

FOREST ARCHITECTURE IN TERRACE RIMU FOREST OF SALTWATER FOREST, SOUTH WESTLAND, AND ITS IMPLICATIONS FOR MANAGEMENT

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ABSTRACT

Parts of the terrace rimu (*Dacrydium cupressinum* Lamb.) forest of Saltwater Forest in South Westland, New Zealand, were found to be naturally regenerating in an even-aged group pattern; the size of the even-aged groups varied from 0.2 to 20.0 ha, the majority being 3 to 10 ha. Studies of forest architecture and age structure identified five main growth phases - (a) a senility/regeneration phase, (b) an early competition phase, (c) a competition phase, (d) a homeostatic phase, and (e) a late homeostatic phase.

The results, together with past studies of attempts to manage these forests, suggest that future silviculture could be based on a group regeneration system. Careful logging is required, but good silvicultural tending should ensure long-term productive management in this type of forest.

Keywords: podocarps; hardwoods; rimu forest management; forest architecture; regeneration.

INTRODUCTION

"A good silvicultural system is not chosen but formulated as a solution to a specific set of circumstances. The formulation . . . should start with an analysis of the natural and economic factors that are likely to affect the growing timber crop" (Smith 1962, p.359).

The management of terrace rimu forests of South Westland has been the subject of much controversy. This is due partly to the preservation lobby pressing for logging to cease, and partly to foresters looking for appropriate management techniques to enable long-term production.

The quotation from Smith (1962) aptly describes the situation here, as foresters have been grappling to understand the nature of these forests and to find methods which will ensure their long-term productivity, yet meet other practical requirements. Unfortunately, in the past logging requirements have tended to dominate silvicultural needs to the detriment of the forest. The objective of the work described here was to have a fresh look at the natural architecture, age structure, and regeneration patterns of the forests to provide a better ecological basis to silviculture.

Dense rimu forests occur on lowland terraces between the Southern Alps and the Tasman Sea. These fluvioglacial terraces were formed during the last glaciation of the late Pleistocene, as were the moraines which occur along with them (Chavasse 1962). Characteristic soils on the flatter terraces are gley podzols, peaty gley podzols, and organic soils. On the better-drained moraines and terrace edges, podzolised yellow brown earths occur, while recent soils and organic soils are found along the river flood plains. Our study was concerned solely with rimu forests on the glacial terraces.

The mild super-humid climate of the area has had a profound effect on soil and forest development. The mean annual temperature is approximately 11°C with a mean daily minimum of about 6°C and mean maximum of almost 15°C (New Zealand Meteorological Service 1973, 1978). January and February are the warmest months, and June and July the coldest. Rainfall is very high, being about 4000 mm/year at Harihari, with the driest months (June to August) receiving about 260 mm each and the wettest months (January and February) some 360 mm. There is also an increasing rainfall gradient from the coast towards the mountains, and in the study area in Saltwater State Forest the mean annual precipitation is estimated to be about 3500 mm.

The terraces naturally support a dense podocarp forest, mainly of rimu but with some miro (*Prumnopitys ferruginea* (D. Don) de Laub.)* and kahikatea (*Dacrycarpus dacrydioides* (A. Rich) de Laub.), and a shrub hardwood understorey. In boggy areas there is a greater proportion of silver pine (*Lagarostrobos colensoi* (Hook.) Quinn) and *Libocedrus bidwillii* Hook. f. Typically, the stands occur as a mosaic of even-aged groups on the flat terraces and semi even-aged, mixed-aged groups on rising country (Hutchinson 1932; A. D. Griffiths, unpubl. data; I. L. James, unpubl. data). In the mature rimu forests, rimu comprises 76–93% of trees > 30 cm d.b.h. (Chavasse 1964) and often forms a continuous upper canopy (Wardle 1977) between 25 m and 40 m. Below this (25 m to 9 m) is a second broad layer (sometimes broken and discontinuous) consisting largely of kamahi (*Weinmannia racemosa* L.f.), quintinia (*Quintinia acutifolia* Kirk), miro, and occasional thin-barked (Hall's) totara (*Podocarpus cunninghamii* Col.) and silver pine. Below this second layer is a shrub and treefern storey merging with a ground layer of bryophytes and ferns. Epiphytes and lianes are common within the forest.

* Recent name changes (Edgar & Connor 1983) which have affected some species are listed here – *Prumnopitys ferruginea*, previously *Podocarpus ferrugineus* D. Don; *Dacrycarpus dacrydioides*, previously *Podocarpus dacrydioides* A. Rich.; *Lagarostrobos colensoi*, previously *Dacrydium colensoi* Hook. *Podocarpus cunninghamii* Col. is now recognised (Hunt 1972) as having priority over *Podocarpus hallii* Kirk under the International Rules. All other names are according to Allan (1961).

The merchantable volume and growth of the mature forest as well as other growth phases have been well documented (Franklin 1973; A. D. Griffiths, unpubl. data). However, research into natural regeneration and mortality has had less attention and little is known about the architecture and age composition of these lowland terrace forests. This paper concentrates on these aspects and their relationship to management.

METHODS

The study was carried out in virgin stands of Saltwater State Forest, South Westland (Fig. 1). The study area was mapped into more-or-less homogeneous growth phases on the basis of canopy structure and density, height, and, where possible, species. Aerial colour photographs (scale 1:18 000) together with field checking were used as a basis for mapping.

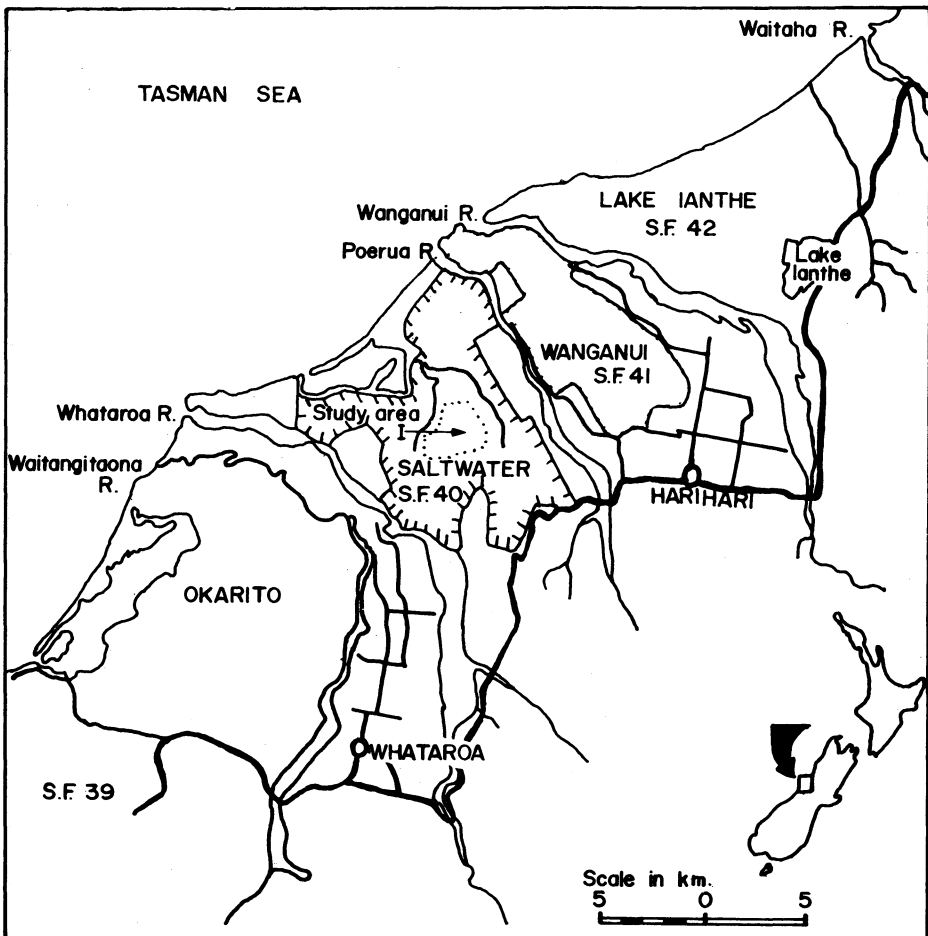


FIG. 1—Location of the study area in Saltwater State Forest, South Westland.

