SELECTIVE LOGGING IN PODOCARP/TAWA FOREST AT PUREORA AND WHIRINAKI

M. C. SMALE, A. E. BEVERIDGE*, G. F. PARDY,
and G. A. STEWARD
Ministry of Forestry, Forest Research Institute, Private Bag, Rotorua, New Zealand

(Received for publication 4 August 1986; revision 13 January 1987)

ABSTRACT

In Pureora and Whirinaki Forest Parks 30–40% of total merchantable timber volume was harvested in 1961 from two unreplicated 15-ha blocks of podocarp/tawa forest; a further block remained unlogged as a control. In 19 years after logging at Pureora, the actual number of merchantable trees lost in the two logged blocks was considerably lower than in the control, although the rate of residual tree loss was similar. This suggests that logging has, in part, anticipated natural mortality and has not adversely affected stability. In 22 years after logging at Whirinaki, mortality of merchantable trees occurred at similar rates in all blocks, suggesting that logging has not adversely affected stability there either.

Logging appears to have had little impact on regeneration of canopy species. Naturally regenerated **Beilschmiedia tawa** (A. Cunn.) Kirk (tawa) seedlings are widespread in both localities, and podocarp seedlings are widespread at Pureora but scarce at Whirinaki where podocarp population structures in virgin forest are not stable.

At Pureora, gross volume increment in merchantable trees, mostly podocarps, was higher in the unlogged control and in one logged block than the other (0.5–0.6 cf. 0.3 m^3/ha/annum). Net decrement occurred in all blocks, but was much higher in the control than either logged block. Total net decrement (i.e., including non-merchantable trees) is likely to be considerably higher. Growth plots in logged and virgin forest at Pureora indicate a likely average recovery period, for 80% of equilibrium basal area, of nearly 100 years for selectively logged forest.

Keywords: podocarps; selective logging; mortality; volume increment; canopy replacement; succession; regeneration; **Beilschmiedia tawa**.

INTRODUCTION

Traditional logging practice in the podocarp-rich forests of the central North Island of New Zealand involved harvesting virtually all merchantable podocarps, and often some tawa and other merchantable hardwoods as well. Although it was frequently followed by conversion to exotic plantation, substantial areas remained in a "cutover" condition. During the late 1950s, interest was renewed in the possibility of managing indigenous forests for a sustained timber yield (Cameron 1960).

---

* Current address: 180 Kawaha Pt Rd, Rotorua, New Zealand.

The trials discussed in this paper represent the first monitored attempts at selective logging in indigenous forests in the North Island. Several aspects of the long-term impact of selective logging are reviewed – the effect on stability and productivity, and on canopy replacement, as well as natural succession on logging-disturbed ground.

BACKGROUND

Pureora Forest Park

The study area lies in the upper Waipapa River catchment at an altitude of 500–550 m a.s.l., 8 km north of Pureora Forest village (Fig. 1), and consists of an undulating plateau dissected by broad shallow valleys. Soils are podsolised yellow-brown pumice soils derived from rhyolitic Taupo pumice (Rijkse 1977). Climate is mild and humid, with a mean annual temperature of 10°–12.5°C and a relatively constant annual rainfall of c. 2000 mm. About 80 ground frosts occur per year (Beveridge 1973; Wards 1976).

The forest type is podocarp/tawa (Type M2; McKelvey 1963) which was once relatively extensive at West Taupo and consisted, before logging, of scattered rimu (*Dacrydium cupressinum* Lamb.), matai (*Prumnopitys taxifolia* (D. Don) de Laub.), and miro (*P. ferruginea* (D. Don.) de Laub., occasional totara (*Podocarpus totara* D. Don) and rare kahikatea (*Dacrycarpus dacrydioides* (A. Rich) de Laub.) emergent at c. 40 m over dense hardwood tiers dominated by tawa, with some kamahi (*Weinmannia racemosa* L.f.), hinau (*Elaeocarpus dentatus* Vahl.), and maire (mostly *Nestegis cunninghamii* (Hook. f.) L. Johnson) (Table 1). Podocarps were concentrated on high ground; tawa was ubiquitous except in valley bottoms which were dominated by tree-ferns and shrub-hardwoods. Widespread fallen totara trees, up to 2 m or more in diameter and most common in depressions, indicate that this species was a much more important component of the forest during the last few centuries than it is today.

Diameter distributions of merchantable rimu, matai, and miro were unimodal before logging, while tawa approached the negative exponential distribution (Fig. 2). Although unimodal distributions are characteristic of even-aged stands (Carron 1968), podocarps here are uneven-aged; of a 1961 sample of eight sound cut stumps, seven were estimated by ring counts to be between 440 and 620 years old.

Introduced pigs (*Sus scrofa* L.) have probably been present for over a century, and remain locally common. Red deer (*Cervus elaphus* L.) and brush-tailed possum (*Trichosurus vulpecula* Kerr) have increased markedly since the early 1960s when they were virtually absent, and they are now common (McKelvey 1963; R. W. Dale, unpubl. data; S. Krzystyniak, unpubl. data).

The trial consisted of three contiguous rectangular blocks, each of 15 ha, and surrounded on all sides by virgin forest. Before logging, blocks were similar in composition, although matai and kahikatea were progressively rarer on more dissected ground to the north-west (Block C), and Block B had relatively few merchantable hardwoods (Table 1). Block A (control) was not logged, but was modified very locally by the poisoning of some hardwoods and tree-ferns in 1961. Block B was selectively logged in 1961 with the removal of c. 34% of total merchantable volume, chiefly from the centres of natural groups of trees.

