SELECTIVE LOGGING OF DENSE PODOCARP FOREST AT WHIRINAKI: EARLY EFFECTS

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ABSTRACT

A selective logging trial was established in 1979 at Whirinaki State Forest Park in the North Island, New Zealand, in dense podocarp forest dominated by rimu (**Dacrydium cupressinum** Lamb.) to determine whether forest of this kind could be logged and remain a podocarp-dominant high forest with multiple values intact. Three different tree-selection criteria were used in the removal of 9–15% of merchantable wood volume from three blocks – preferential removal of apparently unstable trees (S), individual tree selection (I), and group selection (G).

An immediate assessment of logging-induced damage showed more widely dispersed slash and a somewhat higher incidence of more serious kinds of damage to residual trees in Block S. There were large numbers of small, mostly ephemeral, naturally regenerated, podocarp seedlings but very few larger ones – a situation which is not well understood. Conversely, regeneration of the dominant hardwood, tawa (**Beilschmiedia tawa** (A. Cunn.) Kirk), was well represented in all sizes. Differences between blocks were slight.

In the first 3-year period after logging, tree mortality (almost all wind-induced and mostly during a single major storm) occurred at similar rates in the unlogged control and in Blocks I and G, but was much less in Block S.

Gross volume increment, almost all in merchantable podocarps, was similar in all blocks, but at **c.** 0.9 m^3/ha/annum was lower than has been recorded for similar forest elsewhere in the central North Island and in south Westland, South Island. Net decrement, about half in merchantable trees, occurred in all blocks, but was much lower in Block S (–1 m^3/ha cf. –5 m^3/ha/annum).

Keywords: podocarps; selective logging; growth rate; mortality; volume increment; regeneration.

INTRODUCTION

Dense podocarp forest is classed as containing between 50 and 90 merchantable podocarp trees per hectare, and a merchantable volume of 300–600 m^3/ha (Beveridge 1983). It has traditionally been an important source of native timber in the central North Island of New Zealand where, until recently, management practice usually involved clearfelling followed by conversion to plantations of exotic conifers. Since 1975, in line with the new Management Policy for New Zealand's State indigenous Forests (New Zealand Forest Service 1977), logging in this class of forest in State Forest tenure has been on a selective basis only. The many other special values (for example, wildlife habitat – Moynihan *et al.* 1979) have become increasingly recognised and most of the remaining area has been set aside in biological reserves.

The first experimental selective logging in dense podocarp forest in the central North Island took place in 1974 in the Tihoi Block of Pureora State Forest Park, west of Lake Taupo, and involved removal of 30% and 55% of merchantable podocarp volume from two blocks (Herbert & Beveridge 1977). Early results (Herbert 1980) indicated that lower volumes should be removed if forest structure and stability were to be maintained; criteria were suggested which would reduce the impact of logging on the forest.

A selective management trial was set up in dense podocarp forest in Whirinaki State Forest Park to evaluate the success of different logging methods in harvesting a small volume of timber while retaining a stable residual stand with canopy gaps suitable for seedling development (New Zealand Forest Service 1981a). In this trial, three different tree selection criteria were used in removing 9–15% of merchantable volume in mid-1979, and some improvements in logging methods were adopted. This paper discusses (a) logging damage to ground and residual trees, (b) stability, (c) productivity of both logged and unlogged stands, and (d) natural and artificially established regeneration.

BACKGROUND

A large part of Whirinaki State Forest Park lies between the eastern edge of the Kaingaroa Plateau and the Whirinaki River. It occupies dissected greywacke and ignimbrite bedrock overlain by deep deposits of rhyolitic volcanic ash, which give rise to yellow-brown and podzolised yellow-brown pumice soils (W. C. Rijkse, pers. comm.). The area is sheltered and has a moderately sunny climate with a rather variable annual rainfall of *c.* 1400 mm. About 130 ground frosts occur per year (Nicholls 1969; Wards 1976). The trial is situated on undulating terrain in the upper Tauranga Stream catchment, at altitudes of 450–550 m, 4 km west of Minginui village, and is bisected by Okurapoto Road (Fig. 1).

Before logging, the forest consisted of large rimu up to 60 m in height, smaller matai (*Prumnopitys taxifolia* (D. Don) de Laub.)*, and miro (*P. ferruginea* (D. Don) de Laub.), scattered kahikatea (*Dacrycarpus dacrydioides* (A. Rich) de Laub.), and occasional totara (*Podocarpus totara* D. Don) forming a dense main canopy, with a scattered subcanopy of tawa and occasional other hardwoods (Table 1) (Types L1 and L2, McKelvey & Nicholls 1957). The widespread occurrence of decaying stumps and boles of podocarp trees indicates an even greater tree density in the recent past.

Diameter distributions of the major species are shown in Fig. 2. Those of rimu and matai are unimodal, characteristic of similar dense podocarp forest elsewhere in Whirinaki (McKelvey 1973) and of even-aged stands (Carron 1968). However, rimu and matai in the trial area (A. Katz, unpubl. data), and matai in similar forest elsewhere in

* Recent name changes (Edgar & Connor 1983) are **Prumnopitys taxifolia** previously **Podocarpus spicatus** R. Br. ex Mirb., and **Prumnopitys ferruginea** previously **Podocarpus ferrugineus** G. Benn. ex D. Don. All other names are according to Allan (1961).

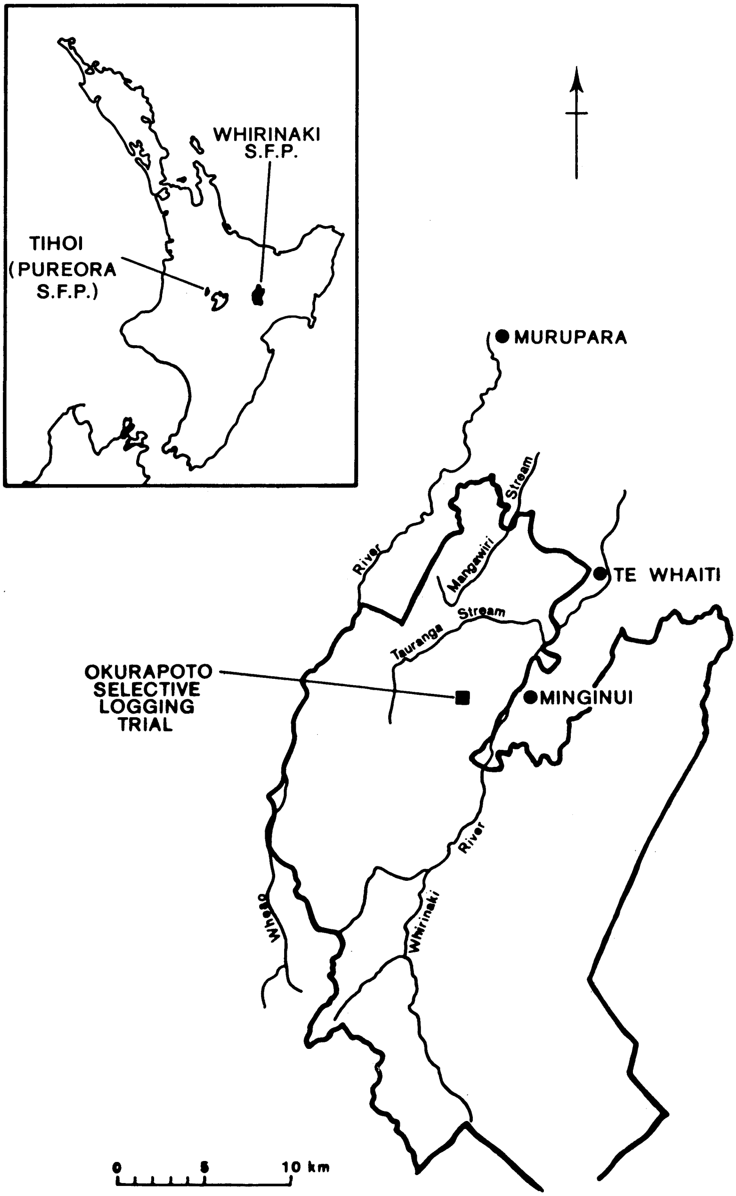

FIG. 1—Location of Whirinaki State Forest Park and Okurapoto selective logging trial.

