STRUCTURE AND GROWTH OF DENSE PODOCARP FOREST AT TIHOI, CENTRAL NORTH ISLAND, AND THE IMPACT OF SELECTIVE LOGGING

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ABSTRACT

In rimu (Dacrydium cupressinum) *dominated forest at Tihoi, 61% of a sample of 120 sound rimu trees had between 400 and 500 growth rings, which were assumed to be annual. A further 14% were 500 to 574 years old and 25% were between 200 and 400 years old. On average, matai* (Podocarpus spicatus) *were older and miro* (Podocarpus ferrugineus) *younger than rimu.*

Cross-sections at stump height often showed a characteristic diameter growth pattern. After an initial period of very slow diameter growth (usually 60 years) was a period (average 72 years) of relatively rapid growth. Then followed a long period of more even and slower diameter growth culminating in a period of very slow growth (average 65 years) for almost half the sample. Although the largest trees tended to be older than the smallest trees, diameter was an unreliable indicator of age.

Older trees tended to have larger and more healthy looking crowns than younger trees. This may reflect reduced growing space available to younger trees.

Estimated stand increment in a 12 ha control block was 1.79 $m^3/ha/yr$, and measured natural losses over the 3-year period were 2.47 $m^3/ha/yr$. Logging has resulted in an increase in mortality with an estimated net loss of 3.44 $m^3/ha/yr$ in the 30% logged block and 7.89 $m^3/ha/yr$ in the 55% logged block. If the short-term pattern of logging-induced losses is maintained, the values of the forest may be seriously diminished. However, the 3-year measurement period provides an inadequate base for the extrapolation of long-term mortality patterns, and both the mortality and increment data require further experimental verification. The spread of internal rots also requires study.

The experience gained from this trial has provided a good basis for drawing up criteria for future selective logging in dense podocarp stands of similar structure. These criteria are currently being tested in new trials established in Whirinaki State Forest.

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INTRODUCTION

In 1974-5 a selective logging trial was established in a stand of dense mixed podocarps in Tihoi State Forest (Herbert and Beveridge, 1977). After logging, the growth pattern of rimu (*Dacrydium cupressinum*) was examined on cross-sections removed from the stumps. Sections from several matai (*Podocarpus spicatus*) and miro (*Podocarpus ferrugineus*) stumps were also examined. Information arising from ring counts has been used in this preliminary study of stand increment in central North Island dense podocarp forest.

The stand developed on Taupo pumice gravels and sands at 660 m a.s.l. The terrain is flat to undulating and the stand was located midway between Mt Pureora and Mt Titiraupenga near the northern end of the Hauhungaroa Range.

Rimu was dominant being generally tall (to 45 m) and slender with small crowns, some of which were storm battered. Matai was abundant and usually subdominant to rimu. Malformed stems and internal rots were frequent but most crowns were healthy. Miro was common in the subcanopy. Hall's totara (*Podocarpus hallii*) and kahikatea (*Dacrycarpus dacrydioides*) were rare. There was a sparse subcanopy including hinau (*Elaeocarpus dentatus*), maire (*Nestegis cunninghamii*), mahoe (*Melicytus ramiflorus*), *Pseudopanax edgerleyi,* and kamahi (*Weinmannia racemosa*), and an open understorey of pepperwood (*Pseudowintera colorata*), tree-ferns (*Dicksonia* and *Cyathea* spp.), and ground ferns (*Blechnum, Todea, Asplenium* spp.). Small gaps resulting from natural windfall were occupied by putaputaweta (*Carpodetus serratus*), broadleaf (*Griselinia littoralis*), *Rubus* spp., and other climbers.

The trial was divided into a control and two experimental blocks, all of about 12 ha. Thirty and 55% of the merchantable podocarp volume was removed from the trial blocks. In the trial blocks the average stocking of podocarps over 30 cm d.b.h. was 81 stems/ha of which 47 rimu, 7 miro, 7 matai, and one other podocarp were considered merchantable. Mean merchantable volume was 552 m^3/ha.

STAND STRUCTURE AND GROWTH PATTERN OF RIMU

Methods

Control and trial blocks were 100% cruised and tagged, and all trees 30 cm d.b.h. were mapped before logging. Subjective assessments were made of crown and stem condition, size and location of natural gaps, and patches of regeneration.

