PRESENT SNOWLINE IN FIORDLAND

Altitudes of the lower limits of present permanent snowfields in Fiordland are shown on Fig. 1; these are based on estimates made in the field, often from distant views from neighbouring peaks, and are probably accurate only to within 200 ft. Moreover, many of the snowfields are obviously diminishing in size and their lower limits are rising. However, contours based on the figures indicate a convex shape for the present snow-line, similar to that demonstrated by Willett (1940) for the Pleistocene snow-line. The relation of the present snow-line to the present upper timber-line is not known, but they are probably approximately parallel.

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THE ALTITUDINAL GRADIENT IN FOREST COMPOSITION, STRUCTURE AND REGENERATION IN THE HOLLYFORD VALLEY, FIORDLAND

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INTRODUCTION

The forest on the eastern side of the Hollyford Valley in the vicinity of the Deadman's Hut-Harris Saddle track was analysed to describe the changes in composition, structure and regeneration of the forest associated with a change in altitude from the valley floor at 300 ft. a.s.l. to the treeline at 3250 ft. Such an approach resembles the "gradient analysis" of Whittaker (1956), although the method used was somewhat different.

Results of a similar study made recently on undisturbed forest at Blanket Bay, Secretary Island, about 70 miles to the southwest (Mark 1963), provide a useful comparison.

The work described here was done by a party of botany students and staff during a University of Otago Science Students' Association expedition in May, 1960.

Financial assistance from the J. Speden Bequest Fund, administered through the Dunedin Garden Club, is gratefully acknowledged, as also is the field assistance of M. Holdsworth and Misses A. Adams, E. Begg, P. Berry, C. Cotton, E. Fair, R. Gore, J. Greenall, R. Hobson, G. Macdonald, J. Miles, M. Murrell and G. Parsons.

GEOLOGY

According to Grindley (1958), three types of geological material occur in the area studied. The site on the Hollyford Valley floor consists of outwash and moraine of the last glaciation. The upper Hollyford Valley consists of diorite and diorite gneiss of the Fiordland Complex, while the main area of study on the eastern side of the valley consists of sub-schistose greywackes of the Caples Group, which are sub-metamorphic upper Palaeozoic sediments. The term "greywacke" here covers "a monotonous succession of dark green-grey, massive siltstones, sandstones and fine intraformational, sub-schistose breccia."

TOPOGRAPHY

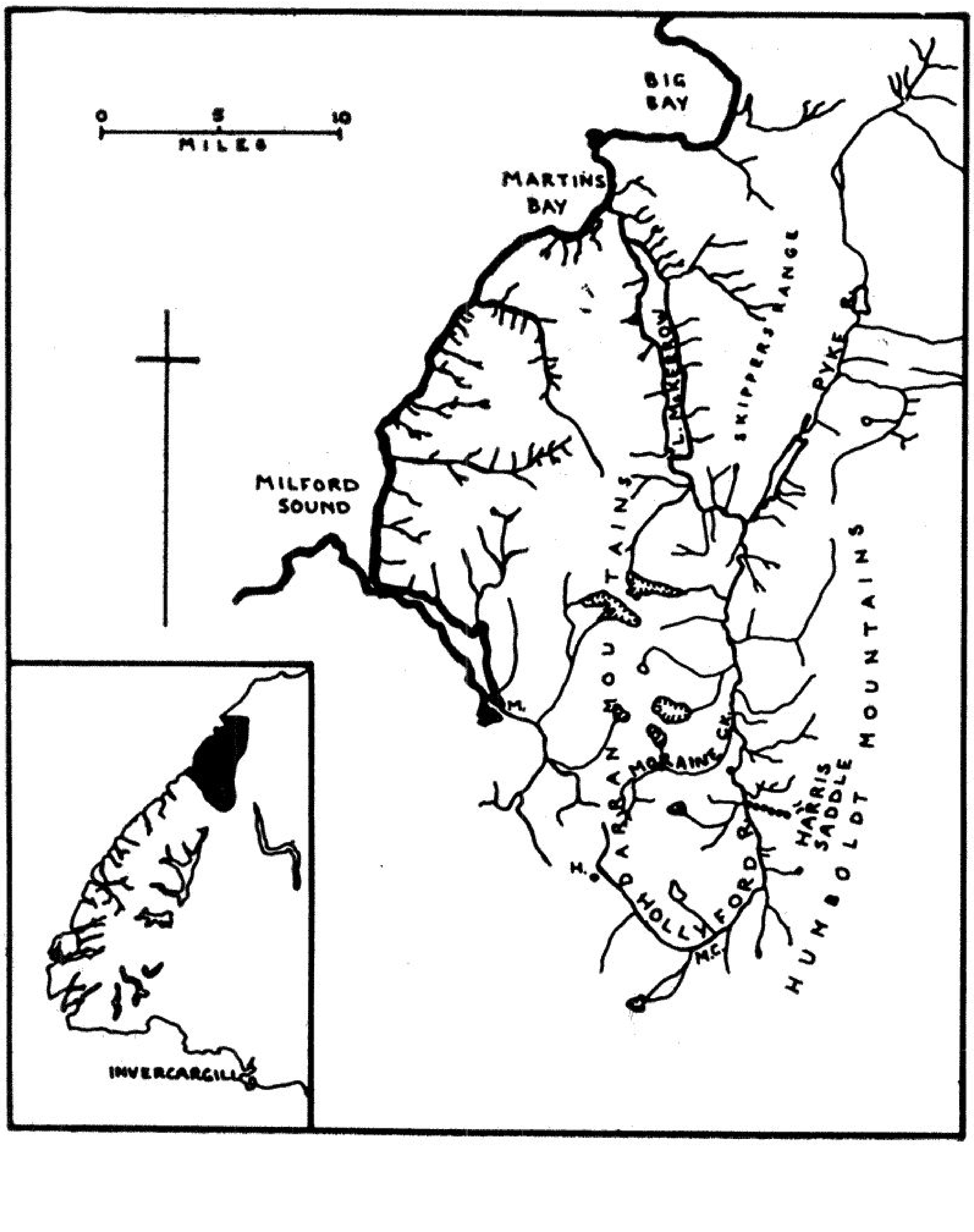
The narrow valley floor is almost flat but the sides rise very steeply. The angle of slope decreases gradually from 32° on the lower slopes (550 ft.) to 21° at 2100 ft., beyond which it increases slightly to the treeline at 3250 ft.