Within the study area five sites were chosen subjectively to depict the development of terrace rimu forest. At each site a band transect was used to determine forest architecture, stand age, and size structure. To prevent "overcrowding" in the final two-dimensional diagrams, the widths of the transects were varied (5–10 m) according to stand height. Transect length (70–90 m) was determined by the variability within each growth phase. Special attention was paid to ensuring that each transect had only one growth phase present.

Within each transect the location of each tree and shrub over 4 m in height was recorded and its d.b.h.o.b. was measured (to the nearest millimetre), height (to the nearest 0.1 m), height to first green branch (to the nearest 0.1 m), and crown dimensions (to the nearest 0.25 m). The centre of the crown was also recorded to enable the assessment of the angle and direction of lean, and broken leaders and tops were also noted. The general shape of the tree was drawn as seen from a point perpendicular to the base line. From this information profile diagrams were drawn (Fig. 2–6).

To sample herbs, ferns, shrubs, and trees under 4 m, continuous line transects of 1 × 1-m plots were located immediately outside and parallel to the band transects (for details see Six Dijkstra 1981). Presence of species was recorded and soil depth to the underlying gravels was measured by probing with an iron rod. Soil descriptions were made at two or three points along the transect.

ABBREVIATIONS USED IN PROFILE DIAGRAMS (Fig. 2–6)

Conifers (excl. toatoa) printed in green

Dc	<i>Dacrydium cupressinum</i>	rimu
Lc	<i>Lagarostrobos colensoi</i>	silver pine
Pc	<i>Podocarpus cunninghamii</i>	thin-barked totara
Pf	<i>Prumnopitys ferruginea</i>	miro

Others (incl. toatoa) printed in red

A	<i>Ascarina lucida</i>	
Cl	<i>Coprosma lucida</i>	
C	<i>Cyathea smithii</i>	
D	<i>Dicksonia squarrosa</i>	
E	<i>Elaeocarpus hookerianus</i>	pokaka
G	<i>Griselinia littoralis</i>	broadleaf
H	<i>Hedycarya arborea</i>	pigeonwood
M	<i>Myrsine australis</i>	
N	<i>Neomyrtus pedunculata</i>	
P	<i>Phyllocladus alpinus</i>	toatoa
P1	<i>Pseudopanax colensoi</i> var. "ternatus"	
P2	<i>Pseudopanax crassifolium</i>	lancewood
P3	<i>Pseudowintera colorata</i>	pepper tree
Q	<i>Quintinia acutifolia</i>	quintinia
W	<i>Weinmannia racemosa</i>	kamahi

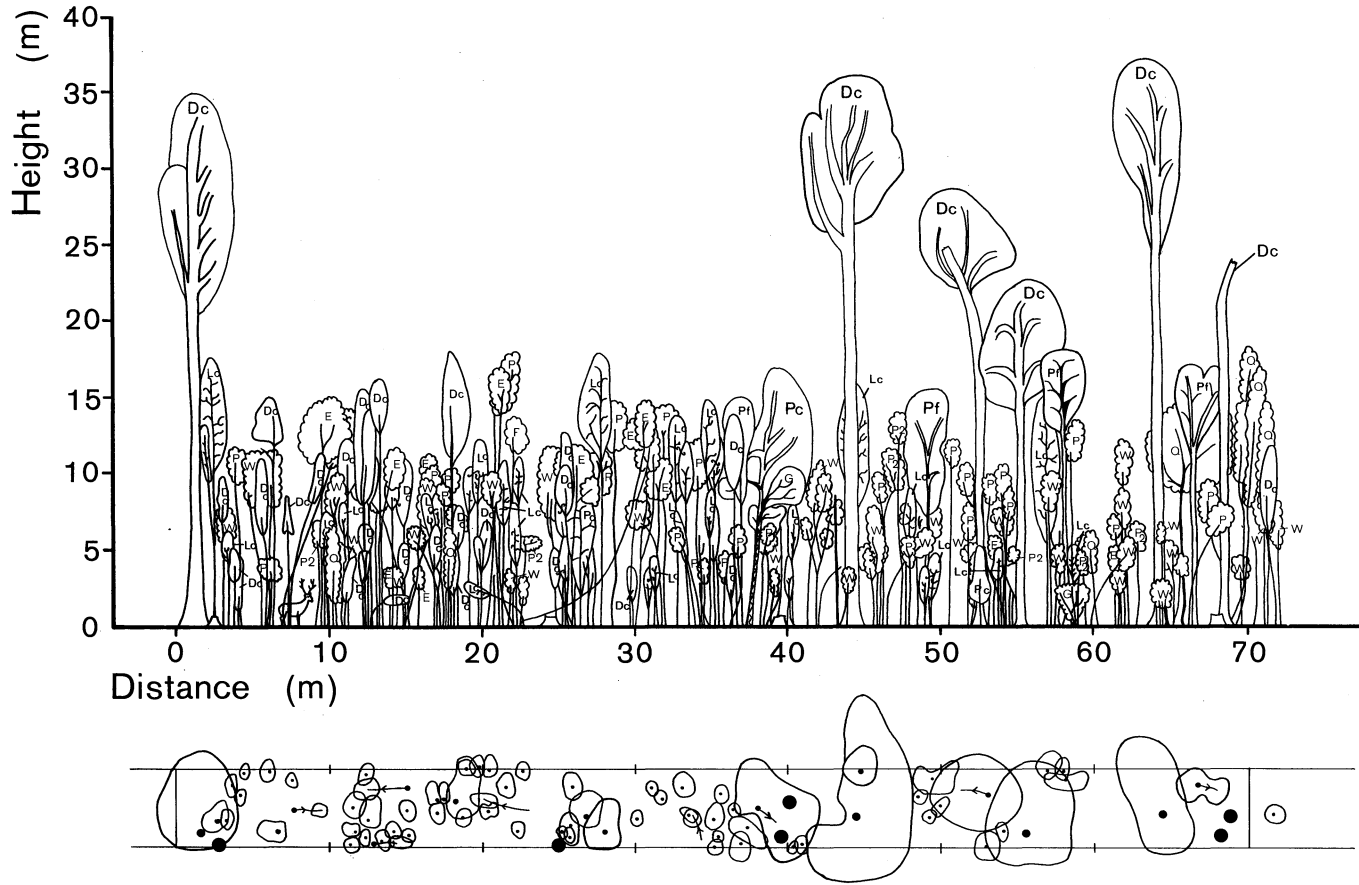


FIG. 2—Profile 1: senility/regeneration growth phase.