An average cross-section or wedge was removed from all sound rimu stumps that could be readily located after logging. In all, 120 rimu (10.2% of all merchantable rimu in the blocks), 14 matai, and 5 miro were sampled.

One core measuring 8 cm wide by 2 cm deep and extending from pith to bark was cut from each cross-section or wedge. Rings were counted under a variable-powered dissecting microscope and for the purposes of this paper it is assumed that latewood bands were formed annually. This is supported by results for Westland rimu where Franklin (1969) records the regular occurrence of conspicuous rings indicating that they were formed contemporaneously in all relatively fast-growing trees. These "marker" rings correlate with cool autumn temperatures in the years in which they were presumed to have formed.

Unless stated otherwise, measurements and results refer to stump height (about 60 cm above ground level). Whole-tree growth rate means have been calculated by dividing the breast height diameter (o.b.) by age at stump height. This results in a slight underestimate of increment as the period taken for an established seedling to grow from stump height to breast height (possibly 10 years) has not been taken into account.

Results

1. *Age Class Distribution.* Figure 1 shows the age class distribution of all sampled rimu trees. Most trees (61%) were between 400 and 500 years old, with 14% between 500 and 574 years and 25% between 200 and 400 years at stump height (60 cm above ground level). Thus, for rimu over 30 cm d.b.h. there was an age span of about 400 years although 61% of these trees established within a 100-year period.

Of the 14 matai, 9 were between 619 and 676 years old, and the remainder 458 to 582 years old at stump height. Five miro trees were 331, 414, 456, 457, 472 years old at stump height.

2. *Diameter/Age Relationships and Size Class Distribution.* Figure 2 shows stump-height age of rimu against o.b. breast height diameter. Although there is a tendency for the largest trees to be older than the smallest trees, there is much variation and diameter is an unreliable guide to age. Beveridge (1973) and others aged a total of 75 rimu trees by stump analysis. The age ranges were similar to the Tihoi stand and in each case diameter was an unreliable indicator of age.

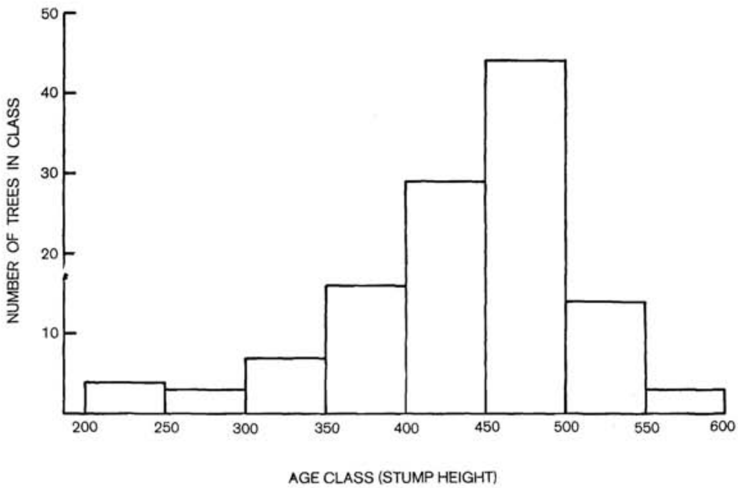

FIG. 1: *Age-class distribution of rimu sampled from Tihoi dense podocarp stand.*

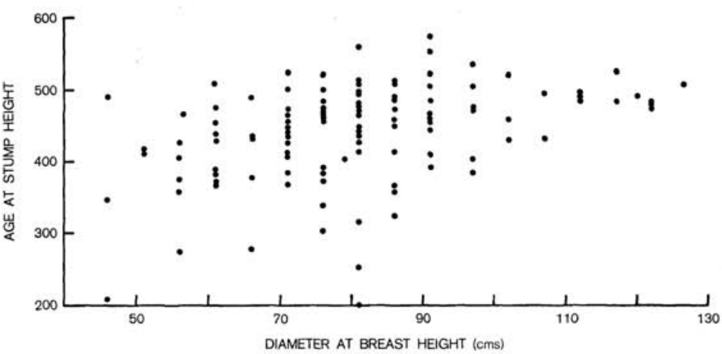

FIG. 2: *Diameter/age relationship for rimu sampled from Tihoi dense podocarp stand.*

3. *Pattern of Growth.* Most trees showed three and sometimes four distinct phases of diameter growth, with each phase apparently related to a developmental stage.