TABLE 1 – Composition of dense podocarp forest, Whirinaki, before logging*

	Rimu	Matai	Miro	Kahikatea and totara	Tawa†	Other hardwoods	Total
Group removal							
(Block G)							
Density (stems/ha)	54.3	19.0	33.8	1.2	21.2	1.6	131.1
Mean diameter (cm)	95.1	79.5	47.9	101.9	40.6	47.7	(71.3)
Basal area (m^2/ha)	42.2	10.0	6.5	1.0	2.9	0.3	62.9
Merchantable volume‡ (m^3/ha)	485.3	40.4	50.6	13.0	16.3	2.1	607.7
Unstable tree removal							
(Block S)							
Density (stems/ha)	49.8	22.2	20.5	1.8	26.1	2.2	122.6
Mean diameter (cm)	96.7	84.0	48.8	77.8	41.0	50.6	(73.4)
Basal area (m^2/ha)	40.1	13.1	4.1	1.1	3.7	0.5	62.6
Merchantable volume‡ (m^3/ha)	467.0	77.4	33.7	11.9	20.7	3.1	613.8
Individual tree removal							
(Block I)							
Density (stems/ha)	43.7	35.5	17.7	7.6	28.8	2.3	135.6
Mean diameter (cm)	99.7	68.0	48.7	108.9	40.4	44.2	(71.8)
Basal area (m^2/ha)	37.3	14.1	3.5	7.9	3.9	0.4	67.1
Merchantable volume‡ (m^3/ha)	433.3	52.8	26.9	80.5	23.4	2.0	618.9
Control							
(Block C)							
Density (stems/ha)	55.7	27.0	24.1	5.7	28.0	1.3	141.8
Mean diameter (cm)	94.1	78.4	45.8	94.0	40.6	39.3	(71.8)
Basal area (m^2/ha)	42.1	14.0	4.2	4.7	3.8	0.2	69.0
Merchantable volume‡ (m^3/ha)	450.9	64.3	30.7	56.7	23.7	0.9	627.2

* Stems greater than 30 cm d.b.h. only.
† Density and basal area substantially under-estimated because few cull trees were assessed.
‡ For trees cruised as "merchantable" only.

Whirinaki (R. J. Cameron, unpubl. data) are uneven-aged; thus dense podocarp forest here exhibits the apparent "even-aged aspect" described by Jones (1945) as common in temperate forests of the Northern Hemisphere. Diameter distributions of miro (also uneven-aged) and tawa are of the "reverse J" kind, characteristic of uneven-aged stands (Carron 1968), particularly of shade-tolerant species undergoing continuous replacement.

In 1945–46 a number of live and dead podocarp trees, mostly totara, were extracted from parts of the trial area, but the impact has been minimal.

Introduced brush-tailed possums (*Trichosurus vulpecula* Kerr) have been present for at least 15 years (Nicholls 1969), probably several decades longer, and remain moderately common (J. E. Knowlton, unpubl. data). Red deer (*Cervus elaphus* L.), present for several decades, were considerably scarcer in 1981–82 (Knowlton, unpubl. data) than in 1976–77 (G. T. Jane, unpubl. data). Feral cattle (*Bos taurus* L.) were present in the Whirinaki Valley some 35 years ago (Nicholls 1969) but are now extinct. Feral pigs (*Sus scrofa* L.) have probably been present for a century and a half and remain locally common (Knowlton, unpubl. data).

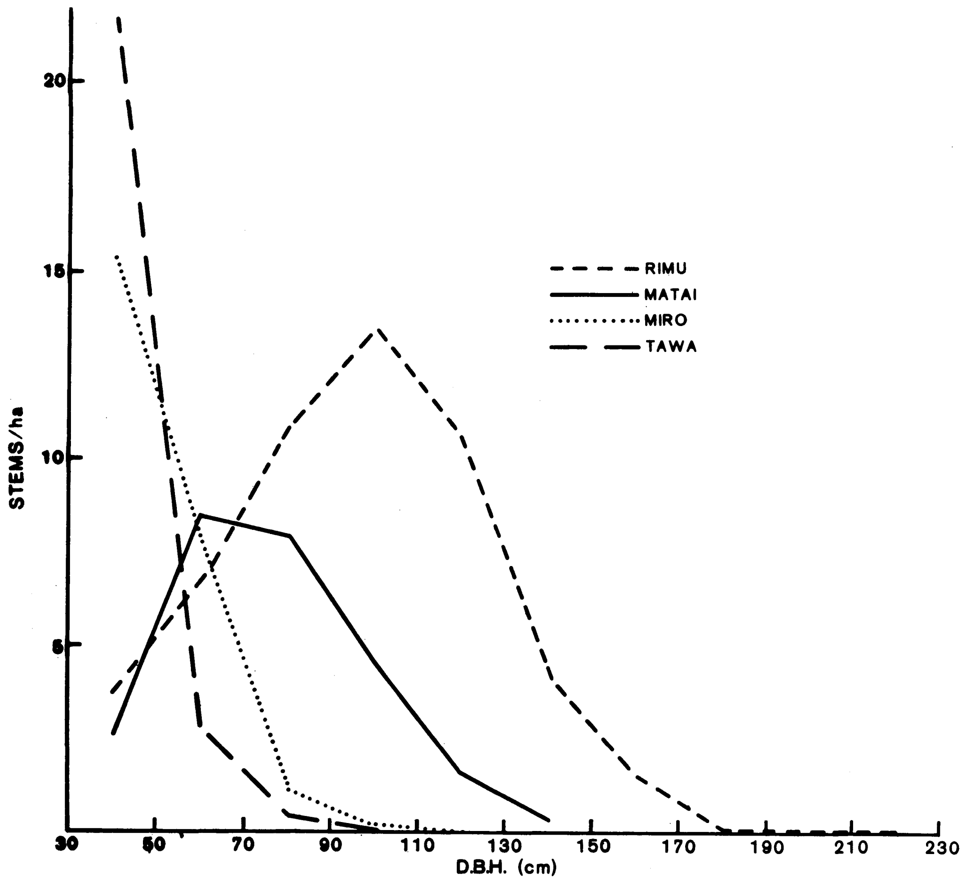

FIG. 2—Diameter distributions of major species in 43 ha of dense podocarp forest at Whirinaki, before logging.

