A SELECTIVE LOGGING TRIAL IN DENSE PODOCARP FOREST IN THE CENTRAL NORTH ISLAND

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Abstract

This paper reports a first attempt at selective logging in dense podocarp forest (mean merchantable volume 555 m³/ha), with tree marking based on silvicultural and ecological principles.

Three trial blocks were established, one being an unlogged control. In the second block 20 trees/ha were logged to remove 183 m³/ha, amounting to 30% of the merchantable volume, and in the third block 29 trees/ha were logged to remove 266 m³/ha, amounting to 55% of the volume.

An important objective was to remove small, discrete groups of trees, leaving other groups intact. In marking trees for removal or retention emphasis was on the condition and structure of the residual crop rather than on the quality of extracted timber.

The early impact of logging was assessed by recording the degree of damage sustained by residual trees and the nature and degree of ground disturbance. In general it was found that the heavier logging (55%) did not result in more extensive or superior sites for regeneration than the 30% logging, and that in the 55% block the residual forest structure, condition, stability, and appearance were substantially inferior.

Long-term results will be assessed in the future by recording windfall, vigour of residual trees, and natural regeneration trends.

INTRODUCTION

During 1974 the Forest Research Institute, in conjunction with Rotorua Conservancy, established a selective logging trial in dense podocarp forest in Tihoi State Forest, West Taupo. The main aims were to test the practicability of selective logging in dense podocarp forest and to monitor the immediate and long-term effects of such an operation. The trial stand contained 64 merchantable trees/ha with a mean merchantable volume of 555 m³/ha.

The term "selective logging" has previously been used rather loosely in New Zealand to cover any form of logging that re-

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moves only part of the forest crop. Thus it has been applied to logging operations that remove only one favoured species, all or any species with an arbitrary diameter limit, or only the best timber trees; such forms of logging do not necessarily incorporate criteria based on silvicultural and ecological principles and their application in the past has often resulted in destruction of the forest structure. Selective logging as applied in New Zealand bears little resemblance to the selective management techniques developed in Europe where management of shade-tolerant species is carried out in intimate mixed-age forest and is aimed at improving both the quality of the forests and the quality and quantity of timber produced.

In this paper the term "selective logging" is used to refer to a form of logging whereby trees are removed according to a set of criteria based on silvicultural and ecological principles. Priority is given to leaving the residual forest in a stable, healthy condition with minimum impairment of forest values: the quality and quantity of timber removed are of less importance than the condtion and structure of the residual forest.

In 1961 two trials with this objective were established in podocarp/tawa (*Beilschmiedia tawa*) forests in the central North Island forests of Pureora and Whirinaki. These trials are now providing some of the longer-term results of selective logging (Forest Research Institute, 1975; and see Forest Research Institute Annual Reports).

In the South Island a selective logging technique has been developed over the past 14 years in the mixed-size-class rimu (*Dacrydium cupressinum*) forests of the coastal terraces of Westland (Gover, 1972). Here many of the intrinsic values of the forest are being maintained, and the option of re-logging for a further yield at a later date remains.

The Dense Podocarp Forests of the Central North Island

In the North Island the dense podocarp forests have generally been restricted to easy terrain, often on upland sites (500 to 750 m altitude). They have naturally been a prime target for logging, with the result that the only extensive legally-available stands remaining are in Tihoi and Whirinaki State Forests. In the past a single complete logging has usually resulted in almost total destruction of the forest, with subsequent conversion to farmland or exotic conifer crops. A controlled selective logging was rarely considered and was thought to have poor prospects of succeeding. The highest-volume stands, particularly where rimu is dominant, consist of trees with long, slender boles and small crowns. Podocarps with diameters between 10 cm and 40 cm are rare, and regeneration usually consists of small suppressed seedlings of miro (*Podocarpus ferrugineus*) and rimu. Margins of such stands exposed by clearfelling have often suffered from severe windfall, accelerating the natural tendency for the high, even canopy to thin out and develop gaps which are initially colonised by tree ferns, low shrub hardwoods, and climbers.

The dense podocarp forest types vary considerably in composition and form according to site, altitude, topography, and history. An account of these types in the West Taupo region has been given by McKelvey (1963). Selective logging practice will differ according to the various types. For example, much better prospects for naturally regenerating logged areas exist in rimu-dominant stands than in matai (*Podocarpus spicatus*) or matai/totara (*Podocarpus totara* and *P. hallii*) types. Rimu has the capacity to become established and to develop on a wide range of sites, whereas matai and totara are more successful on fresh gravelly or sandy sites which normally occur as the result of natural catastrophes.

The existing rimu-dominant Tihoi stands were suitable for testing the practicability of selective logging. With the natural deterioration or death of many trees, the formation of shrub hardwood gaps, and the development of full deep crowns on relatively isolated trees, the structure was well suited to such an operation.