(a) Growth during the small pole phase — age was measured at 4, 8 and 16 cm diameter. Aging was at stump height and on average 22 years must be added to age estimates to obtain total age. This value was obtained by making ring counts, at ground level, of 18 rimu seedlings between 40 and 60 cm high, growing in subdued light in the trial blocks.

Although Table 1 shows that initial growth rates were very slow, in general they did increase as the saplings and poles grew older.

The 12 rimu analysed by C. R. Cruttwell (unpubl. rep.) in 1949 also showed an initial period of very slow growth (mean age 104 years at 15 cm diameter) whilst Beveridge's (1973) sample trees had taken from 100 to 150 years to reach 15 cm diameter. The trees in the Tihoi sample have therefore been faster growing in the pole phase than those measured by Cruttwell or Beveridge.

TABLE 1: GROWTH PATTERN OF RIMU DURING THE SMALL POLE PHASE

Stump Height Diameter (cm)	*Mean Age ± S.E.*	*Rings/cm of Radius*	*Age Range*	*Mean Total Age*
4	23.9 ± 0.7	12.0	10– 51	46
8	39.5 ± 1.1	7.8	20– 81	62
16	56.8 ± 1.5	4.3	33–108	79

(b) Rapid growth phase — to minimise bias resulting from prolonged eccentric growth along the sample radius, this analysis was confined to the 94 trees where the radius of the sample core was approximately half the diameter of the stump. With one exception all trees showed marked increase in growth rate between 8 and 16 cm diameter and this was often continued as a "rapid growth phase". For the purpose of analysis a "rapid growth phase" was defined as a period of at least 20 years when the average growth rate was at least twice that of the whole tree mean. The limits of this phase were subjectively chosen but were usually quite obvious. On this basis 43 trees had a period of rapid growth. In 80% of them rapid growth commenced within ± 15 years of attaining 16 cm diameter, and for 77% of the trees rapid growth was sustained for 50 to 100 years (average 72 years). The mean annual diameter increment over the period of rapid growth was 4.4 ± 0.17 mm.

(c) Steady growth phase — all trees had a long period following on from the two previous phases, during which the bulk of the tree's growth took place. This phase usually commenced between ages 80 and 150 years and sometimes continued to the time of felling.

(d) Slow growth phase — during the investigation it became clear that some trees had grown exceptionally slowly over the last few decades. This feature was examined for the 38 cores remaining after the balance were expropriated, presumably for firewood. In this case the mean annual increment over a period of 20 or more years was required to be less than half the whole tree mean. Nine trees had no decrease in growth rate and 11 trees had periods of reduced growth but with means in excess of half the whole tree means. By definition 18 trees had a period of "slow growth". On average the period of slow growth lasted for 65 years (range 22 to 117 years) with a mean annual diameter increment over the period of 0.89 ± 0.05 mm.

4. *Crown Condition and its Relation to Age and Growth Rate.* Before logging, the crowns of all trees were visually assessed and scored as superior (3), average (2), poor (1). Although subjective the assessment provided a relative estimate of apparent health and vigour. Many of the crowns were storm battered (by wind and infrequent snow storms) and only a few could be classed as superior compared with the best-crowned trees in some other central North Island localities at lower altitudes.

From Table 2 it appears that the trend is for older trees to have healthier crowns than younger ones. While the crowns were developing after the pole phase some of the older trees would have had space to develop large spreading crowns; younger trees would have had progressively less space and a proportion of them would develop thin wispy crowns typical of some rimu growing in crowded conditions.

For the 38 cores examined for present growth rate in the above section there was no correlation between crown condition and present growth rate. Mean crown condition indices for the 18 slow-growing, 11 intermediate, and 9 evenly growing trees were 1.61, 1.18 and 1.67, respectively.