The trial consists of three 10- to 13-ha blocks from which 9–15% of total merchantable volume was removed in several different logging patterns, and a fourth unlogged control of similar size (Table 2). Owing to lack of adequate available areas of forest of similar composition and also to economic constraints, replication of treatment blocks could not be undertaken. Although this inevitably precluded the use of statistical analysis, thus imposing limitations on the interpretation of results, it was considered that the trial could still provide valuable information.

Before logging, the four blocks were similar in composition, with only minor differences between blocks in abundance and diameter distribution of species (Table 1). In the silvicultural selection (S) block, only trees which appeared unstable were felled; included were those with advanced internal rots, declining crowns, or a substantial

TABLE 2 - Selective logging treatments: numbers, mean diameters, and volumes of trees removed

	Rimu	Matai	Miro	Kahikatea	Tawa	Other hardwoods	Total
Group removal							
(Block G)							
Stems/ha	8.61	1.86	2.17	0.08	2.02	0.16	14.90
Mean d.b.h. (cm)	91.9	78.5	50.3	101.0	44.1	54.6	(77.3)
Volume (m^3/ha)	75.57	9.60	4.15	0.99	2.00	0.27	92.58
Merch. vol. removed (%)	15.4	15.2	7.7	7.7	12.1	12.6	(13.9)
"Unstable" tree removal							
(Block S)							
Stems/ha	7.20	2.80	1.40	0.20	5.1	0.2	16.9
Mean d.b.h. (cm)	77.4	83.3	45.1	73.3	44.3	58.0	(65.5)
Volume (m^3/ha)	43.87	15.01	2.12	1.12	6.06	0.43	68.61
Merch. vol. removed (%)	9.1	8.5	4.4	9.4	24.7	7.1	(9.3)
Individual tree removal							
(Block I)							
Stems/ha	7.18	3.90	1.03	0.72	1.13	0.10	14.06
Mean d.b.h. (cm)	95.3	72.8	50.5	128.1	36.3	34.5	(82.5)
Volume (m^3/ha)	66.16	18.18	1.94	14.51	0.72	0.05	101.56
Merch. vol. removed (%)	14.9	23.0	5.6	21.5	2.9	0	(15.1)

lean. Trees were felled in small groups where possible. Additionally, some larger tawa were felled to provide gaps for restorative planting and some apparently sound podocarps were removed to allow for felling and tracking.

In the individual tree selection (I) block, trees were removed singly or in small groups, so as to avoid creating large canopy gaps. Sound trees with smaller crowns and which were reasonably accessible for felling, were removed in preference to large-crowned, obviously defective, or inaccessible ones. In the group selection (G) block, discrete groups of 5–6 or 10–12 trees were felled; these were groups of mostly merchantable trees that could be felled into a common gap. Logging in Blocks S and I created canopy openings of a variety of shapes and sizes; in Block G, larger gaps were formed.

Topography varied somewhat, with Blocks C and I occupying undulating terrain, and Blocks S and G steeper ground.

Logging equipment used (180 h.p. Caterpillar D7E, 160 h.p. International T.D. 20, and 130 h.p. T.D. 15 crawler tractors) was typical of machinery in use in selective logging in Whirinaki Forest and elsewhere. In all blocks, logging was carefully executed with maximum use of directional felling by hydraulic wedge and of winching to minimise machine movement and the need for haul tracks within the stand. Tractor blades were removed to prevent damage to residual trees. "Pretracking" was carried out in Blocks S and G as in the earlier trial at Tihoi (Herbert & Beveridge 1977).

Proportions of tree species removed in logging were similar in the three logged blocks, although a relatively high proportion of tawa was felled in Block S. Mean diameters of harvested trees closely approximated those in the original forest, although the predominantly defective/senescent rimu trees felled in Block S were generally smaller than average. Thus the volume removed from Block S was somewhat lower than from the other blocks (Table 2).

Trees cruised as "merchantable" provided nearly all of the volume harvested in Blocks I and G, and most in Block S. An associated experiment (J. C. Vaney, pers. comm.) was carried out with matai to determine conversion rates and grade recovery from "cull" trees, i.e., those assessed as unmerchantable because of defects such as internal rot, hollow boles, or poor form. Culls provided about half of the total volume of matai removed.

Although not originally prescribed, salvaging of accessible windthrown trees was undertaken in the first 3 years after logging, using a low-ground-pressure FMC skidder.

Immediately after logging ceased, nursery-raised seedlings of rimu and kahikatea, and some matai and totara, were planted in clusters in logged gaps. This was considered necessary because in previous selective logging trials here and at West Taupo, podocarp regeneration after logging was poorly distributed and slow to establish (A. E. Beveridge and J. W. Herbert, pers. comm.).

LOGGING-INDUCED DAMAGE

Method

Six months after logging, an assessment of ground condition in all blocks was undertaken, using transects 25 m apart and contiguous 1-m^2 plots within these; this gave a mean sampling intensity of 1.24%. In each plot, type of ground disturbance was recorded in one of five categories (undisturbed, recent extraction track, old extraction track, logging gap, other) and amount of slash accumulation in one of three categories (absent, light, heavy).

An assessment of condition of residual trees in logged blocks was completed 4 months after logging. All trees likely to have been affected by logging (over one-quarter of those remaining) were inspected for five kinds of damage:

(1) Crown damage caused by felling of adjacent trees, in one of three categories (none, less than 50% of crown lost, more than 50% of crown lost);

(2) Bole debarking caused by felling or extraction of other trees, in one of three categories (none, less than 20% of circumference debarked, more than 20% of circumference debarked);

(3) Slash accumulation on rootplate, in one of three categories (none, light, heavy);

(4) Compaction caused by tracking over rootplate, in one of three categories (none, tracking over less than 50%, tracking over more than 50%);

(5) Undercutting or severance of lateral roots, in one of two categories (present, absent).

Results and Discussion

Amount of logging-disturbed ground was similar in Blocks G and S, accounting for about one-fifth of the sampled area, although major extraction tracks were somewhat more extensive in Block G and logging gaps and minor tracks in Block S (Table 3). The amount of logging-disturbed ground was somewhat lower in Block I, reflecting the easier terrain and absence of machine-made clearings for restorative planting.

TABLE 3 – Ground disturbance and slash accumulation (percentage of sampled area)

	Group removal (Block G)	"Unstable" tree removal (Block S)	Individual tree removal (Block I)	Control (Block C)
Ground disturbance –				
Major extraction tracks*	5.4	3.6	3.2	1.5
Logging gaps/minor extraction tracks	13.1	17.5	11.1	0
Total	18.5	21.1	14.3	1.5
Slash† –				
Light	11.1	18.5	10.5	1.3
Heavy	13.5	20.4	12.8	0.6
Total	24.6	38.9	23.3	1.9
Logging-disturbed ground plus heavy slash on undisturbed ground	25.8	32.2	22.2	2.1
Ground undisturbed by logging or slash	68.3	56.4	71.0	96.6

* Includes very limited extraction tracks from earlier totara logging.

† Light slash = logs/branches less than 15 cm in diameter or foliage less than 15 cm deep.
Heavy slash = Larger logs/branches and deeper foliage.

Slash was more widely dispersed in Block S, covering about two-fifths of the sampled area as opposed to about one-quarter in Blocks G and I. Light and heavy slash were recorded in similar amounts, most (*c.* 60%) falling on otherwise undisturbed ground. Significant logging disturbance of any kind was rather more widespread in Block S than the other logged blocks and the proportion of totally undisturbed ground correspondingly lower.