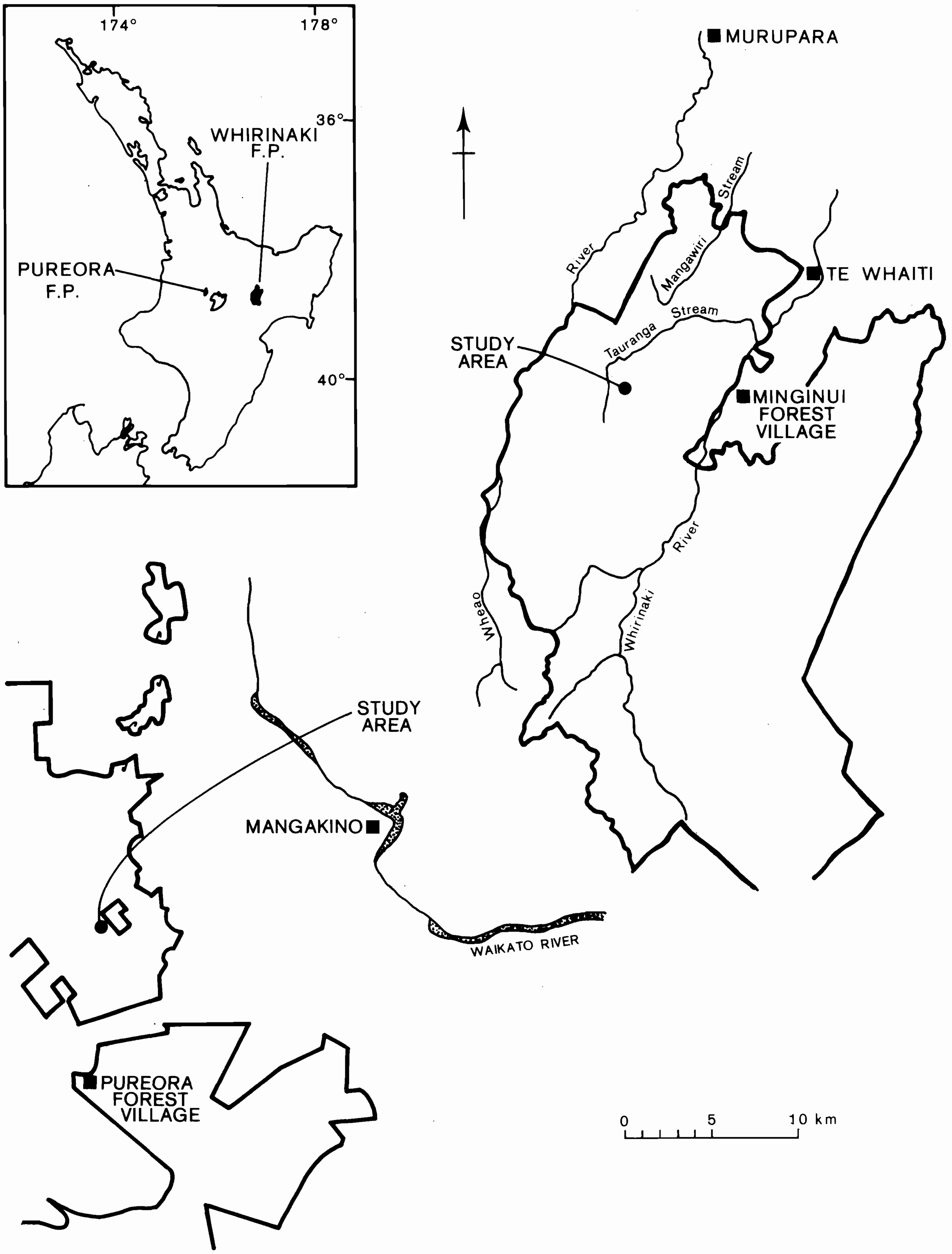


FIG. 1—Location of the study areas.

Block C was also selectively logged in 1961, c. 30% of total merchantable volume being removed, mostly from the edges of natural groups. Similar proportions of each species were removed from both blocks (Table 2). In both logged blocks, the aim of tree selection was to fell small groups of trees in order to contain logging disturbance, and leaning or thin-crowned trees were chosen in preference to apparently stable ones.

TABLE 1—Forest composition* in 1959 before logging (merchantable trees only)

Species	Block A			Block B			Block C		
	Density (stems/ha)	Mean diameter (cm)	Merchantable volume (m^3/ha)	Density (stems/ha)	Mean diameter (cm)	Merchantable volume (m^3/ha)	Density (stems/ha)	Mean diameter (cm)	Merchantable volume (m^3/ha)
Pureora									
Rimu	17.9	96.5	119.9	23.7	104.1	192.3	18.8	101.6	129.4
Matai	2.8	81.3	11.5	1.9	82.6	8.9	1.1	94.1	6.4
Miro	4.2	68.6	12.8	3.5	71.4	11.1	4.4	76.5	16.1
Kahikatea/totara/ tanekaha	3.1	84.1	17.7	1.9	94.7	13.2	0.5	74.9	4.1
Tawa	11.9	67.6	20.2	5.3	61.0	10.0	10.4	72.1	17.5
Hinau/rewarewa	1.7	63.5	3.0	0.6	74.5	1.7	1.5	62.8	2.8
Total	41.6		185.1	36.9		237.2	36.6		176.3
Whirinaki									
Rimu	7.0	111.8	85.0	12.9	106.7	135.6	16.6	101.6	145.8
Matai	2.6	81.3	13.2	3.1	96.5	21.1	3.4	111.8	25.6
Miro	1.8	76.2	6.3	2.3	61.0	6.0	4.8	66.0	16.7
Kahikatea	0.5	111.8	4.6	0.6	116.8	7.6	0.5	106.7	4.8
Tawa	16.5	43.2	15.1	13.3	45.7	13.1	16.1	43.2	14.3
Other hardwoods	2.0	21.3	3.3	2.6	50.1	3.7	1.8	52.3	3.1
Total	30.4		127.5	34.8		187.1	43.2		210.3

* Trees greater than 30cm dbh only

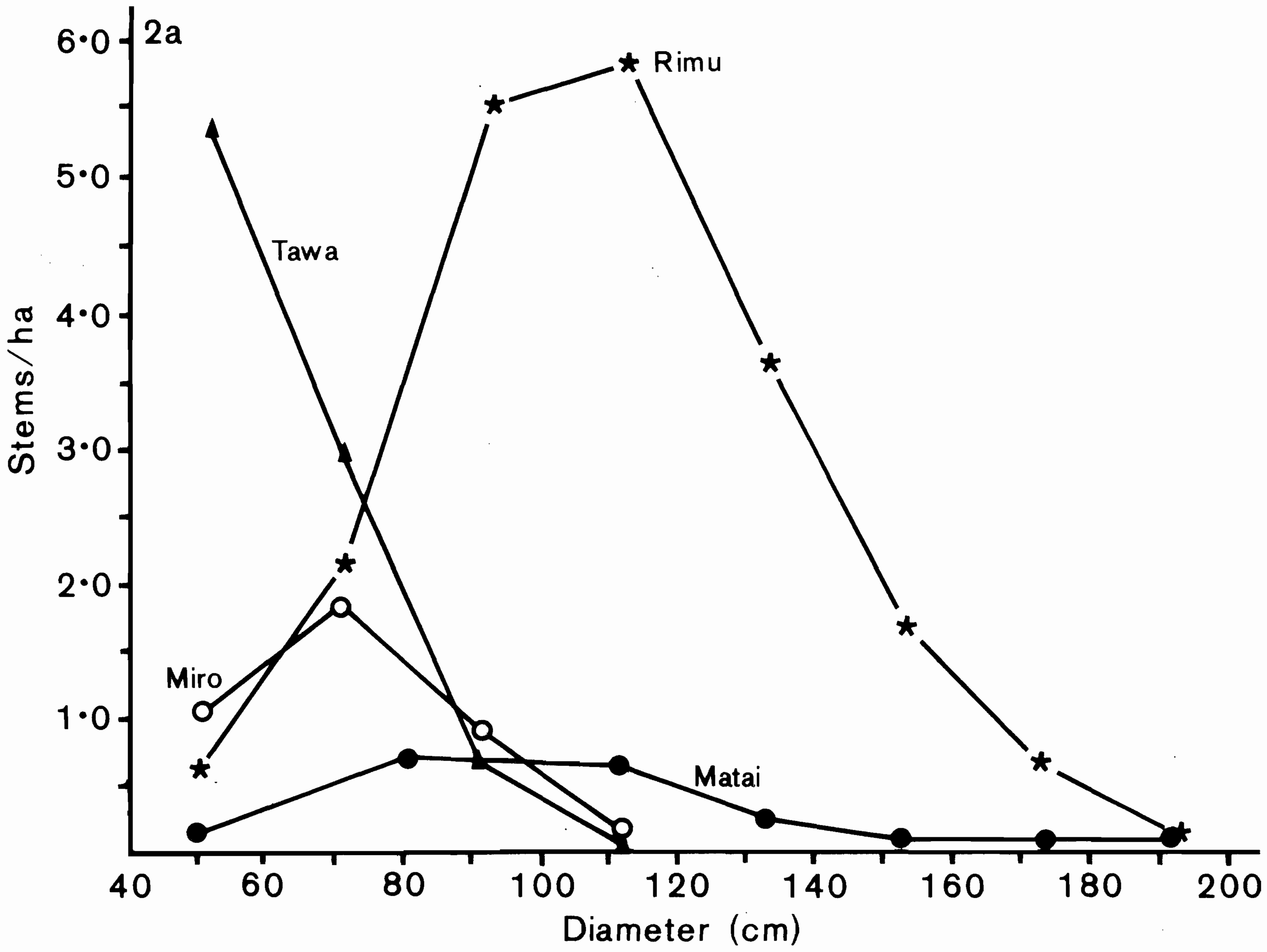
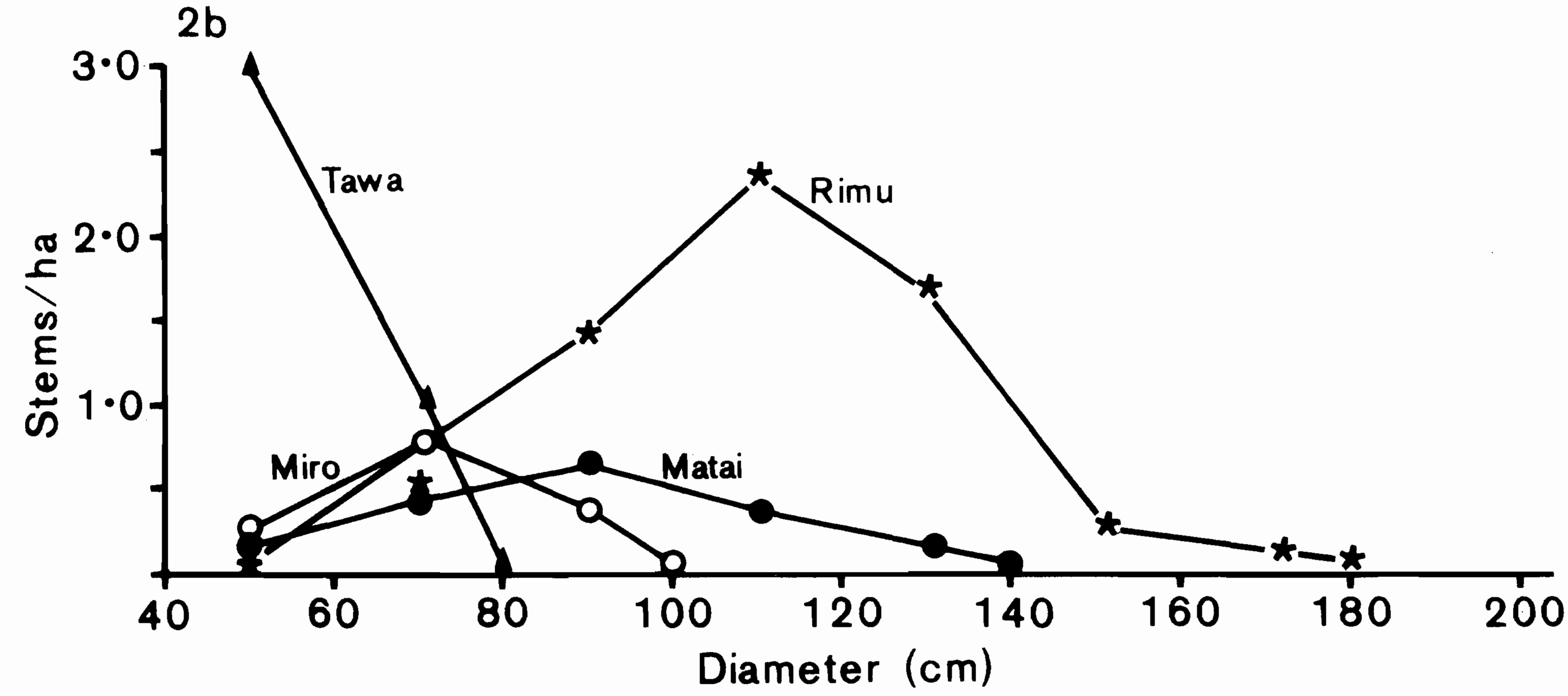