THE TRIAL AREA

The stand selected for the trial had developed partly on easy terrain on the west and south-west side of a depression, with a variable depth of Taupo pumice gravels and sands (maximum 100 cm), and partly on more undulating terrain draining into an incised tributary stream on the north-west side of the block, at an altitude of 660 m a.s.l. Several shallow, incised streams, developed since the overlying pumice was laid down 1800 years ago, drained into a swamp area adjacent to the trial block (Fig. 1.).

Forest Structure in the Trial Area

The dominant trees were rimu, generally tall and slender (to 45 m high) with small crowns. They were mainly mature and some of them could be described as senescent, with small storm-battered crowns and dead spikes. Matai occurred frequently and was usually sub-dominant to rimu. It had a high incidence of stem malformation or decay, but the canopy was normally healthy. Miro was common but always sub-

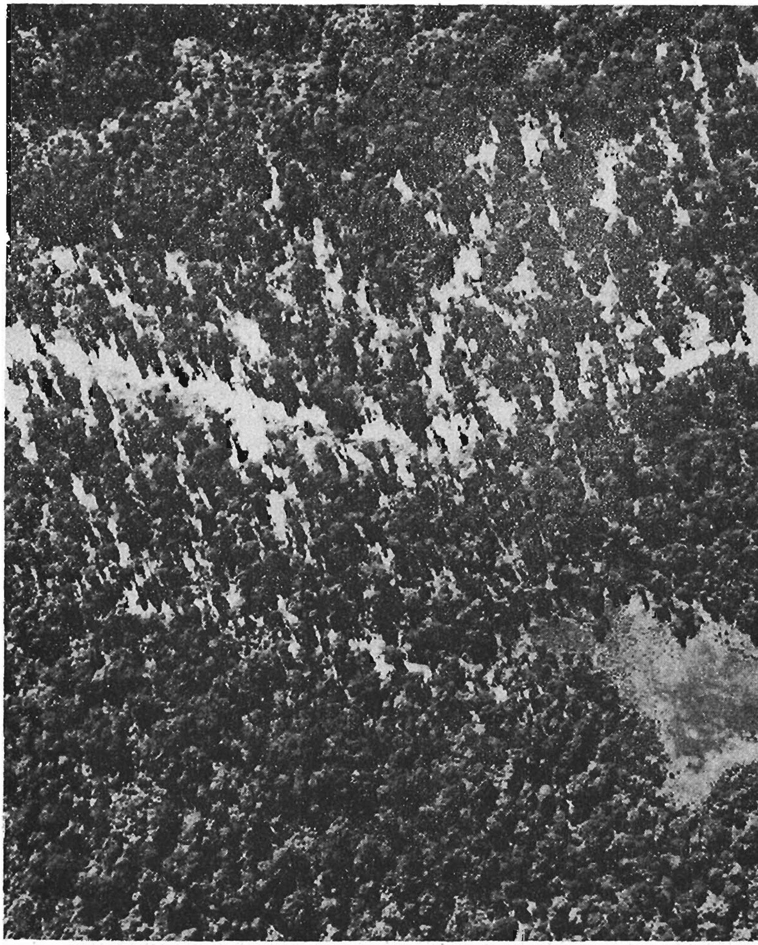

Fig. 1: Aerial view of selective logging trial in Tihoi State Forest: 55% of the merchantable volume of timber has been removed from the area above the logging road, and 30% from the area below it. An unlogged control block is seen towards the bottom of the picture, and the whole area is surrounded by an unlogged buffer zone.

dominant and of smaller diameter than rimu or matai; crowns were generally healthy and well formed. Rare Hall's totara and kahikatea (*Podocarpus dacrydioides*) were present in the overstorey. There was a generally sparse subcanopy of hinau (*Elaeocarpus dentatus*), maire (*Nestegis cunninghamii*), mahoe (*Melicytus ramiflorus*), *Pseudopanax edgerleyi*, kamahi (*Weinmannia racemosa*), and an open understorey of pepperwood

(*Pseudowintera colorata*), tree ferns (*Dicksonia* and *Cyathea* spp.), and ground ferns (*Todea, Asplenium, Blechnum* spp.).

There were localised clumps of rimu regeneration up to 2 m tall, and frequent well-distributed miro seedings but little effective matai or totara regeneration.

Based on ring-counts made on stumps, 23% of the rimu were between 200 and 400 years old, 62% between 400 and 500 years, and the remainder over 500 years old. The bulk of the matai was 600 to 700 years old, and the few miro that were examined were 300 to 470 years old. There was some evidence that growth rates of most rimu had deteriorated over the past 30 to 80 years.

