of Winns Bush.

Seasonal abundance of New Zealand pigeon, bellbird and tui

New Zealand pigeons, bellbirds and tuis are all known to travel extensively between habitats to exploit seasonal food sources. We therefore analysed our counts of these species for differences between areas in the seasonal pattern (Fig. 4).

In most native forest areas counts of New Zealand pigeons were highest in autumn, during the main fruiting season, and lowest in spring when many of these birds move out of the forests to feed on leguminous foliage in other habitats (unpublished). The seasonal pattern of pigeon numbers in pine plantations was very different from that in adjacent native forest ($\chi^2 = 14{\cdot}64$, $P < 0{\cdot}005$). Pigeons did not occur in the plantations in winter, probably because the most attractive fruiting species in these areas (e.g. *Aristotelia serrata*, *Fuchsia excorticata*) have ceased fruiting by early autumn.

For bellbirds, several departures from the expected (i.e. overall) seasonal pattern were detected (Fig. 4), but the most consistent ones were in autumn and winter. Four plantations had more bellbirds than expected in autumn, but this was reversed in winter when the three plantations farthest from native forest had fewer than expected and the two native forest patches had more than expected. This latter pattern suggests that in winter bellbirds moved from those plantations which did not have nearby native forest and concentrated

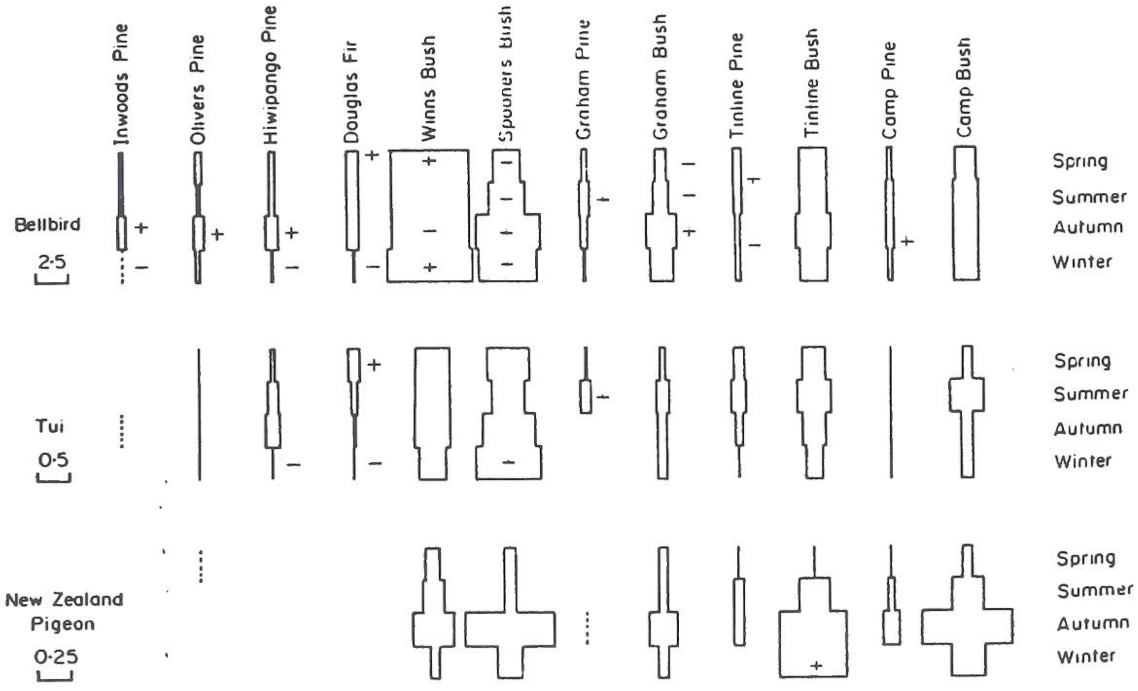

FIG. 4. Seasonal abundance (mean number per 5-min count) of bellbird, tui and New Zealand pigeon, showing results of χ^2 texts on contingency tables of totals. Horizontal scales show the number per count, and significant departures ($P < 0{\cdot}05$) from the overall seasonal pattern are shown by + = higher and − = lower numbers than expected for the season in question.

in native forest patches. In those plantations with adjacent large areas of native forest there was no evidence of any such movement.

For tuis, there were fewer departures from the expected seasonal pattern, but they all mirrored those for bellbirds (Fig. 4). In winter there were fewer tuis than expected in the plantations farthest from native forest and more than expected in the native forest remnant of Spooners Bush. Once again, this suggests a winter movement away from those plantations without nearby native forest. Tuis and bellbirds were both more abundant than expected at Graham Pine in summer and at Douglas Fir in spring. The reason for the apparent summer influx at Graham Pine is unclear, but at Douglas Fir both species were seen feeding in large patches of flowering *Fuchsia excorticata* in spring.

Distribution of introduced birds between study areas

Of the twelve introduced bird species which we recorded, two (house sparrow and yellowhammer) were considered vagrant, because they did not occur anywhere more than twice. The remaining ten species were hedge sparrow, redpoll, Californian quail, song thrush, blackbird, chaffinch, goldfinch, greenfinch, skylark and starling. All of these originate in the Northern Hemisphere and none of them (with the possible exceptions of blackbird and chaffinch) naturally favours the continuous closed habitat which is typical of mature native forest in New Zealand. Their distribution between study areas (Table 5 & Appendix I) reflects this fact: most of the introduced species were commonest in conifer plantations and none of them showed a preference for native forest.

Hedge sparrows prefer low, dense cover and were most common in the younger, thinned plantations which had bracken understoreys. Redpolls are typical inhabitants of coniferous woodland in northern Europe, so their preference for plantation habitats in our study is not surprising. They were commonest in young plantations, including the unthinned stand of Graham Pine. Both hedge sparrows and redpolls were more abundant at Winns Bush than in any other native forest area, possibly because this 23 ha isolate has an incomplete canopy and is surrounded by young pine plantations. Californian quail were commonest in the young plantation at Inwoods Pine, where they were often seen on a grassy firebreak. Their preference for relatively open habitats with patches of dense ground cover probably explains their virtual absence from native forest. Song thrushes were in highest numbers at Inwoods Pine, Hiwipango Pine and Douglas Fir and were relatively uncommon in all native forest areas (Table 5).

Blackbird and chaffinch have successfully invaded most habitats in New Zealand, including dense native forest, and both species were common in all of our study areas. Blackbirds showed no consistent contrasts in abundance between habitat types, but chaffinches were generally much more abundant in plantations than they were in native forest. The exceptions to this pattern were the dense young stand of Graham Pine, which had relatively few chaffinches, and the small isolate of Winns Bush, which had more chaffinches than any other native forest area (Table 5).

Goldfinch and greenfinch also occurred in all study areas, although the greenfinch was recorded less often and was merely vagrant in the dense young stand of Graham Pine. Goldfinches were least abundant in the largest native forest areas and were more common in plantations than native forest in each of the paired study areas at Rai-Whangamoa (Table 5).

The occurrence of chaffinches, goldfinches and greenfinches in native forest was apparently influenced by an unusually heavy *Nothofagus* seedfall in autumn 1979 (M. N. Clout & J. A. V. Tilley unpublished), which attracted large flocks of finches in the succeeding months. Chaffinches ($F = 39{\cdot}14$, $P < 0{\cdot}01$), goldfinches ($F = 20{\cdot}30$, $P < 0{\cdot}01$) and greenfinches ($F = 13{\cdot}73$, $P < 0{\cdot}01$) were all much more abundant in native forest areas in May–October 1979 than they had been in May–October 1978, and their numbers were especially high in the remnant patches of Spooners Bush and Winns Bush.

Skylark and starling both occurred in open areas at Inwoods Pine, but starlings were also vagrant in four other areas.

Structural diversity of the vegetation and bird species richness

An index of the structural diversity of the vegetation in each study area was calculated from the vegetation profile derived from PHI analysis (Figs. 1 & 2). This foliage height diversity (FHD) index was calculated according to the widely used formula:

$$\mathrm{FHD} = -\Sigma P_i \log_e P_i$$

where P_i = proportion of the total number of vegetation intercepts (live and dead) formed by the ith height interval. The relationship between FHD and bird species richness (BSR) was then examined. BSR was the number of bird species recorded in an area, excluding vagrants. In the context of avifaunal conservation, this is probably more meaningful than an 'equitability' index of bird species diversity, and in any case such an index cannot be validly calculated without estimates of density.

FHD and total BSR are not significantly correlated ($r = 0{\cdot}387$, $P > 0{\cdot}1$). This is largely because of the several introduced bird species which favour open or structurally simple habitats, resulting in a negative relationship with FHD for these species ($r = -0{\cdot}896$, $P < 0{\cdot}001$) (Fig. 5a). When only native birds are considered, BSR is positively correlated with FHD ($r = 0{\cdot}842$, $P < 0{\cdot}001$) (Fig. 5b). The number of native bird species is lowest in young, structurally simple plantations and higher in older, more diverse stands, but it does not continue to rise past nine species in any plantation with either increasing FHD or stand age. Some older plantations have similar FHD to native forest, but there are always more native bird species in the latter habitats.

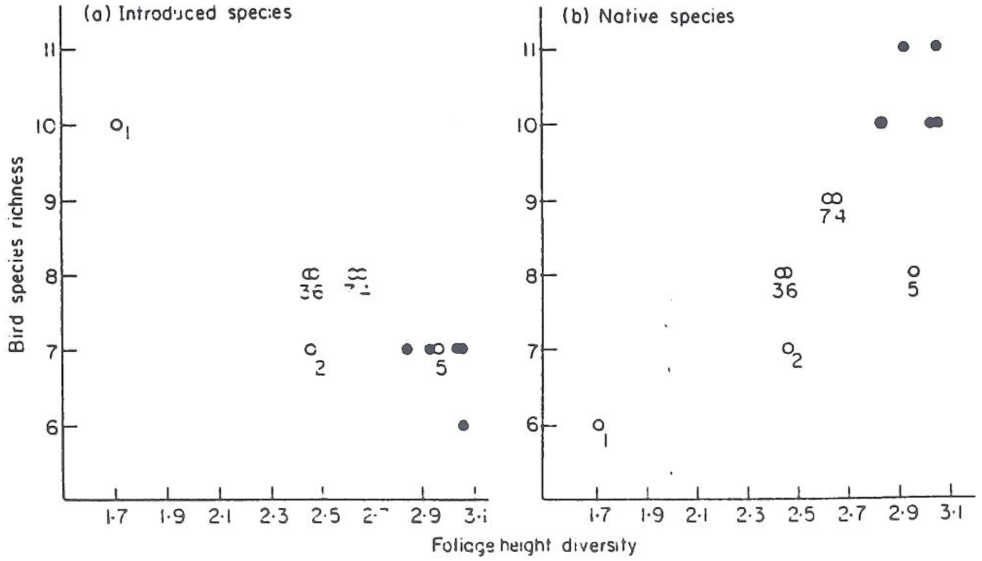

FIG. 5. Relationship between foliage height diversity (FHD) and bird species richness (BSR). (○ 1–7), conifer plantations, numbered in order of increasing age; (●), native forest. (a) Introduced species ($r = -0{\cdot}896$, $P < 0{\cdot}001$). (b) Native species ($r = 0{\cdot}842$, $P < 0{\cdot}001$).

DISCUSSION

Bird populations of conifer plantations

Studies in Europe (Moss 1978a. Nilsson 1979), North America (Noble & Hamilton 1976) and Australia (Disney & Stokes 1976; Suckling *et al.* 1976; Driscoll 1977; Friend 1982) have invariably found that conifer plantations support fewer bird species and a lower total density of birds than natural forests. However, our study and earlier work by Gibb (1961) and Kikkawa (1966) shows that neither of these patterns holds true in New Zealand (Table 6). We found that there were not always more bird species in natural beech/podocarp forest than there were in conifer plantations, and Kikkawa (1966) found total densities in undisturbed beech and podocarp forests similar to those calculated by Gibb (1961) for conifer plantations.

In New Zealand the main effect of replacing native forest with conifer plantations is not a reduction in overall bird species richness (BSR) or bird density, but a change in avifaunal composition. Our results show that conversion to plantations reduces the numbers of fruit and nectar-feeding birds and obligate hole-nesters, whilst insectivores and seed-eaters which do not nest in tree holes are less affected and sometimes benefit from the change. There are several introduced species in this latter category. Our study areas did not contain all of the bird species in New Zealand which might be affected by plantation forestry, but the results of other studies (Gibb 1961) and surveys (Jackson 1971; Heinekamp & Ramsay 1973; Bull 1981) confirm the general nature of our conclusions. When the forest-dwelling birds still extant in the North and South Islands are classified according to their occurrence in conifer plantations (Table 7), all of those commonly present are introduced or native insectivores or seed-eaters which do not nest in tree holes, and most of those absent are native frugivores or obligate hole-nesters. Those species which sometimes occur in plantations include native frugivores, nectar-feeders and hole-nesters, together with weka, New Zealand falcon and the brown kiwi (which occurs in some pine plantations in the North Island; Reid 1983).

The predominance of small insectivores and seed-eaters which is evident in New Zealand plantations is also a feature of those in the Northern Hemisphere (Lack & Lack 1951; Moss 1978a; Nilsson 1979: Noble & Hamilton 1976) and Australia (Disney & Stokes 1976; Suckling *et al.* 1976: Driscoll 1977; Friend 1982). In Australia the change in avifaunal composition following conversion of native forest to pine plantations is especially

TABLE 6. Total summer densities (pairs per km^2) and species richness of birds in conifer plantations and natural mixed forest (excluding modified or regenerating forest)

	Density		Species richness	
	Conifer plantations	Natural forest	Conifer plantations	Natural forest
Scotland (*)	150–600	1590–1740	6–10	17–18
Sweden (†)	170–480	1440	10–26	33
U.S.A. (‡)	190–350	1940	13–22	33
Australia (§)	370	2370	9	30
New Zealand	300–600 (c)	170–460 (**)	6–18 (c††)	10–20 (**††)

(*) Moss 1978a. (†) Nilsson 1979. (‡) Noble & Hamilton 1976. (§) Disney & Stokes 1976. (c) Gibb 1961. (**) Kikkawa 1966. (††) this study.

TABLE 7. Occurrence of forest-dwelling birds in conifer plantations in New Zealand. Species listed below the line are introduced European passerines

Commonly present	Sometimes present	Absent
Silvereye†	Bellbird†	Kokako†
Grey warbler	Tui†	Yellow-crowned parakeet*†
Fantail	N.Z. pigeon†	Red-crowned parakeet*†
Tomtit	Rifleman*	Kaka*†
Whitehead	N.Z. kingfisher*	Kea†
Shining cuckoo	Morepork*	Yellowhead*
Long-tailed cuckoo	N.Z. robin	Great spotted kiwi
Blackbird†	Brown creeper	
Songthrush†	Weka	
Hedge sparrow	N.Z. falcon	
Chaffinch	Brown kiwi	
Goldfinch		
Redpoll		
Greenfinch		

* Obligate tree-hole nester.
† Partially frugivorous or nectarivorous.

similar to that in New Zealand, because in both countries nectar-feeders, frugivores and obligate hole-nesters are major components of the native avifauna.

Several studies of birds in conifer plantations have demonstrated changes in avifaunal composition with the changing age and structure of stands, but conclusions have varied as to which growth stage supports the greatest variety of birds. Lack & Lack (1951) recorded more species in 8–9 year-old stands than in those up to 27 years, but other authors (Noble & Hamilton 1976; Nilsson 1979; Suckling *et al.* 1976; Friend 1982) have found old stands to have the most species. Moss (1978b) surveyed woodlands and old (25–50 years) conifer plantations and showed that bird species diversity (BSD) was positively correlated with foliage-height diversity (FHD). Our finding that overall bird species richness (BSR) did not increase with either age of stand or FHD is in apparent contradiction to the results of these other studies, but this is because of the confounding presence of some introduced species which favour young or simple plantations. When only native birds are considered there are more species in older stands and there is a positive correlation between BSR and FHD. We conclude that young conifer plantations are particularly poor habitats for New Zealand native birds.

Management implications

On current trends there will be in future, a smaller proportion of conifer stands at optimal stages for native birds in New Zealand, because of the continuing reduction in mean rotation length. In 1976–80 the mean age of *Pinus radiata* at clearfelling was 48 years, but this is expected to decline to 29 years by 1996–2000 (Levack 1979). Current practice is to prune and thin *P. radiata* stands to a final crop density of *c.* 300 stems ha^{-2} before they are 10 years old and to clearfell at 25–30 years, or even earlier where trees are being grown for pulp. In future there will be virtually no old pine stands (>30 years), which suggests that hole-nesting species (e.g. rifleman, New Zealand kingfisher, morepork) and other birds favouring old stands (e.g. New Zealand robin, brown creeper) will occur in conifer plantations less often.

Some amelioration of the generally adverse effects of plantation forestry on native birds is, however, possible. Studies in North America (Scott 1979; McClelland, Fischer &

Halvorson 1979; Mannan, Meslow & Wight 1980) have demonstrated the value of retaining old or dead trees within managed stands as nest sites for hole-nesting birds and it is likely that retention of a few old (especially dead) trees per stand from one rotation to the next would encourage colonization of plantations by hole-nesting birds in New Zealand. The more expensive option of providing suitable nest-boxes is also feasible, as shown by Gibb (1961) for tomtits in a North Island plantation. Management for local habitat diversity, by juxtaposition of stands of varying age and type, would benefit birdlife in general and would facilitate colonization by species with poor dispersal ability (e.g. New Zealand robin) as stands reach a suitable stage for them. Frugivores and nectar-feeders (e.g. New Zealand pigeon, bellbird, tui) could be encouraged by judicious planting of amenity (i.e. non-productive) areas with species of known attractiveness, to provide a succession of nectar flowers and fruit throughout the year.