FIG. 2—(a) Diameter distributions of merchantable trees of major species in 45 ha of podocarp/tawa forest at Pureora, before logging.



(b) Diameter distributions of merchantable trees of major species in 24 ha of rimu/matai-tawa-kamahi forest at Whirinaki, before logging.

TABLE 2—Selective logging treatments

Species	Block B			Block C		
	Number removed (trees/ha)	Volume removed (m^3/ha)	Merchantable volume removed (%)	Number removed (trees/ha)	Volume removed (m^3/ha)	Merchantable volume removed (%)
Pureora						
Rimu	5.9	59.61	31.0	4.4	36.23	28.0
Matai	0.7	3.63	30.9	0.5	1.87	32.7
Miro	0.7	3.44	40.7	1.1	5.27	29.2
Kahikatea	1.3	9.13	69.1	0.1	0.67	26.0
Tawa	2.2	4.03	40.4	3.9	6.95	39.8
Hinau	0.2	0.63	38.2	0.3	0.57	20.8
Total	11.0	80.47	33.9	10.3	51.56	29.2
Whirinaki						
Rimu	5.5	59.45	43.8	6.5	56.68	38.9
Matai	1.0	7.35	34.9	1.13	6.78	26.5
Miro	0.88	2.94	48.9	1.63	5.21	31.2
Kahikatea	0.25	2.40	31.5	0.25	0.96	20.1
Tawa	1.75	2.71	20.8	1.13	1.61	11.3
Hinau	0.13	0.13	2.3	0.50	0.81	26.2
Total	9.51	74.98	40.1	11.14	72.05	34.7

After logging was finished in Block B, nursery-raised bare-rooted seedlings of rimu, kahikatea, and totara were planted in groups in logged gaps, and also in residual forest under groves of poisoned tree-ferns. In Block C, groups of bare-rooted *Eucalyptus delegatensis* R.T. Bak. were planted in logging gaps and along minor haul tracks.

Whirinaki Forest Park

The study area lies at an altitude of 600 m a.s.l., 8 km west of Minginui Forest village (Fig. 1). Blocks B and C consist of undulating plateau in the upper Okahu Stream catchment, while Block A occupies more dissected terrain in the upper Oriuwaka Stream catchment. Soils are predominantly yellow-brown pumice soils derived from rhyolitic Taupo pumice (Rijkse 1986). Climate is moderately sunny and sheltered, with a mean annual temperature of 10°–12.5°C and a rather variable annual rainfall averaging 1400 mm. About 130 ground frosts occur per year (Nicholls 1969; Wards 1976).

As at Pureora, the forest type is rimu/matai-tawa-kamahi (Type M2; Nicholls 1969), also once relatively extensive at Whirinaki (Table 1). The trial area here consists of two adjacent rectangular blocks, each 8 ha in extent and surrounded on each side by selectively logged forest.

The third (control) block, also of 8 ha, lies 300 m away and is surrounded by virgin forest. Before logging, forest composition in the three blocks differed substantially, B and particularly C having considerably more merchantable rimu and miro than A, and correspondingly higher volumes (Table 1).

Block A (control) is virgin. Blocks B and C were selectively logged in 1961 with the removal of c. 40% and 35% of total merchantable volume respectively. As at Pureora, groups of three or four trees were removed in both B and C, and similar tree-selection criteria were used. Similar proportions of trees were harvested from both blocks (Table 2). Logging here reduced differences between blocks in forest composition.

Diameter distributions of merchantable trees of major species (Fig. 2) are similar to those at Pureora, although stockings are considerably lower. Analysis of sound cut stumps in forest of this type at Whirinaki gave ring counts ranging from 285 to 438 years in rimu and 544 to 1093 years in matai (R. J. Cameron, unpubl. data).

Introduced possums have been present for at least 30 years, probably several decades longer, and remain common (J. E. Knowlton, unpubl. data). Red deer, present for several decades, were considerably scarcer in 1981–82 (J. E. 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 have probably been present for a century and a half, and remain locally common (J. E. Knowlton, unpubl. data).

In the year after logging, groups of rimu and kahikatea seedlings were planted in Block B in logged gaps within and beside four sets of mammal-proof exclosures. In Block C, groups of *E. delegatensis* were planted in logged gaps.

STABILITY

Method

Before logging, each block at Pureora was demarcated into five large rectangular plots, and a detailed assessment of the forest made in each. All merchantable trees were measured for diameter at breast height (1.4 m) (dbh) and merchantable height, and were mapped and permanently tagged for future identification. Cull trees were also mapped.

Assessments of mortality of merchantable trees were made in 1974 and 1980–81, in which mode of death (uprooting, snapping, standing death) and direction of fall were noted. In the second assessment diameter of a sample of living tagged trees was remeasured.

Initial demarcation and assessment at Whirinaki followed that at Pureora, reassessments being made in 1974 and 1982–83.