Trial Layout

The most homogeneous area available totalled 44 ha and was subdivided into three approximately equal-sized blocks, comprising an undisturbed control block and two trial blocks (Fig. 1). Buffer strips of varying width were retained along unprotected margins. The control and trial blocks were permanently gridded into 1 ha units for ease in marking, mapping, and relocation of trees.

Prior to any operations being carried out, all blocks were 100% cruised and all trees over 30 cm d.b.h. tagged. The location of each tree was mapped along with topographical features, existing gaps, areas of regeneration, and recognisable windfalls. During mapping trees were marked for retention by a band of paint, or for removal by a vertical slash indicating the most desirable felling direction. The crown condition of each tree was recorded as good, moderate, or poor, along with any factors which might have some bearing on its future stability or longevity — *e.g.*, butt or stem rots, lean, dead leaders.

Proportion of Crop Market for Removal

With no previous experience in this forest type, the arbitrary proportions of 30% and 60% of the cruised merchantable volume were marked for removal in the trial blocks. In practice 30% of the volume was removed from one block and 55% from the other. This amounted to 30% and 47% of the number of merchantable trees, respectively, and only 25% and 34% of the total number of trees.

There were differences in stand structure between the two selectively-logged trial blocks and this had some effect on the results. In the 30% block the mean total stocking of trees over 30 cm diameter at breast height (d.b.h.) was 83 stems/ha, of which 15 were cull trees. Mean merchantable volume was

619 m^3/ha. In the 55% block the mean total stocking of trees over 30 cm d.b.h was 84 stems/ha, of which 23 were cull trees. Mean merchantable volume was 486 m^3/ha (Table 1). All but 2% of the merchantable trees were podocarps and 22% of the cull trees were hardwoods (hinau, maire, kamahi). Thus although total stocking was similar in these two blocks, there was a considerable difference in the mean merchantable volume. Rimu in the lower volume 55% block tended to be shorter-boled with heavier crowns although there were occasional groups of very tall trees with small crowns. Amongst matai there were many stems of small diameter and frequent cull trees.

Tracking Before Logging

In order to plan the orderly extraction of timber, to avoid areas of regeneration and groups of trees marked for retention, and to minimise random machine movement, the whole area was tracked by Rotorua Conservancy staff prior to logging. Because of the location and shape of the blocks it was impossible to avoid long up-hill hauls which resulted in extraction problems in wet weather. In addition, no alternative logging blocks were available when skids or tracks deteriorated, and more damage than necessary resulted both to residual trees and to tracks and skids. Productivity was also affected (see Results — Cost of Logging).

In this particular operation, trees were marked prior to tracking and this caused unnecessary difficulties in siting some tracks. The ideal sequence would be track alignment and construction, followed by tree marking, and finally logging.

MARKING FOR SELECTIVE LOGGING

The overall aim was to harvest an arbitrary proportion of the crop whilst leaving the residual forest in a healthy, stable condition, with the forest structure and associated values reasonably intact. The guiding principle is contained in the FDC Report of the Working Party on Indigenous Forest Policy, App. I, p. 3, which states ". . . logging should be conducted in such a way that maintains the diversity of age, tiers, and species within the indigenous structure to provide a wide range of social, economic, and environmental values . . ." (Forestry Development Conference, 1975).

Given a skilled and motivated contractor, it is firmly believed by the writers that the success of the operation and the long-term stability of the forest structure are determined by the criteria applied when marking trees for retention or removal.

Consequently our marking criteria are discussed in some detail.

1. *Tree Vigour and Stability*

Trees were marked for removal on an ecological and silvicultural basis. Wherever possible, merchantable trees with inferior crowns or signs of instability were removed. These included leaning, obviously unstable or unhealthy trees, or trees with small or extensive damaged crowns. Particular emphasis was placed on retaining vigorous stable trees with deep, healthy crowns. Such trees have often developed in isolation and are almost invariably stable and vigorous, and are likely to produce heavier and more frequent seed crops than trees with small or defective crowns. Although the trees removed were generally undesirable from a silvicultural point of view, there was no significant effect on log quality: 7% of the total volume extracted was of peeler quality; the measured volume of logs extracted was 46% in excess of estimated standing (cruised) volume; very few marked trees were rejected on grounds of poor quality; and there was little residue left on the forest floor.

2. *Group Selection*

Even in dense podocarp forest the mature podocarps often occur in groups of three to six trees. Where possible, small but complete groups of trees were marked for removal, leaving other groups completely undisturbed (Fig. 2). With this pattern of marking, machine movement between trees is minimised and damage to the understorey restricted. It was often possible to fell all trees of a selected group into the same shrub hardwood gap, thus concentrating slash and debris into a small area. The alternative is individual tree selection which in this forest type means virtually complete elimination of the understorey, some damage to most residual trees, and generally lighter but more diffuse ground disturbance and slash distribution.