TABLE 2: MEAN CROWN CONDITION INDEX BY AGE CLASS

Age Class (yr)	*200-300*	*301-400*	*401-500*	*501-600*
No. trees	3	21	62	15
Mean crown condition	1.33	1.24	1.72	1.86

5. *Stand Growth.* The mean annual diameter increment of all rimu trees sampled was 1.89 mm. With increments of 1.86 mm, 1.91 mm, and 1.84 mm for trees with superior, average, and poor crowns, respectively, there was no correlation between mean annual diameter increments and crown condition. The lack of correlation is to be expected since over a period of 400 to 500 years changes in the crown status of individual trees are likely to have

TABLE 3: ESTIMATED INCREMENT BY TREE SPECIES AND MERCHANTABILITY CATEGORIES, TIHOI SELECTIVE LOGGING TRIAL. STOCKING IS POST-LOGGING STOCKING (SEPTEMBER 1975) AND SLIGHTLY OVER-ESTIMATES CURRENT STOCKING AND INCREMENT

Species	Diameter Increment (mm/yr)	*Control*		*30% Block*		*55% Block*	
		Stocking (stems/ha)	Increment (m^3/ha/yr)	Stocking (stems/ha)	Increment (m^3/ha/yr)	Stocking (stems/ha)	Increment (m^3/ha/yr)
MERCHANTABLE							
Rimu	1.89) see 0.89) text	37.6	1.46	35.4	1.38	16.8	0.65
Miro	1.37	4.1	0.06	5.3	0.08	6.7	0.10
Matai	1.16	3.8	0.06	0.9	0.01	5.2	0.08
Subtotal		45.5	1.58	41.6	1.47	28.7	0.83
UNMERCHANTABLE (CULL)							
Rimu	1.89 0.89	2.3	0.09	3.2	0.13	2.1	0.09
Miro	1.37	1.4	0.02	2.9	0.04	1.8	0.03
Matai	1.16	6.6	0.10	4.3	0.06	13.1	0.20
Subtotal		10.3	0.21	10.4	0.23	17.0	0.32
Grand total		55.8	1.79	52.0	1.70	45.7	1.15

occurred. For generally smaller trees (diameters between 15 and 70 cm) C. G. R. Chavasse (unpubl. rep.) regarded crown condition, in particular the freedom of crowns, as a diagnostic feature in assessing the relative vigour of rimu trees in Westland.

There was no consistent correlation between age and present growth rate, or diameter and present growth rate, for the 38 stems measured for this parameter. For Westland rimu, Franklin (1973) found that the greatest diameter growth was generally made by the largest trees.

STAND INCREMENT AND THE INFLUENCE OF SELECTIVE LOGGING

Gross Volume Increment

Volume production for podocarps over 30 cm d.b.h. has been estimated. These estimates are for those parts of the tree that would be regarded as potential saw timber if sound. Increments have been calculated on the basis of post-logging stocking (Table 3) using the data from stump analyses as an estimate of current mean annual diameter increments.

Trees cruised as merchantable — *i.e.*, over 30 cm d.b.h. — and from which more than 50% of the log volume was recoverable made up the bulk of the stand and provided most of its increment. There were some differences in stocking and composition between the blocks but all would be typed as "L_1 — dense podocarp forest". Before logging total rimu stocking was about 40 stems/ha in the control and 55% blocks, 58 stems/ha in the 30% block. Miro and matai occurred at 33 stems/ha in the 55% block and at 15 stems/ha in the control and 30% blocks.

According to the data from stump analyses of the sub-sample of 38 trees, 47% of rimu were currently slow-growing (0.89 mm diameter increment/annum) and it is assumed that the same proportion of all trees in the stand had similar current growth rates. Measurements of current growth rate for all trees other than the 18 classed as "slow growing" were not obtained and the stand average annual growth rate of 1.89 mm diameter increment has been substituted for the actual current growth of the remaining stand trees. Although these figures can give only an indication of the true current growth rates of the trees remaining after logging, general observations throughout the area suggest that they are realistic for this stand.

Butt logs provide most volume increment but there was an average of 0.79 head logs/merchantable rimu. Head logs have been assigned the same growth increments as butt logs in the same proportion of "slow" and "other" trees and are included under "Rimu" in Table 3.

Miro and matai generally fluctuate less in growth rate than rimu. Estimates of volume increment are based on the average growth rate of each species (miro 1.37 mm and matai 1.16 mm diameter increment per annum). Only 1.2% of miro and 11.6% of matai had head logs and the insignificant contribution to increment of the head logs has been ignored.

Estimates of volume increment for trees cruised as culls have been made on the same basis as for merchantable trees.

During logging all felled trees were accurately measured and the cruise data were shown to have underestimated tree volume by 48.9%. Excessive allowance for defects, underestimating log lengths and over-estimating shatter have been the main sources of error. All volume estimates based on cruise data have therefore been adjusted upwards to correspond with scaled volumes.