Results

At Pureora, considerably more merchantable trees died in the unlogged control (0.17 trees/ha/annum) than in either logged block (0.08 and 0.1 trees/ha/annum) (Table 3). Proportions of residual trees and of residual volume lost were comparable, however, because of the lower stocking and volumes left after logging in Blocks B and C. Wind was the commonest immediate cause of tree death, accounting for nearly two-thirds of mortality; snapping was twice as common as uprooting, although the reverse was true in miro (Table 4). Standing death was the commonest single cause of death in hinau and rimu.

TABLE 3—Mortality of residual merchantable trees

Species	Block A (control)				Block B (selectively logged)				Block C (selectively logged)			
	Trees lost/ha/annum		Volume lost/ha/annum		Trees lost/ha/annum		Volume lost/ha/annum		Trees lost/ha/annum		Volume lost/ha/annum	
	(No.)	(%)	(m^3)	(%)	(No.)	(%)	(m^3)	(%)	(No.)	(%)	(m^3)	(%)
Pureora 1959–80												
Rimu	0.08	0.45	0.99	0.83	0.05	0.28	0.69	0.52	0.06	0.42	0.49	0.52
Matai	0.01	0.36	0.03	0.26	0.01	0.83	0.04	0.67	0.01	1.50	0.03	0.56
Miro	0.03	0.71	0.08	0.62	0.01	0.36	0.07	0.90	0.02	0.61	0.07	0.64
Tawa	0.04	0.34	0.11	0.55	0.01	0.32	0.02	0.25	0.01	0.15	0.02	0.20
Hinau	0.01	0.58	0.03	0.99	0	0	0	0	0	0	0	0
Total	0.17	0.41	1.24	0.67	0.08	0.31	0.82	0.52	0.10	0.38	0.61	0.49
Whirinaki 1959–83												
Rimu	0.07	1.88	0.92	1.08	0.10	2.54	0.14	1.50	0.09	1.67	0.82	0.92
Matai	0.02	1.43	0.11	0.85	0.01	0.88	0.03	0.25	0.02	1.67	0.16	0.85
Miro	0.01	1.07	0.03	0.50	0.01	1.36	0.01	0.18	0.01	0.60	0.01	0.12
Tawa	0.06	0.68	0.08	0.54	0.02	0.33	0.03	0.25	0.02	0.25	0.02	0.15
Rewarewa/ hinau	0.03	2.81	0.05	1.63	0.02	1.58	0.03	0.90	0.02	3.0	0.03	1.52
Total	0.19	1.17	1.19	0.94	0.16	1.19	1.24	1.10	0.16	0.94	1.04	0.76

TABLE 4—Mode of death of merchantable trees (trees/ha/annum) in all blocks

Species	Uprooting	Snapping	Standing dead	Indirect
Pureora				
Rimu	0.013	0.023	0.030	
Matai	0	0.004	0.002	
Miro	0.010	0.004	0.004	
Tawa	0.001	0.014	0.003	
Hinau	0	0.003	0.004	
Total	0.024	0.048	0.043	
Whirinaki				
Rimu	0.06	0.043	0.016	0.002
Matai	0.002	0.010	0.004	0
Miro	0.002	0.004	0	0.002
Tawa	0.005	0.024	0.004	0.002
Rewarewa/hinau	0	0.017	0.002	0.002
Total	0.035	0.098	0.026	0.008

Mortality rates were highest in matai and miro (0.6% of residual trees/annum), lower in rimu (0.4%), and lower still in tawa and hinau (0.3%). Interestingly, mortality occurred between 1974 and 1980 at over three times the rate recorded in the preceding 13 years after logging, in both unlogged and logged blocks. This may reflect the mature to overmature nature of the podocarp component of the stand.

At Whirinaki, a similar number of trees died in each block, virgin or logged (Table 3), and in the two successive assessment periods; proportional rates of residual tree loss were also similar in all blocks. Wind was the immediate cause of most tree death, with snapping nearly three times as common as uprooting (Table 4).

Mortality rates were highest in rimu, rewarewa, and hinau (c. 2.0% of residual trees/annum), lower in matai (1.3%) and miro (0.9%), and lower again in tawa (0.4%). Both rimu and matai were described in 1959 as having a high incidence of defect (butt and stem rots) (P. V. Wastney, unpubl. data). Most windfall was oriented toward the north-east quarter, a reflection of the prevailing south-south-westerly wind direction.

Discussion

At Pureora, selective removal of one-third of total merchantable volume has not adversely affected the stability of podocarp/tawa forest over the following 19 years. The higher actual mortality in the control than logged blocks suggests that logging has, in part, merely anticipated natural mortality. In spite of quite considerable differences in forest composition between the control and at least one logged block (C) at Whirinaki, similar mortality rates between blocks in terms of proportions of residual trees lost do imply that logging there has not adversely affected stability either. In both Pureora and Whirinaki trials, similar proportional rates of residual tree loss between logged and unlogged blocks suggest that the mortality-prone element amongst merchantable trees has not been preferentially removed by logging.

Few tree deaths in either trial were obviously related to logging damage; two-thirds of the area of logged blocks at Pureora were virtually undisturbed by logging (Beveridge & Herbert 1978), and a similar proportion is likely at Whirinaki. The major predisposing factor in mortality in dense podocarp forest at Whirinaki appears to be the presence of substantial natural defect (Smale *et al.* 1985); the same is probably true in podocarp/tawa forest there and at Pureora.

Because canopy-podocarp densities are considerably lower at Whirinaki than at Pureora, and actual mortality rates are similar, proportional rates of residual tree loss have been higher at Whirinaki. If current mortality rates at Whirinaki continue most existing podocarp trees are likely to die within the next century.

PRODUCTIVITY

Method

For Pureora, merchantable tree volumes in 1959 were calculated by diameter class (10 cm wide) for each block using Ellis' (1979) volume formulae for mature rimu, mature tawa, and native hardwoods, based on mean dbh and mean merchantable height. Periodic mean annual increments were derived from dbh remeasurements in 1980 on a sample of 232 cruised trees of major species in each block, the significance of differences in increments between pairs of blocks being assessed by the Mann-Whitney test. Increments were applied to diameter-class means to obtain merchantable volume increment for each class; no changes in merchantable height were assumed to have occurred over the period. Gross volume increments obtained thus were combined with mortality volumes (adjusted for the period 1961–80) to produce net increments.

Because original cruise data for the Whirinaki trial could not be located, information on diameter increment, and thus stand volume increment, was not available.

Results and Discussion

No relationship between diameter increment and initial diameter was evident in major species at Pureora (Table 5), in contrast to a dendrometer band study in dense podocarp forest at Whirinaki (Smale *et al.* 1985) where a significant though weak relationship was found. Neither did it differ significantly between blocks, except that rimu grew significantly faster ($p < 0.01$) in Block B (2.3 mm/annum) than in Blocks A or C (1.1 mm/annum), perhaps due to the thinning effect of logging.

TABLE 5—Periodic mean annual increment (1959–80) and mean annual diameter increment in major tree species at Pureora (standard errors in parentheses)

Species	Periodic mean annual increment (mm)	Mean annual increment* (mm)
Rimu	1.05 (±0.16)	1.78 (±0.47)
Matai	0.74 (±0.23)	1.45 (±0.24)
Miro	1.49 (±0.25)	1.51 (±0.08)
Kahikatea	1.01 (±0.19)	—
Tawa	1.59 (±0.06)	—
Hinau	2.37 (±0.39	—

* From analysis of eight, sound, cut stumps

Periodic mean annual increment in rimu was similar at Pureora (Table 5) to current annual increment in dense podocarp forest at Whirinaki, but in matai, miro, and tawa was considerably faster, probably because of lower basal area at Pureora. As in earlier studies (Herbert 1980; Smale *et al.* 1985), a marked age-related decline in diameter growth was present in rimu and matai, although not in miro (Table 5).