CLIMATE

Precipitation data are available from the Hollyford Valley, at Homer Tunnel (2800 ft.) near the head of the valley and at Marian Camp (1130 ft.) about five miles upstream from Deadman's Hut (see Map).

Data on rainfall for these stations and for Milford Sound, about 7 miles northwest of Homer Tunnel (Table 1), were kindly supplied by the Meteorological Service.

These results show both the high precipitation which characterises the Fiordland region and the relatively steep gradient of precipitation in the Hollyford Valley. The steepness of this gradient may depend both on altitude and on increased distance from



Map of the Hollyford Valley and vicinity showing location of the area studied. Each of the eight sites is indicated by a small dot. Locations of the rainfall stations cited in the text are indicated as follows: M. = Milford Sound; H. = Homer Tunnel; M.C. = Marian Camp.

TABLE 1. *Mean and minimum monthly and annual rainfalls (inches) and mean monthly and annual raindays (days with at least* 0.01 *in. rain) for two sites in the Hollyford Valley and at Milford Sound.*

Station	*Period*	*Jan.*	*Feb.*	*Mar.*	*Apl.*	*May*	*June*	*July*	*Aug.*	*Sep.*	*Oct.*	*Nov.*	*Dec.*	*Year*
MEAN RAINFALL														
M.	1921–50	25.5	23.1	22.3	21.8	21.6	14.7	14.7	17.3	19.8	26.0	23.1	23.4	253.3
H.	1921–50	28.0	25.4	24.4	24.0	24.0	16.8	17.5	20.0	22.2	28.0	24.0	25.0	279.3
M.C.	1921–50	16.4	15.4	16.4	15.6	15.4	11.7	11.7	13.7	15.4	17.3	15.4	15.4	179.8
MINIMUM RAINFALL														
M.	1929-60	3.49	6.81	6.16	7.29	3.84	3.63	3.55	1.92	7.57	8.27	7.15	11.41	192.95
M.C.	1944–52	5.86	3.06	4.30	4.68	3.22	2.47	9.98	3.80	5.09	5.59	6.97	9.22	111.32
RAINDAYS														
M.	1929–60	17	16	15	15	16	15	14	16	17	19	17	18	195
M.C.	1944–52	14	15	15	13	14	14	14	15	15	17	15	17	178

M.=Milford Sound (16 ft.); H.=Homer Tunnel (2800 ft.); M.C. = Marian Camp (1130 ft.)

the coast. The difference in precipitation between Milford Sound and Homer Tunnel is not great, although they are separated by 2784 ft. elevation and by a distance slightly greater than that separating the two stations in the Hollyford Valley.