In terms of residual trees, by far the commonest form of damage was slash accumulation on rootplates (commonly heavy), followed by compaction (Table 4). A higher proportion of trees was affected by slash accumulation, compaction, and undercutting in Block S than in Blocks G or I, and by crown and bole damage in Block I than Blocks G or S. Thus fewer trees were unaffected by logging in Blocks S or I than in Block G; in Block S this was attributable partly to the naturally scattered distribution of "unstable" trees (necessitating more dispersed machine movement), and their frequent occurrence amidst groups of healthy trees.

TABLE 4 - Logging-induced damage (percentage of residual trees affected)

	Block G		Block S		Block I	
	Podocarps	Tawa	Podocarps	Tawa	Podocarps	Tawa
Crown damage (loss)						
< 50%	2.5	4.0	3.4	8.1	7.5	11.4
> 50%	0.2	0	0.1	0	0.2	0
Total	2.7	4.0	3.5	8.1	7.7	11.4
Bole damage (circumference debarked)						
< 20%	1.3	2.4	1.5	0.5	2.4	3.4
> 20%	2.7	3.2	2.8	3.8	2.9	4.4
Total	4.0	5.7	4.3	4.3	5.3	7.8
Slash on rootplate						
Light	6.7	5.7	12.2	10.0	6.9	8.1
Heavy	16.0	8.9	23.9	14.8	14.8	8.1
Total	22.7	14.6	36.1	24.8	21.7	16.2
Rootplate compaction						
< 50%	10.9	8.5	15.5	11.0	10.3	7.4
> 50%	1.3	0.8	1.3	1.4	1.8	1.1
Total	12.2	9.3	16.8	12.4	12.1	8.5
Undercutting	5.5	5.7	7.0	8.0	4.8	4.1

In the earlier selective logging trial in dense podocarp forest at Tihoi, slash was dispersed over a broadly comparable area (32%) in the 30% logged block, and a larger (47%) area in the 55% logged block (Herbert & Beveridge 1977). The proportion of totally undisturbed ground was considerably lower in both blocks. Slash accumulation was the commonest form of damage to residual trees, occurring at a similar rate to that at Whirinaki, followed by compaction. The incidence of compaction and undercutting was similar at Tihoi to that in Block S, but higher than in Blocks G or I.

Clearly, therefore, lower volume removals at Whirinaki have reduced ground disturbance and some kinds of damage to residual trees. Of the three logging methods tested, individual tree selection and selection of apparently unstable trees appear to have caused greater disturbance and damage than group selection, with individual tree selection producing a somewhat higher incidence of damaged crowns and boles, and unstable tree selection leaving slash around more trees and a somewhat higher incidence of compacted and severed rootplates. The first three kinds of damage may be of minor significance; compaction and undercutting, however, may have serious long-term consequences for tree health and stability (Herbert & Beveridge 1977), so that unstable tree selection must be regarded as least favourable in this regard.

STABILITY

Method

Before logging, each block was demarcated into several large plots. A detailed assessment of the forest was carried out in each block, in which diameters over-bark at 1.4 m, merchantable heights, merchantable status, and bole condition of all podocarps and of all merchantable and some cull hardwood trees (mostly tawa) were recorded. All trees thus assessed were permanently tagged for future identification. Several assessments of mortality have been made in the 3-year period since logging to record mode of death (uprooting, snapping, standing death), cause of death (primary, secondary), and direction of fall.

Results

Tree mortality occurred at similar rates in logged Blocks G and I and in the control (1.11, 1.10, and 1.07 trees/ha/annum respectively), but was considerably less in logged Block S (0.43 trees/ha/annum) (Table 5). In particular, rimu – the largest species present – incurred much less mortality in Block S, so that the difference in volume lost between Block S and other blocks greatly exceeded the difference in tree losses. In Blocks G, I, and C, merchantable trees comprised just over half the wood volume

TABLE 5 – Annual tree mortality from 1979 to 1982: numbers, mean diameters, and volumes of dead trees

	Rimu	Matai	Miro	Kahikatea	Tawa	Other hardwoods	Total
Group removal (Block G							
Stems/ha	0.33	0.31	0.25	0	0.19	0.03	1.11
Mean d.b.h. (cm)	96.3	83.9	52.1	–	39.8	38.8	(72.0)
Volume (m^3/ha)	3.19	1.75	0.49	0	0.13	0.03	5.59
Volume lost (%)	0.75	2.05	0.97	0	0.85	0.99	(0.95)
"Unstable" tree removal (Block S)							
Stems/ha	0.07	0.13	0.07	0	0.13	0.03	0.43
Mean d.b.h. (cm)	127.0	77.0	40.0	–	42.0	62.0	(73.2)
Volume (m^3/ha)	0.89	0.66	0.07	0	0.14	0.09	1.85
Volume lost (%)	0.20	0.59	0.22	0	0.67	2.63	(0.30)
Individual tree removal (Block I)							
Stems/ha	0.38	0.24	0.21	0.03	0.21	0.03	1.10
Mean d.b.h. (cm)	111.9	72.2	51.5	138.0	40.5	46.2	(77.4)
Volume (m^3/ha)	4.09	1.02	0.37	0.68	0.16	0.03	6.35
Volume lost (%)	1.07	0.85	1.31	1.15	0.68	0.98	0.99
Control (Block C)							
Stems/ha	0.25	0.23	0.28	0.03	0.25	0.03	1.07
Mean d.b.h. (cm)	107.0	87.0	53.7	134.8	41.5	30.0	(73.9)
Volume (m^3/ha)	2.81	1.53	0.47	0.57	0.25	0	5.63
Volume lost (%)	0.57	1.19	1.33	0.96	0.93	1.03	(0.77)

lost; in Block S, some four-fifths. Over-all, there was a slight tendency for windthrown podocarps to be larger than the stand average. Diameter distributions of fallen trees (Fig. 3) show a general resemblance to those in the stand before logging (Fig. 2).

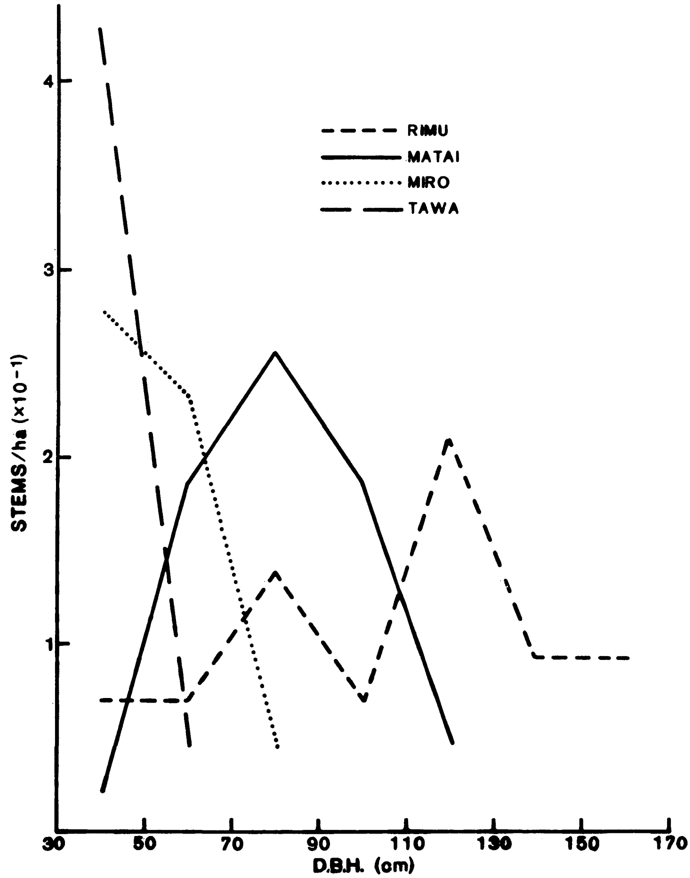

FIG. 3—Diameter distributions of windthrown trees of major species in all blocks.