Periodic gross volume increment at Pureora (in merchantable trees only) was markedly higher in Blocks A and B (0.48 and 0.57 m^3/ha/annum) than in Block C (0.31 m^3/ha/annum) (Table 6). Net volume decrement occurred in all blocks, but was much higher in the unlogged control than in either logged block (Table 6). Podocarps accounted for 75% or more of gross increment, and most or all of net decrement. However, because few tawa were cruised, this species contributes rather more to productivity than the figures suggest.

Gross increment in merchantable trees, at c. 0.5 m^3/ha/annum, was lower, as expected, than in dense podocarp forest, where estimates ranging from c. 0.8 m^3/ha/annum (Whirinaki, Smale *et al.* 1985) to 1.58 m^3/ha/annum (Tihoi, Herbert 1980) have been obtained.

TABLE 6—Periodic gross volume increment and periodic net volume increment (m^3/ha/annum) 1961–80 at Pureora in merchantable trees only

Species	Block A (control)		Block B (selectively logged)		Block C (selectively logged)	
	Gross	Net	Gross	Net	Gross	Net
Rimu	0.26	-0.64	0.49	-0.13	0.19	-0.25
Matai	0.02	-0.01	0.01	-0.03	0.01	-0.02
Miro	0.05	-0.02	0.03	-0.02	0.04	0.03
Other podocarps	0.04	0.04	0.01	0.01	0	0
Tawa	0.11	0.01	0.03	0.01	0.06	0.04
Other hardwoods	0	-0.03	0	0	0.01	0.01
Total	0.48	-0.65	0.57	-0.17	0.31	-0.19

Net decrement in merchantable trees also occurred in dense podocarp forest at Whirinaki (Smale *et al.* 1985) and in the selectively logged blocks in similar forest at Tihoi (Herbert 1980). In those trials, however, culls made a disproportionately high contribution to mortality, of the order of 40–50% of volume lost. Together with a small (10–20%) contribution to increment, this suggests that total net decrement at Pureora is likely to be considerably higher than that reported here for merchantable trees only, perhaps –1.2 m^3/ha/annum in the control and c. –0.5 m^3/ha/annum in logged blocks.

CHANGES IN GROWTH PLOTS AT PUREORA

Method

In early 1960, ten 0.04-ha circular plots were subjectively located in Block A and in adjacent virgin forest, in areas of prolific tawa or podocarp advance growth. In each plot, all stems over 10 cm dbh (poles and trees) were mapped and tagged, and dbh was measured. Crown class was also assessed. Six similar plots were located in mid-1961, immediately after logging, in Blocks B and C in tawa advance growth around stumps of freshly felled podocarps. In all 16 plots, every stem over 5 cm dbh (larger saplings, poles, and trees) was mapped, tagged, and measured. The circular plots were completely reassessed in the summer of 1983–84.

Each of the 10 circular plots in unlogged forest was classified twice – first on the basis of its predominant phase in the forest growth cycle (i.e., whether "building" or "mature"), and then on the occurrence or not of mortality of tall canopy trees in the plot over the 23-year assessment period. "Building phase" is defined here as the period between the end of a gap's receptivity to colonisation, and the regeneration in the gap reaching predominant canopy height. Predictably, many plots did not coincide exactly with "patches" of either building-phase or mature forest; it appears that the average size of patches at north Pureora is less than 0.04 ha. In tawa-dominant forest at Rotoehu, Bay of Plenty, which had been lightly logged some 40 years earlier, canopy gap size averaged 0.01 ha in one study area and 0.025 ha in the other (Smale & Kimberley 1983).

Results

The six plots in logged blocks consisted of tawa advance growth, formerly under emergent podocarps. Of the 10 virgin plots, five were in the late mature phase with two consisting of tawa advance growth predominantly under emergent podocarps, two of podocarp advance growth under a high tawa canopy, and one of podocarp advance growth predominantly under a podocarp canopy. The other five were in the building phase and comprised four of predominantly podocarp advance growth formerly under a kamahi canopy, and one of tawa advance growth formerly under emergent podocarps.

Development of tawa advance growth beneath emergent senescing podocarps is a recognised regeneration strategy of tawa in mature forest (Knowles & Beveridge 1982); development of miro advance growth, at least to sapling size, beneath a high tawa canopy, also appears to be a common replacement sequence. Advance growth of podocarps, mainly rimu, beneath large senescent hardwoods, especially kamahi, commonly occurs in podocarp/tawa forest at Pureora (Beveridge 1973); thus three, locally important, replacement sequences are illustrated by these plots. Although mortality of tall canopy trees (mostly podocarps) did occur in six of the 10 virgin plots, trees died standing or fell outside plots, and in only one was a large canopy gap created.

Stocking

No differences in initial stocking of poles and trees were evident between either phase, or between virgin and logged blocks (Table 7). However, poles (10–30 cm dbh) and trees (>30 cm dbh) were present in similar numbers in mature forest, while trees were relatively scarce in building-phase and logged forest. Logged and building-phase forest showed significant net increases in pole and tree stocking over the assessment period, compared to mature-phase forest in which stocking remained static or declined (Table 7).

TABLE 7—Stocking and basal areas of stems > 10 cm dbh only in permanent 0.04-ha plots in podocarp/tawa forest at Pureora, and changes over 23 years

Parameter	Logged	Virgin	
		Building*	Mature
Intitial stocking (stems/ha)	354a	575a	405a
Initial basal area (m^2/ha)	25.2a	33.1ab	80.0b
Net change in stocking (stems/ha/annum)	10.6a	20.2a	-1.1b
Net change in basal area (m^2/ha/annum)†	0.44a	-0.65ab (0.71a)	-0.78b (0.25ab)

Values followed by the same letter are not significantly different at p = 0.05

* Phase of the forest growth cycle at the start of the assessment period

† Plots without canopy mortality in parentheses

Basal area

Initial basal area in mature-phase forest was significantly higher ($p < 0.05$) than in logged forest (Table 7). Logged forest, and building-phase forest in which no canopy mortality occurred, showed significant net increases in basal area compared with mature forest in which canopy tree death and marked reductions in basal area occurred (Table 7). Such increases are characteristic of the building phase in tropical rain forest, when net productivity is greatest and growth rates are fastest (Whitmore 1983).

Annual basal area increment averaged over 23 years was significantly ($r^2 = 53\%$, $p < 0.01$) correlated with mean basal area over the period as follows

$$BA_{increment} = 0.73 - 0.013\ BA_{mean}$$

where $BA_{increment}$ = annual basal area increment (m^2/ha/annum)

and BA_{mean} = mean basal area (m^2/ha)

reflecting increasing competition between individuals with increasing occupancy of growing space.

Other functions tested did not differ significantly from this linear one which, solved as a differential equation, gives the basal area recovery function

$$BA_T = 55.9 + (BA_O - 55.9)\ (0.9870)^T$$

$$\text{or } T = -76.4 \ln \frac{(0.73 - 0.013\ BA_T)}{0.73 - 0.013\ BA_O}$$

where BA_T = basal area (m^2/ha) after time period T (years)

BA_O = basal area at time O

T = time period

This appears in Fig. 3, along with 95% confidence limits, and indicates an "equilibrium" basal area (Horne & Gwalter 1982) of stems >10 cm dbh of c. 56 m^2/ha, about which the basal area of substantial blocks of forest of this type would be expected