Average log lengths and breast height diameters were calculated from the complete cruise data for miro and matai and from the 120 sample stems for rimu (a 10.2% sample of the trial blocks). Annual increment was taken to be the difference between two calculations of volume: one was derived from average d.b.h. plus a value representing current annual diameter increment, and average log length for each species and category; the second was determined from average d.b.h. and log length.

The volumes were calculated from the Mature Rimu Volume Equation (Ellis, 1980). Because this expression is derived from rimu representing a range of growth forms in the region, it probably slightly underestimates volume and hence increment for the exceptionally tall, clean-boled trees in the Tihoi stand.

Results are shown in Table 3. In calculating increments in the trial blocks no allowance has been made for response to logging. James and Franklin (1977) recorded an 11% positive response to selective logging for trials in a vigorous terrace stand in Wanganui State Forest.

Gross annual increment in the control block is estimated to be 1.79 m^3/ha, of which 89% is from merchantable trees. Rimu provides 90% of the increment. With its higher stocking, gross annual increment in the 30% block could have been about 2.6 m^3/ha. This compares with Westland terrace forest increments ranging from 1.50 m^3/ha (gross — Franklin, 1973) to 4.14 m^3/ha (net — James and Franklin, 1977).

In the 30% block, 91% of felled trees were rimu; in the 55% block, 77% were rimu. Assuming no growth response by residual trees to logging, gross annual increments are of the order of 1.70 and 1.15 m^3/ha, respectively.

Decrement

Measurable wood losses have been from natural and induced standing death and windthrow (Table 4). Standing dead trees, usually resulting from logging damage to root systems, account for 9.5% of tree losses in the trial blocks (none in the control).

In the control block, decrement (2.48 m^3/ha/yr) exceeds estimated gross increment (1.79 m^3/ha/yr) by a relatively small amount. With the limitations of the data and the short period since logging, it is reasonable to assume that losses about equal gains although the data and the frequency and size of canopy gaps in the block do suggest the stand may be opening up.

Substantial additional tree losses have accrued since forest modification by logging: in the 30% block, losses (5.14 m^3/ha/yr) exceed estimated increment (1.70 m^3/ha/yr) by three times; in the 55% block, losses (9.04 m^3/ha/yr) exceed estimated increment (1.15 m^3/ha/yr) by eight times.

TABLE 4: DECREMENT (WINDFALLS AND STANDING DEAD TREES) AND ESTIMATED INCREMENTS FOR PODOCARPS IN THE 3-YEAR (NOV. 1975 TO NOV. 1978) POST-LOGGING PERIOD IN TIHOI SELECTIVE LOGGING TRIALS

	Control			*30% Block*			*55% Block*		
	Merch.	*Cull*	*Total*	*Merch.*	*Cull*	*Total*	*Merch.*	*Cull*	*Total*
Decrement	1.41	1.07	2.48	2.94	2.20	5.14	2.54	6.50	9.04
Gross increment	1.58	0.21	1.79	1.47	0.23	1.70	0.83	0.32	1.15
Net increment	+0.17	–0.86	–0.69	–1.47	–1.97	–3.44	–1.71	–6.18	–7.89

If only merchantable trees are considered the status quo is about maintained in the control block, whilst in the 30% block losses (2.94 m^3/ha/yr) exceed estimated increment (1.47 m^3/ha/yr) by two times; in the 55% block losses (2.54 m^3/ha/yr) exceed estimated increments (0.83 m^3/ha/yr) by three times. Logging has therefore had a major impact on the pattern of wood production and loss and if this pattern of loss is maintained the multiple values of this forest as podocarp high forest could be seriously impaired.

Table 5 illustrates the relatively high susceptibility of cull trees to windthrow and standing death.

TABLE 5: PROPORTIONAL LOSSES OF CULL TREES

	Control		*30% Block*		*55% Block*	
	Merch.	*Cull*	*Merch.*	*Cull*	*Merch.*	*Cull*
No. trees windthrown or died	6	4	22	11	25	37
Culls as % of virgin stand	18		15		23	
Culls as % of tree losses	40		33		60	
Culls as % of volume losses	43		43		72	

In the control block cull trees make up 40% of tree losses and 43% of volume losses whilst comprising only 18% of the original stand. Little change has occurred in the 30% block but with increased opening up in the 55% block relative losses from cull trees have greatly increased to 60% of tree losses (from 23% of the original stand). From a timber production viewpoint these losses may appear of little consequence but this ignores the substantial ecological and amenity values of cull trees and, furthermore, overlooks the fact that accelerated loss of cull trees has led to major openings in the stand and increased the risk of merchantable trees being windthrown.