Wind was the immediate cause of almost all tree death; standing death was negligible (Table 6). In most species, trees were windthrown directly (i.e., uprooted or snapped by the force of the wind) far more commonly than indirectly (i.e., uprooted or snapped by the weight of other falling trees). Uprooting and snapping were equally important causes of death from both direct and indirect windthrow in dominant rimu and co-dominant matai. Subdominant miro, in contrast, was windthrown indirectly as often as not, uprooting causing more of the deaths from direct windthrow and snapping more of the deaths from indirect windthrow. Snapping was relatively rare in tawa which, as a subcanopy species here, has relatively small root-plates.

TABLE 6 – Mode of death (stems/ha/annum) in all blocks

	Rimu	Matai	Miro	Kahikatea	Tawa	Other hardwoods	Total
Uprooting							
Direct*	0.08	0.11	0.05	0.01	0.09	0	0.34
Indirect†	0.01	0.01	0.03	0	0.03	0.01	0.09
Total	0.09	0.12	0.08	0.01	0.12	0.01	0.43
Snapping							
Direct	0.09	0.08	0.03	0	0.01	0.01	0.22
Indirect	0.01	0.01	0.05	0	0.01	0.01	0.09
Total	0.10	0.09	0.08	0	0.02	0.02	0.31
Standing death	0.01	0	0	0	0	0	0.01
Cause unknown							
Direct	0.03	0.03	0.01	–	0.03	–	0.10
Indirect	0.01	0.03	0.04	–	0.03	–	0.11
Total	0.04	0.06	0.05	–	0.06	–	0.21

* Windthrown directly by the force of the wind.
† Windthrown indirectly by the weight of other falling trees.

Amongst major species, the mortality rate was lowest in rimu, substantially higher in miro and tawa, and twice as high in matai as in rimu. The high mortality rate in matai reflects the relatively high incidence of detectable defects in this species (Table 7), which in turn may reflect its status as the oldest species present in the forest (A. Katz, unpubl. data). The susceptibility of obviously hollow and/or rotten trees to

TABLE 7 – Stem condition (as cruised) of dead trees in all blocks (figures in brackets show condition of all trees remaining after logging)

Species	Sound (%)		Defective (%) Hollow		Defective (%) Rotten	
Rimu	59.4	(92.0)	6.2	(1.9)	34.4	(6.1)
Matai	36.7	(52.5)	60.0	(0.7)	3.3	(46.8)
Miro	79.2	(91.9)	20.8	(0.2)	0	(7.9)
Kahikatea	50.0	(91.1)	50.0	(2.9)	0	(6.0)
Tawa	95.8	(97.0)	0	(0)	4.2	(3.0)
Other hardwoods	66.7	(90.3)	0	(0)	33.3	(9.7)
Total	64.7	(85.1)	3.5	(1.0)	31.9	(13.9)

windthrow is also evident in the other major podocarps present. A similar picture emerges from Table 8; podocarps are classified as "cull" usually because of detectable defect rather than poor form.

TABLE 8 – Merchantable status (as cruised) of dead trees – percentages of trees and volume made up of culls (figures in brackets show status of all trees remaining after logging)

Species	Percentage of trees		Percentage of volume	
Rimu	28.1	(4.4)	35.5	(4.4)
Matai	73.3	(29.1)	73.8	(52.3)
Miro	25.0	(9.5)	25.7	(9.1)
Kahikatea	0	(6.0)	0	(6.0)
Tawa	25.0	(9.6)	26.9	(12.6)
Other hardwoods	33.3	(16.7)	74.1	(20.7)
Total	38.8	(15.4)	42.4	(13.7)

Orientation of most direct windthrow towards the north-west quarter (Fig. 4) is a result of the prevailing wind direction of the storm of 9–10 April 1982, tropical cyclone "Bernie", which passed along the east coast of the North Island. Within

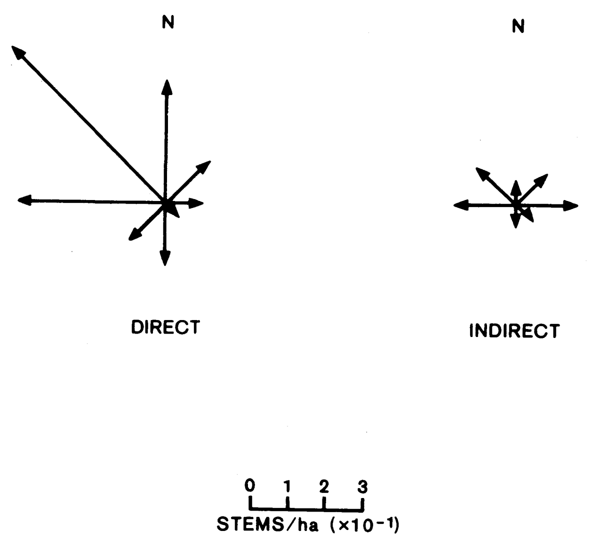

FIG. 4—Direction of fall of windthrown trees of all species in all blocks (direct = uprooted or snapped by the force of the wind; indirect = uprooted or snapped by the weight of other falling trees).

adjacent Urewera National Park, the wind direction varied between east-south-east and south-south-west (Shaw 1983). Indirect windthrow occurred in no such obvious pattern.

Discussion

Early results show that removal by selective logging of 9–15% of total merchantable volume has not adversely affected the short-term stability of dense podocarp forest in this area of Whirinaki Forest. This is in stark contrast to results over an equivalent period from the earlier trial in rather younger but otherwise similar forest at Tihoi. There, removal of 30% and 55% of merchantable podocarp volume accelerated mortality and reduced net increment; standing death, usually resulting from logging damage to root systems, accounted for a significant proportion of mortality (Herbert 1980). As at Whirinaki, however, cull trees were also relatively susceptible to windthrow and standing death.

Again in contrast to Tihoi, individual tree deaths at Whirinaki could seldom be related definitely to logging disturbance. Indeed, the major predisposing factor in mortality here appeared to be the presence of substantial defect, especially that of butt and stem. This was illustrated by the relatively high mortality in obviously defective trees and particularly in matai, the oldest and most defective species present. Root rots caused by pathogens including *Armillaria* spp. are frequently observed in uprooted rimu here (I. A. Hood, pers. comm.).

In the absence of replication, no definite relationship between logging treatment and stability can be established. Nevertheless, the susceptibility of defective trees to windthrow, and the relatively small number of cull deaths in Block S, do imply that selective removal of trees considered to be unstable has, in fact, reduced mortality in this block compared to others. However, the somewhat sheltered location of Block S below a prominent ridge leeward of the 1982 storm's wind direction, may also be a contributing factor to this reduced mortality.