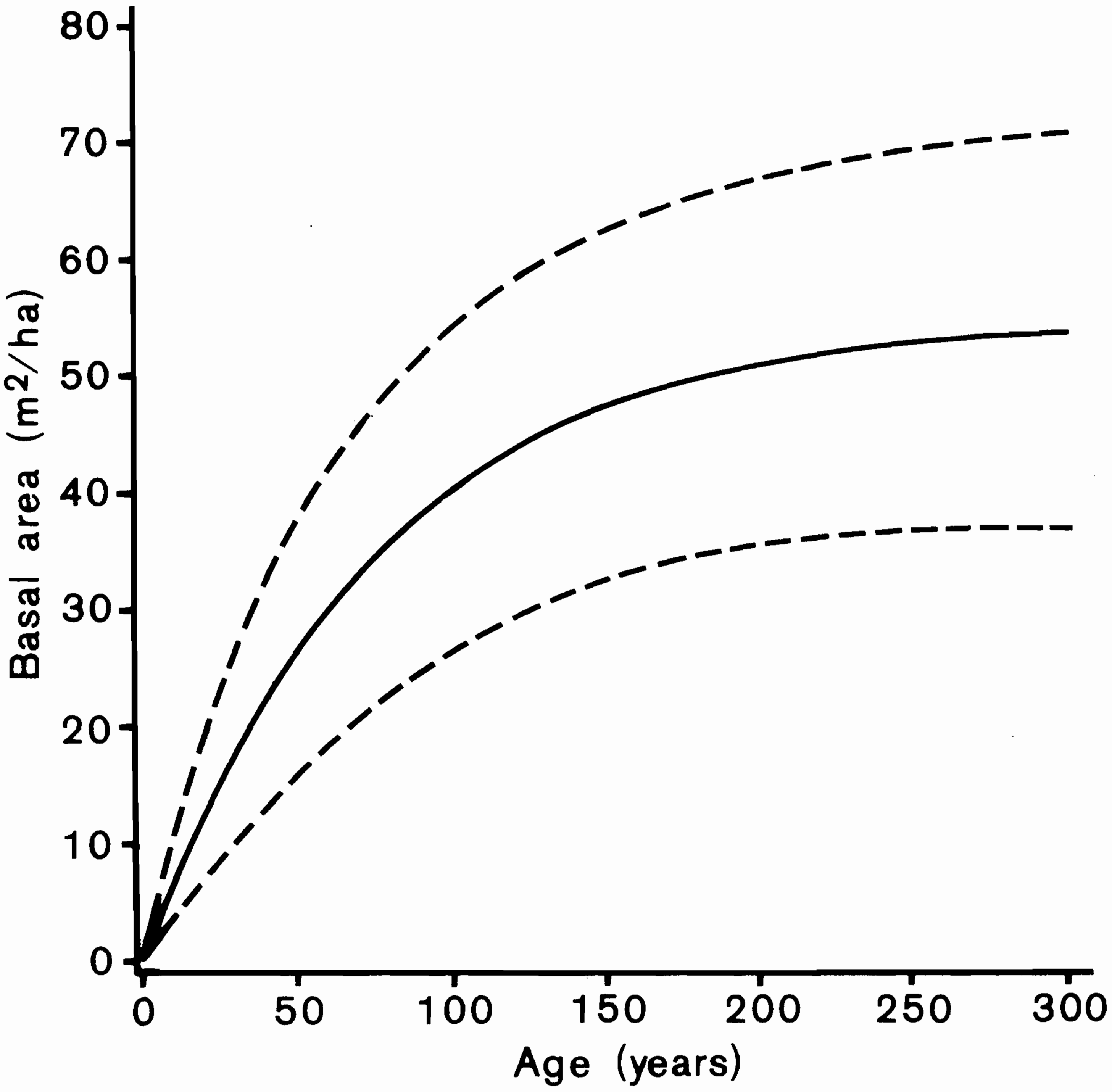


FIG. 3—Basal area recovery curve, with 95% confidence limits, for podocarp/tawa forest at Pureora (see text for implicit assumptions).

to fluctuate in the absence of major disturbance. Unpublished data from a 0.4-ha permanent plot in forest adjacent to Block A, and from 0.4-ha and 0.8-ha plots in similar forest at Whirinaki indicate that $56\,m^2/ha$ is a reasonable estimate of equilibrium basal area for this forest type.

The function also indicates that after removal of 69% of equilibrium basal area (the average reduction in the six logged circular plots), a period of c. 95 years will be needed, on average, for 80% of equilibrium basal area to be restored; restoration of full basal area will take a much longer time. Implicit in this function are several assumptions:

(1) That no major changes in forest composition (e.g., relative importance of podocarps and canopy hardwoods) occur over the period;

(2) That no major changes in environmental factors (i.e., soil and climate) occur over the period;

(3) That no major disturbances (e.g., catastrophic windthrow) occur over the period.

Predictions of basal area recovery time beginning with initial basal area near zero entail the additional assumption that, after full canopy removal, sufficient advance growth is present and survives to take immediate advantage of all available growing space. If not, basal area is likely to accrue slowly at first, until available growing space is fully utilised.

Discussion

The similarity of net changes in stocking and basal area in logged and building-phase plots without canopy mortality suggests that selective logging (i.e., removing emergent podocarps in the presence of well-developed tawa advance growth) has merely hastened the inevitable transition from mature to building-phase forest, in effect accelerating the forest growth cycle. The effect of logging in other situations (e.g., of removing canopy trees in the presence of podocarp advance growth) remains to be assessed. However, like tawa, many podocarps (including the prominent species rimu and miro) are capable of responding to release from overtopping vegetation after long periods of suppression (Beveridge 1973). Thus, a similar acceleration of the canopy replacement process by logging seems likely in these situations too, especially after senescence and death of gap-colonising hardwoods such as wineberry (*Aristotelia serrata* (Forst.) Oliver).

PLANT SUCCESSION AFTER LOGGING AT PUREORA

Method

In 1961, six 0.28-ha cruciform plots were located in Blocks B and C at Pureora through groups of podocarp trees marked for felling. After logging, type of ground disturbance was recorded at fixed intervals along each arm. In 1963, 1965, 1974, and 1985 subjective descriptions of vegetation cover (using abundance classes – abundant, frequent, occasional, rare) were made at each point.

For analysis, plots were grouped according to type of ground disturbance (scraped compacted ground, light slash, heavy slash), and frequencies of major species (shrub hardwoods, ferns and sedges) were derived, for each group of plots in each assessment year (Tables 8, 9, 10). Although the number of observation points was very small, vegetation changes were confirmed by general observations made during regular visits to the trial over the past 24 years.

TABLE 8—Frequency (%) of major species on scraped, compacted ground at Pureora (five plots)

	1963	1965	1974	1985
Shrub hardwoods/tree-ferns				
Wineberry	1.0	0.8	0.6	—
Fuchsia	0.8	—	—	—
Putaputaweta	0.4	0.6	0.6	0.6
Coprosma spp.	—	—	—	0.8
Sedges/ferns				
Hook sedges	0.6	1.0	0.6	—
Waterfern	—	0.4	0.6	0.6
Kiwakiwa	—	—	0.6	0.4
Pigfern	0.6	0.8	—	—
Kiokio	0.6	0.4	0.2	—

TABLE 9—Frequency (%) of major species on light slash at Pureora (10 plots)

	1963	1965	1974	1985
Shrub hardwoods/tree-ferns				
Wineberry	0.6	0.7	0.7	—
Fuchsia	0.6	—	—	—
Five-finger	—	0.3	0.3	0.3
Kamahi	—	0.3	—	—
Wheki	—	—	—	0.15)
Coprosma spp.	—	—	—	0.4)
Grasses/sedges/ferns				
Hook sedges	—	0.6	0.6	0.4
Waterfern	—	—	0.25	0.3
Kiwakiwa	—	—	0.5	0.3
Rice grass	—	—	—	0.3

TABLE 10—Frequency (%) of major species on heavy slash at Pureora (20 plots)

	1963	1965	1974	1985
Shrub hardwoods/tree-ferns				
Wineberry	0.6	0.6	0.6	0.14
Fuchsia	0.45	—	—	—
Five-finger	0.25	0.35	—	—
Kamahi	—	0.25	0.2	—
Wheki	—	0.25	0.3	0.45
Sedges/ferns				
Hook sedges	—	—	0.35	—
Waterfern	0.3	0.25	0.3	0.3
Kiwakiwa	—	—	0.4	0.5
Pigfern	—	0.2	—	—

Results

The coloniser *par excellence* on all disturbed sites has been wineberry, which was already present in most plots 18 months after logging, and forming a canopy 2–3 m high in 4 years. The other widely successful coloniser was fuchsia (*Fuchsia excorticata* (Forst. f.) L.f.) which did not persist, however, having virtually disappeared 4 years later.