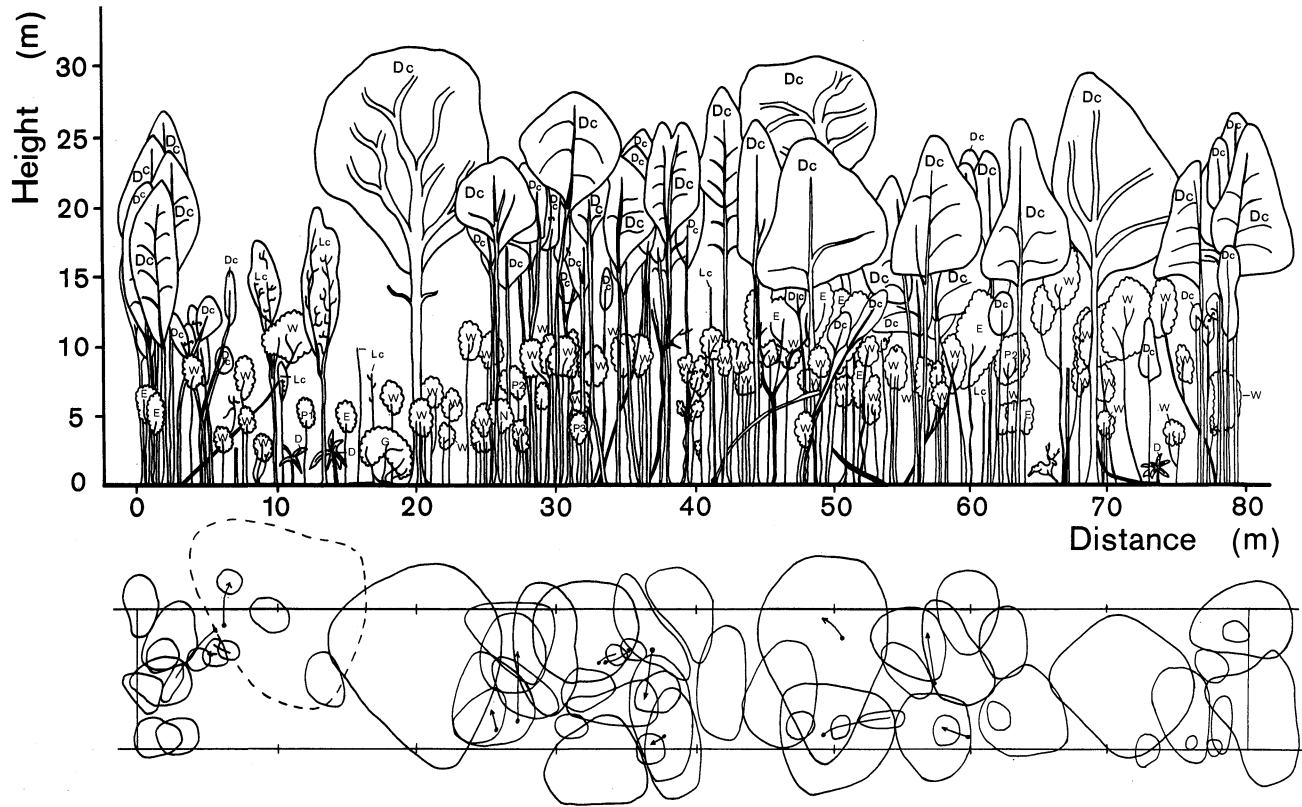


FIG. 3—Profile 2: early competition growth phase.

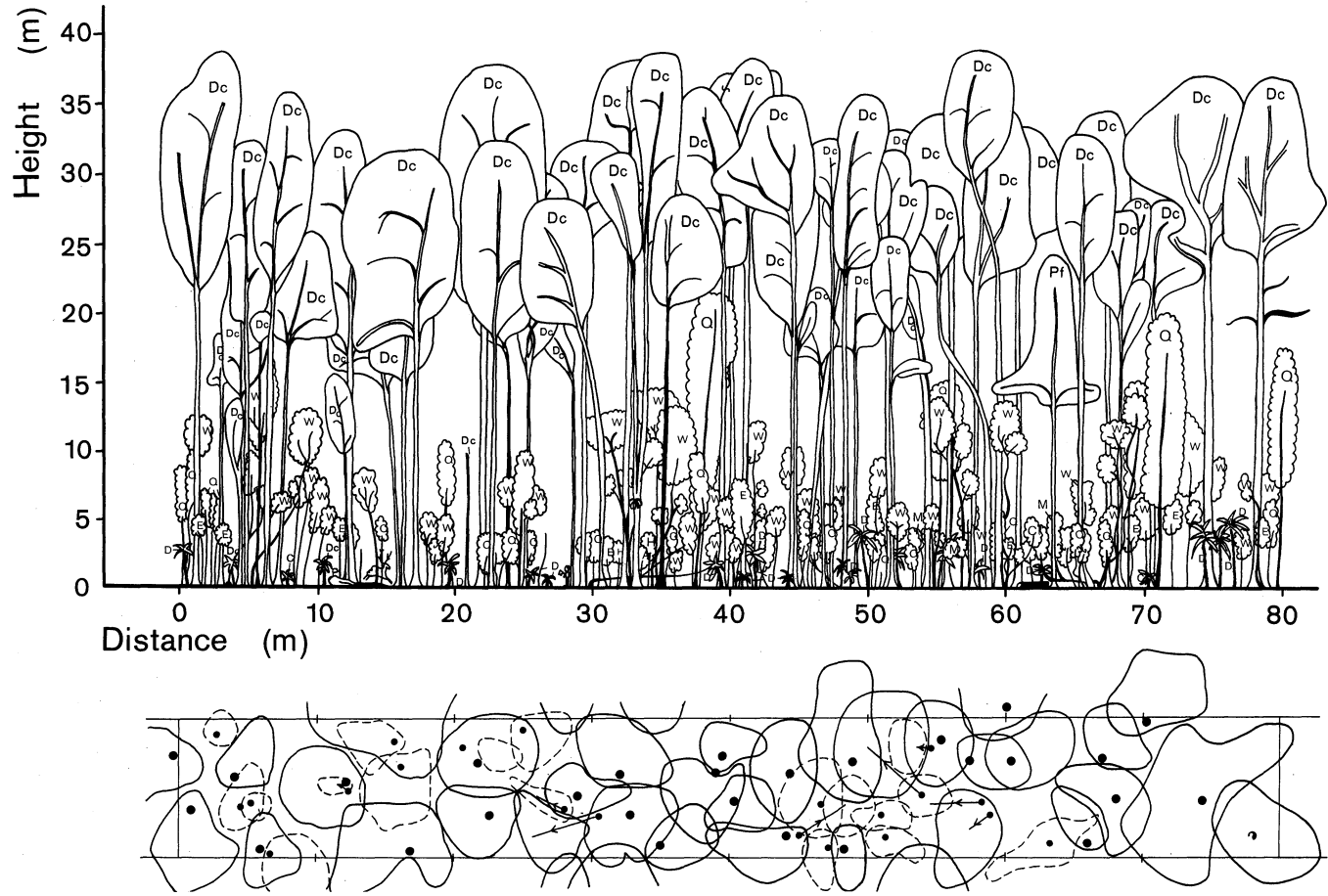


FIG. 4—Profile 3: competition growth phase.