In 2 days, the storm of April 1982 accounted for about twice as much tree mortality as happened in the rest of the 3-year period (New Zealand Forest Service 1983). In this region storms with wind peaks of such velocity occur relatively infrequently, only once in a matter of decades (Shaw 1983), and the return time for any given site is probably even longer. Thus mortality rates over the 3-year period have almost certainly been abnormally high, and are unlikely to be sustained, other things being equal. However, the substantial and sometimes severe damage to a significant proportion of residual trees resulting from such storms is likely to have a continuing effect on mortality. Moreover, mean ages of the major canopy species also suggest that mortality is likely to continue at a significant rate in the foreseeable future. Because age data are derived from sound trees only, true mean ages may be rather higher but they are estimated at *c.* 500 years for rimu and 600 years for matai (A. Katz, unpubl. data). The normal life span for rimu is 600–800 years (Franklin 1968), and the maximum ages recorded for matai are 676 years at Tihoi (Herbert 1980), *c.* 775 years at Okurapoto (A. Katz, unpubl. data), and 883 years elsewhere in this forest type at Whirinaki (R. J. Cameron, unpubl. data). Most of the current canopy trees are therefore expected to die within the next 200–300 years.

GROWTH AND PRODUCTIVITY

Method

Growth

Five 0.125-ha permanent growth plots were established in the control block in April 1979. It is difficult to measure radial increment by diameter tape over short periods in very slow-growing older podocarps, where annual growth is typically less than 0.1% of d.b.h. Dendrometer bands as described by Palmer & Ogden (1983) were therefore used. These were placed 1.4 m above ground level on all trees, and read annually for 4 years. Radial increment in the faster-growing hardwoods, chiefly tawa, where annual growth is of the order of 0.5% of d.b.h., was measured in all trees greater than 10 cm d.b.h. by diameter tape 1.4 m above ground level.

No attempt was made to obtain increment cores for the purpose of correlating dendrometer results with annual ring widths, in view of well-known dendrochronological problems (e.g., indistinct ring boundaries, ring wedging, and lobate growth) in the main podocarps present (Dunwiddie 1979; A. Katz, unpubl. data). A recent study in kauri (*Agathis australis* (D. Don) Lindl.), however, showed a highly significant correlation between radial expansion measured by bands and annual ring width (Palmer & Ogden 1983). A similar degree of correlation is assumed to apply here. Diameter measurement by tape is generally recognised as giving the most consistent estimates of basal area and basal area increment (Loetsch *et al.* 1973).

Mean annual radial increments were obtained from the last 3 years' growth, first-year increments being discarded because of the likelihood of initial slack in the bands being taken up over this period. Data from bands giving anomalous measurements (e.g., interrupted growth, excessively high increments), probably due to interference or mechanical failure, were discarded.

Examination of the relationship between breast-height diameter increment and breast-height diameter showed increment to be positively related to d.b.h. in all species, but more closely related to its square in rimu, miro, and matai. Least-squares regressions of annual breast-height diameter increment on $(\text{d.b.h.})^2$ in these species, and on d.b.h. in tawa, were calculated.

Productivity

Merchantable tree volumes were calculated for each block using d.b.h., merchantable height, and Ellis' (1979) volume formulae for mature rimu and mature tawa. Diameters were not reduced to allow for defect in this study, because of the proven difficulty of estimating defect accurately (Herbert 1980). Nominal volumes were calculated for cull trees on the same basis as for merchantable ones. Diameter increment regressions derived from growth plots in the control block were applied to initial tree diameters to obtain merchantable volume increments; no changes in merchantable height were assumed to have occurred over the 3-year period. The rimu increment regression obtained was also used for totara and kahikatea, and the tawa regression for all other hardwoods. Gross volume increments thus obtained were combined with mortality data to produce net increments.

By calculating diameter increments in logged blocks using regressions derived from the control block, no allowance has been made for changes in growth that may have occurred as a result of stand modification by logging. In the case of podocarps, smaller suppressed trees may have responded most to the reduced stocking after logging (James & Franklin 1977), but any response is unlikely to be of great significance. Diameter re-measurements of a random sample of cruised tawa in the logged blocks failed to show any statistically significant differences with growth in the control.

Results and Discussion

Growth

Diameter increment regressions for the major species (Fig. 5) show a significant, though weak, relationship with initial size, the relationship in podocarps being stronger than in tawa. Some unexplained variation may be due to measurement error, and some to differences in age; age and diameter were only weakly related here (A. Katz, unpubl. data) and in similar forest elsewhere in the central North Island (Herbert 1980) where growth rates were very similar. A similar pattern of diameter growth in rimu has been observed in mature stands within dense rimu-dominant forest in southern Westland; growth rates there, however, are higher, with smaller mean diameters and higher stockings (James & Franklin 1977) and probably younger mean ages (Six Dijkstra 1981). A somewhat similar pattern in tawa occurs in tawa-dominant forest on the Mamaku

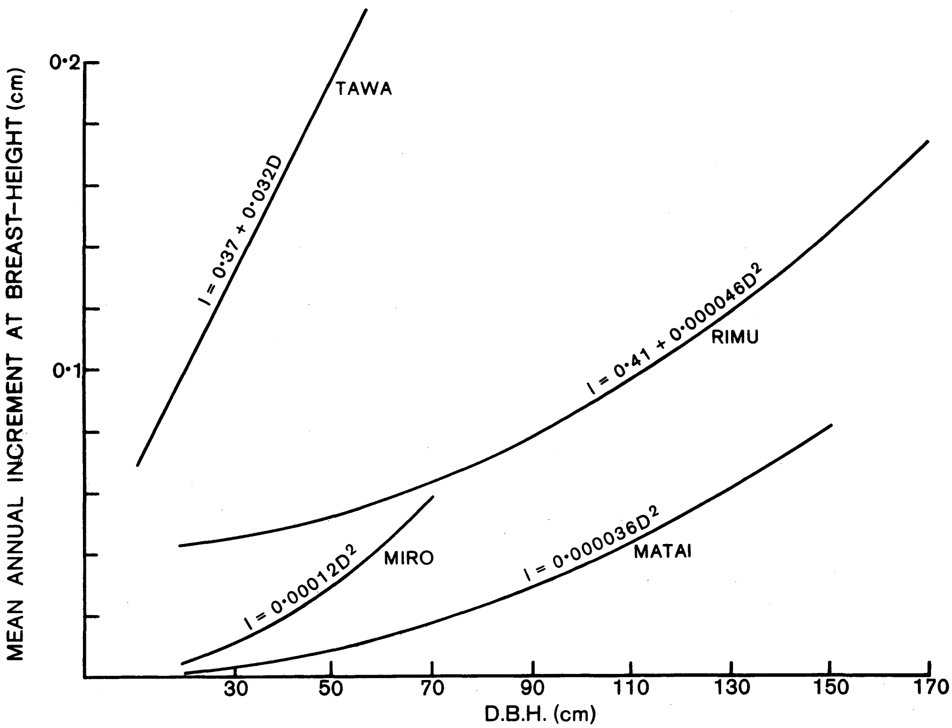

FIG. 5—Diameter increment functions of major species in virgin dense podocarp forest, Whirinaki (percentage of variance accounted for: rimu, 15.2%; matai, 24.5%; miro, 12.7%; tawa, 9.7%).