It is clear, however, that the best way of maintaining a variety of native birds within extensive conifer plantations is to retain as much native forest as possible in the local area. For instance, it is unlikely that bellbirds or tuis can exist without some access to native forest. At Kaingaroa, which is an extensive area (137 000 ha) of plantations in the central North Island, there is virtually no native forest and bellbirds and tuis are recorded only irregularly (Gibb 1961; unpublished). However, at Golden Downs (35 000 ha), which includes several native forest patches, both species occur throughout the year. For these mobile birds native forest patches provide essential seasonal sources of fruit and honeydew, but they may act as stable foci of distribution for more sedentary species and provide nest-sites for hole-nesters.

This raises the question of what is the best distribution of native forest reserves for the conservation of native birds within a large area of plantations. According to the ideas promulgated by Diamond (1975), a single large reserve will conserve more species than a group of smaller reserves of the same total area, although this and other applications of island biogeographic theory to reserve design have recently been questioned (Margules, Higgs & Rafe 1982; Simberloff & Abele 1982). Following the theory, a large representative reserve should be best for local conservation of the fullest complement of native birds in a forested region where plantations are being established. Species which are restricted to native forest may indeed be best conserved by this sort of reserve design, although some of them (e.g. kaka, parakeets) may require such large areas that their effective conservation within the boundaries of an exotic forest is unlikely. However, most of New Zealand's forest-dwelling native birds are not restricted to native forest. Of those considered in our study, only the rifleman was limited in this way, and this was also the only species showing a possible sensitivity to reduced patch size. For all of the other species, native forest patches within plantations do not represent islands in any real sense; they are merely areas of one habitat surrounded by another (albeit less preferred) habitat. Reserve designs based on island biogeographic theory are largely meaningless for such species. Instead, they would probably benefit most from a network of smaller reserves (for seasonal foods and nest-sites) throughout the plantations.

Since it is unlikely that the entire avifauna of a region could be adequately conserved inside the boundaries of an exotic forest, we conclude that the most appropriate aim for bird conservation within New Zealand's conifer plantations is to maximize native bird species richness *throughout* these areas. This can be achieved partly by enhancement of the plantations themselves as bird habitat, but mainly by retaining areas of native forest within existing plantations and creating an even distribution of native reserves in new exotic forests.

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4.4 Plant species richness in exotic forests

Finally in this section we will consider aspects of the potential for development of native plant species in exotic tree plantations, and again we use the published results of a scientific study to illustrate the importance and the value of objective information. This is clearly only one facet of a very large subject, but it is included to make you think carefully about the influence of a tree canopy on understorey vegetation.

You may find the results of this investigation rather surprising, but evaluate the data for yourself and draw your own conclusions about its relevance to the general issue of plant conservation. This paper would also provide a useful template on which to plan your own investigation for the UNIT 4 assignment.

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PLANT SPECIES RICHNESS UNDER *PINUS RADIATA* STANDS ON THE CENTRAL NORTH ISLAND VOLCANIC PLATEAU, NEW ZEALAND

Summary: Exotic pine plantations constitute a significant landscape feature in the North Island of New Zealand but their conservation value for native plant species is not often documented. Pine stem density, height and basal area of nine plantations of *Pinus radiata* ranging in age from 6 to 67 years in Kinleith Forest was determined. Pines reached heights of 60m, and stand basal areas up to 183 ± 14 m^2ha^{-1}. The abundance of woody shrubs, tree ferns and ground ferns was assessed in each stand. Understorey composition of shrubs and ferns was reflected on the first two axes of DCA ordinations and correlated with the age of the pines. Adventive shrubs predominated in stands < 20 years old. Light-demanding native shrubs with bird dispersed fruits predominated in older stands, with more shade-tolerant species in the oldest site. Species richness increased rapidly in the first 11 years, but thereafter more slowly. Twelve native shrub species and 22 ferns were recorded from the most diverse stands. Richness and species composition were related to stand age, and probably also to topographical heterogeneity and aspect. Tree ferns reached densities of 2000 - 2500 ha^{-1} and basal areas of 20 - 30 m^2ha^{-1} in the older stands. Initially the tree fern population was strongly dominated by *Dicksonia squarrosa*, which comprised 84% of individuals overall. Five species were present by 29 years. The faster growing *Cyathea medullaris* and *C. smithii* achieved greater heights than the *Dicksonia* spp., and their relative biomass was greatest in the oldest stands.

Key words: Biodiversity; species richness; *Pinus radiata*; plantations; ground ferns; tree ferns.

Introduction

Exotic tree crops are a feature of the landscape in many countries throughout the world. Frequently such tree plantations are regarded as short-lived low diversity forests, with economic, ammenity and recreational values, but of little relevance in the conservation of native biota. However, in New Zealand it has been recognised that pine plantations sometimes have relatively high plant species richness and value in maintaining populations of native birds (Gibb 1961; Clout & Gaze 1984; Allen *et al.*. 1995b). Pine plantations - mainly *Pinus radiata* - cover about 5% of the New Zealand landscape (Newsome 1987). Plantation forests are particularly extensive on the central North Island Volcanic Plateau, where they have replaced a fire-induced mosaic of indigenous forest, shrubland, heathland and tussock grassland (Ure 1950) either directly, or indirectly following a period during which the land was farmed. The exotic monocultural appearance of these forests has obscured the fact that they harbour a wide range of indigenous plants, birds, and invertebrates. The forest understorey beneath pines commonly comprises native shrub and fern species, many of which also occur in and around canopy gaps in native forest. This assemblage often contains nectar and fruit bearing species which are particularly important for some indigenous birds. Despite some recognition of this link (Clout & Gaze 1984), the sequence of plant species colonisation and the features which control it have received relatively little attention (McQueen 1961; Allen *et al.* 1995b).

Plantation forests provide opportunities for the study of the patterns of vegetation assembly because they comprise a mosaic of areas which differ primarily in known stand age. Other features may also differ between stands, for example topography and soil, thinning regimes or the genetic characteristics of the pines, but with careful site selection many of these confounding variables can be eliminated, or their effects considered in the interpretation of the results.

The aims of our study were: 1) to describe the changes in understorey species composition in progressively older stands of *Pinus radiata*; 2) to quantify the changes in the composition and structure of the tree fern populations in the stands, and 3) to obtain data on tree fern height growth

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rates. Here we describe the changes in shrub and fern species composition occurring in stands of different ages.

Nomenclature follows Allan (1961) except where superseded by Connor & Edgar (1987) for indigenous angiosperms and gymnosperms, and Brownsey & Smith-Dodsworth for pteridophytes, except where indicated.

Study area

The study area was located in Kinleith Forest south-east of Tokoroa (Fig. 1). The area is a dissected plateau with the highest points approximately 750m altitude. The substrate is composed of ignimbrites from numerous eruptions, the most recent being the rhyolitic Taupo Tephra, which was deposited c. 232 AD (Sparks *et al.* 1995). The deep deposits of pumice are responsible for the characteristically coarse textured and free draining nature of the soils, which are relatively homogeneous on level surfaces over large areas. The local climate is cool and humid, with a mean annual rainfall of 1600mm. At Kinleith, 383 m altitude, mean monthly maximum temperature is 17.4°C in February, and the mean July minimum is 6.9°C (NZ Met. Service 1980). Clear nights with radiation frosts are a feature of the central North Island climate in winter, and the pooling of cold air in basins is thought to be one of the important environmental factors determining plant distribution patterns.

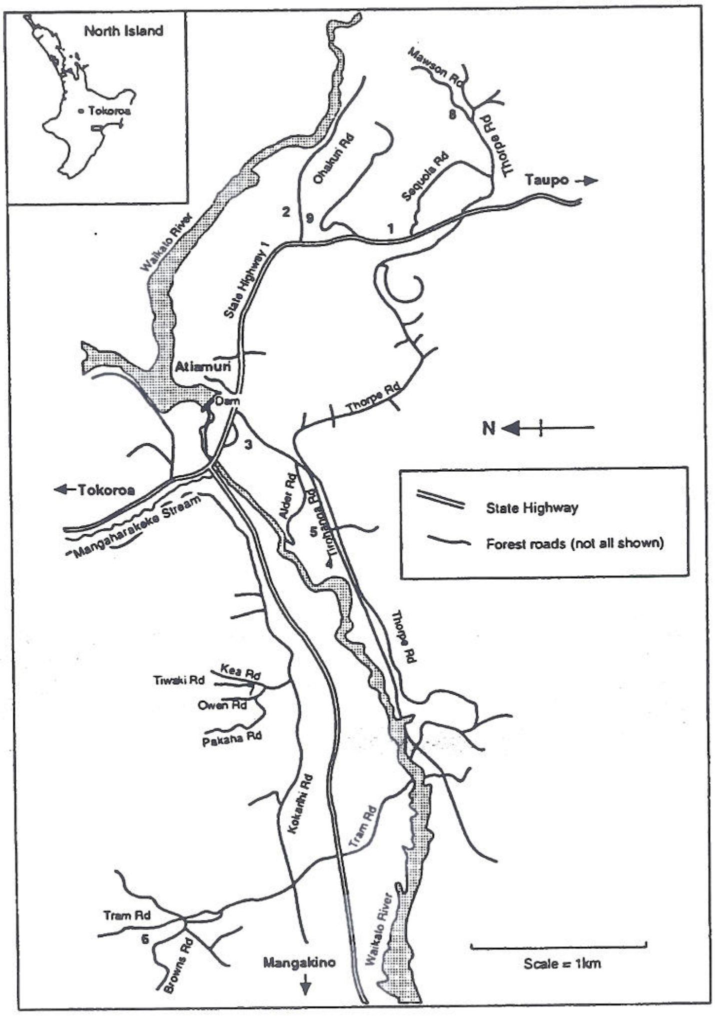

Figure 1: *Map showing site locations and (inset) general location of study area in North Island. Numbers refer to site numbers in Table 1.*

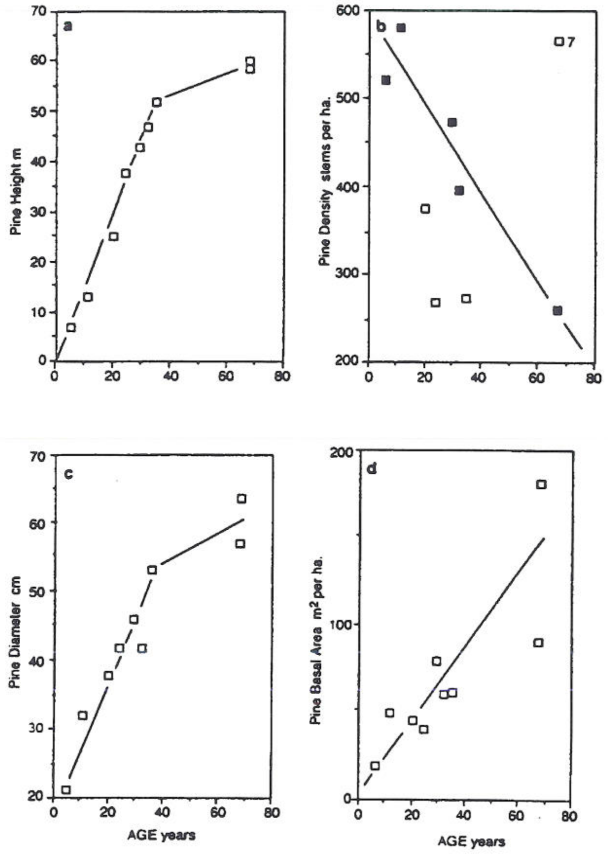

Figure 2: *Relationships between stand age and (a) mean pine tree height m, (b) stand density* ha^{-1} *(c) mean tree diameter cm and (d) stand basal area* $m^2.ha^{-1}$. *Curves are fitted by eye. In (b) the line is fitted to unthinned stands only (filled squares) and represents the natural self-thinning trajectory. The exceptional Stand 7 is indicated.*

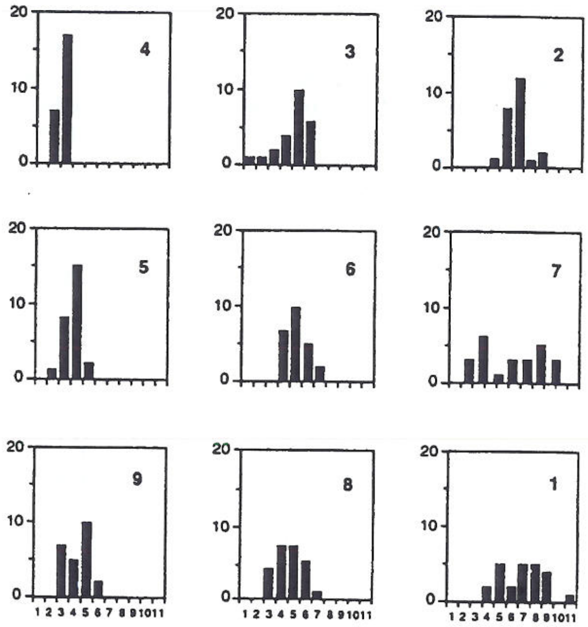

Figure 3: *Size frequency distributions of pines in each stand (numbers), based on 24 measured diameters per stand. Horizontal axis is in 10 cm diameter classes.*

years old also contained 10 - 30 % basal area of tree ferns and some native shrub species with diameters > 10 cm. Total stand basal areas are thus even greater: 202 and 120 $m^2.ha^{-1}$ respectively for stands 7 and 1.

Size frequency distributions (Fig. 3) document the increasing structural complexity of the stands with time. As the modal and maximum size both increase, intraspecific competition between individual trees in the stands causes the spread of sizes to widen. Other structural differences are due to silvicultural treatments (Table 1). In the two oldest stands, the size frequencies indicate the establishment of a second generation of self-sown pines as these stands were opened up by natural mortality of the planted cohort.

Shrub frequency

Ubiquitous introduced shrubs, especially blackberry (*Rubus fruticosus*), predominate in the two youngest stands (< 20 years) which show the highest similarity in shrub composition as a consequence (Table 3). These introduced shrubs and trees are bird- (*Rubus, Leycesteria*) and wind-dispersed (*Erica, Salix*). Subsequently adventives give way to native species, predominantly *Coprosma robusta, Pittosporum tenuifolium, Fuchsia excorticata* and *Aristotelia serrata.* Of the adventive shrubs, only *Rubus fruticosus* maintains a significant presence in the older pine stands. *Coprosma robusta* was the only species found at all sites, and comprised 21% of the total summed frequencies. The first native species all produce small succulent fruits and are readily dispersed by native and introduced frugivorous birds such as silvereyes (*Zosterops lateralis*) and blackbirds (*Turdus merula*). The two oldest sites (> 40 years) showed an increase in *Brachyglottis repanda* and *Weinmannia racemosa*, and more shade tolerant species such as*Schefflera digitata, Coprosma grandifolia, Pseudopanax arboreus, Melicytus ramiflorus,* and *Geniostoma rupestre.* Most of these species are also bird dispersed, but *Brachyglottis* and *Weinmannia* are wind dispersed.

Except in the youngest stand, the total diversity of native species ranged from 6 to 12 shrub species per 0.06ha sample. The highest diversities were in stands 3 (24 years) and 1 (67 years), which also had higher total abundances, implying greater understorey cover. Comparisons between the younger stands showed a trend of decreasing similarity in composition with increasing stand age, but this was not maintained in the three oldest stands (Table 3).