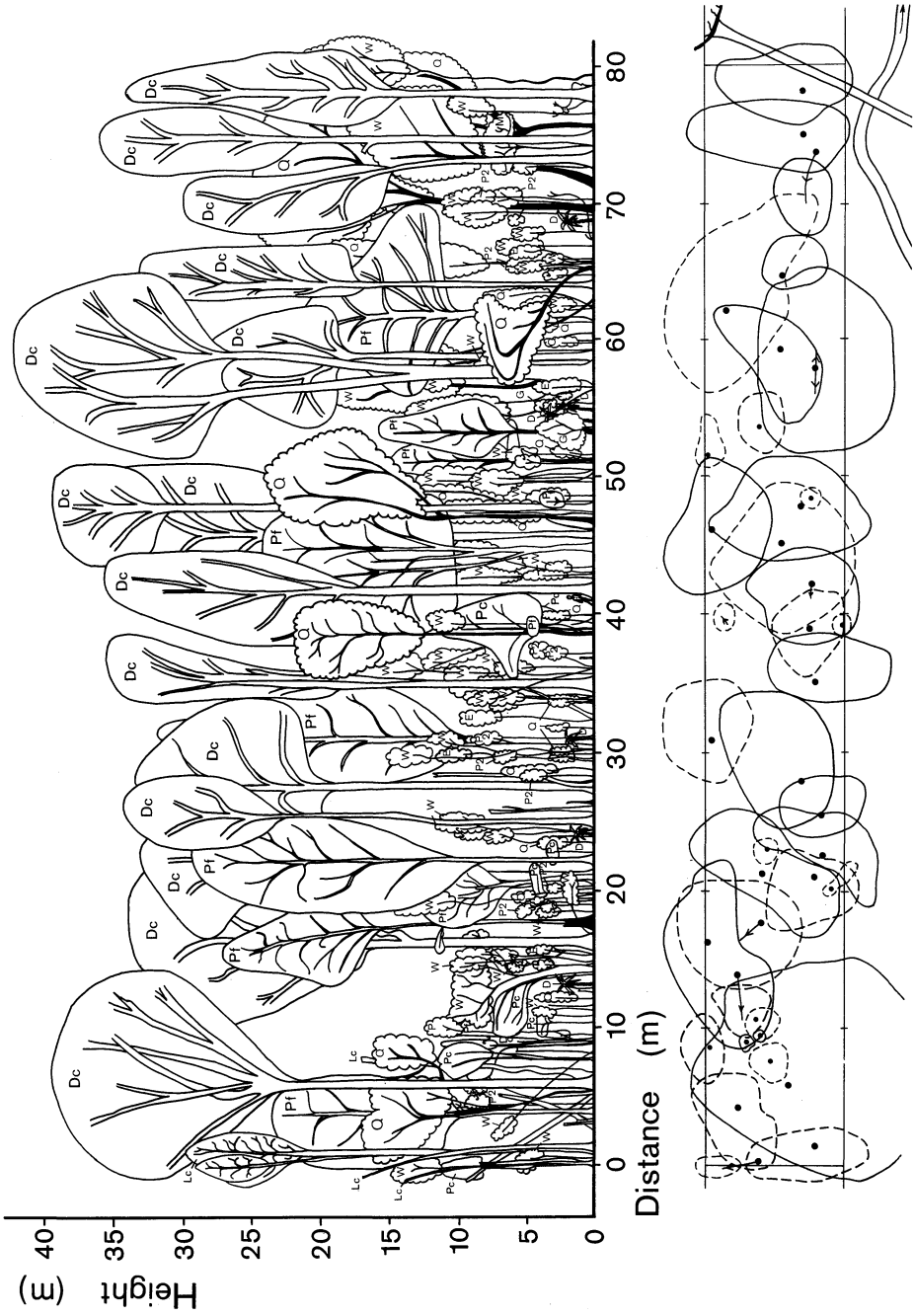


FIG. 5—Profile 4: homeostatic growth phase.

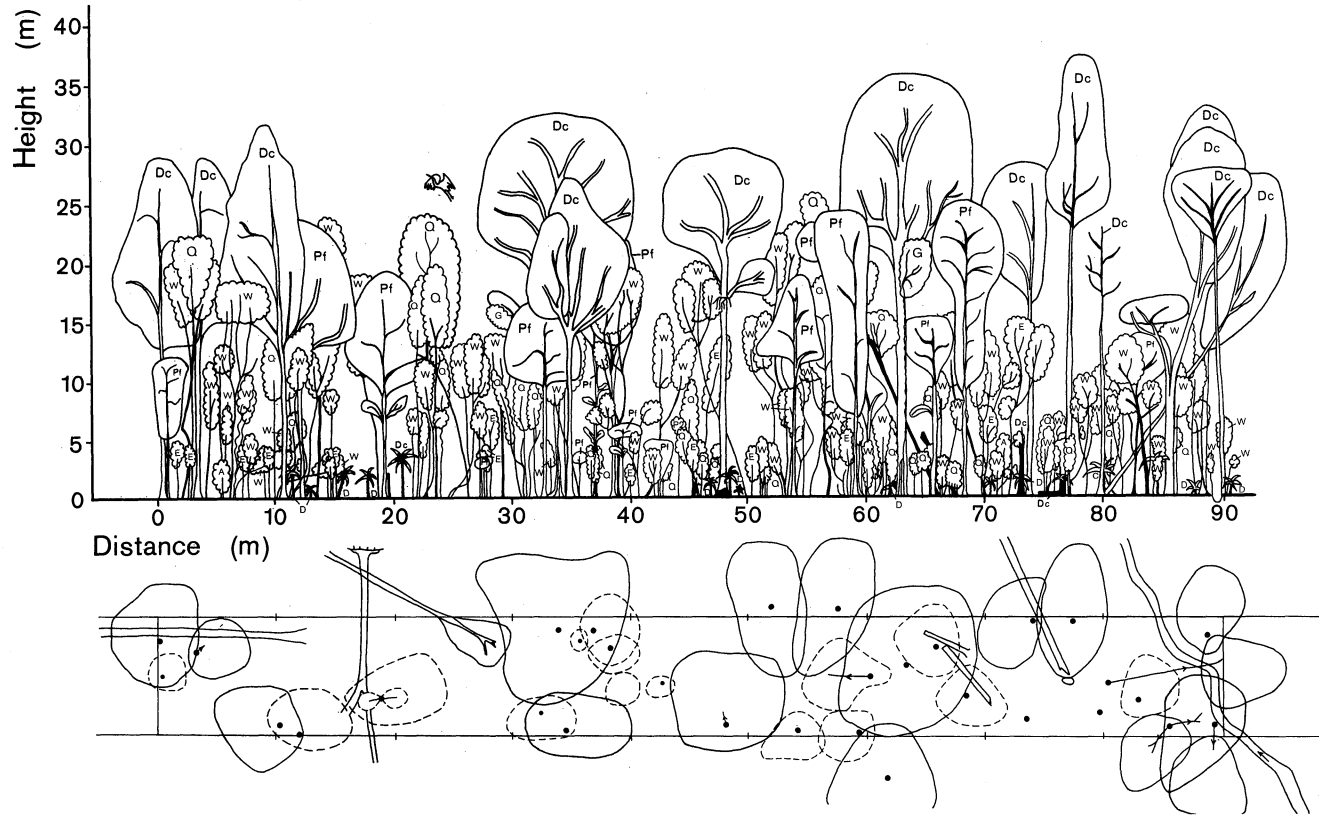


FIG. 6—Profile 5: late homeostatic growth phase.