3. *Felling Direction*

The most desirable felling direction was marked on each tree. This was normally into a shrub hardwood gap, away from patches of regeneration and away from retained groups. Unless trees had a pronounced lean or extensive butt rot it was possible, by using wedges, to exert sufficient control even over very large trees. Retained trees were clearly marked with a band of paint to enable easy recognition from a distance and the planning of immediate machine movement and felling sequence to avoid disturbing these trees.

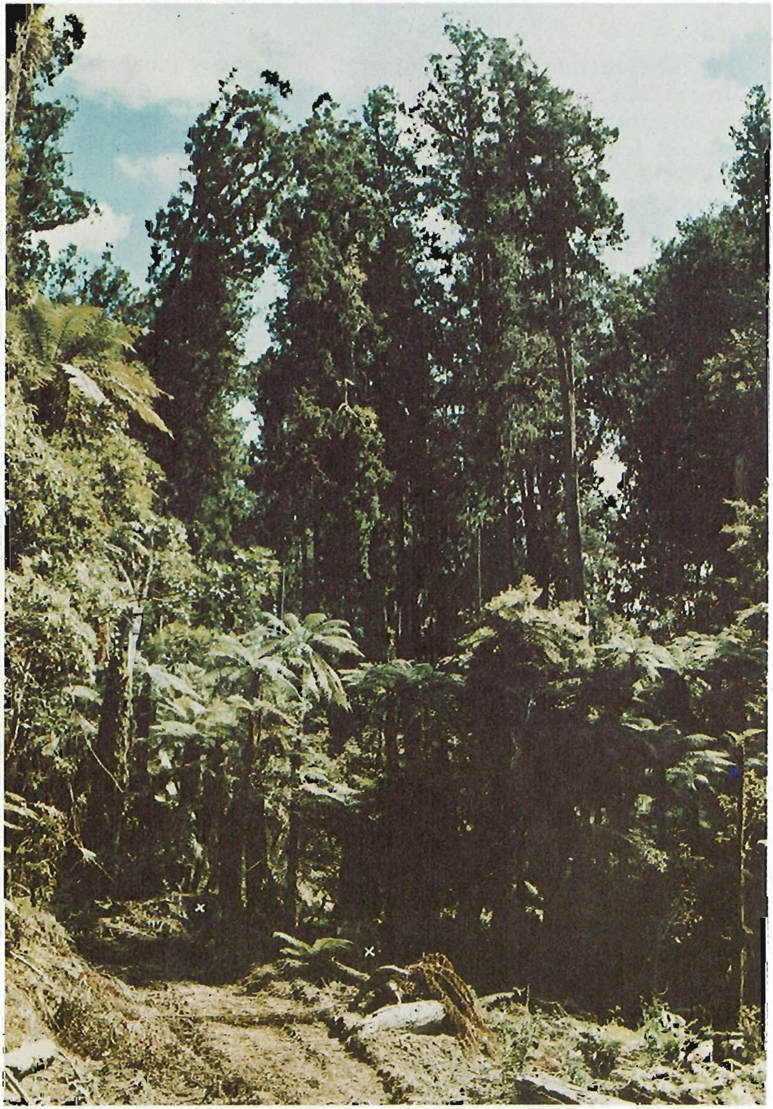

FIG. 2: *Portion of 30% logged block. Note stumps in foreground. The photo is not typical of the whole block but illustrates the aim of group selection logging. A whole group of trees has been removed from the foreground, leaving intact an adjacent group centred on a healthy, stable tree. The associated vegetation is similarly undamaged.*

4. *Species Selection*

Miro was almost invariably retained because:

(1) The crowns are normally healthy and exposure-resistant.

(2) It is not a sought-after timber species in this locality.

(3) It is an important food source for pigeons in autumn.

Matai is a good timber species but is not effectively regenerating in this forest. A large proportion of the matai was cruised as cull trees because of hollow stems, but where sound trees occurred they were normally felled.

Rimu provided the bulk of merchantable timber. It is the predominant and most sought-after timber tree and is the podocarp species which has the greatest capacity to regenerate naturally after logging and so perpetuate the character of the forest. Although good seed crops are produced at irregular intervals, and then only by a limited number of trees, rimu seedlings are extremely persistent on a wide range of sites and under a variety of canopy conditions.

Hall's totara and kahikatea were rare and normally were retained to add to the residual forest diversity.

Hinau, kamahi, maire, and pokaka were occasionally cruised as merchantable but, in fact, were unsaleable and retained.

5. *Cull Trees*

Cull trees were invariably marked for retention. Their important role is recognised in providing special niches for certain species of animals and plants and a habitat for an abundant invertebrate fauna. In this locality portions of podocarp stems are intensively used by kaka in their search for grubs. It is known that stem holes are favoured by parakeets as nesting sites, and tits have been found nesting in hollow butts. The following features are of importance:

(1) Cull trees add to the diversity of structure and form.