Further Volume Losses

Internal rots, which occur in all podocarp species, eventually cause sound trees to deteriorate. Already 18% of podocarps in the stand are unsound, and the rate of internal decay and windthrow will increase as the predominant age class of rimu (400- to 500-year-old trees) approaches the end of the normal life span. Of 195 aged rimu from Tihoi, Whirinaki, and Mahinapua State Forests, only two exceeded 700 years old. This may indicate the order of life span to be expected and, if so, about 75% of rimu in this stand could be expected to die in the next 300 years (from Fig. 1). The potential annual losses from internal decay must therefore be regarded as substantial.

DISCUSSION AND MANAGEMENT IMPLICATIONS

Despite the superficially even-aged appearance of the stand, the age range of podocarps spans about 500 years. This implies a long regeneration period, with matai then rimu colonising the site under a hardwood nurse. Miro established under the matai and rimu canopy. The rate at which rimu established built up rapidly over 100 years to reach a maximum 500 years ago. By 1580 some 61% of existing rimu had established. Thereafter the rate of establishment decreased until 200 years ago, since when there has been almost no further recruitment of rimu. Podocarp regeneration over 2 cm d.b.h. is now barely represented in the stand although there were over 1200 seedlings/ha (30 cm to 2 m tall) in this forest type before logging. It appears that the development of regeneration requires opening of the overstorey and there is evidence from regeneration surveys along the eastern Hauhungaroa Range for this (*e.g.*, Herbert, 1978). This is not necessarily so in other districts where hardwood competitors may restrict podocarp regeneration to the most favourable sites.

The effect of differences in the life-histories of individual trees has resulted in very little correlation between diameter and age. However, four phases of growth can normally be recognised. An initial period of slow growth (60 to 80 years from seed) resulting from partial suppression under a nurse crop was followed by a surge of relatively rapid growth starting at about 16 cm diameter, lasting 50 to 100 years, and coinciding with the poles' penetration of the nurse crop. Then followed an extended period of more or less steady growth which in most trees terminated, on average, 65 years ago, since when growth has been slower.

The trial has provided valuable short-term information on the effects of high levels of selective logging in dense podocarp forest.

Gross annual increments before logging were probably of the order of 1.8 to 2.5 m^3/ha, depending on stocking, with natural windfall possibly slightly exceeding increment. The removal of 30% and 55% of the merchantable volume in a single operation has had a major impact on the pattern of stand mortality with estimated net volume increments in the two trial blocks being of the order of —3.44 and —7.89 m^3/ha/yr, respectively. As a first operation in forest of this type, it does not appear to have been successful in maintaining the structure and stability of the residual forest, nor is it likely to have provided conditions suitable for a major growth response by residual trees to compensate for induced losses.

However, it has provided a firm base on which to structure future logging operations in forest of this type. Experience from the trial operations and from subsequent monitoring indicates that the following requirements should be incorporated in logging operations:

(1) Greater use of wedges for directional felling

(2) Emphasis on the quality of the operation rather than on production

(3) Use of smaller tractors

(4) Strict control over tractor movement

(5) Increased use of winch ropes to reduce machine movement

(6) Reduction of log lengths to a 3 to 6 m range

(7) Removal of the blade from the tractor to increase manoeuvrability and decrease incidental damage

(8) Emphasis on summer rather than winter logging operations to reduce track deterioration and damage to trackside trees.

Furthermore, it is clear from these trials that the volume removed must be reduced if the forest condition is to be maintained, and a change in marking criteria is required if sustained yield management is the aim. It has been demonstrated that there is presently a considerable level of natural mortality and it is possible that the level will increase as the stand ages. If it were possible to identify the potentially unstable or senescent trees and to remove them without increasing mortality, this would reduce natural damage to the stand (by directional felling rather than random windthrow), provide a small yield of timber, and facilitate restocking of the stand with nursery-raised seedlings.

These criteria are currently being tested in a trial established in 1978-9 in dense podocarp forest in Whirinaki State Forest. However, recognising the susceptibility of this forest type to modification it would be prudent to reduce management-scale operations in such stands to a minimum until such time as the technique has been proven ecologically sound.

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