The first two axes of the stand DCA accounted for c.71% of the total variance (Fig. 4a). Stand loadings on axis 1 were strongly correlated with age ($y = 6.3595 - 4.4870*\log x$; $r = .8602$, $df = 7$, $P < .01$. y = axis 1 loading, x = stand age in years). The logarithmic relationship suggests that species composition changes relatively quickly at first, but thereafter more gradually, corresponding to the shift from mainly adventive to mainly native species after c. 20 years. The transitional 20 year stand (stand 9) was separated on axis 2. This was the only stand thinned twice. (cf McQueen 1973). The species ordination (Fig.4b) emphasises the shift in species

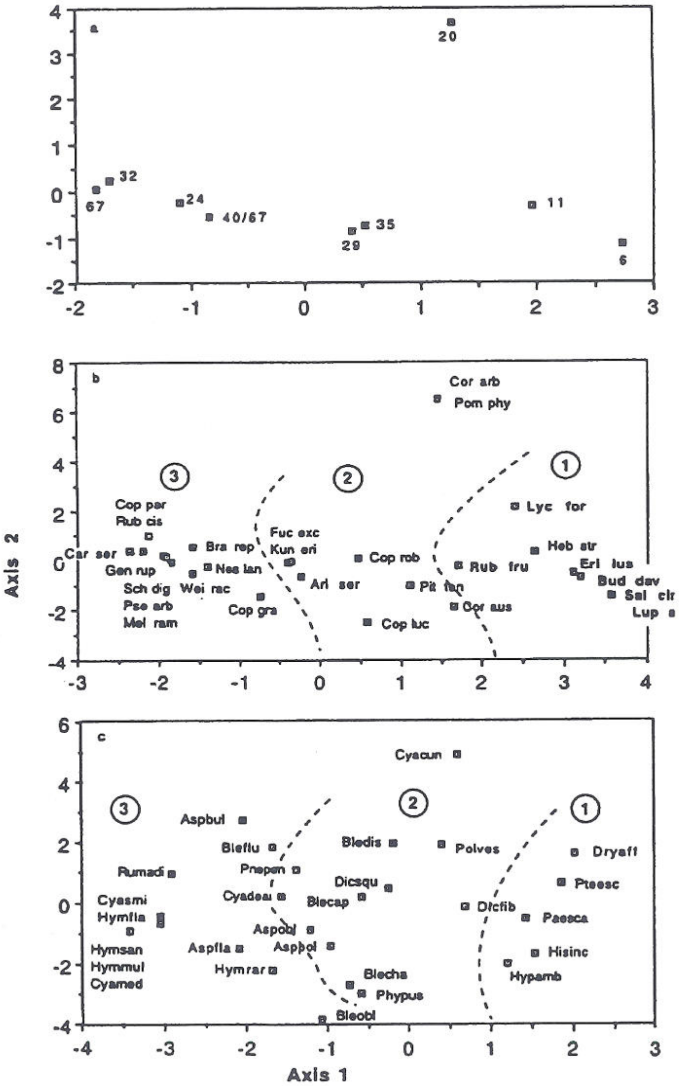

Figure 4: *DCA stand and species ordinations. (a). Stand ordination based on shrub data; stand ages superimposed. (b). Shrub species ordination. Ordination areas: 1, mainly introduced woody weeds; 2, native pioneer shrubs; 3 light requiring native trees and gap colonists. (c). Ground fern species ordination. Ordination areas: 1, colonising rhizomatous species: 2, larger ground ferns and some tree ferns; 3, species requiring more shade and/or moisture (eg filmy ferns). Names are first three letters of generic and specific names; see Tables 3 and 4.*

composition with age, and the isolated occurrence of *Coriaria arborea* and *Pommaderris phylicifolia* in stand 9.

Ground fern abundance

Thirty six species of ground ferns (including seedling tree ferns, and some low epiphytes) and fern-allies were identified, but of these only 6 comprised 75% of the fern ground cover (Table 4). The most abundant species were juveniles of the tree fern *Dicksonia squarrosa,* and *Blechnum capense* (*sensu* Allan 1961). *Pteridium esculentum* was abundant in the youngest site, and persisted throughout. *Paesia scaberula, Pteridium esculentum, Histiopteris incisa* and *Dicksonia fibrosa* seedlings were common in stands 9, 3 and 6 (20 - 30 years). The large ground ferns *Blechnum capense* and *Pneumatopteris pennigera* were particularly abundant on the steep shady slope sampled at site 8. The smaller *Hymenophyllum* spp. and *Trichomanes* spp. were most common in the oldest site (stand 1), where five species were recorded. Fern species abundance and diversity increased in the early stages of forest colonisation (< 20 years), but thereafter showed no clear pattern

Table 3: *Shrub frequency. Values are numbers of points out of six at each site at which the species was recorded. (1) Similarity coefficient: 2w / a + b, where w is the sum of the lowest abundance values for species in common to both stands, and a and b are the respective stand totals.*

	Sites										
	4	5	9	3	6	8	2	7	1	Overall	
Site age (yr)	6	11	20	24	29	32	35	40/67	67	frequency	%
Species											
Rubus fruticosus	4	3	1	1			3		1	13	6.0
Buddleja davidii	6	4								10	4.6
Leycesteria formosa	1	3	2							6	2.8
Erica lusitanica	1	1								2	0.9
Salix cinerea	2									2	0.9
Lupinus arboreus	1									1	0.5
Coprosma robusta	4	6	6	6	6	3	6	6	2	45	20.8
Pittosporum tenuifolium	3	1	1		3		6	1	1	16	7.4
Fuchsia excorticata		1	1	2		5	6	1		16	7.4
Aristotelia serrata		1	1	2	6			1	3	14	6.5
Schefflera digitata				2		5		2	5	14	6.5
Brachyglottis repanda			1	2		3	1	1	6	14	6.5
Coprosma grandifolia				1	1		2	6	1	11	5.1
Pseudopanax arboreus				4		1			4	9	4.2
Melicytus ramiflorus				1		2		2	3	8	3.7
Weinmannia racemosa				3				2	2	7	3.2
Geniostoma rupestre				1		1			5	7	3.2
Kunzea ericoides		1		3						4	1.9
Coriaria arborea			4							4	1.9
Cordyline australis	1				1		1			3	1.4
Pommaderis phylicifolia			3							3	1.4
Coprosma sp. (cf.parviflora)						2				2	0.9
Hebe stricta		1								1	0.5
Coprosma lucida					1					1	0.5
Rubus cissoides						1				1	0.5
Carmichaelia sp.									1	1	0.5
Nestegis lanceolata				1						1	0.5
Number of species	9	10	9	13	6	9	7	9	12	27	
Number of native spp	3	6	7	12	6	9	6	9	11	21	
Total abundance	23	22	20	29	18	23	25	22	34	216	100
Total native abundance	8	11	17	28	18	23	22	22	33	182	
Adventive abundance	15	11	3	1	0	0	3	0	1	34	
Similarity with next older stand	0.62	0.55	0.41	0.38	0.15	0.37	0.47	0.43			

associated with stand age, although the highest diversity was recorded in the oldest stand. As with the shrubs, stand 3 was notable for its high species diversity. The adjacent stands 2 and 9 had low ground fern diversity. Tree fern seedlings and *Blechnum capense* generally increased in abundance in the older (> 30 year old) stands. All three *Cyathea* species had more juveniles in the oldest stand than elsewhere.

The first two axes of the DCA accounted for c. 75% of the variance, with axis 1 again significantly correlated with stand age ($y = -1.8871 + .057441 * x$; $r = .7912$; $df = 7$; $P < .02$. y = axis 1 loading, x = stand age in years). The first axis of the species ordination (Fig. 4c) separates species typically colonising open sites (eg. *Pteridium esculentum, Paesia scaberula*) from those more characteristic of moist forest interiors (e.g. filmy ferns, *Asplenium bulbiferum*). The larger abundant ground ferns and tree ferns occupy the central region of the ordination space, reflecting their overall abundance throughout the chronosequence.

Table 4: *Ground fern abundance. Numbers in the body of the table are a relative abundance index with a maximum possible value of 108 for any species in any stand (see text). (1)The following species were recorded in one plot only, and have not been included on the table, except in the totals:* Blechnum filiforme, Hymenophyllum demissum, H. dilatatum, H. scabrum, Lastreopsis glabella, Pteris tremulans, Tmesipteris elongatum, Trichomanes venosum, *Unidentified b.* Blechnum *spp. was misrecorded, its true identity is unknown.* Dryopteris affinis *is adventive. (2) Similarity defined as 2w / (a + b), where w is the sum of the lowest values for species in common to both stands, and a and b are the respective stand totals.*

	Sites										
	4	5	9	3	6	8	2	7	1	Overall frequency	%
Site age (yr)	6	11	20	24	29	32	35	40/67	67		
Species (1)											
Dicksonia squarrosa	16	66	60	72	65	72	96	66	90	603	20.3
Blechnum 'capense'		24	50	60	78	102	84	40	90	528	17.7
Paesia scaberula	4	4	90	9	96		60	40	1	304	10.2
Pteridium esculentum	72	28	96	20	30		16	20	9	291	9.8
Asplenium polyodon	2		6	42	25	16	9	66	30	196	6.6
Histiopteris incisa			66	16	78	1	4	1		166	5.6
Pneumatopteris pennigera		4	4	1	30	78	4	1	28	150	5.0
Dicksonia fibrosa		16	30	16	40	12	4	12	4	134	4.5
Cyathea dealbata		9	4	4	4	1	2	15	60	99	3.3
Asplenium flaccidum				30	1	12		25	25	93	3.1
Phymatosorus diversifolius				50	28	1		1	9	89	3.0
Polystichum vestitum		24	16	4	4	12	20		1	81	2.7
Cyathea medullaris									50	50	1.7
Hypolepis ambigua		1	6	4	35		1			47	1.6
Cyathea cunninghamii		20			1					21	0.7
Blechnum fluviatile					4	16				20	0.7
Asplenium bulbiferum subsp. *gracillimum*		1			1	16				18	0.6
Blechnum chambersii			1	9	2	1			1	14	0.5
Cyathea smithii						1		1	12	14	0.5
Hymenophyllum flabellatum							1		9	10	0.3
Hymenophyllum multifidum									9	9	0.3
Hymenophyllum rarum				4		1			1	6	0.2
Blechnum spp.				4						4	0.1
Hymenophyllum sanguinolentum									4	4	0.1
Unidentified a				4						4	0.1
Blechnum discolor		1			1	1				3	0.1
Dryopteris affinis	1	1			1					3	0.1
Rumohra adiantiformis				1		1			1	3	0.1
Asplenium oblongifolium								1	1	2	0.1
Total abundance index	95	201	429	350	524	344	301	289	437	2970	100
Number of species	5	15	12	21	19	17	12	13	22	36	
Similarity with next older stand (2)	.33	.50	.49	.58	.50	.58	.61	.53			

Tree ferns

Tree ferns were prominent in the older stands, with densities of 2000 - 2500 ha.$^{-1}$ and basal areas of 10 - 30 m^{2}.ha^{-1}. *Dicksonia squarrosa* was the numerical dominant, comprising 84% of all tree ferns (including seedlings) within the sample plots. The other species were ranked as follows: *Dicksonia fibrosa* (7%), *Cyathea dealbata* (4%), *C. medullaris* (3%) and *C. smithii* (2%). Total tree fern basal area and height sum per hectare are highly positively correlated (Fig. 5; Table 5), and both increased rapidly from 20 - 40 years, and thereafter more slowly. Tree fern stem volume is the product of these measures, but is also influenced by species composition, the thick trunks of *D. fibrosa* contributing relatively more than the thin trunks of *D. squarrosa*. The high volume of the oldest stand, where the adult and juvenile tree fern population density is less than in some younger stands, is mainly a consequence of the presence of tall tree ferns, especially *C. medullaris* and *C. smithii.*

Seedlings and juveniles of *Dicksonia squarrosa* were present in the youngest stand (6 years). The juveniles were probably derived vegetatively from trunks not killed by the logging and silvicultural treatments, but the seedlings were probably mostly derived from gametophytes. By eleven years (stand 5) seedlings of *Cyathea dealbata* and *Dicksonia fibrosa* were also present. Seedlings of *Cyathea smithii* and *C. medullaris* were not recorded until 20 years, although by this time juveniles (and even adults of *C. medullaris*) were also present, suggesting that these species also established quite early in the second decade of colonisation. Adults of all five species were present by 29 years (stand 6). *C. medullaris* had no seedlings in the older stands, was totally absent from some stands and usually formed patches, suggesting that conditions for its establishment are less frequent in space and time than is the case for the other species.

Although all species of tree ferns were present from 20 years onwards, their population structures and relative proportions changed. Initially the tree

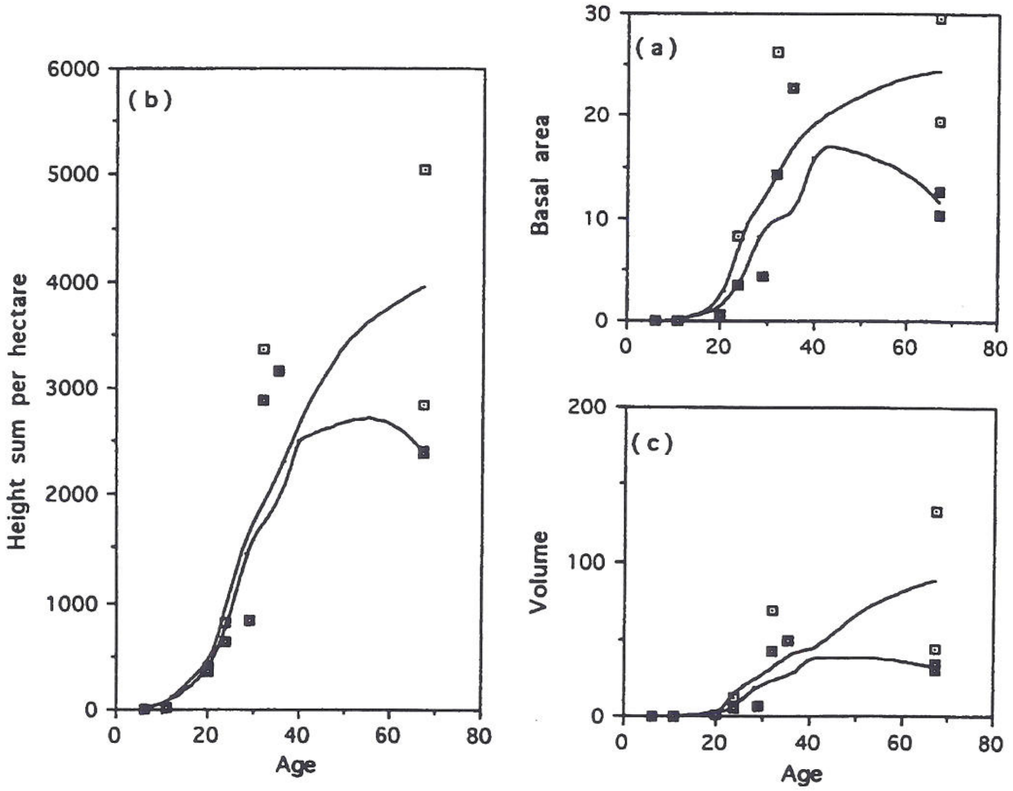

Figure 5: *Trends in (a) tree fern basal area (m^{2}ha^{-1}), (b) height sum (m ha^{-1}), and (c) volume (m^{3}ha^{-1}), with stand age. Trend lines obtained by smoothing: y (smoothed) = ((2y) + Si) / (2 + j), where Si represents the addition of the j values for stands within 10 years of y. Filled squares,* Dicksonia squarrosa*; open squares, all tree fern species combined.*

Table 5: *Tree fern abundance, height and basal area.*

		Sites								
		4	5	9	3	6	8	2	7	1
Site age (yr)		6	11	20	24	29	32	35	40/67	67
Species[1]										
C. dealbata	No.[2]	-	s	+	60	20	80	20	110	170
	Height[3]	-	*0*	*1.3*	*1.4*	*1.1*	*2.3*	*0.2*	*3.7*	*2.6*
C. medullaris	No.	-	-	+	-	20	-	-	40	380
	Height	-	-	*1.9*	-	*4.1*	-	-	*5.4*	*9.2*
C. smithii	No.	-	-	+	s	s +	100	-	s +	90
	Height	-	-	*0.2*	*0*	*1.9*	*2.6*	-	*5.3*	*8.2*
D. fibrosa	No.	-	s	100	140	320	100	40	80	30
	Height	-	*0*	*0.8*	*2.5*	*1.4*	*2.6*	*0.8*	*4.7*	*2.8*
D. squarrosa	No.	20	100	880	640	700	1720	2040	1980	940
	Height	*0.2*	*0.8*	*1.8*	*2.9*	*2.8*	*5.2*	*4.3*	*5.1*	*7.8*
Total adult + juvenile. ha^{-1}		20	100	980	840	1060	2000	2100	2210	1610
Total including seedlings.		140	1610	1780	2420	1800	2340	2280	2680	1980
Basal area, $m^2.ha^{-1}$		0	0	0.7	8.2	4.3	26.3	22.7	19.5	29.5
Height sum, $m.ha^{-1}$		2	28	394	821	836	3358	3161	2848	5054
Volume, $m^3 \cdot ha^{-1}$		0	0	1	12.8	6.7	68.6	49.8	44.5	132.2

[1] C. = *Cyathea*, D. = *Dicksonia*.

[2] Number of stems (juvenile + adult) – ha^{-1}; s: 'seedlings' only present; + indicates present in the stand, but not in the enumerated area.

[3] Trunk height (m) to base of lowest fronds of tallest individual measured in the sample area or in the stand.

fern population was strongly dominated by the two *Dicksonia* species, especially *D. squarrosa*. However, *Cyathea* species were gradually added, and this genus (mainly *C. medullaris*) comprised c. 40% of the juvenile and adult tree ferns in the 67 year stand. Consequently *Dicksonia squarrosa*, although dominant throughout, showed a relative decline in the oldest stands, where *Cyathea medullaris* and *C. smithii* were generally taller than *D. squarrosa* . The shift from a mainly seedling to an adult dominated population stucture is illustrated in Fig. 6.

Ordination of the tree fern data (with each species represented as four categories: seedling, juvenile, adult and dead) accounted for 61% of the variance on axes one and two, with the former again highly correlated with pine age ($r = 0.8187$; $df = 7$; $P < .01$). The species ordination (Fig. 7) shows the change in population structure from right to left across the ordination, coinciding with the changes in composition of the shrub and ground fern understorey illustrated in Fig. 4b and 4c respectively. The separation of the *Cyathea* spp. (especially adult and dead *C. medullaris*) on the second axis could imply that these species are spatially segregated from the *Dicksonia* spp.