(2) Felling would only create more slash and debris for no purpose.

(3) Some cull trees will produce some seed.

(4) They provide a suitable habitat for most epiphytic shrubs, ferns, orchids, and mosses and can even act as a "refuge" for some species of vascular plants that have been almost eliminated from the forest floor by browsing.

6. *Logging*

Logging in the 30% block began in April and finished in June. In the 55% block logging began in June and ceased in August. The proportions of the crop removed by volume and stem numbers for the various sub-blocks and in total are shown in Table 1.

TABLE 1: VOLUMES* AND NUMBERS OF STEMS PER HECTARE REMOVED AT LOGGING

Sub Block	*Total merch. volume per ha*	*Volume/ ha removed*	*% Volume removed*	*Total merch. stems per ha*	*No. merch. stems/ha removed*	*% Merch. stems removed*	*No. culls/ha retained*
			30% LOGGED				
1	368	69	21.5	40	8	20.0	9
2	656	225	34.3	67	22	32.8	9
3	661	182	27.5	62	20	32.3	19
4	778	250	32.1	73	23	31.9	17
5	722	203	28.1	71	21	29.6	13
6	731	251	34.3	82	27	32.9	21
7	324	92	28.4	46	14	30.4	12
8	795	237	29.8	86	27	31.4	14
9	737	260	35.3	79	31	39.2	2
10	613	180	29.3	77	21	27.3	12
11	501	138	27.5	46	12	26.1	17
12	589	110	18.6	85	18	21.2	26
13	566	180	31.8	61	20	32.8	29
Means	619	183	29.7	67.3	20.3	30.2	15.4
			55% LOGGED				
1	461	248	53.8	68	29	42.7	17
2	548	285	52.0	63	30	47.6	26
3	569	326	57.3	74	38	51.5	28
4	459	252	54.9	57	23	40.3	21
5	467	233	49.9	51	22	43.1	26
6	532	310	58.3	69	39	56.5	20
7	352	164	46.6	38	12	31.6	28
8	517	288	55.7	66	31	47.0	24
9	477	252	52.8	54	23	42.6	17
10	839	474	56.5	100	49	49.0	33
11	314	168	53.5	42	25	59.5	23
12	301	188	62.5	41	21	51.2	17
Means	486	266	54.6	60.3	28.5	47.3	23.3

*Volumes (m^3/ha) were scaled after logging

After logging, ground surveys were carried out in order to quantify the effects of logging operations on ground condition and the residual crop. The main visual impact of selective logging is in the amount and distribution of slash, and tracking. The proportions of each were measured along continuous transects 1 m wide spaced at 50 intervals.

RESULTS

The differences between the two blocks are in the greater amount of slash and the lesser proportion of completely undisturbed ground in the more heavily logged block (Table 2). Because of the differences in structure between the two blocks, only 1.4 times as many trees were removed in the 55% block as in the 30% block. This obviously had some bearing on the results and in part explains the fairly small differences in slash distribution and ground condition between the two blocks, despite the fact that the 55% block had almost twice the proportion of crop removed.

TABLE 2: PERCENTAGE ABUNDANCE AND TYPE OF SLASH, AND CONDITION OF GROUND CLEAR OF SLASH, FOR THE 30% AND 55% BLOCKS

	Block	
	30%	*55%*
Slash:		
Dense	24.9	33.9
Light	6.8	13.2
Total	31.7	47.1
No Slash:		
Disturbed humus	7.8	6.2
Ground heavily disturbed	17.4	15.0
No disturbance	43.1	31.7
Total	68.3	52.9

Each felled tree created 165 m^2 of slash (0.13% of the total area per tree). The proportions of disturbed humus and heavily disturbed ground are virtually the same in the two treated blocks — this is a reflection of degree of machine movement and tracking and is discussed below.

The full significance of these figures to the future of the forest is not immediately apparent. However, it may be said that:

(1) Dense slash is inimical to podocarp regeneration for several decades (even when it does break down the sites will be colonised first by tree ferns and shrub hardwoods) although small podocarp seedlings may become established on partially decayed, moss-covered crown and bole sections of felled and windthrown trees.

(2) Certain sites classified as having light slash will provide a suitable seedbed for podocarps.

(3) The "disturbed humus" and a portion of the "heavily disturbed" sites will support podocarp regeneration but the bulk of the "disturbed humus" sites will also be colonised by shrubs and tree ferns which will tend to suppress any podocarps that do become established.

(4) From a recreation and amenity viewpoint, the larger the proportion of completely undisturbed ground the greater is the attractiveness of the residual forest.