On scraped compacted ground (Table 8), the other important coloniser has been putaputaweta (*Carpodetus serratus* J.R. et G. Forst.), which has outlived wineberry to form 5-m-high thickets, accompanied by small-leaved coprosma (*Coprosma rotundifolia* A. Cunn. and *C.* sp. aff. *parviflora* Hook f.) (Table 8). Important early groundcover species were hook sedges (*Uncinia* spp.), kiokio (*Blechnum* sp. aff. *capense* (L.) Schlecht.), and pigfern (*Paesia scaberula* (A. Rich.) Kuhn); the latter two have not persisted. In recent years, waterfern (*Histiopteris incisa* (Thunb.) J. Sm.) and kiwakiwa (*Blechnum fluviatile* (R. Br.) Salom.) have become important.

Successions on slash have been more varied. On light slash, five-finger (*Pseudopanax arboreus* (Murr.)) Philipson has been important in one-third of plots since 5 years after logging (Table 9). Wineberry has now all but disappeared leaving climber-tangles in places, while small-leaved *Coprosmas* and wheki (*Dicksonia squarrosa* (Forst. f.) Swartz) have become more important. Amongst ground-cover species, hook sedges have been prominent from an early stage, and have been joined more recently by waterfern, kiwakiwa, and rice grass (*Microlaena avenacea* (Raoul) Hook. f.).

On heavy slash, five-finger was initially important but did not persist (Table 10). Wineberry has virtually disappeared, while wheki has steadily increased in prominence. Amongst ground-cover species, waterfern has been prominent in one-third of plots since 4 years after logging, while kiwakiwa has become common more recently.

Discussion

The early demise of fuchsia on all disturbed sites was probably due to browsing by deer and possums; to a lesser extent, the same may be true of kamahi and five-finger. In contrast, the relatively short life-span of wineberry here (15–20 years) is a normal phenomenon not associated with browsing (Forest Research Institute 1975).

Studies of ground disturbance in low-volume-removal selective logging trials (Herbert & Beveridge 1977; Smale *et al.* 1985; Beveridge & Herbert 1978), coupled with the fact that one-third of the logged blocks at Pureora was disturbed (Beveridge & Herbert 1978), suggest that the amount of scraped compacted ground is likely to be of the order of 10%, of ground occupied by light slash c. 8%, and of ground occupied by heavy slash c. 15%. Scraped compacted ground provides an ideal seedbed for rimu (Franklin 1968); some 4700 rimu seedlings/ha were recorded on logging tracks in Blocks B and C in 1977 (Beveridge & Herbert 1978), the tallest of which are now 3 m high. The putaputaweta and small-leaved *Coprosma* species prevalent on these sites provide suitable overhead cover for continuing development. Thus, ribbons of dense podocarps, mainly rimu, can be expected to occupy logging tracks and their margins, where reasonable drainage exists.

Dense slash generally deters podocarp regeneration for several decades (Herbert & Beveridge 1977) but not tawa which, with its strong taproot, can easily establish on deep humus (Cameron 1963). The wheki groves which currently occupy some such sites, while themselves inimical to podocarp regeneration, provide suitable habitat for epiphytic hardwoods, especially kamahi. These in turn are often eventually replaced by podocarps (Beveridge 1973). Tawa, and ultimately podocarps too, can therefore be expected to occupy heavy slash sites. Light slash is generally more receptive to podocarp regeneration (Herbert & Beveridge 1977), and so podocarps can be expected earlier in the succession here.

All three types of logging disturbance mimic natural disturbance in virgin forest caused by canopy tree mortality, but are more widespread. Upturned rootplates of uprooted trees expose bare mineral soil, while the crowns and boles of windthrown trees produce varying amounts of slash. Since snapping and standing death account for c. 80% of tree death at Pureora, scraped compacted ground as occurs on logging tracks appears to be the least natural kind of disturbance there, and is also the one destined to lead to a forest least like the existing one.

However, general observation suggests that successions back to high forest may be being interrupted by browsing pressure from introduced mammals on some scraped compacted and slash sites. Some larger logging gaps remain dominated by dense swards of hook sedges and ground ferns 25 years after logging, and present little if any evidence of regeneration of canopy trees. The hardwoods (especially kamahi) epiphytic on tree-ferns in the podocarp regeneration cycle on slash sites are being depleted by possums; a recent reassessment of 28 plots in lowland forest in the district revealed an average reduction in the basal area of possum-preferred hardwoods of 20% over 7 years (F. Deuss & K. Broome, unpubl. data). Thus, tree-fern groves may be expected to persist on some slash sites, and it seems possible that the amount of high forest on the area may be reduced indefinitely.

REGENERATION OF PODOCARPS AND TAWA

Method

Regeneration surveys were carried out before logging at Pureora in 1959 and at Whirinaki in 1961, and 11–12 years after logging at both localities. A systematic sampling method adapted from Barnard (1950) was used in which seedlings (0.15–3 m high) were recorded in contiguous milliacre (0.0004-ha) plots along 200-m lines. The most vigorous established seedling was recorded as the "preferred seedling" in stocked plots; moribund, severely suppressed, and epiphytic seedlings were ignored.

Results

Both podocarp and tawa seedlings were widely distributed before logging at Pureora (Table 11), and have remained so (Table 12). Tawa seedlings were widely distributed before logging at Whirinaki (Table 11) and remain thus (Table 12); podocarp advance growth was very rare, and there was little recruitment in the decade or so following logging.

TABLE 11—Percentage of milliacre plots stocked with healthy podocarp and tawa seedlings (0.15–3 m high) in Pureora and Whirinaki selective logging trials before logging

	Block A (control)	Block B (selectively logged)	Block C (selectively logged)
Pureora (1959) n = 600			
Rimu	20.5	7.0	9.5
Matai	1.5	2.0	0.5
Miro	26.0	20.0	8.5
Kahikatea	1.5	1.5	0
Tanekaha	0	0	3.5
Tawa	26.0	39.5	29.5
Total	77.0	70.0	52.5
Whirinaki (1961) n = 1200			
Rimu	0	0.25	0
Kahikatea	1.0	0.25	0
Tawa	39.25	26.5	32.5
Total	40.25	27.0	32.5

In both localities tawa was the most widespread regenerating tall canopy species; miro was the most widespread regenerating podocarp at Pureora, and kahikatea at Whirinaki (Tables 11, 12). However, rimu is the most effective regenerating podocarp at both localities, i.e., the one most likely to contribute to the fixture canopy.

Kahikatea and totara seedlings planted in logged gaps at Pureora showed moderate survival rates over the first 15 years (63% and 73% respectively), and maximum mean annual height increments of c. 18 cm over the first 19 years. Seedlings planted in poisoned tree-fern groves have been less successful, with 15-year survival rates of only 27% in rimu and 50% in kahikatea, and 19-year maximum mean annual increments of c. 17 cm. Survival and growth of *E. delegatensis* have been very variable; although the larger surviving trees are now c. 25 cm in diameter, most are much smaller than this and exhibit some dieback.

At Whirinaki, kahikatea and rimu seedlings planted in deer-proof exclosures and deer- and possum-proof exclosures had significantly higher survivals ($p < 0.05$, chi-square) and grew significantly faster ($p < 0.01$, ANOVA) than those outside over the first 14 years. Survival rates were c. 99% and 77%, and mean annual increments were c. 13 cm and 7 cm, respectively. In the first two winters after planting, many unprotected seedlings were heavily browsed.