To study the age structure on each transect, 6–10 discs were taken at about 40 cm above ground-level over the range of tree diameters. Rings were counted using a vari-powered binocular microscope after the surface had been carefully prepared. To obtain the true age it was necessary to estimate the time taken to reach 40 cm height. Ring counts made on seedlings about 30 cm tall indicated ages from 5 to 20 years.

RESULTS

The initial mapping and field survey revealed that the scale of regeneration, by growth phases, was the most variable factor. On the flat areas relatively close to the sea, the regeneration pattern appeared to be large-scaled (1–20 ha), and possibly initiated by massive windthrow (Hutchinson 1932). On slopes away from the sea, where the soils may have been better drained, the regenerated areas were smaller (0.2–2 ha) and some involved only small groups of 5–10 trees. With increasing slope the soil changed from Kini and Okarito to Waiuta set soils (Chavasse 1962; G. Mew, pers. comm.). The majority of areas were between 3 and 10 ha.

Of the five growth phases studied, three were chosen to depict the large-scale regeneration pattern; Transect 5 was on slightly sloping ground (<2%) and sampled group regeneration (Fig. 6); and Transect 2 (Fig. 3) was located on a site intermediate between this and those depicting the large-scale pattern.

All transects were on very wet soils with perched watertables at between 6 and 25 cm. The soils varied from deep mucks (>120 cm) in Transect 2, to mucks over gleys in Transect 1, to peaty humic gley podzols over gravels (at between 35 and 150 cm) in Transects 3, 4, and 5. Detailed soil and ground vegetation descriptions have been given previously (Six Dijkstra 1981).

The five growth phases also show a progression from the replacement of senile stands with young regeneration, though two stages where rimu crowns strongly show the effect of competition, to the homeostasis growth phase (Fig. 2–6, Profiles 1–5).

The senility/regeneration growth phase (Fig. 2, Profile 1): This consisted of young saplings of rimu and silver pine with scattered, tall, senile, rimu trees and a few other senescent miro and thin-barked totara. Three sets of trees were clearly recognisable – the set of the past, i.e., trees that have passed their maximum potential development; the set of the present, i.e., trees that have responded to their maximum potential; and the set of the future, i.e., trees that will form the forest of tomorrow. Each of these can be subdivided into "structural ensembles" according to discrete height levels (Hallé *et al.* 1978).

The set of the past was represented by two structural ensembles of 20–30 m high and 10–18 m high. The first structural ensemble were senile, small-crowned, rimu remnants of the previous crop occurring as scattered single trees or small groups at about 100 stems/ha. These trees were usually unhealthy and showed signs of decay in the form of broken tops, snapped off branches, and stem rot. Their ages ranged from 539 to 646 years (Fig. 7), and their average diameter was 57 cm (Fig. 8). Other characteristics of this crop were the frequent stumps and standing dead stems encountered throughout the stand. The ensemble 10–18 m high, found beneath the groups of

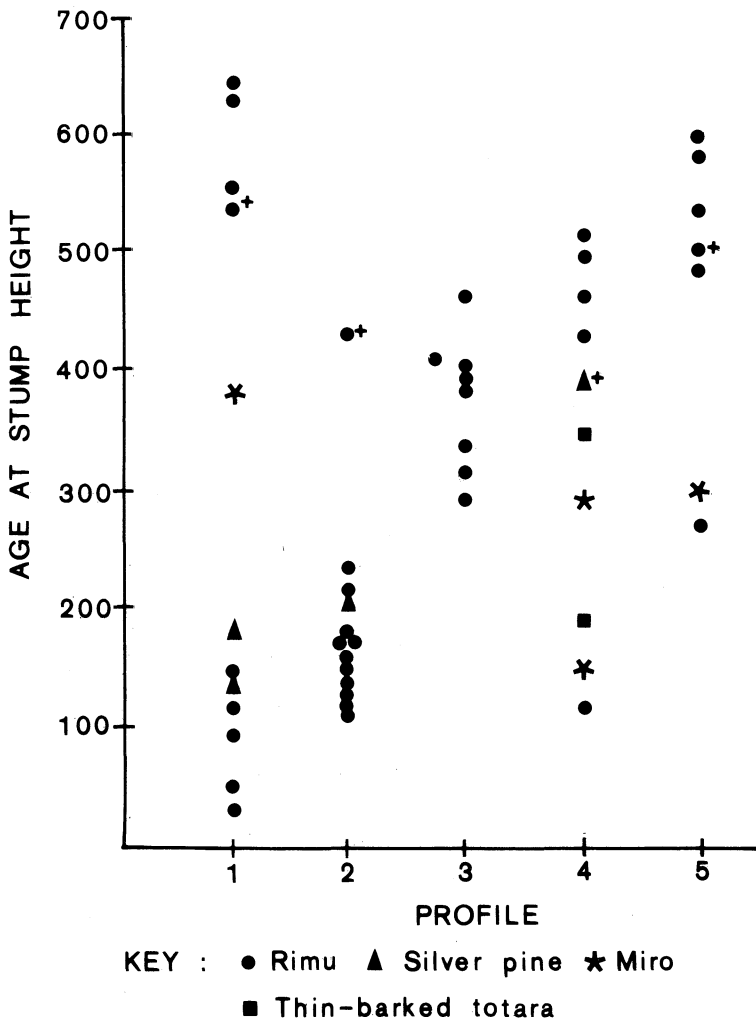


FIG. 7—Age structure of five growth phases of Saltwater State Forest (+ indicates minimum age at stump height).

senile trees, consisted of suppressed and battered shade-tolerant miro and thin-barked totara; the tallest miro in this group was 385 years old. Occasionally some big kamahi and quintinia were encountered.

The set of the present was represented by a nearly continuous structural ensemble of dense, small-crowned, small-diameter hardwoods 6–18 m tall (Fig. 2 and 9). The main species were kamahi, quintinia, and pokaka (*Elaeocarpus hookerianus* Raoul) and, judging by their crowns, growth appeared to have stagnated.