TABLE 3: PERCENTAGE OF GROUND DISTURBED BY MACHINE MOVEMENT

	Block 30%	55%
Deeply incised (>30 cm deep)	10.5	9.7
Shallowly incised (<30 cm deep)	4.4	1.9
Churned	9.3	13.0
Walked by tractor	1.7	2.4
Total disturbed	26.0	27.0
No tracking	74.0	73.0

The proportion of machine-disturbed ground (Table 3) scarcely differed between the two blocks although it should be emphasised that only 1.4 times as many trees were removed from the 55% block. In this trial we tended to remover larger groups in the 55% block; the amount of machine movement to get to the groups would therefore not be much greater than in the 30% block. If an individual tree selection method were used, the proportion of machine-disturbed ground would be increased.

The significance of the results in Table 3 cannot be clearly established in the short term. The following points are made:

(1) Heavily incised tracks (up to 2 m deep) detract from the appearance of the area and damage tree root systems but piled loose soil along their edges will provide some seedbed for both podocarps and hardwoods.

(2) Shallowly incised tracks damage tree root systems, provide good walking access, and will provide some improved

seedbed, particularly along their edges. Ferns and hardwoods invade vigorously along the edges of these tracks.

(3) The effects of churned ground on regeneration will be similar to those of heavily disturbed ground. Parts will be suitable for podocarp establishment (and some shrub-hardwoods), some areas will support vigorous shrub hardwood regrowth, particularly margins, and some heavily compacted sites will be sterilised for some seasons.

Damage to Residual Crop

Physical damage to the residual crop was, first, severance of lateral roots (undercutting) caused by deep tracking: damage was recorded as depth of undercutting, distance from bole of tree, and proportion of circumference of the root plate affected. Secondly, machine movement over root plates caused compaction and damage to superficial feeding roots: compaction was measured as a proportion of the circumference of the root plate. The crowns of some residual trees were damaged during felling: the proportion of crown affected was recorded. Stem or butt debarking was caused by falling trees, or by logs dragged around the base of residual trees. Debarking of stem and butt was estimated in m^2. Finally, debris, slash, and soil accumulated around the butts of some trees, especially those around skids and alongside tracks. Debris accumulation was assessed as light, medium, or heavy. The assessed results are presented in Table 4, and the types of damage are illustrated in Fig 3.

TABLE 4: SUMMARY OF DAMAGE

Data are expressed as percentage of residual trees showing damage.

	Block 30%	Block 55%
Undercutting (proportion of circumference affected):		
1-30	3.8	2.3
31-60	4.6	4.3
> 60	0.4	0.3
Root plate compaction (proportion of circumference affected):		
1-30	6.7	8.8
31-60	7.8	6.6
> 60	1.1	2.2
Felling damage	8.8	16.9
Accumulation of debris at the base:		
Light	7.5	8.8
Medium	5.6	3.0
Heavy	11.1	9.6
Undisturbed	68.9	63.1

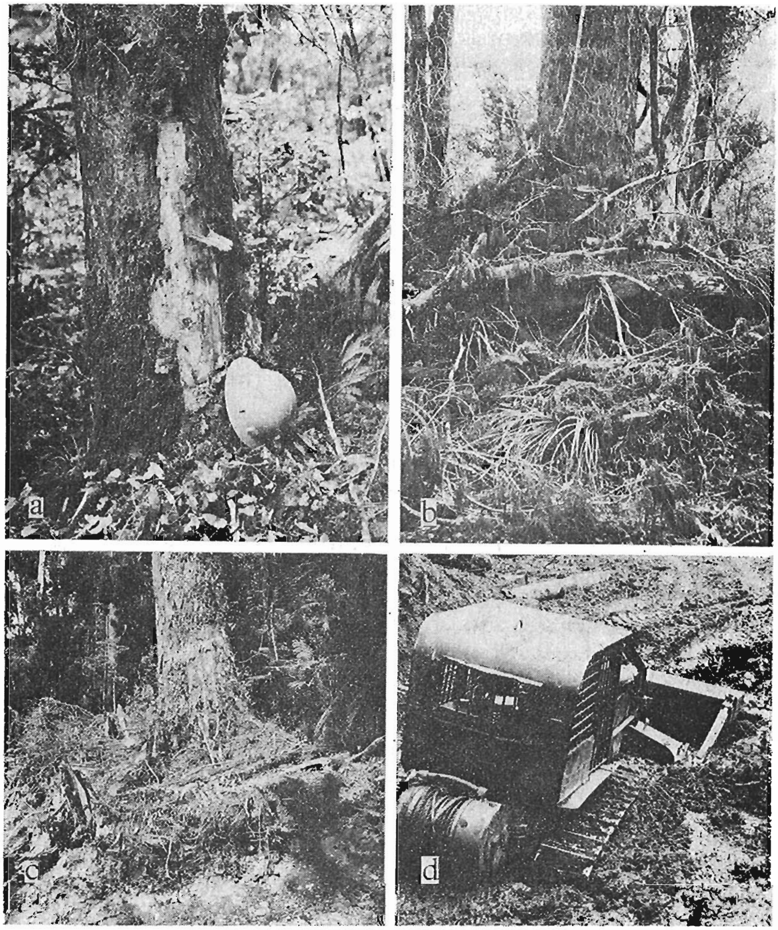

Fig. 3: Various forms of damage in the logging blocks. Much of this damage is avoidable if care is taken during felling and extraction.