The different tree fern species appear to have different height growth rates and maximum sizes (Table 5). This aspect of the results will be presented in more detail in a later paper; here we note that maximum heights and growth rates appear to decline in the following sequence: *C. medullaris* > *C. smithii* > *D. squarrosa* > *D. fibrosa* > *C. dealbata*. Assuming that they began trunk growth at a pine stand age of 15 years, the *maximum* height growth rate of *C. medullaris* (fastest) and *C. dealbata* (slowest) was about 18 cm. yr^{-1} and 5 cm.yr-1 respectively.

Discussion

Biodiversity is often considered to be an indicator of ecosystem health, stability, and resilience (O'Connor *et al.* 1990), which increases with successional age (Odum 1969). However, ecosystem disturbance, creating new niches for establishment, can also lead to increased biodiversity (Connell 1978). Felling of forest and the planting of a new tree crop is a disturbance which allows the invasion of herbaceous plants and shrubs and can thus locally increase plant diversity. In New Zealand, however, many such invasive plants are adventive, so that the increased species richness may have negative implications for the conservation of the indigenous biota.

Native communities are variously assembled beneath pines through time according to substrate, aspect, topography, distance from seed sources and so on. Allen *et al.* (1995a) ordinated data from plots within three differently aged *Pinus radiata* compartments in Kinleith Forest. In agreement with

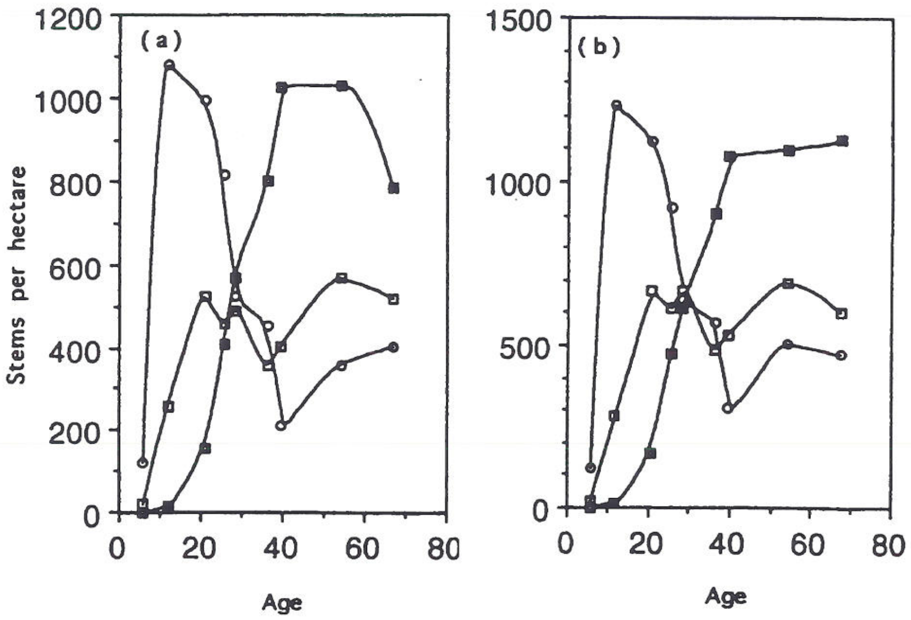

Figure 6: *Changes in population structure of tree ferns with stand age. (a)* Dicksonia squarrosa. *(b) All tree ferns combined. Smoothed as in Figure 5. Open circles, seedlings; open squares, tree ferns < 1m trunk height; filled squares, tree ferns > 1m trunk height.*

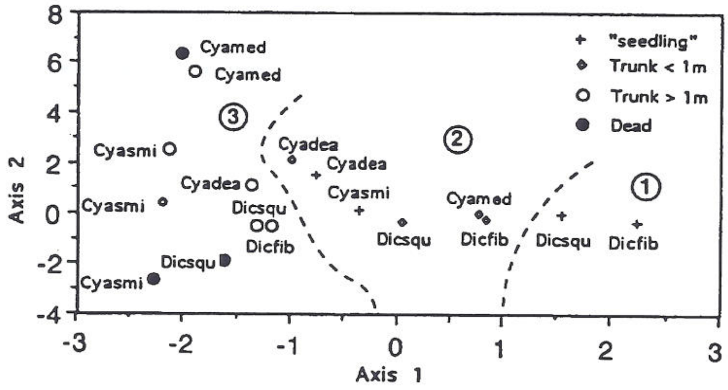

Figure 7: *DCA species ordination for tree fern population data. Abbreviated names are first three letters of generic and specific names. Numbers divide the ordination space into three areas of increasing tree fern and stand age, as in Figure 4b and c.*

earlier studies in the same area by McQueen (1961, 1993), their results indicate the importance of topography, soil nutrients and moisture status in the determination of the invasive vegetation pattern. Because only three stand ages (1, 13 and 29 years) were included in their study the significance of the age trend cannot be assessed with confidence. Likewise, in the current study, because the differently aged plots were not replicated on different substrates or topographies, the relative importance of these variables cannot be compared with that of age. However, the results agree with the earlier work in that they indicate that site characteristics such as aspect and microtopography are important in determining total plant diversity. For example, site 1 was the oldest stand studied, but it was also south facing and relatively moist. These environmental variables could explain the higher abundance and diversity of filmy ferns (*Hymenophyllum* spp.) in this site. In contrast, the equally old but mainly north facing Site 7 was noticeably drier, and had a much lower adundance and diversity of ground ferns. Site 3 (aged 24 years) had unexpectedly high shrub and fern diversity. Large boulders in this site created more microtopographical variation than the other stands, with well-lit raised microsites allowing the establishment of wind-dispersed light-demanding species such as *Weinmannia racemosa* and *Kunzea ericoides,* and damp niches favoring the establishment of ferns. These stands indicate that the gradual temporal trends in species recruitment into pine plantations are strongly influenced by site factors other than the age of the pine overstorey.

While the importance of topographic and associated variables is acknowledged, the first axes of the shrub and fern ordinations summarise shifts in composition which are significantly correlated with the age of the pines, indicating that, directly or indirectly, this is an important influence on the species composition of the understorey. The relative proportions of different tree fern species and their population structures and total biomass likewise show a strong relationship with stand age. These results suggest that stand age is the primary control on species richness, with secondary gradients associated with topography and soil type.

Allen *et al.* (1995a) pointed out that invasive adventives often have r-selected traits (*sensu* Grime 1979), and that competitive sorting through time should increase the proportion of longer-lived and shade tolerant native species, and also increase compositional predictability. These two temporal trends can be discerned in the species richness results: an initial invasion of adventives, followed by their reduction and a gradual accretion of native species.

Following site clearance, preparation and planting with pines, the initial invasion phase is dominated by adventive weeds. In addition to the woody species recorded here there are herbaceous species such as *Holcus lanatus, Lotus pedunculatus, Conyza albida, Circium arvense, Senecio* spp., and *Sonchus asper.* Adventive shrubs and herbs had almost disappeared in stands 20 - 30 years of age, by which time the modal pine diameter class was 40-50cm and stand height was in the range 25 - 45m. Some native shrubs, especially *Coprosma robusta, Pittosporum tenuifolium, Fuchsia excorticata,* and *Aristotelia serrata* are also capable of early invasion. These species may be brought in by birds, but it seems likely that germination from buried dormant seeds also occurs . Likewise, the early arrival of the robust native ferns *Dicksonia squarrosa, Pteridium esculentum* and *Paesia scaberula* could be from resprouting rhizomes. Unlike the adventives, these early arriving native species generally maintain a presence in older stands.

The second temporal trend was the gradual acquisition of native species as the pines age. Seral native broadleaved species, and more shade-tolerant gap-colonists, become more frequent as the adventive species decline, and are commonest in sites aged from c. 30 to 40 years. Older stands have relatively high shrub and fern richness, a varied tree size structure, abundant tree ferns of several species, and canopy heights and total basal areas comparable to those in native podocarp and kauri forests (Lusk & Ogden 1992; Ahmed & Ogden 1991). Ferns comprise 50 - 70% of all vascular plant species in these stands. Ferns, and probably bryophytes and lichens also, become more important as components of overall species richness with time.

Although management practices to conserve native biodiversity were not included in the aims of this study, the results have implications for them. The New Zealand Government and the forest industry recognised their obligation to conserve indigenous species richness by signing the Convention for Biological Diversity and the New Zealand Forest Accord respectively. Plantation forestry involves the development of a crop and an associated assemblage of adventive and native species which increases in indigenous diversity through time. The latter, however, is largely eliminated when the crop is harvested and the site sprayed with a plant dessicant before re-planting. The level of indigenous plant species richness in planted areas is thus largely a question of the proportion of the landscape maintained as older pine stands or left in indigenous cover. Unless the industry has a conservation policy recognising the significance of older pine stands and/or maintaining pockets of native forest within the managed area, overall native biodiversity becomes largely a function of mean rotation time. Shorter rotations imply a reduction in native plant richness (and its associated fauna) and an increase in the proportion of the landscape in the early stages of succession, dominated by young tree crops and adventive species.

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5 TREES FOR ENERGY, LAND TREATMENT OF EFFLUENT, CARBON SEQUESTRATION AND LANDSCAPING

5.1 Energy and land treatment

Trees are efficient collectors of solar energy. During the photosynthesis process it is converted into chemical energy and stored as ligno-cellulose, i.e. wood: or as it is commonly called when talking of Renewable Energy supplies – Biomass.

Since man first invented fire it has been well understood that the process of burning wood converts the energy into heat useful for cooking and keeping warm. Many homes in New Zealand use firewood as a heating source mainly from sawmill slab. Also several forest processing plants use wood residues for producing steam and even generating electricity. In the USA more electricity is generated from biomass than the total electricity demand of New Zealand.

Recently there has been a revived interest in growing trees specifically for use as an energy source. These could be in a short rotation plantation where traditional forest species are close planted (2000-3000/ha) then clear-felled after 7-10 years. Replanting is then necessary which is costly. An alternative silviculture regime being given considerable study in many countries such as Sweden, UK, USA, Canada, and New Zealand is **coppicing**, (from the French word couper – to cut).

Selected species of trees, mainly hardwoods such as willows, poplars, and eucalypts are close planted into cultivated land at around 5000 trees/ha (2 m rows x 1 m spacing). Establishment is more akin to a horticulture crop than a forestry crop. To assist the cash flow of the investor, the trees are cut at 3-4 years of age when the whole tree is available for fuelwood purposes.

Several weeks after harvest new shoots appear on the cut stump. Three or four shoots become dominant and the tree is ready for harvesting again some 3-4 years later. How many coppice rotations are possible is not fully understood and it varies with the coppicing vigour of the species. In a trial at the Aokautere Research Centre, near Massey, of 23 species of Eucalyptus harvested 4 times over a 12 year period, some died out after the first harvest, others produced more biomass yield (in terms of dry matter/ha/year) at each harvest. No weed control, irrigation or fertiliser was applied, since for crops used for energy, which is relatively low value compared with food and fibre crops, such expensive inputs are not warranted.

Of course by continually harvesting such crops, which yield up to 120-150 tonnes of biomass/hectare at each harvest, the site is being depleted of nutrients. In years to come it may be that all the P, K and trace elements can be recycled by returning the wood ash from combustion to the soil. During efficient combustion the ligno-cellulose is converted to the two major end products CO_2 and H_2O which of course are easily recycled during natural growth. A small amount of NO_x(a range of nitrogen based oxides) are also produced and lost as emissions so nitrogen will need to be replaced in the field unless leguminous tree crops are grown, or molecular engineering creates nitrogen-fixing Eucalypts.

Meanwhile, until such research is undertaken, growing energy tree crops can be criticised as being an unsustainable system.

Another characteristic of short rotation tree crops is their ability to uptake relatively large volumes of water. In fact in Portugal, growers of Eucalyptus trees for pulpwood occasionally have their crops destroyed by landowners lower down the catchment who were concerned there would be insufficient water left for their crops and animals. But it is this characteristic that makes Eucalyptus a suitable crop for the land treatment of wastewater.

Effluent from city sewage treatment plants, wool scours, meatworks and dairy farms are all prone to polluting nearby waterways and groundwater using traditional disposal methods. Under the Resource Management Act of 1991 this may result in heavy fines. An alternative method is to apply the effluent to fast growing short rotation plantations. The trees transpire large volumes of water, especially in the summer season (up to 8 mm/day) and also take up a proportion of the nutrients contained in the effluent – even polluting heavy metals such as cadmium, zinc and nickel present in some industrial effluents. The exact role of the tree in such a land treatment system is not clear and the process is undergoing extensive research both at Massey and elsewhere.

Combining the production of biomass with the land treatment of effluent has exciting possibilities. For example the treated effluent from Palmerston North sewage plant could be pumped and applied to a nearby coppice plantation instead of polluting the Manawatu River. The trees would be harvested, processed, and combusted. The steam produced would drive a turbine to produce electricity which is then fed back to the city ratepayers. At Richmond meatworks, Oringi, the 100 ha of trees could be used to replace coal in their boiler (see papers following). On a smaller scale a dairy farmer could harvest the trees grown near to the dairy shed and either sell the wood for firewood; use it to heat the cleaning water for the milking plant, or perhaps produce electricity for use on the farm and/or sale to the national grid.

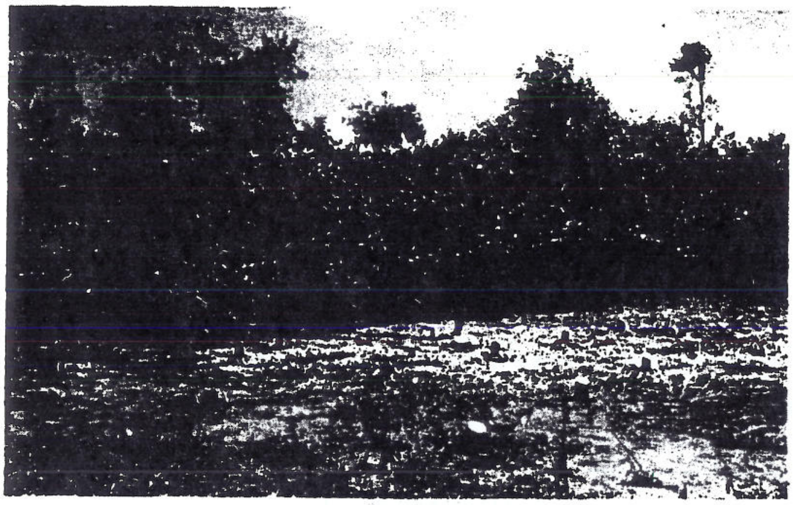
However at this time the use of biomass as a fuel (biofuel) is uneconomic. Unless energy prices increase in price dramatically biofuel will not be able to compete with traditional sources of energy such as oil, gas and coal. The introduction of a carbon tax would help improve the competitiveness of biofuel but unless the tax is very large is unlikely to result in a large increase in the use of biofuels.

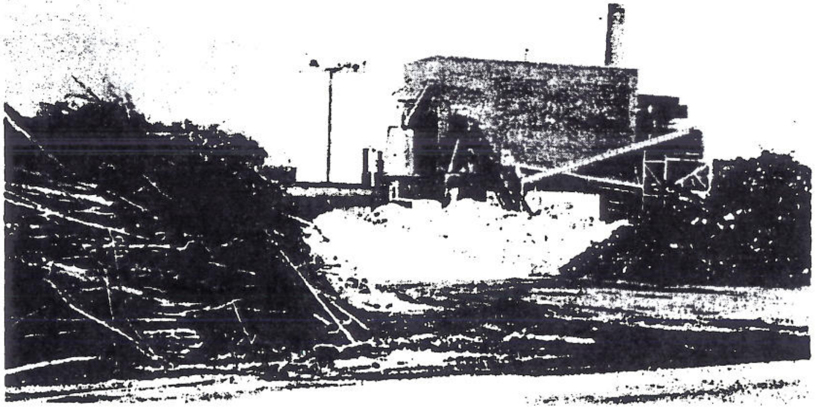
The recovery of waste wood from forest skid sites probably offers the best opportunity for utilising biofuels. Currently waste wood is just bulldozed into piles and left to rot. Given the scale of the forest industry in N.Z. there is potentially a huge resource available. However even as waste its use is not economic. Simply transporting and processing prior to use means that the energy is this wood is more expensive than that from fossil fuels or electricity.

The following papers outline the issues surrounding the use of biofuels from short rotation energy plantations and recovery of waste wood from *P. radiata* plantations. They were presented at a workshop on 'Renewable Energy from Biomass' held at Massey University 21-22 May, 1991.

WOOD FUEL SUPPLY AND UTILISATION FROM SHORT ROTATION ENERGY PLANTATIONS

MINISTRY OF ENERGY CONTRACT 881 MAY 1990





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EXECUTIVE SUMMARY

WOOD FUEL

1 Wood, regardless of species and form, is a useful fuel containing 18-21 MJ/kg of oven dry material. Basic density varies with tree species; bulk density varies with piece size and form; and calorific value varies with moisture content. Thus for an industrial fuel, air-dried hardwood in the form of logs is preferred, though comminution into more easily handled chips or chunks is the usual practice. Drying rates and combustion properties are also improved with smaller piece size.

2 Wood fuel recovery of forest residues remaining after logging is limited due to access, depletion of soil nutrients and cost. Integrated harvesting of whole trees or sections may be a future option on fertile sites. Highly mechanised energy plantations may be feasible depending on comparative returns from competing land based enterprises. Wood processing residues are largely utilised already either for fuelwood or export pulp chips. Wood residues from agricultural/horticultural operations are generated only in small volumes leading to high recovery costs.