The set of the future consisted of saplings of rimu and silver pine 1–18 m high with an average diameter of 7 cm (Fig. 8), and ages ranging from 34 years for a

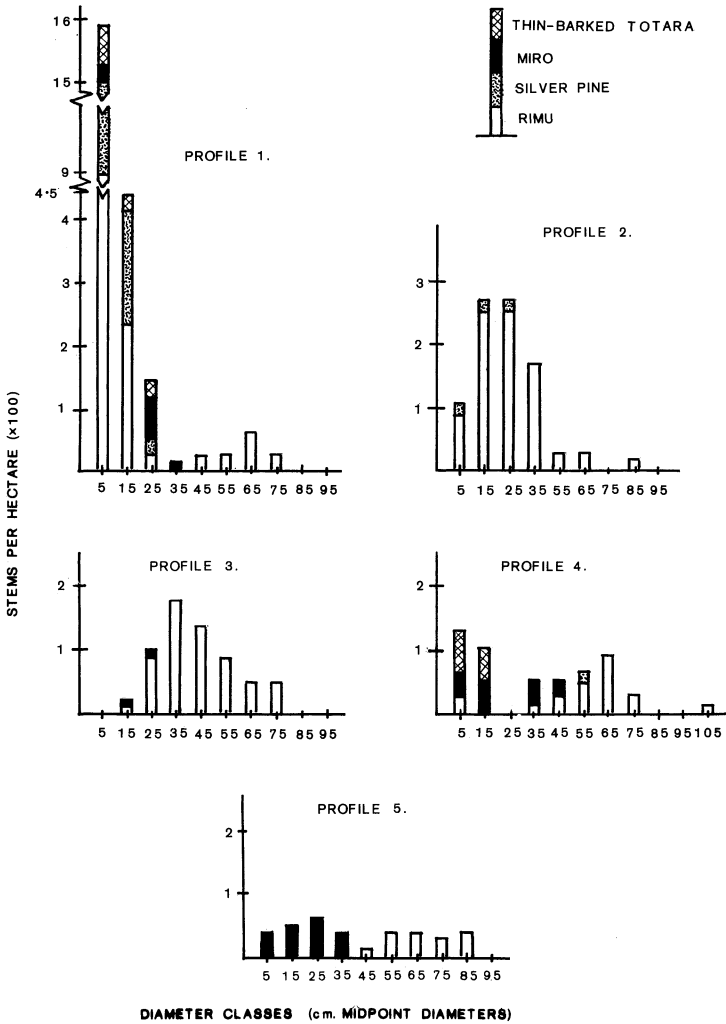


FIG. 8—Podocarp diameter size-class distribution - growth phase study (stems/ha).

1-m-high rimu to 190 years for the tallest silver pine (Fig. 7). This set occurred mainly where there was no overstorey of old rimu trees; the groups of senile trees were largely devoid of saplings. It is interesting to note that some rimu and silver pine saplings had just started to break through the hardwood layer and these will eventually comprise part of the set of the present.

In Fig. 8, therefore, the two distinct sets of trees are clearly visible - the set of the present with a skewed distribution of small-diameter trees, and the set of the past with older larger trees. Such distributions have not been described before in South Westland, although they can be found in other forests (Smith 1962).

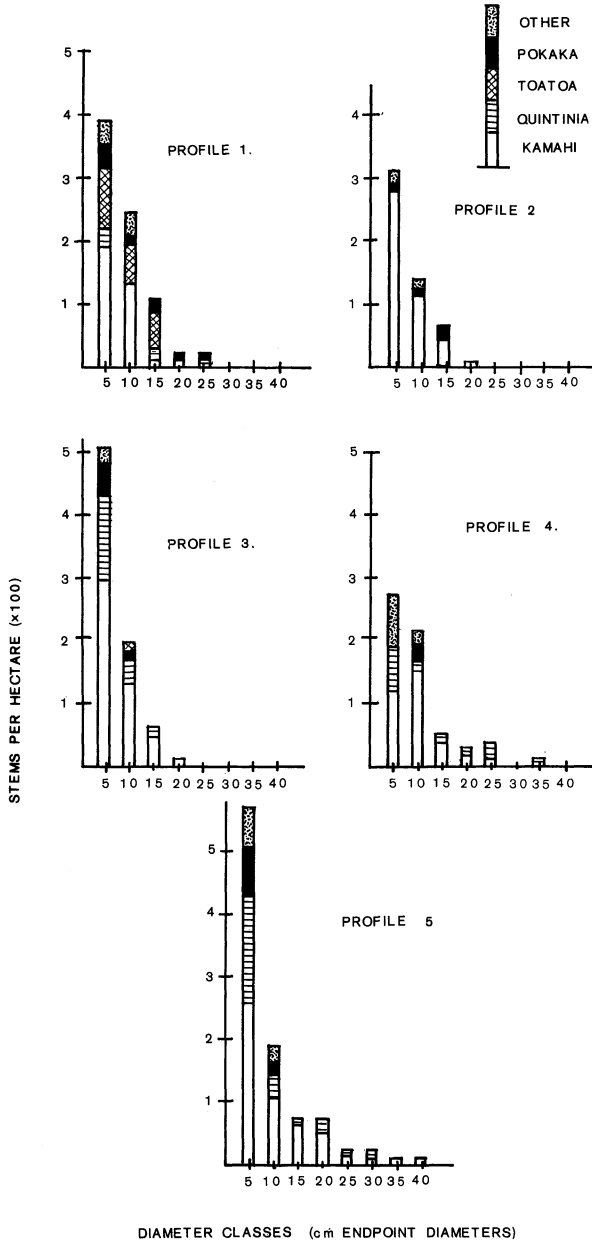


FIG. 9—Diameter size-class distribution for hardwoods and toatoa - growth phase study (stems/ha).

The early competition growth phase (Fig. 3, Profile 2): Here the set of the past was represented only by fallen and standing dead silver pine stems present throughout the transect mainly beneath dense sapling and pole-sized rimu trees. This is a sign that they were outgrown and out-competed by the faster-growing rimu saplings.

Two structural ensembles made up the set of the present. Between 14 and 30 m height the set was dominated by dense saplings and poles of rimu (and the occasional silver pine), with scattered mature rimu trees. The saplings and poles were putting on rapid height growth, resulting in their narrow, pyramidal, and often interwoven crowns forming a nearly continuous canopy with the crowns of the mature rimu trees. The sapling and pole-sized trees averaged 21 cm d.b.h. (Fig. 8) and they ranged in age from 115 to 243 years (Fig. 7). Note that the diameter distribution showed less skewness than is seen in Profile 1 (Fig. 2). Similar development occurred under two heavy-crowned rimu trees (at the 48 and 69 m mark, respectively). Here tall hardwoods grew up to the available light, being able to cope better than the more light-demanding podocarps. These large rimu trees are older, the one sampled being > 432 years (the stem was partly rotten and its age could not be determined exactly and so the figure is the number of annual rings counted).

There was also a stagnant set of the present in the form of suppressed hardwoods under the saplings and poles. *Quintinia* was not observed in this particular stand.

In one place two heavy-crowned, mature, rimu trees (one outside the plot) limited the podocarp regeneration. Under these conditions there was a small set of the future consisting of hardwoods that could be expected to grow into the empty space. Possibly shade-tolerant podocarps could regenerate here at a later date.

The competition growth phase (Fig. 4, Profile 3): This was a dense semi-mature growth phase with tall poles to medium-sized rimu trees. This stand consisted entirely of trees belonging to the set of the present in three structural ensembles. The dense structural ensemble from 18 to 38 m was formed by rimu trees with small, irregular but interwoven, poorly developed crowns. The shape of the crowns indicated that height competition had ceased and had been succeeded by a period of lateral crown expansion and competition. The rimu trees averaged 55 cm in diameter and measured ages ranged from 316 to 467 years (Fig. 7 and 8).