Plateau west of Rotorua (unpubl. data), although there diameter increment levels off after trees reach *c.* 30 cm d.b.h. and remains relatively constant thereafter. Again, growth rates there are higher.

Differences in diameter growth between podocarp species were confirmed by analysis of growth rings on cut stumps of felled trees (Table 9) and were also observed at Tihoi (Herbert 1980). The faster growth of tawa than of podocarps may reflect a younger population in this species, which has a probable life-span of some 400 years (Knowles & Beveridge 1982), considerably shorter than in the podocarps.

A comparison of current annual increment, as measured by dendrometer bands, and mean annual increment (from analysis of cut stumps) (Table 9) reveals a marked age-related decline in growth in all podocarp species examined, and emphasises the essentially mature nature of the stand. Reduced diameter growth commonly occurs in "overmature" rimu (Franklin 1968), and was described by Herbert (1980) from Tihoi where a virtually identical diameter growth-rate (0.89 $\pm$ 0.05 mm/annum) was recorded in slow-growing rimu trees.

TABLE 9 – Current and mean annual diameter increment in major tree species (standard errors in brackets)

Species	Current annual increment (mm)*	Mean annual increment (mm)†
Rimu	0.87 ($\pm$ 0.081)	1.90 ($\pm$ 0.11)
Matai	0.28 ($\pm$ 0.067)	1.30 ($\pm$ 0.08)
Miro	0.23 ($\pm$ 0.068)	1.3
Tawa	1.00 ($\pm$ 0.087)	–

* Measured by dendrometer bands in control block.
† Unpublished data of A. Katz, based on analysis of cut stumps in logged blocks. Standard error not given for miro. No data available for tawa.

Productivity

Periodic gross volume increment, at *c.* 0.9 m^3/ha/annum, was similar in all blocks, logged and control (Table 10). Net volume decrement occurred in all blocks, but was much lower in Block S than elsewhere (–1 m^3/ha/annum cf. –5 m^3/ha/annum) because of the lower mortality there (Table 11). Merchantable trees accounted for almost all (*c.* 90%) of gross increment in all blocks, but for about half or less of net decrement in Blocks G, I, and C, reflecting the predominance of merchantable trees in the forest and the disproportionately high contribution of cull trees to mortality (Table 8). In Block S, however, merchantable trees contributed over two-thirds of net decrement, because of fewer cull deaths. Podocarps, particularly rimu, accounted for most of gross increment, and podocarps for almost all of net decrement, a direct result of their overwhelming predominance in the forest. However, because few cull trees were assessed, tawa increments are substantially under-estimated, and so it is likely that the tawa understorey contributes more to productivity than these figures suggest.

TABLE 10 - Periodic gross volume increment (m^3/ha/annum) (figures in brackets show percentages made up of merchantable trees)

Species	Group removal (Block G)	"Unstable" tree removal (Block S)	Individual tree removal (Block I)	Control (Block C)
Rimu	0.55 (96)	0.58 (97)	0.50 (98)	0.61 (93)
Matai	0.05 (40)	0.08 (63)	0.07 (29)	0.08 (50)
Miro	0.07 (86)	0.04 (100)	0.03 (100)	0.05 (80)
Kahikatea & totara	0.02 (100)	0.02 (100)	0.13 (69)	0.08 (100)
Tawa*	0.13 (92)	0.17 (65)	0.20 (95)	0.23 (87)
Other hardwoods	0.02 (100)	0.02 (100)	0.02 (100)	0.01 (100)
Total	0.84 (92)	0.91 (90)	0.95 (88)	1.06 (89)

* Substantially under-estimated because few cull trees were assessed.

TABLE 11 - Periodic net volume increment (m^3/ha/annum) (figures in brackets show percentages made up of merchantable trees)

Species	Group removal (Block G)	"Unstable" tree removal (Block S)	Individual tree removal (Block I)	Control (Block C)
Rimu	-2.64	-0.32	-3.60	-2.21
Matai	-1.70	-0.59	-0.96	-1.45
Miro	-0.43	-0.03	-0.34	-0.43
Kahikatea & totara	0.02	0.02	-0.56	-0.49
Tawa*	-0.01	0.03	0.03	-0.04
Other hardwoods	-0.01	-0.06	-0.01	0
Total	-4.77 (53%)	-0.95 (71%)	-5.44 (54%)	-4.62 (41%)

* Substantially under-estimated because few cull trees were assessed.

Rather higher estimates of gross increment were obtained from the control and 30% selectively logged blocks in similar dense podocarp forest at Tihoi, and a very similar value in the 55% logged block (Herbert 1980). A somewhat higher value of gross increment (1.5 m^3/ha/annum) was also estimated from increment cores in a systematic sample of 500 ha of dense rimu forest in south Westland (Franklin 1973); higher increments still, up to 6.13 m^3/ha/annum (James & Franklin 1977), have been estimated from much smaller areas of such forest. Gross increment at Whirinaki, therefore, is lower than reported for similar forest elsewhere in the central North Island and for dense rimu forest in south Westland.

As at Whirinaki, net decrement occurred in all blocks at Tihoi, including the control; merchantable trees comprised a similarly high proportion of gross increment, and cull trees of net decrement. Unlike Whirinaki, however, decrement at Tihoi appeared to be directly related to degree of logging, being highest in the more heavily logged block and lowest in the control (Herbert 1980).

REGENERATION

Method

An assessment of natural regeneration was carried out 6 months after logging, at the same time as the assessment of damage and ground condition. Density of seedlings of podocarps, tawa, .nd other hardwoods was recorded in each plot in one of three height classes: 0–10 cm, 10–30 cm, and 30 cm to 1.5 m. Density of saplings (taller than 1.5 m, less than 10 cm d.b.h.) and poles (10–30 cm d.b.h.) was also recorded.

Results

Over 23 000 tree seedlings/ha were recorded in the control block; of these 61% were podocarps, 35% tawa, and the remaining 4% other hardwoods. Density of regeneration was somewhat lower in all three logged blocks than in the control (Table 12) but, because no comparable assessment was undertaken before logging, this cannot be attributed unequivocably to logging-induced ground disturbance. However, the poor podocarp seedfall in the autumn of 1979 followed immediately afterwards by logging did mean little new seedling recruitment on disturbed ground in logged blocks.

TABLE 12 – Density (stems/ha) of podocarp and tawa seedlings 0–1.5 m high (standard errors in brackets)

Species	Group removal (Block G)	"Unstable" tree removal (Block S)	Individual tree removal (Block I)	Control (Block C)	All blocks
Rimu	2970 (± 230)	1660 (± 150)	2020 (± 160)	1900 (± 180)	2138 (± 287)
Matai	1980 (± 160)	2120 (± 180)	2630 (± 200)	3740 (± 250)	2618 (± 399)
Miro	2660 (± 190)	1860 (± 180)	2270 (± 150)	2420 (± 180)	2303 (± 168)
Kahikatea	1520 (± 180)	1320 (± 180)	3790 (± 130)	6180 (± 390)	3203 (± 1140)
All podocarps	9130 (± 420)	6960 (± 400)	10710 (± 470)	14240 (± 560)	10260 (± 1533)
Tawa	7350 (± 370)	5880 (± 300)	6280 (± 340)	8080 (± 400)	6898 (± 502)

Nearly 95% of all podocarp regeneration was less than 10 cm high, and only 0.6% (62 stems/ha) was over 30 cm high (Table 13). Most could therefore be regarded as ephemeral, with nearly half of the smallest seedlings being cotyledonary. Most of the larger seedlings appeared strongly suppressed and had been damaged by introduced mammals or insects. Podocarp saplings and poles were extremely rare.