3 This report concentrates on the thermo-conversion of wood via direct combustion, a process which is well understood. Many examples of small and large wood-fired boilers are in use in New Zealand and overseas. Design changes are continually being developed to improve combustion efficiency, fuel handling systems, or stack emissions (which can be adequately controlled though often they are not). Ash removal is a lesser problem with wood than coal. Dual combustion of both these solid fuels is feasible and may have certain benefits.

4 The handling, transport and storage of fuelwood should be designed as an integral system if it is to be cost effective. Well designed methods of storage are necessary to achieve the desired maximum fuel moisture content but with minimal decomposition of the fuel. Factors relating to the relatively low energy density of fuelwood, compared with other fuels, causes considerable concern by potential users.

5 Traditional supplies of fuelwood arising from land clearing, forest residues, sawmill residues, timber processing residues, scavenging, and orchard prunings are expected to decline in the future due to competing uses and diminishing supplies. However the 20% of wood processing residues currently dumped or burnt to waste due to lack of local demand could be utilised. Additional demands would have to be met from improved forest residue recovery or energy plantations.

6 The annual demand for domestic firewood (approximately 7 PJ) is increasing in order to supply the total number of wood burning stoves recently installed. The small proportion of industrial heat demand supplied annually from fuelwood (approximately 7-10 PJ) has, if anything, declined in recent years due to competition from other fuels, inconvenience and insecurity of supply. The concept of a utility company supplying heat under contract to an organisation which no longer has the chore of operating a boiler is worth exploring.

MARKET ASSESSMENT OF DEMAND

7 All organisations within "selected" industries judged to be more likely to be interested in fuelwood were surveyed by telephone. A random sample of 515 "other " industry boiler users were mailed a screening questionnaire of which 46% provided useful returns.

8 40% of "selected" and 28% of "other" industries expressed a general interest in using wood as a fuel with a greater interest shown by South Island respondents. Meatworks, hospitals, tanneries, woolscourers, dairy factories, breweries, farms and tobacco growers were the types of industry most interested.

9 Coal, lpg or oil users were more interested in the potential of using fuelwood than were diesel, gas or electricity users who valued convenience and (with the exception of gas users) tended to run smaller boilers. The age of boiler plant had little effect on the interest of respondents.

10 Organisations with total boiler capacities of 5-20 MW were more interested in fuelwood use. Those with smaller boilers valued the convenience of other fuels and those with larger boilers envisaged technical difficulties with storing and handling large quantities of fuel (but were perhaps unaware of some of the latest systems being successfully employed at this scale).

11 The major perceived limitations to using fuelwood were: storage and handling; additional labour; security of supply; control of stack emissions; boiler problems after conversion; suitability of present boilers; loss of convenience; and insufficient heat output after conversion of existing boilers.

12 The survey indicated a potential national industrial demand (in addition to current demand) for 17.4 PJ/annum of energy derived from fuelwood, assuming all organisations expressing an interest were to actually convert. If air-dry wood (calorific value 14.7 MJ/kg) was burnt in wood-fired boilers which averaged only 70% efficiency, this energy demand could be met from 1.3 million tonnes of air dry fuelwood produced annually. A sustainable supply of this quantity could be produced from around 55000 ha of land assuming recoverable biomass yields of 20 oven dry tonnes (ODt)/ha/year were achievable on a large scale. This area is equivalent to 4-5% of that currently planted in exotic forest.

COMPETITIVE PRICES

13 To establish the market price with which fuelwood must compete in order to offer a viable alternative source of energy, fuel prices, capital investment costs and any additional boiler running costs must all be evaluated. Attempts were made to obtain reliable information concerning the capital and running costs of wood-fired boilers but insufficient data was available to make accurate assessments.

ENVIRONMENTAL AND SOCIAL ISSUES

14 Public concerns relating to nuclear power, fossil fuel emissions, acid rain and climate change have led to renewed interest in renewable energy opportunities. Coupled with the need to reduce unemployment the use of wood as an alternative energy source replacing fossil fuels has some merit. Substituting a "Greenhouse aggravating" fuel (e.g. oil/coal) with a "Greenhouse mitigating" fuel (e.g. wood, as long as the trees regrow or are replaced), would provide more time to assess how serious climate change effects are likely to be.

SUPPLY

15 Forest harvesting residues, if recovered economically from areas with reasonably fertile soils, could supply over ½ million ODt of fuelwood, rising to over 1 million ODt after the year 2006 as harvested areas increase. In addition, available but currently unused wood processing residues could provide almost 200,000 ODt which could be doubled by the year 2006.

16 Woodfuel can be supplied from specialist energy plantations based on either traditional forestry, short-rotation forests or coppice plantations. Short rotation intensively cultivated systems (SRIC) have merit but there is concern over soil nutrient depletion on some sites if the total biomass including leaf and branch is continually removed - unless nutrient stripping is an added objective as discussed below.

17 As a guideline approximately 0.014 ha of land is required to give sufficient sustained yield of fuelwood to provide 1 MWh of average actual boiler output (assumed to be 60% of rated output).

18 Harvesting equipment suitable for a range of tree types, sizes and growing conditions occurring in SRIC energy plantations has been developed to the prototype stage. Harvesting costs are likely to remain a significant proportion of the total fuelwood production costs and further research development and demonstration is required before an economic and reliable harvesting system suitable for a wide range of tree sizes and shapes can be commercialised. Harvesting must be integrated with drying, handling, transport and processing of large volumes of biomass material to give the cheapest overall cost of delivered fuelwood.

PULPWOOD AND FUELWOOD

19 Hardwood pulp chip production from indigenous forests is likely to be constrained in the near future. SRIC plantations could be developed to provide an alternative pulpwood resource together with fuelwood. Over 10,000 ha would need to be planted to sustain a pulpwood yield equivalent to the current level of hardwood chip exports. Compared with traditional forest plantations, SRIC forests would provide a resource in the short term, leading to a more rapid return on investment, particularly if increased growth rates could also be achieved.

20 The pulp and papermaking characteristics of young hardwood trees such as Eucalyptus have been shown to be good for fine paper production. The bark may not have to be removed. If small scale pulp plants (say 250 t pulp per day) based on modified environmentally improved technology can be shown to be feasible, the prospects of pulpwood and fuelwood production from SRIC plantations are good.

EFFLUENT DISPOSAL

21 Land disposal of industrial effluent and sewage is well understood. Using forests, particularly SRIC systems, for stripping nutrients is showing promise resulting in improved tree growth rates. However the build up of trace elements in the soil over time must be carefully monitored. The combination of the disposal of effluent over land planted with trees and the utilisation of the biomass produced as an energy source merits further investigation. In particular work is required to determine yields and renovation rates after several years application.

22 Over 3/4 of industries surveyed produced effluent with almost 50% of the "selected" industry group producing more than 1000 m^3/day. Discharge into sewer systems was the common method of disposal for 63% of organisations surveyed. Discharge to rivers, lakes or sea was practiced by 20% of those industries producing effluent whilst 18% of "selected" and 4% of the "other" industries used land disposal.

23 Three quarters of industries discharging into sewers were often urban based, had little or no land area available and tended to have no interest in fuelwood. Conversely a large proportion of those discharging effluent into surface water had reasonable areas of land available (often in excess of 100 ha), and were more interested in possibly using fuelwood. The few respondents already using a land disposal system mostly owned or leased land and were interested in the concept of fuelwood production.

24 There is opportunity for local authorities to undertake effluent/sewage land disposal projects. Users would be charged for disposal and a return would be received from the trees produced, either for pulp or fuel or both. It is feasible that discharge to surface water will soon no longer be permissible and that land disposal will become the most suitable and economic alternative. Research, development and demonstration projects should be encouraged, and those already being monitored assessed to see whether fuelwood produced could be used on-site.

ECONOMIC FEASIBILITY

25 A computer model was developed to ascertain the economic potential for short rotation fuelwood and fuelwood/pulpwood production from biomass coppice plantations. It used the following base assumptions of costs, crop maintenance requirements, yield and revenue in a discounted cash flow analysis.

Site preparation costs	$200/ha
Tree seedling	$0.60/tree
Tree planting	$0.10/tree
Fertiliser application	$250/ha - once in every 3 years
Herbicide spraying	$220/ha - once in every 3 years
Pest and disease control	$130/ha - once in every 3 years
Average maintenance costs	$200/ha/year
Harvesting costs	$31/ODt for 5 year rotation or less using specialised biomass harvester $63/ODt for 8 year rotation
Transport costs	$0.35/ODt/km
MAI	20 t/ha/year above ground dry matter
Fuelwood price	$50/ODt delivered
Chip price on wharf	$150/ODt

26 For the base assumptions, fuelwood production using each of three silvicultural regimes considered (5000 stems/ha, 3 year rotation; 4000 stems/ha, 4 year rotation; 2500 stems/ha, 8 year rotation) was not profitable at a 7% discount rate. A fuelwood price of at least $72/ODt delivered would be required to give the grower a 7% real return on investment whereas $50/ODt was considered the maximum price affordable if fuelwood was to compete with current coal prices and if the capital investment costs and additional running costs were included.

27 The need for low cost, harvesting/processing systems was highlighted by the model. Harvesting costs below $16/ODt were required to provide a 7% return on even the best silvicultural regime using the base assumptions. Increased yields would improve the return but the calculated breakeven mean annual increments (MAI) of 3-4 times the 20 ODt/ha/year achieved at present would be unrealistic.

28 Establishing short rotation plantations purely to supply biomass for industrial fuelwood is not economically viable unless significant reductions in inputs (particularly harvesting/processing) and/or increases in yield and fuelwood price can be obtained compared with the base assumptions used. Where land disposal of effluent through irrigation of fuelwood plantations is economically and environmentally sound, the value of the fuelwood as a means of offsetting the cost of disposal could make it a viable venture.

29 Combining pulpwood production with fuelwood production is a more profitable option due to the higher value of the pulpwood component. Internal rates of return of 12-19% were obtained for all three silviculture regimes assuming pulpwood fetched $150/ODt and fuelwood $50/ODt. A 7% return could still be realised if the pulpwood price fell to $80/ODt or if the pulpwood price remained at $150/ODt and no fuelwood was sold. The 4000 stems/ha, four year rotation regime was the most profitable of the three studied though the harvesting/processing costs for this option may have been underestimated due to insufficient data.

30 Breakeven harvesting costs where fuelwood and pulwood were produced were higher than the base assumptions of $31 or $63/ODt. Since these estimates were based on little factual data it was encouraging to note that if harvesting/processing operations proved to be more expensive following further technological research and development, the co-production of pulpwood and fuelwood would remain a viable proposition. Similarly crop yields could fall to 50-75% of the assumed MAI and still provide a 7% return.

31 Pulpwood production from short rotation plantations could remain profitable even if there was no available market for fuelwood residues. (A comparison with pulpwood production using traditional forest management regimes with 20 or more year rotations was not made). Production of fuelwood as a joint product with pulpwood was a more attractive option than producing fuelwood alone.

32 Sensitivity analyses of one fuelwood option (worst case) and one pulpwood/fuelwood option (best case) showed MAI, harvesting costs, and seedling costs had the largest effect on equivalent annual annuities ($/ha). Site preparation costs, transport distance and maintenance costs had lesser effects.

CASE STUDIES

33 Sixteen organisations selected from the screening survey as showing potential for fuelwood use and which provided a range of industry type, size and location, were visited and a more detailed questionnaire was conducted on site. A simple economic model was developed to analyse the data and determine such site specific factors as fuelwood volumes required, conversion and running cost estimates, and simple payback periods for a range of fuelwood prices. The estimates of capital investment for conversion to fuelwood and the extra running costs involved to operate the plant were based on a survey of wood-fired boiler manufacturers and users. Nevertheless the data was limited and can not be treated with confidence. Current effluent production and disposal methods were discussed along with land availability to assess if irrigation of a fuelwood plantation would be a feasible proposition.

34 For each case study a practical conversion strategy to fuelwood was developed and the annual fuelwood demand calculated. Storage, handling and transport arrangements were considered. Converting current oil and gas users to fuelwood would involve constructing storage and handling facilities. Coal users already have such facilities but modifications would generally be required. Deliveries of fuelwood did not appear to be a major problem except for large urban-based organisations with limited access for large trucks.

35 The land area requirements to supply the total fuelwood demand to the sixteen case studies ranged from 9 to 474 ha. Of the sixteen sites examined four had sufficient land area available to supply their total energy demand from "home-grown" fuelwood. The land area required to treat any effluent generated (assuming an irrigation rate

of 20 mm/week) was considerably less than that needed to supply total fuelwood demand for eleven sites but around 30% more for two sites, (with two sites not producing effluent and one producing unknown quantities). There appeared considerable scope for several of the case study organisations to employ fuelwood plantation/effluent treatment systems.

36 Organisations which could achieve an acceptable payback following conversion to fuelwood tended to have a high boiler utilisation and hence high fuel use. They also paid a relatively high fuel price due to their location. Present coal users (excluding lignite) generally obtained better paybacks than current gas or oil users with the surprising exception of one large suburban based gas user which provided the lowest payback period of all. If fuelwood was delivered to this site for $50/ODt and the estimated additional annual running costs of $125,000 could be achieved, a payback of 3.2 years would result on an estimated $1.2 million capital investment. Five other case studies achieved a payback of less than ten years using similar base assumptions.

37 A sensitivity analysis conducted on two of the case studies showed:

- a 30% increase in fuelwood volume and hence land area would be required if wood was burnt green rather than air dry;
- using fuelwood with higher moisture contents would increase the payback period proportionately;
- an increase in the current fuel price would significantly reduce the payback period;
- a 5% improvement in boiler efficiency would reduce fuelwood volume demand by 6-8% thus reducing the payback period;
- the additional running costs of a wood-fired boiler can have a major effect on payback periods.

FUTURE RESEARCH

39 The concept of a utility company to supply heat and power to a number of industrial users is worthy of exploration. It could use waste material, harvested biomass and other fuels to supply heat; could produce fuelwood on local plantations; and sell effluent treatment services using irrigated land disposal. It would thus control the entire fuelwood energy supply system.

40 A number of issues raised in the report will require further research if fuelwood production is to become a viable proposition. In particular species selection; optimising MAI; evaluating harvesting/handling/storage systems; developing improved combustion systems for wood of high moisture content; production of pulpwood from SRIC plantations; land disposal of effluent on to forest plantations should be studied as part of a major research programme.

Liaison with international research organisations working on biofuels should continue and be further encouraged as environmental benefits from using such fuels are apparent.

> "IN PARTICULAR IT IS NECESSARY THAT NEW ZEALAND REMAIN WELL INFORMED OF TECHNOLOGY DEVELOPMENTS OVERSEAS IN RENEWABABLE ENERGY AND, ALSO MAINTAINS DOMESTIC "RENEWABLES" RESEARCH AND DEVELOPMENT, PARTICULARLY IN AREAS WHERE THERE IS ALREADY A BODY OF KNOWLEDGE".

"Responding to Climate Change".
A discussion of options for New Zealand.
New Zealand Climate Change programme.
Ministry for the Environment, May 1990.
Page 51.

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RECOVERY OF WOOD FOR COMMERCIAL ENERGY PRODUCTION

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BACKGROUND

Over the last 60 years, New Zealand has been developing extensive plantation forests of predominately radiata pine which now total about 1.25 million hectares. These forests are scattered unevenly throughout the country. Conventional forestry practice is aimed at supplying solid and reconstituted product markets. However normal recovery for these products only takes about 80-85% of the total above-ground woody biomass, thus a considerable volume is currently left in the forest unutilised.

The opportunity exists to collect this unutilised material for use as an energy fuel, however its recovery presents special problems which must be overcome before it can be achieved economically.

ENERGYWOOD LOCATION

Energywood values cannot usually compete with other wood raw material product values, such as sawn timber and wood pulp. The energy market must therefore take what the other markets do not want. This residue material which is to be available for an energy product is physically arranged about the harvesting site in different ways.

1. Scattered over the cutover. The remnants of typical motor-manual harvesting operations are from breakage and shattering occurring from felling impacts, and from stem trimming being undertaken on the cutover. Measurements by FRI Harvesting staff have shown that typically 60 to 70 OD tonnes per hectare are left on the cutover. Much of this volume (50-70%) consists of small material, mainly branches, twigs, needles and cones.

2. Accumulated at the road edge or landing. Normal harvesting practice in New Zealand is to extract the stem to a convenient location and there undertake final product allocation. The remaining branches are removed and the various log grades manufactured. Residue material from the branches and non-merchantable section remains are accumulated. This material is also of small but variable piece size consisting of branch material, off-cuts and short stem segments.

3. Thinnings residues. Normal silvicultural practice in plantation forestry is to plant many trees and remove those not required at an early stage in the rotation. The extra trees allows 'insurance' against malformation, and tree death, and also provide a degree of branch size control. Trees removed can be utilised as pulp, post, or potentially,

energy products. An advantage in their recovery is that they are large compared to items 1 & 2 above, however they are scattered throughout the stand, and can even be a marginal proposition when recovering conventional products with conventional harvesting machinery unless located close to a market.

4. Whole stand. Under special circumstances it may be possible to recover all the trees within a stand as an energy product. This usually implies that there is no other market for the product, as energywood has traditionally commanded the lowest product value. If the trees are of a sufficient size then economies-of-scale are possible during harvesting. This situation will seldom occur in New Zealand unless the stand has been grown specifically for the energywood market.