A light to moderately dense layer at 4–9 m (mainly *kamahi* and *quintinia*) formed the second highly irregular structural ensemble. This ensemble appears to have stagnated because of low light levels. Occasionally there was a tall *quintinia* or *miro* which had obviously responded to a small gap in the canopy; these trees formed the third indistinct structural ensemble from 9 to 24 m.

The homeostatic growth phase (Fig. 5, Profile 4):* This was a late mature stand approximately 38 m in height with moderately dense, heavy-crowned, rimu trees, which had reached their maximum potential height. Underneath this canopy there was a well-developed subcanopy of shade-tolerant podocarps (mainly *miro*, some silver pine, and occasional thin-barked *totara*). The hardwood component was two-tiered – scattered,

* Homeostasis in an ecological sense is a community (here a forest) in steady state, with minimal free energy (Hallé *et al.* 1978).

often leaning, kamahi and quintinia up to 25 m tall with well-developed crowns, and a second tier of minor hardwoods, mainly *Pseudopanax crassifolium* (A. Cunn) C. Koch, *Coprosma lucida* J.R. et G. Forst., pokaka, and *Myrsine australis* (A. Rich). Allan, up to 10 m tall. Shade-tolerant saplings of miro and thin-barked totara occurred frequently throughout the transect.

Throughout the stand there were many dead silver pine either standing or fallen. Their diameter ranged from 10 to 49 cm and they appeared to have died 25 to 75 years ago. These, together with dead stems and stumps of rimu and hardwoods, represented the set of the past.

The trees of the present occurred in three interwoven structural ensembles, the two bottom ensembles each merging with the one above. The highest structural ensemble was formed entirely by mature rimu trees averaging 62 cm in diameter and with an age range of 431 to 562 years. Merging into this were miro, silver pine, and quintinia trees from the second ensemble, with each of these species displaying specific characteristics. Miro and quintinia coming from underneath had long wide crowns to intercept as much light as possible. Quintinia often grew where gaps in the top canopy occurred. Silver pine had the characteristics of a pioneer species surviving strong competition in its initial growth phases (i.e., small narrow crowns and a clean bole) only to be outgrown and overshadowed once it had reached its maximum height. The shade-tolerant podocarps ranging in age from 154 to 367 years (Fig. 7) were younger than the mature rimu. The third structural ensemble (up to 14 m high) comprised minor hardwood species and stagnant kamahi and quintinia which, for the time being at least, were limited in their growth by the heavy canopy above.

The set of the future was made up of saplings of miro and thin-barked totara and, very occasionally, rimu; they are apparent in the diameter distribution (Fig. 8). However, scope for future development was limited because their niche had already been filled by larger quintinia or trees of the same species. A ring count made on one of the occasional rimu saplings indicated that they were at least 120 years old.

The "late" homeostatic growth phase (Fig. 6, Profile 5): This transect was complex and the processes involved were small-scaled. The diagram showing the projected cross-sectional area of the crowns facilitates an understanding of this growth phase.

The set of the present consisted of three structural ensembles – two more or less distinct although irregular, and a third highly irregular, sometimes absent. Three groups of rimu trees, each in a different stage of development, formed a broken open-topped canopy at 18–32 m. One group was formed by small rimu trees (approximately 35 cm d.b.h.o.b.) which were still increasing in height, with long pyramidal crowns (on the left-hand side of the profile). The age of this group, based on one sampled, was 279 years. The second group was made up of tall scattered rimu trees with large well-developed crowns. They had an average age of 595 years. The third group was a moderately dense group of rimu trees that appeared to have reached their maximum height. The crowns were cylindrical, though the branches were not yet well-developed. They were intermediate in age, the three trees measured averaging 514 years. The three groups were separated by two gaps, where trees had recently died or been blown over.

The other structural ensembles of the trees of the present were similar to those described for the homeostasis growth phase and were best developed beneath the tall scattered rimu trees. The hardwood development in the gaps was at an early stage as the gaps were of recent origin. Only small shade-tolerant podocarp saplings were present under the two younger groups of trees. There was a general absence of silver pine trees in this stand.

Saplings of miro and small kamahi and quintinia, forming the set of the future, definitely had more scope for development than the same set in the previous growth phase.

In Fig. 10 the diameter/age relationship is given for the five growth phases together. Similar variable results were found in the central North Island (Herbert 1980).

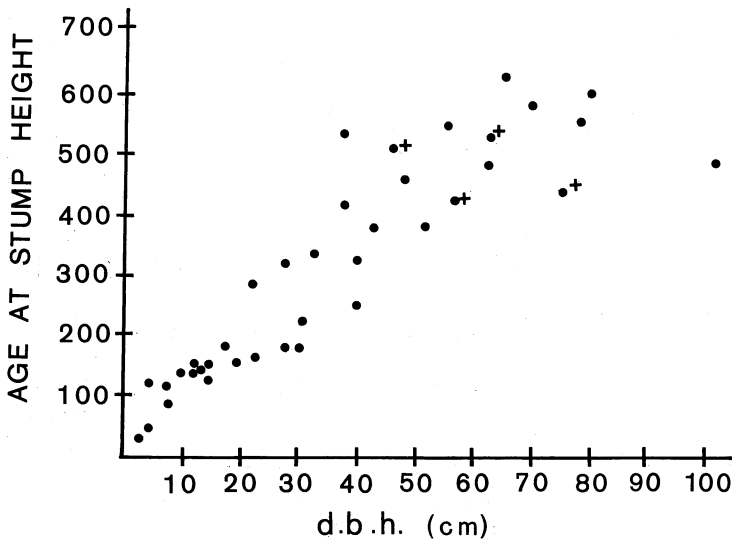


FIG. 10—Diameter/age relationships for rimu sampled from five different growth phases at Saltwater State Forest (+ indicates minimum age at stump height).

DISCUSSION

Natural Replacement Pattern

This study confirms that at Saltwater State Forest the rimu forest growing on the gley podzols of the flat terraces is regenerating in even-aged groups of variable size. The age spread of the dominant rimu trees is usually about 100 years out of a life-span of about 650 years; this would usually be defined as even-aged even where distinct sets of trees are present (Smith 1962). In Profile 3 (Fig. 4) the spread of ages (including sub-dominant and suppressed trees) was somewhat greater being about 170 years, or 26% of the age-span of these forests. The stands also have a typical even-aged archi-

ture as can be seen from the tree shapes in the profiles and the changes in size-class distributions. Profile 1 (Fig. 2) indicates that the homeostatic growth phase may disintegrate over a long period leaving single rimu trees or small groups of trees of about the same age standing in a sea of highly competitive saplings. It is only as these older trees disappear that the new set becomes fully established (Fig. 3, Profile 2). Although the regeneration period may be long, it is still only a fraction of the natural life-span of the forest.

In the study area the size of these even-aged groups ranged from areas involving only a few trees (0.2 ha) to 20 ha. The size of area is apparently related to topography and soil, with the bigger areas occurring on the flat terraces as has also been found in other studies (C. E. Foweraker & F. E. Hutchinson, unpubl. data; I. L. James, unpubl. data; Simmons 1982). The smaller groups illustrated in Profile 5 (Fig. 6) were located on a slightly sloping area with less-peaty gley podzols of varying depth (40 cm to > 150 cm).