(*a*) *Debarking of residual trees caused by careless use of machine blades or rolling logs around standing trees.*

(*b*) *Accumulation of logs and debris around the base of residual trees.*

(*c*) *Incised track close to a residual tree has resulted in destruction of lateral and feeding roots and extreme instability.*

(*d*) *Overuse of main extraction tracks. May be largely avoided by having alternative felling areas and skids for use during wet weather and by careful planning of extraction routes.*

The most important difference was in the number of residual trees damaged by felling — in the 55% block 17%, in the 30% block 9%. The proportion of trees affected by undercutting, compaction, and, to some extent, debris accumulation, is largely a reflection of tracking intensity. Since the intensity of tracking differed little in the two blocks, no major differences are to be expected in machine-induced damage. The significance of this damage is not assessable in the short term. However, it is expected that:

(1) Severance of lateral roots by undercutting will contribute markedly to instability and will probably reduce the vigour of the trees.

(2) Because compaction has damaged the delicate feeding root system near the ground surface, the effect will be a gradual deterioration of health over a 10- to 15-year period, culminating in death or windfall. However, it is not yet known what degree of damage to the feeding root systems a tree can withstand.

(3) Debris and spoil accumulation round the base of podocarps can result in death of the tree. Again, it is not yet known what degree of debris accumulation podocarps can withstand. From observation, matai appears to be particularly sensitive.

(4) Damage to the canopy of residual trees, provided it is not excessive, is not likely to have a measurable effect on tree health. Storm damage has resulted in considerable damage to crowns in the past and widespread damage by an unusually heavy fall of snow was observed just after logging was completed. Branch stubs do provide access for decay organisms. Debarking of stem or butt, particularly if it is excessive, appears from observation to have a more immediate effect on tree health.

Windfalls

Prior to setting up the trial, it was considered that windfall in the residual crop of originally dense stands would be a major problem. A windfall assessment was carried out in the logged and control blocks approximately 6 months after logging ceased in the 30% block and 4 months after logging ceased in the 55% block (10 months after cruising and tagging). The results are presented in Table 5.

In the 10 months since cruising the percentage of tagged trees windthrown was 0.8 in the control block, 1.7 in the 30% block, and 2.9 in the 55% block.

TABLE 5: TOTAL NUMBER OF WINDFALLS IN TRIAL BLOCKS OVER 10-MONTH PERIOD

	Block		
	30%	*55%*	*Control*
Total windfalls	14	19	6
Culls	6	16	2
Sound merchantable	6	3	1
Hollow merchantable	2	0	3
Uprooted	11	14	4
Snapped	3	5	2
Previously leaning	—	2	2
Logging damage	2	2	—

The results are particularly revealing. Seventy-four percent of the windfalls were cull trees (normally down-graded because of stem or butt rots) or trees cruised as merchantable but with internal rot. The proportion is heavily biased toward cull trees since only 23% of the stems in the trial area are culls. In the logged blocks 480 trees were cruised as culls, of which 22 (4.6%) have been windthrown. There were 1572 residual trees cruised as merchantable and 11 (0.7%) have been windthrown. Of the total windfalls, only 10 trees did not have characteristics predisposing them to windfall — *i.e.*, leaning or hollow trees, down-graded cull trees, and logging damage to root systems. Fourteen matai, 10 rimu, and 9 miro were windthrown. Of the sound windfalls five were miro, four rimu, and one matai.

There is some evidence that sub-dominant miro in dense stands are more likely to be windthrown than the dominant rimu or matai. In the trial area they are younger than the rimu or matai and have grown up under well-sheltered conditions. Thus root systems would not have developed in response to continual wind stress. When miro root systems were excavated and examined in an earlier study at Pureora it was found that they were small, and had less well-developed peg roots than rimu. From observation they appear to uproot rather than snap, again indicating less windfirmness. These observations apply only to miro present in dense stands of tall podocarps; isolated individuals may be very windfirm and tolerant of all climatic extremes.

Cost of Logging

Productivity of the logging gang was affected, but less than expected. Using the full data supplied by the contractor, the extra logging cost (relative to a clearfelling operation in similar stands) for both the 30% and 55% areas is $2.17/m^3$, or an increase of 22%. There was only a slight increase in production in the 55% block relative to the 30% block. Average daily production was 65.3 m^3.