SPECIALIST MACHINERY

Off-the-shelf forest harvesting machines of overseas origin are available for most applications associated with conventional energy recovery. Mobile chippers, skidders, forwarders, tub grinders, etc. can all be readily purchased. Unfortunately, because of the rugged conditions in which most forest equipment is required to operate, forest machines tend to be of solid construction and relatively expensive to purchase.

The size of the New Zealand internal market means that the development of special home-built machinery has invariably been unsuccessful. Trials with overseas specialist harvesting equipment is very expensive and has historically been a limiting factor to the introduction of new techniques into the forest harvesting industry in New Zealand. However without testing machine options and combinations directly under New Zealand conditions it is difficult to calculate the best means of incorporating various units into harvesting systems or establishing product production costs.

A danger with the ownership of specialist forest machinery is that with a downward change in market, or when attempting to trade-in, the contractor can be left with a unit of little or no value. This increases the risk associated with a particular operation and can limit the attractiveness of an enterprise to a contractor, or limit the borrowing options of a willing contractor.

INTEGRATION OF BIOFUELS RECOVERY

The best opportunity to efficiently recover additional biomass from existing plantations appears to lie with integrating the biomass recovery with conventional harvesting operations. In this way not only is the operational recovery of the additional material eased, but the cost of recovering the material can be reduced (Hudson et al, 1990). The incorporation of the collection of energywood into a system which also recovers biomass has been shown to have major economic cost reductions. The Scandinavian system of tree-section logging is a successful illustration of this concept (Andersson & Knutell, 1987), as is the teaming of tub-grinders with flail delimber-debarkers in the southern USA (Watson & Twaddle, 1990).

In New Zealand not all current plantations are on terrain and soils types which facilitate easy harvest, or in locations which may suit an energy market. Specialist plantations may be an answer in certain well defined circumstances, but if the energywood must carry the full production and harvesting costs then these stands are unlikely to be economic. Hardware development for energywood plantations is still at a relatively primitive stage, however a watching brief on overseas developments should be maintained.

The key to successful economic exploitation of either conventional or specialist plantation forests in a favourable market for energywood will be the correct choice of the harvesting system.

SUMMARY

1. New Zealand has a considerable resource of energy in residues from conventional forestry plantations currently being unutilised.

2. Foreign harvesting machinery is available for the recovery of much of this material. Costs will vary considerably depending upon which source of residues are targeted.

3. Overseas experience points to the integration of energywood recovery with conventional products as a least cost option.

4. Without operational trials in New Zealand the development of the most appropriate recovery systems for New Zealand can not be undertaken, nor can production costs be accurately estimated.

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5.2 The Greenhouse Effect

Many climate experts are telling us that the world's climate is changing, the most noticeable change being increasing temperature. There is much evidence to support this contention but there is still considerable debate among climate experts on this issue. The cause of this 'global warming'; is attributed to increasing concentrations of CO_2 in the atmosphere resulting from burning of fossil fuels such as coal, natural gas and oil. While humanity continues to acquire a major portion of its energy requirements from these sources, atmospheric CO_2 levels will continue to rise. This trend has been particularly evident since the Industrial Revolution in the 19th Century.

Why does CO_2 increase global temperatures? The mechanism proposed by climatologists is that CO_2 in the atmosphere acts in a similar manner to a 'greenhouse', reflecting outgoing radiation back to the earth's surface. Consequently more of the suns radiant energy is trapped and this energy results in higher atmospheric and ocean temperatures. Global climate models predict that this warming has the potential to cause mayhem through increased incidence and severity of drought in some areas, increase incidence and severity of floods in other areas and for low lying states e.g. Pacific Islands loss of land area to rising ocean levels. None of this is good news so the global community has initiated measures to try to reduce emissions of CO_2 into the atmosphere.

In June 1992 an 'Earth Summit' was held in Rio, Brazil. At this Summit an International Framework Convention for Climate Change was held and at this convention NZ agreed to reduce CO_2 emissions to 1990 levels by 2000. It is highly unlikely we will achieve this target, a fact which was admitted by the Government at a Tokyo meeting of signatories of the Framework. However the Framework allows for the use of plantation forestry to offset emissions of CO_2 into the atmosphere.

Young, growing forests (such as recently planted *P. radiata*) accumulate biomass or wood, which is approximately 50% carbon, until they are cut down. Thus they act as a carbon sink, removing CO_2 from the atmosphere through photosynthesis. In mature forests there is no net reduction in atmospheric CO_2 because the forest is producing as much CO_2 through death and decay as it is fixing through photosynthesis. These forests are carbon 'neutral' and include the majority of NZ's native forests. The area of plantation forests in NZ has increased by an average of 44,000 ha/annum over the last 20 years, mostly from conversion of pasture to *P. radiata*. These young plantations are accumulating carbon, acting as a sink and reducing atmospheric CO_2. Most plantations will accumulate over 100 tonnes of carbon/ha by the time they are 15/16 years of age. Consequently these plantations are currently offsetting increased CO_2 emissions by NZ industry, car owners etc. This situation will probably continue while the plantation area continues to expand (depending on the rate of expansion), effectively buying time until NZ can find alternative energy supplies to fossil fuels. Expansion of plantations will always be limited by the available land area. Trees can make a permanent contribution to reducing the reliance on fossil fuels if utilised as an energy source. Wood already makes a significant contribution to reducing energy consumption through substitution of alternative products, such as steel and aluminum, used in construction. These alternatives require much more energy to manufacture compared to wood. Much of this energy is sourced from fossil fuels.

The following paper outlines the global warming issue and the government response. The use of plantation forest as carbon sinks, allowed under the ruleso f the 'Kyoto Protocol; are discussed. Published in 2005 Forestry Handbook.

FORESTRY AND THE CARBON CYCLE

J Ford-Robertson – Ford-Robertson Initiatives, Rotorua

BACKGROUND

The Third Assessment Report by the Intergovernmental Panel on Climate Change provides clear evidence that the earth's climate system has changed since pre-industrial times, and that most of the warming over the last 50 years has been caused by human-induced emissions of greenhouse gases. It reports that warming is expected to continue over the next 100 years, with an increase in average temperature of between 1.4 and 5.8°C. This is between two and ten times larger than the warming observed in the 20th century, and could be higher than any estimated in the past 10,000 years. Human actions will affect whether and when these projections are realised.

Human responses include two international agreements directly addressing the threat of climate change. New Zealand is a party to the United Nations Framework Convention on Climate Change (UNFCCC), and ratified its subsidiary agreement, the Kyoto Protocol, in December 2002. The Protocol was expected to come into force internationally in 2003, following ratification by Russia, but this has yet to occur.

The UNFCCC has the objective of ultimately stabilising the concentration of greenhouse gases in the atmosphere. It states that parties to the UNFCCC should limit anthropogenic emissions (sources) and promote conservation and enhancement of sinks and reservoirs of greenhouse gases, including forests and other terrestrial, coastal and marine ecosystems. It requires monitoring and regular reporting of sinks, sources and reservoirs, defining these terms as follows:

> A **sink** is any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor to a greenhouse gas from the atmosphere.

> A **source** is any process, activity or mechanism which releases a greenhouse gas, an aerosol or a precursor to a greenhouse gas into the atmosphere.

> A **reservoir** is a component of the climate system where a greenhouse gas is stored.

The Kyoto Protocol aims to reduce overall emissions from developed countries by at least 5% below 1990 levels in the first commitment period of 2008-2012, assuming that all the signatory parties ratify it. If the USA and Australia do not ratify, as is currently their intention, the reduction may be less. Parties to the Kyoto Protocol with binding commitments (including New Zealand) can use a range of means to meet their obligations, including controls on greenhouse gas emissions, the use of carbon sinks, and international emissions trading. Article 2 of the Kyoto Protocol identifies possible policies and measures for Parties to implement to promote sustainable development as well as making emissions reductions.

Forest sink 'credits' are measured as stock changes over the first commitment period, not in all forests, but only in so-called 'Kyoto forests'. These are largely forests that have been established since 1990 as a result of afforestation and reforestation. In other words, the net change in carbon stocks resulting from growth minus losses e.g. harvesting and fire, are 'counted'. Carbon stock changes on land subject to deforestation since 1990, regardless of the year of forest establishment, must also be accounted for. 'Deforestation' is distinguished from harvesting because the former involves a land use change to a non-forest use. Changes in carbon stocks in forests established before 1990 can be accounted for under a separate "Forest Management" category, if elected by the Party.

Parties are required to account for all changes in the following carbon pools: above-ground biomass, below-ground biomass, litter, dead wood, and soil organic carbon, unless transparent and verifiable information is provided that the pool is not a source. Stocks, stock changes and emissions/removals are estimated according to the approaches and methods described in IPCC 2003.

FORESTRY SINKS AND SOURCES IN NEW ZEALAND

The Ministry for the Environment has reported to the UNFCCC that the land use change and forestry sector sink was equivalent to 33% of all greenhouse gas emissions in 2001. Net removals of CO_2 from the atmosphere in 2001 were almost 10% above net removals in 1990, indicating the sink has been increasing in magnitude. For this sink to continue, let alone increase further, there would have to be either a continued increase in the carbon stock (related to biomass or standing volume) per hectare, and/or a continued increase in the area of forest. The government has committed to quantifying and reporting sources and sinks of greenhouse gases and to the development and implementation of a carbon accounting system. This will include all forests, indigenous and exotic, as well as reverting shrublands.

Afforestation in New Zealand usually occurs on pasture. The establishment of a stand of pines on grassland will tend to increase the total quantity of carbon on site by approximately 250 tonnes/ha over one rotation of 25-30 years (Maclaren 2000). While carbon increases in the majority of carbon pools, there is a relatively small decrease in the carbon content of the surface mineral soil during the first rotation of pine and a redistribution of surface mineral soil carbon to below 30cm depth following harvest disturbance (Oliver *et al.* 2004). Although there are fluctuations in the on-site carbon of each stand, over time the carbon stock of a forest will be substantially higher than in a grassland. Plantations in New Zealand retain a long-term average carbon stock of around 120 tonnes/ha taking harvesting into account, whereas New Zealand indigenous forest typically contains 150-200 tonnes/ha (Green *et al.* 2003).

While forests are sinks in their establishment phase, as the standing volume stabilises (e.g. in a 'normal' forest containing equal areas of each age class) the forest becomes a carbon reservoir. When stands are harvested, the carbon is transferred into the products pool, or into waste that might be burned or left to decay releasing the carbon as CO_2, or CH_4 in anaerobic conditions (e.g. some landfills). Under the carbon accounting rules, the default assumption is that all stemwood carbon in harvested stands is oxidized and emitted at the point of harvest. There is ongoing debate about how emissions from harvesting and wood products are, or will be, included (Ford-Robertson 2003). It is an important issue for New Zealand since two-thirds of the harvested carbon is exported, and therefore the carbon is not emitted in New Zealand, even though New Zealand reports the emissions. This fails to meet the objective of producing accurate national inventories that best represent when and where emissions occur.

As well as the assumed emissions, there is an energy cost associated with forest harvesting and processing. The harvesting and transport energy demands are relatively low compared with processing, but these vary widely in different situations and the type of fuel used affects the quantity of emission. For example in New Zealand, chemical pulp uses approximately 35 GJ/t whereas sawn timber uses 2 GJ/m³, and chemical pulp generates almost 90% of its energy internally using biomass, and sawn timber tends to be around 50% self-sufficient. Energy from biomass is assumed to be 'carbon-neutral' in that it emits CO_2 that was recycled from the atmosphere, and the emissions are already 'counted' at harvest. The emission of fossil carbon estimated for each product is highly dependent on the emission factor used for electricity. The means to calculate the emissions per unit of electricity in New Zealand are currently being established. They could be based on particular generation sources if these can be identified, or some form of average of all generation sources supplying the national grid. Using a New Zealand average value, pulp and paper plants emit 0.1 – 0.2 tonnes of carbon per tonne of product, whereas sawn timber and panels tend to be in the range of 0.01 – 0.02 tonnes.

Each wood or fibre product will release its carbon back to the atmosphere over time, with the duration determined by the use. For example some carbon will be in long-lasting products such as furniture or building components. The carbon in sawdust or used in paper is likely to persist for a shorter period, but if waste wood or fibre is used for energy it can avoid, and perhaps reduce, the release of carbon from fossil fuels. This is known as direct fossil fuel substitution. Indirect substitution also occurs: manufacturing a wooden product means a similar product made from another material is not produced. Since other materials tend to be more energy intensive than wood, each wood product is said to reduce fossil carbon emissions.

A highly positive carbon balance would result from a forest sector using fast-growing species that create a powerful carbon sink, can retain high biomass, and yield durable timber suitable for long-lived products. If the end-products do not require protective treatment or finishes, then there is the potential for bioenergy use after they have served a useful life. Waste from harvesting and milling operations is fed into combined heat and power units that make the sector a net energy exporter. Having all forests and processing operations located near each other minimises transport emissions. Since the Kyoto Protocol also aims to promote sustainable development, it would encourage aspects other than carbon balance alone to be considered.

The future location and form of the forest industry will determine how emission sources change as the available harvest increases. Export of unprocessed logs will tend not to increase emissions, except possibly in the transport sector. Investment in large, capital and energy intensive pulp and paper plants would greatly increase processing emissions, although there are opportunities to increase the bioenergy component of energy supply. A focus on sawmills and added-value processing in forested areas, using wastes for combined heat and power production, could minimise investment requirements and reduce emissions by minimising transport distances and exporting energy.

Climate change and energy are two topics being considered by committees within the government/industry Wood Processing Strategy initiative.

NEW ZEALAND POLICY IMPLICATIONS FOR FOREST INDUSTRY

Cabinet papers note that "New Zealand's primary objective is to meet its obligations in a way that demonstrates integrity and leadership". They recognise "Reducing emissions from business will involve direct costs on business and consumer, and will lead to some indirect costs from economic restructuring and job losses. Some restructuring may be desirable from an environmental perspective to shift the economy away from activities involving high emissions". Furthermore, they note that some proportion of the additional 'credits' from sinks should accrue to those undertaking the activities, and that New Zealand has given international assurances that it will "not shield its domestic emitters" by using sink credits to offset emission increases.

The key criteria used for setting policy in New Zealand are economic efficiency, equity, feasibility, environmental integrity and competitiveness. The principal elements of the national response have been established although there are some issues yet to be resolved. Plantation sinks are a crucial element in the policy mix. It has been estimated that eligible plantation sinks in New Zealand will sequester over 110 million tonnes of CO_2 over the first commitment period 2008-2012 (MfE 2002). Over the same period, the increase in emissions is estimated to be 50 - 75 million tonnes above our target 'assigned amount' of 365 million tonnes. This means that the sink, primarily from plantations established since 1990, exceeds the increase in emissions, making New Zealand a net seller of carbon credits. Reverting shrubland since 1990 may also qualify and further increase available sinks, but Forest Management has not been elected as an activity by New Zealand, since pre-1990 forest may exhibit declining carbon stocks during the first commitment period (Baisden *et al.* 2001).

The New Zealand government has announced that it "will retain sink credits and associated liabilities allocated to New Zealand under the Protocol in recognition of the carbon sink value of post-1990 forest plantings" (Hodgson 2003). The government is now working with industry to conclude a Forest Industry Framework Agreement (FIFA) that "recognises the sector's significant contribution to New Zealand's climate change initiatives". This will include policies "designed to support the forest industry's future growth in the best interests of the environment, wood processors and forest growers" (Hodgson 2003).

A policy to provide incentives to establish "new permanent 'non-harvest' commercial forest sinks" might be one of the elements detailed in the FIFA since some aspects of the policy remain unresolved (NZIF 2003). The FIFA might also address other impacts of policy on the industry. Clearly the emissions charge, due to be introduced in 2007, will have an influence on the cost of fossil fuels and electricity. The emission factor(s) applied to electricity will be a major factor in identifying the effect on wood processing costs. If the charges are applied equally to all sectors, wood products may fare better than their more energy-intensive competitors.

Firms and sectors that face significant risks to their international competitiveness as a result of the emissions charge are eligible to apply for Negotiated Greenhouse Agreements (NGAs). They can obtain relief from all or part of the emissions charge in return for a contractual commitment to achieve international best practice in managing emissions. If NGAs include allowances to increase emissions relative to 1990, these must be offset by sink credits or reductions in gross emissions elsewhere in order to meet Kyoto commitments.

The government has also introduced a projects mechanism, to link to the Joint Implementation mechanism of the Koyoto Protocol. The government will award emission units to projects which "provide emission reductions in the Kyoto Protocol's first commitment period (2008-2012) beyond the reductions that would have occurred without the project". In December 2003, 15 projects were awarded 'carbon credits', including wind-farms, hydro-electricity schemes and industrial heat plants. It is anticipated that bioenergy projects using forest residues and wood wastes will be eligible for this mechanism. Bioenergy offers the opportunity to maintain energy supply and reduce gross emissions relative to 1990, if it replaces an energy source that was emitting greenhouse gases in 1990. Bioenergy can also increase energy supply without the associated increase in emissions from fossil fuels sources, and hence reduces emissions relative to a business-as-usual scenario. Both will contribute to Kyoto commitments, the first by reducing the absolute 1990 emissions, and the second by reducing the rate of increase in emissions. The distinction is similar to that between afforestation (decreases net emissions) and avoided deforestation (avoids increasing emissions).