Although it is apparent that small groups can occur, the usual pattern on the flat terraces is for large-scale group replacement. A possible explanation for this is that stands become unstable once they begin to open up. This lack of stability could well be related to the wetness of the soil and to the development of shallow plate-like root systems in rimu (I. L. James, unpubl. data). However, destruction of the canopy may apparently be either relatively rapid, resulting in whole stand replacement (Hutchinson 1932), or more gradual as depicted in Profile 1.

Although windthrow sometimes explains the large-scale regeneration pattern it is also possible for what may appear as small-scale groups to result in a very large-scale regeneration pattern (*see* Fig. 2, 3, and 6 – Profiles 1, 2, and 5). A time-span of 160 years was observed in the senility/regeneration growth phase. The complexity of this regeneration process is clearly demonstrated when Profiles 1 and 5 are compared with Profile 2. On the one hand (Profile 2), regeneration has established itself away from the tall overstorey trees and eventually, when the mature trees die, the canopy of tall saplings will close (*cf.* 50-m point of Profile 2). This stand will then have lost its present group regeneration character. On the other hand, if the senile trees are grouped (as in Profile 1 at the 55-m point) the original even-aged structure will be replaced by smaller-size groups, even-aged in character, but within an area that has established itself earlier (160 years in Profile 1). The over-all appearance of this stand will be a mosaic – groups within a group but with the regeneration period of the larger group still being a fraction of the rotation length. Profile 5 on sloping ground shows a well-established pattern of separate groups (40 × 50 m in size) that regenerates as the senile trees disappear. It is possible that such groups may also be related to changes in soils as Simmons (1982) suggested. Although further study and verification of this growth phase needs to be done, it appears that the over-all structure of the terrace rimu forests can be explained in terms of a forest that regenerates in both a group fashion and on a whole stand replacement basis. The main underlying factors are apparently wind, stand stability, stand structure in the senility growth phase, and topography with associated soil changes.

It is thus possible to hypothesise that the terrace rimu forest regenerates as follows, starting from the homeostatic growth phase. The tallest trees, approximately 500 years,

are probably the first to die or to be blown over. Their loss leads to the destruction of lower structural ensembles, the remaining upper canopy trees are exposed to the wind and become vulnerable to windthrow, and so the stand deteriorates either suddenly or more gradually. In the more gradual deterioration only single trees or groups may remain and they survive until they are well over 600 years old. Hardwoods are probably the first to react to the opening of the stand but, after they stagnate at about 18–20 m high (cf. Fig. 2, Profile 1), rimu and sometimes silver pine gradually establish themselves in dense thickets. Initial growth under the hardwoods is slow, but it is followed by a period of rapid growth after they penetrate the crowns of the nurse crop. In the meantime any old senile trees (650 years of age) gradually disappear. Once the saplings and poles reach full light there follows a period of intense competition. If silver pine is present it is left behind by the rimu at about 25 m and is often completely suppressed. The competition growth phase (Fig. 4, Profile 3) is the end of this development; the rimu trees have reached their maximum height. A period of lateral crown development follows with the rimu crowns becoming wider but shallower with a corresponding increase in branch size. The more shade-tolerant podocarps, mainly miro, begin to establish themselves 150–250 years later than the rimu or silver pine. They reach their full development in the homeostatic phase (Fig. 5, Profile 4) as the rimu canopy gradually opens up.

Silvicultural Implications

The early studies of C. E. Foweraker & F. E. Hutchinson (unpubl. data) suggested an even-aged structure, which they proposed could be managed under a silvicultural system involving three cutting cycles over a 225-year period. At each cutting cycle the mature and over-mature stands would be removed. They preferred such a system because of the ease of logging and because adequate regeneration was best secured by concentrated clearfellings rather than scattered selection felling.

Later Chavasse studied the regeneration pattern (at Ianthe State Forest) and concluded that, while this stand was even-sized, it was not even-aged (Chavasse 1964). Later still Chavasse & Travers (1966), using the same plots as Foweraker & Hutchinson, concluded that the stand structure was uneven-aged, that regeneration was insufficient for even-aged management, and that selection management was therefore the best option. Furthermore, they suggested that the system should be based on single trees or individual groups although they also recognised that different parts of the forest might require somewhat different treatment. In 1963 trials were begun to test the feasibility of this approach, and in subsequent years a variety of harvesting techniques were tried as a means of implementing their proposals. These included the use of tractors, rubber-tyred skidders, and cable hauling using parallel, diagonal, and radial patterns. The results of these trials have been recorded in detail (A. Katz & I. L. James, unpubl. data; I. L. James, unpubl. data; I. L. James & A. D. Griffiths, unpubl. data; James & Franklin 1977; Six Dijkstra 1981). The general conclusion has been that it is not easy to manage stands on a selection basis, because:

- (1) Economic and practical constraints have in the past dictated a size for the initial cut that was too high, and they prevented the use of the refined techniques required for this type of management;

- (2) It was realised that these forests could not be treated uniformly; in some of the growth phases the results had been acceptable, but in others it had been unacceptable (Six Dijkstra 1981);
- (3) There had often been high mortality resulting in very low and sometimes negative increments. Mortality resulted either from windthrow of the suddenly wind-exposed trees or from damaged roots and stems;
- (4) Although young regeneration was often adequate, the stands were generally not moving towards the ideal size-class distribution. Also the regeneration period appeared to be too long to work on the suggested 225-year rotation.

In recent years there has been a move towards clearfelling small areas or coupes (I. L. James, unpubl. data). Such a system fits into the natural pattern of the forest and is similar to the way the forest regenerates naturally. Initially these clearfellings should be confined to the homeostatic phase. As James has noted, clearfelling would overcome mortality problems and if access were provided it would be easy to retrieve any windthrow around the edges. Logging in the senility/regeneration phase should be confined to removal of the remaining overwood, and should be carefully done to keep damage to regeneration to a minimum. Because of the group pattern of regeneration the coupes should vary in size. James considers that economics would suggest coupes should be greater than 5 ha in area. However, it would probably be more ecologically sound and lead to greater long-term stability if the nature of the pattern at any one site dictated the coupe size so that in some areas coupes might be smaller. Although group size in the study reported here varied from 0.2 to 20 ha, the majority were between 3 and 10 ha.

Planting of the coupes has been undertaken with variable results (I. L. James, pers. comm.). The techniques of artificial establishment need to be perfected as planting holds promise as a method for shortening the initial regeneration period and for producing stands that will be easier to tend as they develop. Thinning of pole-sized stands has also been undertaken, and this too should lead to more uniform crops and shorter rotation lengths, although little is known about optimum tending schedules.

In recent years the use of portable sawmills, together with increasing wood value, has made it possible to harvest lower volumes of wood economically and to decrease the impact on the site. These changes may increase the flexibility of silvicultural practices.

Recommendations

This study and others (e.g., Simmons 1982) have shown the need for further research into the ecology of South Westland's forests, for only through good understanding of the ecology of these forests can good management be achieved.

All South Westland's forest types, and especially the gradients between them, should be studied in detail, with special emphasis on the soil/vegetation relationships. For this purpose adequate scientific, primarily ecological, reserves of all forest types should be set aside and permanently monitored.

Research is also needed on artificial regeneration of podocarps and on other silvicultural and harvesting practices.

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