Tawa, in contrast, was better represented in the larger height classes than the smallest class, reflecting rapid growth of newly germinated seedlings in their first year.

TABLE 13 - Percentage of podocarp and tawa seedlings in each height-class of all blocks (standard errors in brackets)

	0-10 cm	10-30 cm	30 cm-1.5 m
Rimu	98.7 (± 0.5)	1.2 (± 0.5)	0.1 (± 0.1)
Matai	98.1 (± 0.4)	1.8 (± 0.4)	0.1 (± 0.1)
Miro	87.5 (± 1.6)	11.6 (± 1.4)	0.9 (± 0.3)
Kahikatea	94.0 (± 2.3)	5.0 (± 1.9)	1.0 (± 0.4)
All podocarps	94.4 (± 1.1)	5.0 (± 0.9)	0.6 (± 0.2)
Tawa	24.4 (± 4.6)	41.1 (± 3.9)	34.5 (± 3.1)

Over 1000 saplings/ha and 100 poles/ha were recorded, a significant proportion of which are likely to be of vegetative rather than seed origin. Thus tawa is by far the commonest successfully regenerating tree species here.

Seedlings of different podocarp species occurred in similar proportions, except for totara, of which only sporadic seedlings were found in the vicinity of mature trees in Blocks C and I. Thus seedling and mature tree populations differ markedly in composition, with rimu seedlings considerably under-represented in relation to mature trees, and kahikatea grossly over-represented.

Miro and kahikatea were better represented than rimu or matai as large seedlings. With miro this may reflect greater shade-tolerance. Differences between blocks in composition of the seedling population were small, partly reflecting minor differences in canopy composition.

Tree seedlings were well-dispersed, with at least one species present in over 80% of the plots, at least one podocarp in 64%, and tawa in 49% of plots. Seedlings were generally absent under dense tree ferns and ground ferns (for example, in gullies), in canopy gaps, and where large quantities of fallen leaves had accumulated.

Planted podocarp seedlings have shown high survival rates (over 80%) in their first 3 years, with mean annual increments in 1981–82 of 16 cm in rimu and totara and 18 cm in kahikatea, but only 3 cm in matai. Little difference in performance between blocks is apparent, although the larger gaps in Block G and to some extent Block S appear to favour kahikatea and to a lesser degree rimu.

Discussion

An extreme scarcity of well-developed podocarp regeneration and abundance of tawa is a widespread phenomenon in virgin dense podocarp forest at Whirinaki (McKelvey 1973; Gamble 1979), a situation which, despite considerable conjecture, remains something of an enigma. The common occurrence of newly germinated podocarp seedlings, even under closed high canopy, indicates that lack of viable seed production, poor dispersal or inadequate germination cannot be responsible.

Comparative studies of rimu and tawa seedlings growing in podocarp/tawa forest here and elsewhere in central North Island (Cameron 1963) have shown that, unlike tawa, rimu seedlings with their relatively weak root systems and lack of a strong taproot may be prone to seasonal desiccation, particularly in heavy shade and where thick leaf litter occurs. Under these conditions, the same is likely to be true of the other podocarps present, especially kahikatea. In mature dense podocarp forest, therefore, tawa may be the stronger competitor at the seedling stage.

Even where substantial canopy gaps have been created at Okurapoto and growing space has been made available by natural windthrow, development of podocarp seedlings has not occurred. Another factor is the considerable and continuing impact of introduced mammals on understorey plants, including podocarp seedlings. However, the lack of effective podocarp replacement clearly pre-dates the introduction of red deer earlier this century.

In marked contrast to Whirinaki, replacement of podocarps is in progress in dense podocarp forest at Tihoi where seedlings, although much less abundant, are present in a wide range of sizes (B. J. Veale, unpubl. data). There, at 660 m (cf. 500 m a.s.l. at Okurapoto) tawa is scarce, mean annual rainfall considerably higher (in excess of 2000 mm cf. 1400 mm – New Zealand Meteorological Service 1978), and red deer, although not uncommon now, may not have been present for much longer than two decades (G. T. Jane, unpubl. data).

The mode of origin of the existing forest at Okurapoto remains a matter of conjecture, as does future canopy replacement. Available evidence from both selective logging and natural mortality suggests, however, that the tawa understorey has, on the whole, responded positively to a gradual thinning of the podocarp canopy above. Given the current absence of well-developed podocarp advance growth and without a catastrophic collapse of the present canopy, a forest increasingly dominated by tawa seems likely to develop. In logged blocks, podocarp seedlings planted in gaps seem likely to succeed in replacing felled trees, although temporary suppression under colonising shrub-hardwoods is likely to occur.

CONCLUSIONS

In the time since the selective logging trial described here was carried out, management prescriptions (i.e., selective felling in areas zoned for timber production) for Whirinaki Forest (New Zealand Forest Service 1981b) have been altered to allow only salvage of fallen trees within restricted zones. Thus its interest is now largely historical and ecological, but it will provide an indication of the likely effects of recent operational logging in dense podocarp forest elsewhere at Whirinaki.

Of the three tree selection criteria employed, the "silvicultural" one (i.e., removal of apparently unstable trees) mimicked most closely the natural processes of canopy disintegration. However, this method caused a higher incidence of rootplate compaction and undercutting amongst residual trees; both kinds of damage may markedly reduce longer-term stability.

It is, of course, much too early to ascertain the success of the selection system as applied at Okurapoto. While the uneven-aged condition has been maintained, long-term success may depend on the development of artificially established regeneration to provide the younger age-classes currently absent, and on a gradual disintegration of the existing canopy. Although even-aged in appearance, the dense podocarp forest at

Okurapoto is in fact uneven-aged; the majority of current canopy trees are mature or senescent. Natural wind-induced mortality is occurring at a noticeable rate, particularly in deteriorating trees, with rarely-occurring major storms contributing markedly to tree losses. Even in the absence of extreme climatic events, however, net volume decrement is likely to continue. An absence of well-developed advance growth of podocarps and an apparently favourable response by understorey tawa to the gradual canopy opening presently occurring, suggests an essentially seral status, as postulated by McKelvey (1973). Unless a catastrophic collapse of the present canopy occurs, creating conditions favourable for mass replacement of podocarps, tawa is likely to occupy the growing space gradually being vacated by windthrow of existing podocarp trees, thus allowing a forest increasingly dominated by tawa to develop in the immediate future. However, some trees are likely to survive for a further two or more centuries, and some replacement may occur over this period through development of planted seedlings, quite possibly augmented by natural regeneration.

While it is clear that stability and productivity have not been adversely affected in the very short term by careful removal of a small proportion of standing volume, the effects of selective logging in this kind of forest on other important values such as wildlife habitat remain to be assessed. A long period of monitoring, 15 years or more, will be needed if current trends are to be confirmed, and the objectives of the trial fully realised.

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