SUMMARY

Although the sink resulting from afforestation is a one-off increase in carbon stock, fossil fuel substitution is an ongoing benefit of forestry. Every unit of biomass that is used for energy represents fossil fuel conserved, and emissions avoided. Every wood product avoids the release of emissions from manufacturing a non-wood substitute. The optimal climate benefits of forestry therefore result from the application of a sustainable harvest regime that confers ongoing benefits of using wood products and bioenergy.

This is a rapidly evolving and expanding topic area and there are several issues still to be resolved, some of which could play an important role in shaping New Zealand forestry. A key international issue is accounting for emissions from harvesting and harvested wood products. A key domestic issue is the FIFA and its future policies and measures to support the forest industry and hence maintain and enhance forest sinks and reservoirs.

If the government uses the value of the sink credits to support sustainable forestry and renewable energy (e.g. bioenergy) for the expanding forest processing sector, it could create long-lasting benefits in local and national energy security, generate new regional employment, and have added benefits in terms of fossil fuel substitution. If however, the credits are used to offset emissions from manufacturing non-wood products, it could create distortions that would help neither the forest industry nor the national or global carbon balance.

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EMISSIONS TRADING

The emissions trading bill, setting up the New Zealand Emissions Trading Scheme (ETS) passed into law on 10 September 2008. It has been reviewed by the newly elected National Government but is expected to be finalized by the end of 2009. The overall goal of the ETS is to reduce emissions. It achieves this by requiring industries which produce CO_2 emissions to purchase New Zealand emission units to offset these emissions. A NZ emissions unit is equal to 1 tonne of CO_2. Other greenhouse gasses included in the ETS include methane and nitrous oxide but their impact is expressed in CO_2 equivalent units.

A cap on emissions was established by the Kyoto Protocol during its first commitment period (2008–2012). Emissions that exceed the cap must be matched by emission units which are purchased from organisations with emission units for sale, for example forest owners. Forest owners who want to sell emission units must register with the MAF.

Once forest land is registered in the ETS, forest carbon stocks will need to be determined. For post-1989 forests the forest owner is required to file an emissions return to determine the change in carbon stocks of an area of forest at the end of the 1st reporting period (31 December 2012), but may file returns annually if they want. For pre-1990 forests that have been harvested and not replanted (deforested), the owner is required to surrender emission units equal to the forest carbon stocks in the forest prior to deforestation.

For owners of post 1989 forests who elect to register in the ETS, carbon stocks, expressed as tonnes of CO_2/ha, need to be determined at regular intervals so that the amount of carbon sequestered or emitted can be determined and credit/liability for changes in carbon stocks determined.

At present, look-up tables supplied by MAF provide the only way of calculating carbon stocks for an emissions return. However field inventories of carbon stocks may become feasible in the future once more research has been carried out on suitable methodologies and procedures. It is anticipated that look-up tables will only be able to be used for mandatory emissions returns in the case of smaller post-1989 forests.

The values in the look-up tables reflect growth rates for typical forests in regionally (eg *Pinus radiata*) or nationally averaged environments (eg Douglas fir), under average forest thinning and pruning regimes. It is not possible to provide look-up tables that are site specific, because there is insufficient data to calibrate the growth models, so that carbon stocks can be pre-calculated for particular local growth conditions.

Examples of the amount of carbon, expressed as CO_2, sequestered in forests can be seen in Figures 7 and 8. Figure 7 shows the accumulation of carbon over time for *Pinus radiata* growing in the Southern North Island (SNI) compared with the Bay of Plenty (BOP). Carbon stocks are higher in the SNI, a reflection of the greater productivity of SNI sites, mostly due to higher soil fertility (higher basal area potential - see Unit 2). The amount of residual carbon in and on the ground in the form of tree roots and slash for SNI *Pinus radiata* forests is also shown. This represents the amount of residual carbon present 4 years after trees have been harvested. This information can be used to estimate carbon stocks at different times in the life of a forest. For example for *Pinus radiata* planted in 1998 in the SNI the total carbon present at age 10 at the beginning of the first 5 year registration period (2008-2012) is about 210 t CO_2 /ha (Figure 7). In 2012 the forest will be 15 years old and will contain about 361 t CO_2 /ha.

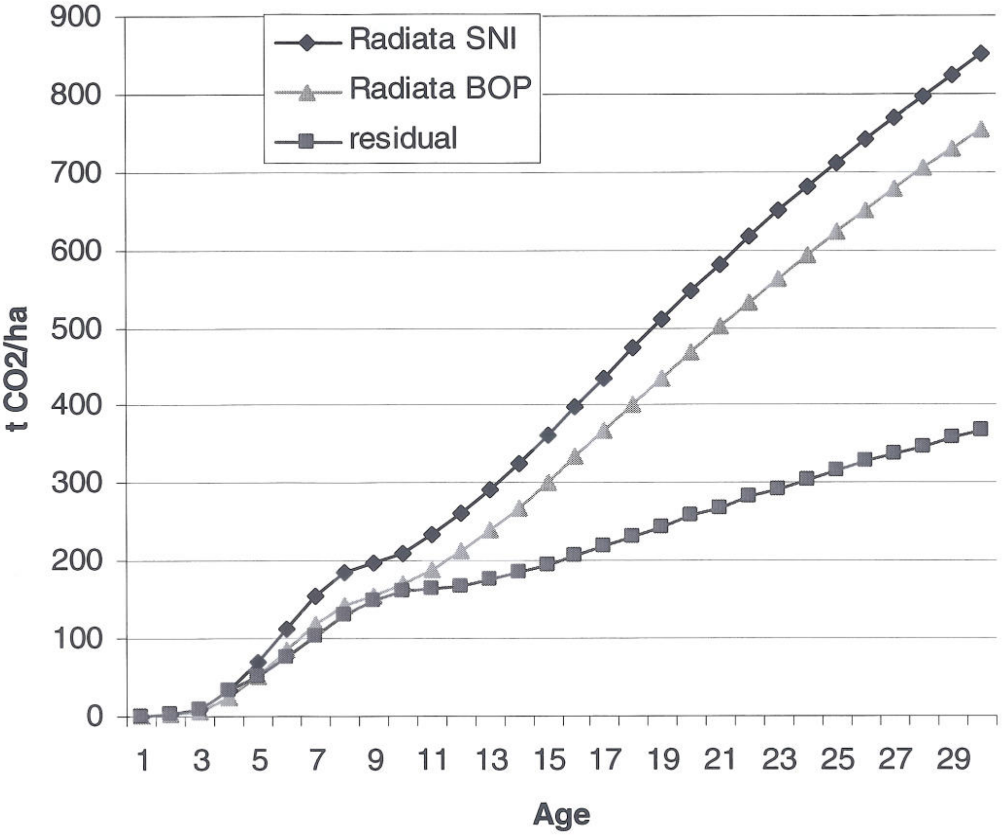


Figure 7 Accumulation of carbon in *Pinus radiata* forests in the Southern North Island (SNI) and Bay of Plenty (BOP) and post harvest residual carbon in SNI forests up to age 30 years. (Adapted from MAF 2009).

Net increase in carbon stocks from 2008 to 2012 is:

361 – 210 = 151 t CO_2 /ha.

This is equivalent to 151 emission units. These units may be sold to individuals and organizations emitting CO_2 What might this be worth? The current indicative value of a NZ unit is NZ$25, so the carbon sequestered in this forest over the 5 years between 2008 and 2012 will be worth $3775/ha. This sum explains the interest in trading carbon credits among many owners of post 1989 forests. However there will be costs to come off this sum, for example sales commission. For BOP forests the amount accumulated over the same period will be about 20 t/ha less. If the owner of this forest later cleared or harvested the trees there would be a liability for the release of carbon stored in the forest but the liability is caped at the number of units claimed, 151 t/ha in the above example.

The amount of residual carbon can be used to estimate the amount of stored carbon in forests in the second rotation. It is assumed that all of the residual carbon from the 1st rotation has gone by 10 years after harvest. So carbon present in the stand in the 2nd rotation will be the balance of accumulated carbon in the 2nd rotation trees less the decay of the residual carbon over the first 10 tears of the 2nd rotation.

Carbon is stored at different rates by different species, according to their productivity. For example in Figure 8 the rate of accumulation of carbon in Douglas fir and native forests is compared. Douglas fir accumulates carbon at a slower rate that *Pinus radiata* over the 30 years post establishment (but is capable of growing and storing carbon over very long periods of time (> 100 years), mostly because of the slow establishment characteristic of the species. Once established it accumulates carbon at a similar rate to *Pinus radiata*. In comparison the mount of carbon stored in regenerating native forest is tiny, again reflecting the slow growth of native trees.

It is anticipated that the next round of global climate negotiations in Mexico 2010 will work towards extending the current carbon trading scheme, albeit with some changes.

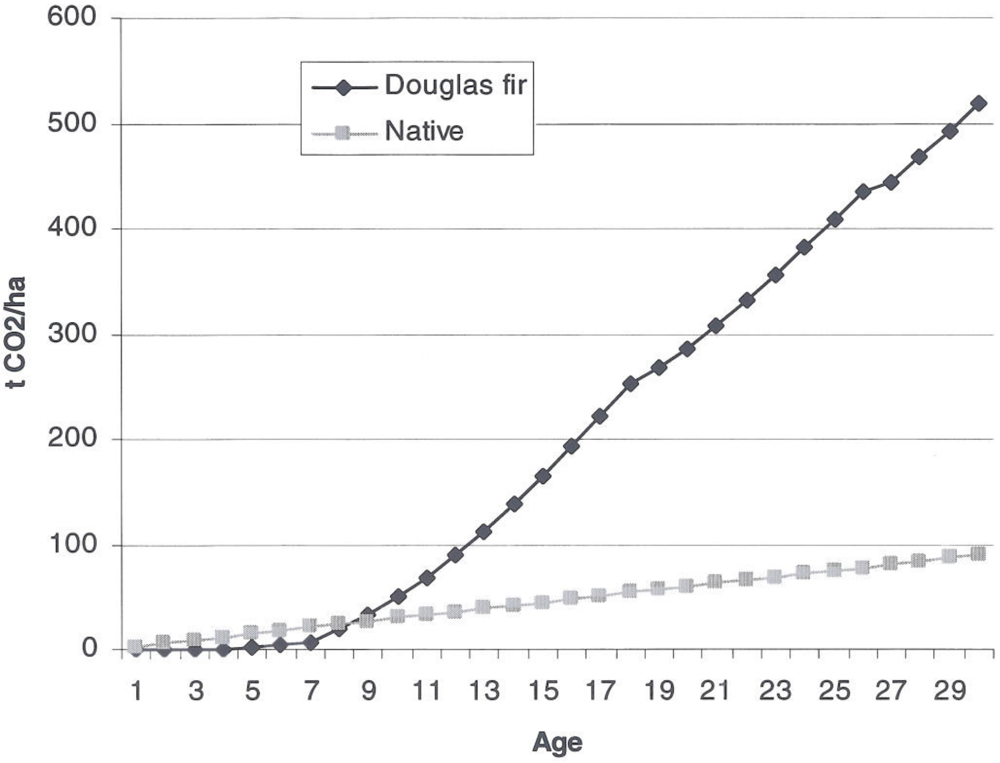


Figure 8 Accumulation of carbon in Douglas fir and native forest up to age 30 years. (Adapted from MAF 2009).

5.3 The New Zealand Landscape

Originally most of NZ was covered with tall rain forest. Agricultural development saw much of this forest removed creating a landscape made up of remnant native forest, pasture, introduced trees and man-made structures such as roads, fences and buildings. Today productive rural landscapes dominate the NZ landscape. Often this landscape is monotonous or boring e.g. 'grass desert'. However productive landscapes can be both productive and visually appealing as well as provide habitat for wildlife.

Most people favour rural landscapes which are productive and combine open pasture with trees. Trees greatly enhance the visual and ecological values of a landscape and are probably the most important component of landscape improvement programmes.

Landscape characteristics influenced by trees

The following landscape characteristics have a significant influence on peoples likes or dislikes of that landscape.

Naturalness:	Trees don't naturally grow in straight lines, yet that is how they are most often planted. Wherever possible use natural landforms such as streams and contour when planning a tree planting programme.
Diversity:	If everything in the landscape looks the same it will usually appear monotonous. This applies to both pasture and forest areas. For example large *P. radiata* plantations are regarded as monotonous by many people. Diversity can be created by varying the species planted to alter the form and colour etc of vegetation.
Coherence:	Landscapes are usually 'large scale' so it is important to establish continuity both within a farm boundary but also between neighbouring farms. Abrupt changes in appearance at a boundary are a common and unattractive feature of the NZ landscape.

Mystery:	Mystery is a difficult quality to measure. It provokes curiosity and interest which tends to draw the viewer into the landscape. Mystery is achieved by creating complexity and structure when planting.

These characteristics can be incorporated into plantings around a homestead and also for shelterbelts/timberbelts, plantations and spaced plantings on pasture. Even native vegetation can be incorporated into planting programmes to add appeal to a landscape. Where possible use species with similar appearance adjacent to native forest and if other species are to be planted, allow a transition area containing a mix of species. Particular attention needs to be paid to boundaries between planted areas and pasture (Figure 9).

Figure 9. Contrasting rural, productive landscapes. Both include pasture and trees. Figure 7a (upper) is much less appealing than 7b. It is questionable whether the trees in this landscape (high pruned *P. radiata*) enhance appeal. They may even look ugly to you? Figure 7b contains many of the landscape characteristics described above. How many can you identify?

5.4 Native Forest Remnants

5.4.1 Introduction

Many farms in NZ have small to medium size native forest remnants (< 1ha to > 100ha). Traditionally these remnants have been abused and neglected meaning that most are in a highly modified state, being heavily browsed or grazed, experiencing little if any natural regeneration and with high mortality rates amongst existing trees. For an increasing number of land owners this is no longer acceptable. Much greater value is attached to retaining these remnants and enhancing their vigour/health. Often they may be the only example of the original native forest cover in the local area. Apart from their conservation value native remnants may also add to aesthetic appeal.

There has recently been renewed focus on the issue of protecting forest remnants because of a Ministerial Advisory Committee report on biodiversity which is addressing the issue of management effects on indigenous biodiversity. While many farmers look at these issues as simply attempted interference with the rights of private land owners others readily admit that much more could be done to maintain or enhance indigenous biodiversity. So if you are interested in biodiversity and have control of a native remnant what can be done?

5.4.2 Physical protection

Any management programme which sets out to protect forest remnants must begin with fencing to exclude stock. Free access by sheep, cattle, goats and deer is probably the most important cause of degradation and failure of regeneration. Excluding stock immediately allows an understory to develop and eventually regeneration of the important canopy species. Wherever possible remnants should be linked to other protected areas such as riparion strips to provide continuity. Given time regeneration will occur through natural succession. For example pioneer species such as manuka and kanuka may respond very quickly to stock exclusion and this can often leave land owners wondering about the wisdom of their actions. However the taller climax species, such as podocarps, will eventually emerge through this initial canopy. In some situations it may be necessary to plant if natural regeneration is not adequate. In these situations it is preferable to source local genetic material. There are large regional differences in many native species and whenever feasible you should try to use local plant or seed sources. Some district authorities now require residents to only use locally sourced plants, for example Waitakere City.

After fencing supplementary planting may often be necessary around the margins particularly on the windward side. This helps prevent wind penetrating the interior of the remnant. Wind dessicates folige and dries soil out, making conditions unsuitable for many native species, eg. ferns. One of the most effective ways of protecting against wind is to revegetate the margins with 'hardy' colonising species such as *Pitosporum sp.* and *Coprosma sp.* In addition it may also be necessary to reduce possum numbers if defoliation is heavy and few shrubs/trees are managing to produce seed. Possums also have a negative influence on some bird species but undoubtebly the biggest problem for birds as far as predatation is concerned are mustelids (stoats and ferets). Weeds which prevent regeneration of native plants or which are capable of smothering exisiting trees will need to be removed or controlled. In this category the infamous 'Old Mans Beard' is probably the greatest threat but other seemingly less vigorous species such as Wandering Jew and Periwinkle also greatly reduce opportunities for natural regeneration because of their mat forming habits.

5.4.3 Legal protection

Landowners wanting to secure long term protection for areas of high scenic value or conservation value (such as forest remnants) can elect to secure legal protection for such land which binds current and future owners. Several options for protection are available including

- Queen Elizabeth II National Trust Open Space Covenant
- Department of Conservation Covenant
- District Council Covenant
- Department of Conservation Private Land Agreement.

Of these the QE II Open Space Covenant is by far the most utilised. The Trust was established in 1977 (by Parliament). Landowners wishing to protect an area of remnant forest can approach the Trust and negotiate an open space covenant which will require the landowner to manage the defined area as per the negotiations while the Trust registers the agreement against the title of the block, binding future owners. In May 2000 there were over 60,000 ha of QE II Covenants plus many other protected area under different schemes. The Trust often provides financial assistance for operations such as fencing, particularly for high value remnants. High value meaning unique, regionally important and in good condition – not too degraded. Fencing to exclude stock is normally a requirement of the Trust.

Those interested in restoration and management of forest remnants may find the following publication very helpful.

Native Forest Restoration. A practical guide for landowners. Tim Porteous, QE II National Trust. 1993.