A significant proportion of the 22% decrease in productivity was due to factors not referable to the trial itself, and would not have the same relative impact on extensive management operations. Of the total of 84 days spent working the block 6 full days were lost because of snow or heavy rain. Short hours were worked on a total of 25 days (wet weather) and 5 days were involved in double handling of logs.

In addition, no alternative skids or settings were available and despite deterioration of the main tracks and skids during wet weather, work had to continue, often in excessively unfavourable conditions. The topography and shape of the blocks did not allow for efficient extraction and long up-hill hauls were the rule, particularly in the 30% block.

A number of other factors designed to minimise damage to the residual crop, or to restrict machine movement had a significant but unknown effect on productivity. These included:

(1) Wedging of trees to control direction of fall. A single hydraulic wedge was used extensively and successfully. On larger trees, hammer-driven wedges were used in conjunction with the hydraulic wedge.

(2) Dragging out winch ropes to a maximum of 40 m (to minimise machine movement).

(3) Some timber was lost through shatter caused by felling trees across stumps or small gullies when no alternative felling direction was possible — *e.g.*, to avoid regeneration or residual trees.

(4) Breaking out was often made more difficult by the need to accommodate the various other priorities.

(5) Log lengths were kept to a minimum to reduce damage to the understorey and residual trees. Two hauls were often necessary when ordinarily one would suffice.

(6) Repositioning of winch ropes during breaking-out to roll a log over a stump or manoeuvre it around a residual tree.

Machinery and Equipment

30% block: Komatsu D60E, Caterpillar D7, replaced part way through by International T.D.20

55% block: Komatsu D60E, Caterpillar D7, Logging arch.

Rigging: Komatsu D60E, 45 m of 25 mm rope
International T.D.20, 45 m of 38 mm rope
Caterpillar D7, 22 m of 25 mm rope
Strops: 5 × 22 m and 4 × 18 mm

Machine hours for both blocks:
Komatsu D60E 338
International T.D.20 358
Caterpillar D7 130
Crane 13
GMC truck and Fordson loader 66

Average total tractor hours per day logging: 12 hours 25 minutes.

DISCUSSION

The present trial has shown that it is practicable to selectively log dense podocarp forest consisting of even-sized, large, mature trees while retaining elements of its original structure and composition. The major factors affecting the changes in composition and structure and the condition of the residual forest are the proportion of trees removed, the amount of machine movement required to remove these trees, and the marking criteria used. The proportions removed in the trial blocks were purely arbitrary and at present a factual statement about the relative success of each operation is not possible. In general it may be said that the 55% block offers no advantage in regeneration sites over the 30% block, and the residual forest structure, condition, and appearance are considerably inferior. If a true comparison between blocks was possible — *i.e.*, if the original forest types and volumes had been more alike — it is certain that the differences between the 30 and 55% blocks would be greater. Although only 1.4 times the volume (and number of trees) was removed from the 55% block, the differences, particularly in appearance and structure, are marked. It should be further emphasised that, of the total podocarp trees in the two blocks, 25% were removed in the 30% block and only 34% in the 55% block. The podocarps are the trees which give the forest its characteristic structure and atmosphere.

In the trial blocks every effort was made to retain the most stable, vigorous, and healthy trees regardless of their worth as timber trees. The prime consideration in marking, and in all subsequent operations, was the residual forest rather than the utilisable crop, and it is here that the approach differs from some other selective logging operations at present being carried out on a much larger scale. Provided strict control is exercised over machine movement, felling direction, and tracking, the results may fairly be extrapolated to other areas of dense podocarp forest selectively logged by a small-group system. However, there will be a marked divergence in stability, longevity, structure, and appearance if significantly different marking criteria are used, and particularly if hollow or decadent trees are relied upon to form the basis of the residual forest.

Whilst it is possible to measure the immediate physical impact of logging in the two blocks, the sum of all the less obvious effects will not become apparent for many years. The accumulation of debris about standing trees, compaction of feeding root systems, severance of lateral roots, stem and butt debarking, ponding on compacted tracks, crown damage to residual trees, and inadvertent creation of wind tunnels will all have some long-term effect on some residual trees. At the present time all that can be said of selective logging in dense podocarp forest is that any method which minimises damage to stable, healthy, residual trees and causes least disturbance to the existing forest will be the most effective in preserving the long-term health, condition, structure, and appearance of the forest. The simplest way to minimise damage and at the same time obtain some logs is by the periodic removal of trees with deteriorating crowns, trees growing on tracks or roadlines, trees with incipent stem or butt rots, and windthrown or badly leaning trees. From the viewpoint of the residual forest structure and its condition, the removal of an arbitrary proportion of the trees or volume from differing forest types in a "one hit" operation is no way to achieve the skills necessary to manage these forests on a sustained yield basis.

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