TABLE 12—Percentage of milliacre plots stocked with healthy podocarp and tawa seedlings (0.15–3 m high in Pureora and Whirinaki selective logging trials 11–12 years after logging

	Block A (control)	Block B (selectively logged)	Block C (selectively logged)
Pureora (1973) n = 1200			
Rimu	16.75	10.75	8.5
Matai	1.75	1.5	0.75
Miro	22.75	16.5	13.5
Kahikatea	1.5	0.5	0.25
Tawa	29.25	30.5	18.5
Total	72.0	59.75	41.5
Whirinaki (1972) n = 1200			
Rimu	0.25	0	0.75
Matai	0.25	0.5	0.5
Miro	0.5	0.5	0.25
Kahikatea	2.75	1.0	1.0
Tawa	41.75	27.25	37.0
Total	45.5	29.25	39.5

Discussion

The relative abundance of both podocarp and tawa regeneration in podocarp/tawa forest at Pureora is well known (McKelvey 1963), as is the scarcity of podocarp and abundance of tawa regeneration in forest of a similar kind at Whirinaki (McKelvey

1973). The general similarity in regeneration before logging and a decade or so later suggests that selective logging has had little impact on it. In both localities, losses due to logging have probably been to some extent compensated for by subsequent colonisation of logging-disturbed ground, as discussed earlier. A slight increase in the amount of podocarp regeneration occurring at Whirinaki has been noted recently, but remains to be adequately quantified.

CONCLUSIONS

The selective logging trials described here provided the basis for operational logging in limited areas of Pureora Forest Park and Whirinaki Forest Park, between the introduction in 1975 of the new management policy for State indigenous forests (New Zealand Forest Service 1977) and the cessation of logging at Pureora in 1981 and Whirinaki in 1984. Thus they will provide an indication of the likely longer term effects of this logging on hundreds of hectares of forest.

The selection system employed, and the level of harvest (about one-third of total merchantable volume), have been successful in maintaining a stable residual forest in both localities. At Pureora, logging has to some extent anticipated natural mortality, which is occurring at a significant rate (0.4% trees/annum) in virgin forest. Most canopy podocarps in the unlogged block are mature or over-mature, and so podocarp densities are likely to decline and net volume decrement to continue for many decades to come. However, sufficient advance growth exists here in both unlogged and logged forest, and generally in this forest type at Pureora (c. 71 saplings/ha, 15 poles/ha – McKelvey 1963) to ensure that podocarps will remain an important component of the forest in the foreseeable future. In the logged blocks, planted podocarp seedlings should also contribute to the future canopy.

Actual mortality rates of podocarps in virgin forest at Whirinaki are similar to those at Pureora. However, because canopy podocarp densities are lower, the proportional rate of loss of residual trees is much higher and, if sustained, most existing podocarp trees are likely to die within the next century. Although increment data are not available, this indicates that net volume decrement is almost certain to be occurring here too. Podocarp advance growth is markedly scarcer than at Pureora, with an average of only about six saplings per hectare and five poles per hectare recorded in the lowland rimu-matai/hardwood forest types (McKelvey 1973). Unless there is an increase in the rate of podocarp regeneration, it seems inevitable that podocarps will become a relatively minor element within the foreseeable future; podocarp population structures are not stable in virgin forest here. Selective logging has involved harvesting decrement during a period of decline and, in the long term, the potential sustainable yield of podocarps is likely to be very low indeed.

While removal of canopy trees in the presence of well-developed tawa advance growth at Pureora has accelerated canopy replacement, more severe logging disturbance (for example, formation of logging tracks and landings) has in places destroyed the existing forest altogether. At some of these sites, general observation suggests that successions back to high forest may be being interrupted by browsing pressure from introduced mammals. Thus, in the presence of substantial populations of introduced mammals, it seems possible that selective logging may lead to a long-term reduction in the amount of high forest cover on the area, and a corresponding reduction in the many values associated with it.

ACKNOWLEDGMENTS

The authors wish to thank Drs J. L. Bathgate, J. W. Herbert, D. J. Mead, and D. S. Preest for helpful comment, and Mr M. O. Kimberley for solving the differential equation. The Whirinaki trial was established by the late Dr R. J. Cameron.

REFERENCES

BARNARD, R. C. 1950: Linear regeneration sampling. **Malayan Forester 13:** 129–35.

BEVERIDGE, A. E. 1973: Regeneration of podocarps in a central North Island forest. **New Zealand Journal of Forestry 18:** 23–35.

BEVERIDGE, A. E.; HERBERT, J. W. 1978: Selective logging trials and their implications for management of the West Taupo forests. Proceedings of New Zealand Forest Service seminar on "Management Proposals for State Forests of the Rangitoto and Hauhungaroa Ranges, Central North Island." New Zealand Forest Service, Wellington.

CAMERON, R. J. 1960: The indigenous forests of New Zealand, intensive and extensive management. **Empire Forestry Review 39:** 185–95.

——— 1963: A study of the rooting habits of rimu and tawa in pumice soils. **New Zealand Journal of Forestry 8:** 771–85.

CARRON, L. T. 1968: "An Outline of Forest Mensuration". ANU Press, Canberra.

ELLIS, J. C. 1979: Tree volume equations for the major indigenous species in New Zealand. **New Zealand Forest Service, Forest Research Institute Technical Paper No. 67.**

FOREST RESEARCH INSTITUTE 1975: Selective logging of indigenous forests. **Forest Research Institute, New Zealand Forest Service, What's New in Forest Research No. 23.**

FRANKLIN, D. A. 1968: Biological flora of New Zealand. 3. **Dacrydium cupressinum** Lamb. (Podocarpaceae) rimu. **New Zealand Journal of Botany 6:** 493–513.

HERBERT, J. W. 1980: Structure and growth of dense podocarp forest at Tihoi, central North Island, and the impact of selective logging. **New Zealand Journal of Forestry 25:** 44–57.

HERBERT, J. W.; BEVERIDGE, A. E. 1977: A selective logging trial in dense podocarp forest in the central North Island. **New Zealand Journal of Forestry 22:** 81–100.

HORNE, R.; GWALTER, J. 1982: The recovery of rainforest overstorey following logging. 1. Subtropical rainforest. **Australian Forest Research 13:** 29–44.

KNOWLES, B.; BEVERIDGE, A. E. 1982: Biological flora of New Zealand. 9: **Beilschmiedia tawa** (A. Cunn.) Benth. et Hook. f. ex Kirk (Lauraceae) tawa. **New Zealand Journal of Botany 20:** 37–54.

McKELVEY, P. J. 1963: The synecology of the West Taupo indigenous forest. **New Zealand Forest Service Bulletin No. 14.**

——— 1973: The pattern of the Urewera Forests. **New Zealand Forest Service, Forest Research Institute, Technical Paper No. 59.**

NEW ZEALAND FOREST SERVICE 1977: "Management Policy for New Zealand's Indigenous State Forests". New Zealand Forest Service, Wellington.

NICHOLLS, J. L. 1969: Ecological survey of New Zealand's indigenous forests. **New Zealand Forest Service, Forest Research Institute, Type Map Series 2, Sheet N95 – Te Whaiti.**

RIJKSE, W. C. 1977: Soil map of the King Country. Sheet 1. Scale 1 : 63 360. **New Zealand Soil Bureau Map 170/1.**

——— 1986: Soils of Taupo region: Interim maps and legend. **Department of Scientific and Industrial Research, New Zealand Soil Bureau Report No. RO 1.2.**

SMALE, M. C.; KIMBERLEY, M. O. 1983: Regeneration patterns in **Beilschmiedia tawa**-dominant forest at Rotoehu. **New Zealand Journal of Forestry Science 13:** 58–71.

SMALE, M. C.; BERGIN, D. O.; GORDON, A. D.; PARDY, G. F.; STEWARD, G. A. 1985: Selective logging of dense podocarp forest at Whirinaki: Early effects. **New Zealand Journal of Forestry Science 15:** 36–58.

WARDS, I. (Ed.) 1976: "New Zealand Atlas". Government Printer, Wellington.

WHITMORE, T. C. 1983: "Tropical Rainforests of the Far East". 2nd edition. Clarendon Press, Oxford.