5.5 The Use of Trees to Reduce Eutrophication of NZ Lakes

Eutrophication of lakes caused by high levels of biological activity, particularly algae, is a long term problem. It has recently become more prominent because of highly publicised negative impacts on some of our most visited lakes in the Rotorua area. Lake Rotoiti for example is in a highly polluted state with much of the water discoloured and toxic to fish because of low oxygen levels. Low oxygen is the result of decay of algae and other micro-organisms. The high populations of algae etc are the result of high concentrations of nutrients in rivers, streams and groundwater which feed into the lake. Phosphorus and nitrogen are the most important. There have been warnings about the state of Lake Taupo, probably New Zealand's best known and most visited lake. Water quality is beginning to decline and only by controlling the amount of nutrients entering the lake can the situation be stabilised. A key to controlling nutrients entering the lake is land use and management in the lake catchment. Some activities, particularly dairy farming, promote nutrient runoff whereas forestry can greatly reduce nutrient runoff. The following article (Farm Forestry Newsletter No. 2) examines the role of land use on the losses of nitrogen from the Taupo catchment and the benfits that conversion of farmland to forestry would provide. The benefits are discussed in terms of nutrient loss and profitability.

Farm Forestry - the Green Solution Newsletter

No. 2
DECEMBER 2003

"Can a careful combination of farming and forestry match the medium to long-term profitability of pastoral-based farming on hill country, and at the same time meet long-term environmental values of reduced soil erosion and improved water quality?"

This is the question being asked by the NZ Farm Forestry Association, with support from the MAF Sustainable Farming Fund. We have already analysed the profitability and environmental merits of radiata pine and poplar for the erosion-prone parts of the Thomsen farm at Patoka, Hawke's Bay (see previous newsletter). This newsletter addresses another important issue: the declining water quality in some of our lakes, and the scope for increased farm forestry in those critical catchments.

Lake Taupo

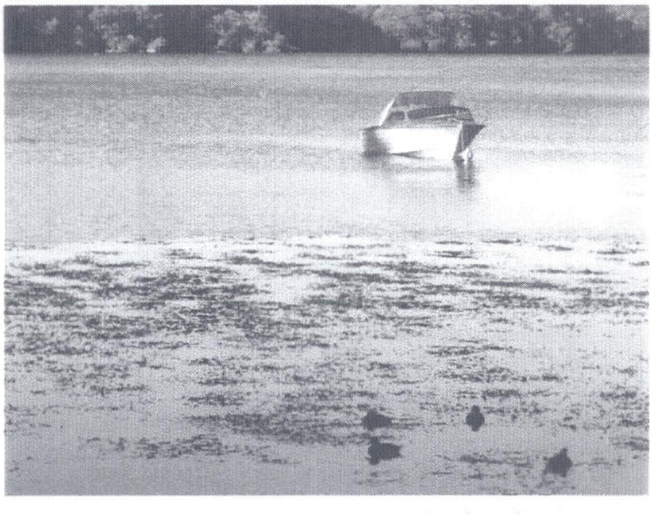
Recent algal blooms and decreased water clarity are clear signs that the health of Lake Taupo is at risk. The quality of water in Lake Taupo is vitally important to us and we have an obligation to protect our natural heritage. Pastoral farming is an important source of nutrients leaching into the lake, however, in terms of income farming is also very important. We need to find ways of securing the income to farmers, while protecting the lake at the same time. Can sheep and beef farmers gradually convert some or all of their land to trees without a reduction in long-term profit? Can farm forestry help stop the degradation of Lake Taupo? These are crucial and topical questions.

Why is the Lake under threat?

Lake Taupo, like so many other New Zealand lakes, once had very clean and clear water. The reason for this is simple: Surrounding land was not intensively farmed. Key plant nutrients, like phosphorus and nitrogen, did not find their way into the lake in excess. Intensification of land use over the last 40 years has, however, changed this situation, and the additional fertility has allowed both microscopic and larger plants to proliferate.

Increased growth of aquatic plants causes change in the colour, clarity and odour of water, and in severe cases algal blooms are formed. Such blooms are unsightly and can be toxic. When they decay, they can deplete the water of oxygen and in extreme cases the lake "dies". Trout cannot survive in such water. But it is not only fishermen who need be concerned. Water pollution and weed growth can harm recreational activities such as boating or swimming, and can affect drinking water.

We can see the effects of severe pollution in some of our smaller and shallower lakes, such as Tutira in Hawke's Bay, Okaro near Rotorua, and Ellesmere in Canterbury. Lake Rotoiti in the Bay of Plenty has also reached a critical state. The sheer size and depth of Lake Taupo has protected it up to now, but unless we reduce our level of pollution its future looks grim.



Declining water quality has major implications for the future of Lake Taupo.

What type of land use is best for the lake?

Nitrogen is the most important nutrient that limits aquatic plant growth in Lake Taupo. Three-quarters of the additional nitrogen entering Lake Taupo comes from diffuse agricultural sources. By "diffuse" we mean sources that are widespread, as opposed to "point" sources such as dairy sheds or septic tanks. Nitrogen is added to the soil directly by nitrogenous fertiliser (e.g. urea), and indirectly by nitrogen fixation from the air, encouraged by fertilising the grass/clover sward with superphosphate. Livestock eat the pasture and excrete the nitrogen in their dung and particularly in their urine.

If the land is under a cover of trees, very little nitrogen is released to the waterways. Studies of many rivers back in the 1990s showed that water samples in the upper parts of catchments dominated by natural vegetation contained low nutrient levels, while water quality declined when the rivers ran through agricultural land. Exotic plantations (e.g. pines or Douglas-fir) were almost as good as undisturbed native forest. The comparison in Figure 1 is very stark and obvious.

The advantage of native forest cover is that no fertilisers are added, livestock are excluded, and the soil is covered continuously with vegetation. The crown of the trees also intercepts a lot of rain, and the forest floor allows water to enter the soil without significant overland flow. The effect is to lessen the quantity of water entering waterways and to smooth flood peaks, hereby reducing surface run-off.

The roots of trees also have a pivotal role in anchoring and binding steep slopes. They are stronger than the roots of grass, penetrate deeper into the soil and often interlock with each other. Studies have shown a tenfold reduction in the level of soil erosion under trees. This is of considerable value where the goal is to reduce the amount of sediment entering the lake, together with the less mobile nutrients that are bound up with it.

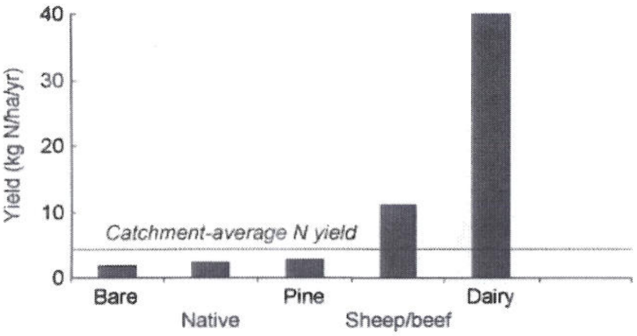


Figure 1 - Annual nitrogen loss from different sources in the Taupo catchment. Source: Environment Waikato – Waikato Regional council

Plantation forests do not achieve quite the same beneficial effect as native forests, because sometimes there is a need for fertilisation at establishment, and there is occasionally some soil disturbance in preparation for planting. Most disruption occurs at the time of roading and harvesting. Also, after harvesting the ground is left bare until the trees regrow, increasing runoff and nutrient leaching. Progressively harvesting a catchment over time can limit this effect.

The main virtue of plantation forestry is, however, that it nearly achieves the very high standards set by our indigenous catchments, while simultaneously providing an income for the landowner. The question is: how does forestry income compare with that from sheep and beef farming?

This study

The focus of this study is a comparison of the profitability of forestry with sheep and beef farming. Two plantation species were examined: radiata pine and Douglas-fir. These comprise 95 percent of the current New Zealand land area in production forests. Data on growth, wood quality, costs, returns and harvest ages are readily obtainable and are relatively uncontroversial.

Measures of profitability

A traditional measure of farm profitability is the *gross margin per livestock unit*. This is livestock revenue less the direct livestock-oriented costs (variable costs). Profitability in forestry is usually expressed in the form of Net Present Value (NPV) for a chosen discount rate. In order to compare forestry directly with agriculture, an indicator termed Equivalent Farming Gross Margin (EFGM) has been constructed. The EFGM translates the NPV of the production forest into an equivalent gross margin per livestock unit displaced. The EFGM thus allows direct comparison between the profitability of forestry and pastoral farming.

Assumptions used

The economic performance of sheep and beef farms near Lake Taupo was inferred from the MAF Monitoring Reports for '*Central North Island Hill Country*' and '*Waikato/Bay of Plenty Intensive*'. These farms provided gross margins per livestock unit for the 2002-2003 year of $35.06/lsu and $56.22/lsu, respectively.

The MAF website and a major Central North Island grower supplied 12-quarter log prices for radiata pine and Douglas-fir. Forestry costs were calculated using work-study standards and a labour rate of $26/hr. Other costs were obtained from recently published information or private sources.

Measures of tree productivity were obtained from 24 radiata pine sample plots on ex-pasture sites in the Taupo Basin. They yielded a radiata pine site index (mean top height at age 20) of 30.3 m and 300 Index[1] of 27.3 m^3/ha/yr. Unfortunately, no appropriate sample plots were available for Douglas-fir, so plots from 50 km away were used. These had a site index (mean top height at age 40 years) of 34 m and a Site Basal Area Potential (SBAP) of 2.1. Using '*Farm Forestry Calculators*', as calibrated by these figures, silvicultural regimes for each species were devised which generated the greatest profit.

Sensitivity analysis

The following were varied to examine how they affected the profitability comparison:

- Livestock carrying capacity: ranged between 4 and 12 lsu/ha.
- Understorey grazing: no grazing or grazing.
- Forestry labour: contract labour or own (free).
- Log prices: raised or lowered by 20%.
- Site indices: ranged between 26 and 34 m (radiata), or 30 and 38 (Douglas-fir).
- Rotation ages: ranged between 24 and 32 years old (radiata), or 40 and 60 (Douglas-fir).
- Discount rates: ranged between 4 and 9 percent.

With a long-term investment like forestry, the effect of discount rate is critically important. For this reason, discount rate was always varied whenever any other assumption was tested. Discount rate represents the *cost of capital*, or the interest that would be expected on an alternative investment in the absence of inflation. The ratio of farming gross margin to the capital value of land and livestock indicates that farmers in the *Central North Island Hill Country* currently are earning an average marginal rate of return of 5.5%, and those in the *Waikato/Bay of Plenty Intensive* 7.4%. These figures were used in the immediate comparison.

Results

The EFGM for woodlots with radiata pine and Douglas-fir are compared to the farming gross margins in Figure 2, Figure 3 and Figure 4. The stumpage values at the time of harvest are $52,564/ha for radiata pine and $114,991/ha for Douglas-fir.

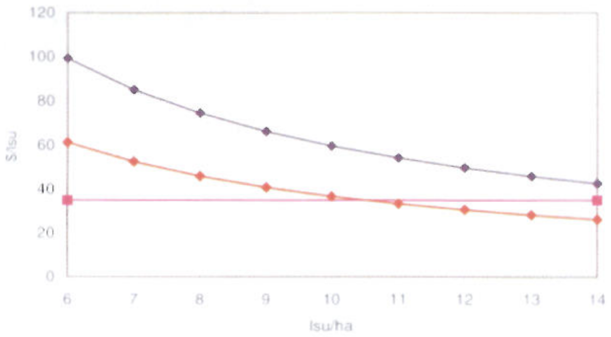


Figure 2 – EFGM of woodlots in comparison to farming gross margin at the current discount rate of 5.5 percent for 'Central North Island Hill Country'. The red and blue lines (diamond symbols) are the EFGM of Douglas-fir and radiata pine, respectively. The purple line (square symbols) is the average farming gross margin.

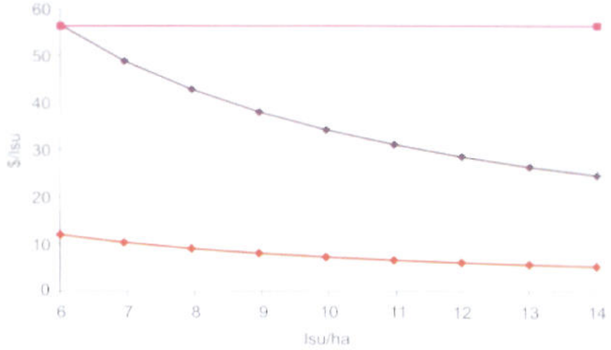


Figure 3 - EFGM of woodlots in comparison to farming gross margin at the current discount rate of 7.4 percent for 'Waikato/Bay of Plenty Intensive'. The red and blue lines (diamond symbols) are the EFGM for Douglas-fir and radiata pine, respectively. The purple line (square symbols) is the average farming gross margin.

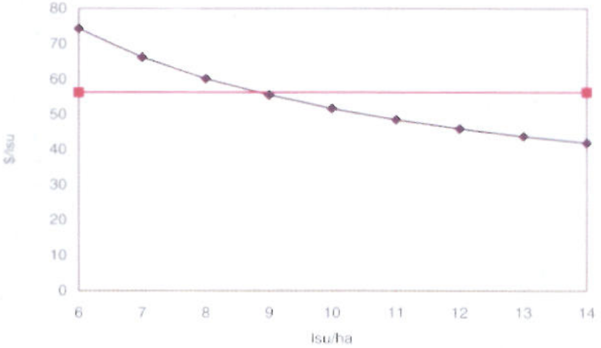


Figure 4 – EFGM of woodlots in comparison to farming gross margin at the current discount rate of 7.4 percent for 'Waikato/Bay of Plenty Intensive', when it is assumed that the farmer does the silvicultural work, the understorey is grazed during first rotation, and the return on sale of displaced livestock is included. The blue line (diamond symbols) is the EFGM for radiata pine. The purple line (square symbols) is the farming gross margin.

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[1] 300 Index for radiata pine. This is a new measure, which describes volume production rather than just height growth. It is the mean annual volume increment (m^3/ha/yr), at an age of 30 years, adjusted to represent a final stocking of 300 stems/ha, timely pruning to 6 m, and thinning to final crop at completion of pruning.

What does this mean for land owners?

The return from radiata pine exceeds that for pastoral farming in the '*Central North Island Hill Country*' at livestock carrying capacities from 4-14 lsu/ha. Douglas-fir is less profitable, but still more profitable than pastoral farming at carrying capacities of less than 10 lsu/ha. The stumpage value for Douglas-fir is, however, more than double the value of radiata pine.

The returns from radiata pine exceed that of the '*Waikato/Bay of Plenty Intensive*' farms at carrying capacities of less than 6 lsu/ha. Given that these farms on average carry 11.3 lsu/ha, woodlots would not be the best choice, unless restricted to marginal parts of the property. On the other hand, if the cost of the farmer's time is excluded (as it is when estimating agricultural gross margins), the understorey is grazed and the sale of displaced livestock is credited to the woodlots, radiata pine is more profitable than pastoral farming on '*Waikato/Bay of Plenty Intensive*' at carrying capacities of less than 9 lsu/ha.

Sensitivity analysis showed that forestry is favoured over farming by:

- Low discount rates.
- High site indices for tree growth.
- Low livestock carrying capacities.
- High log prices.
- Low rotation ages (although this is not critical, especially for Douglas-fir).

Understorey grazing also increases the Equivalent Farming Gross Margin by $2-8/lsu. If the farmer does the silvicultural work and supervision, a further increase of $12-18/lsu is possible. Theoretically, the sale of livestock during conversion to forestry should also be included on the positive side of the ledger for forestry, which would add a further $1-7/lsu.

In conclusion, sheep and beef farmers in the Taupo basin can change their land-use from pastoral farming to a mix of pastoral farming with woodlots, particularly on their least productive land, without compromising their long-term profitability.

This study shows that a careful application of woodlots is as profitable as livestock farming.

Further work

Although it is clear from this study that a farmer can typically profit as much, or more, from forestry as from farming, this must be achieved without problems of cash flow or labour. Whole-farm analysis is necessary, and will be the subject of a future study.

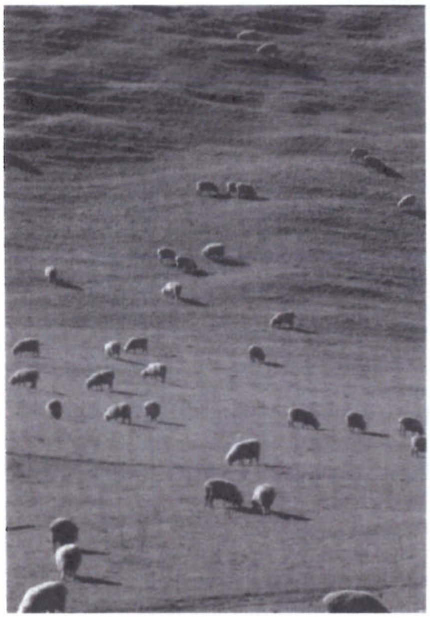

Photo left: Livestock urine is a major source of nutrients.
Photo right: Treecrops displace livestock, but are they as profitable?

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POSTSCRIPT

We hope that you have enjoyed participating in this paper, and that it has served to wet your appetite for further experience with trees – whether this is for productive purposes or as amenity and conservation interests.

We would welcome your comments on the paper, and suggestions for improvement, so please write to us. We hope to meet you again as further "Trees" papers come on stream in future.