The seasonal trend in precipitation from a winter minimum to a summer maximum, together with the values for minimum precipitation and for raindays, indicate that lack of moisture would rarely be a limiting factor for vegetation.

Temperature data are not available for the Hollyford area.

METHOD

Rectangular plots were used to sample the vegetation at six sites at about 500 ft. intervals of altitude along the gradient. Spacing of plots was modified slightly to avoid steep bluffs. As the forest had been destroyed on the valley floor near Deadman's Hut, a sample was taken from the valley floor forest on the western side of the Moraine Creek swing bridge at 300 ft., about three miles down the valley, in order to complete the altitudinal series. A stand of treeline forest (2750 ft. in this locality) near the head of the Hollyford Valley, above the Alpine Club's huts, was also analysed (see Map).

The plots were laid out with a 100 ft. tape run along the contour. Each plot measured 500 ft. in length and was subdivided into 10 sections, each of 50 ft. Both wide (18 ft.) and narrow (9 ft.) strips were centred along the tape. A pole of the proper length held at right angles to the tape served to indicate the edge of the strip.

The following categories were recorded:

Trees: exceeding 4 in. diameter at breast height (d.b.h.).
Small-trees: less than 4 in. d.b.h. but exceeding 15 ft. tall.
Shrubs: 1 ft. to 15 ft. tall.
Herbs: herbaceous species exceeding 6 in. in height.

Tree ferns exceeding 1 ft. tall were entered as shrubs, otherwise they were listed as herbs. Specimens of beech and podocarps under tree size were not included as small-trees or shrubs, but were entered as regeneration.

The regeneration classes recognised were as follows:

Poles: exceeding 8 ft. tall but below 4 in. d.b.h.
Saplings: 3 ft. to 8 ft. tall.
Large seedlings: 6 in. to 3 ft. tall.
Small seedlings: less than 6 in. tall.

Trees, small-trees, poles, saplings and large seedlings were recorded along the wide strip or a total area of 1000 sq. yds., while shrubs, herbs and small seedlings were recorded along the narrow strip or a total area of 500 sq. yds. Diameters of all trees and small-trees were measured at breast height.

Canopy height, aspect and the angle of slope were measured on each plot. An abney level was used to measure angle of slope and the canopy height. Faecal pellet groups of red deer were counted along the narrow strip of each plot.

From the data recorded on each plot the following values have been derived for every species in each category:

1. Density, i.e. the number of plants per unit area.
2. Frequency, i.e. the number of 50 ft. sections of the 500 ft. plot in which the species was present.
3. Dominance (basal area), i.e. the total cross-section area (sq. ft.) of trees and small-trees measured at breast height. If at breast height several stems were present, derived from one base, diameters of all stems were measured for basal area but only one entry was made for density, since only one plant was involved.
4. Relative density, i.e. density of a species expressed as a percentage of the density of all species in the category.
5. Relative frequency, i.e. frequency of a species expressed as a percentage of the sum of the frequencies of all species in the category.
6. Relative dominance, i.e. basal area of a species expressed as a percentage of the total basal area of all species in the category.
7. Importance Value (Curtis and McIntosh 1951), i.e. the sum of 4, 5 and 6 for trees and small-trees (the totals for all species of a category in each plot come to 300) or the sum of 4 and 5 for shrubs and herbs (the totals for all species of each of these categories in each plot come to 200).

The values for kamahi (*Weinmannia racemosa*)* trees are given for one plot (1100 ft.) to illustrate the method of recording and handling of data:

PLOT TOTALS			RELATIVE VALUES				VALUES PER ACRE	
			R.	*R*	*R.*			
Dom.	*Freq.*	*Den.*	*Dom.*	*Freq.*	*Den.*	*I.V.*	*Dom.*	*Den.*
54	10	37	31	43	70	144	261	179

An increment borer was used to remove cores of silver beech (*Nothofagus menziesii*) from five mature trees at each of the sites studied. These cores were stored in drinking straws and later glued to wood for polishing and ring counting. Beginning with the outer wood, each tenth growth ring was marked under a binocular microscope and the widths of 10-ring groups were later measured.

* Nomenclature throughout follows Allan (1961) for ferns, gymnosperms and dicotyledons; otherwise it follows Cheeseman (1925).

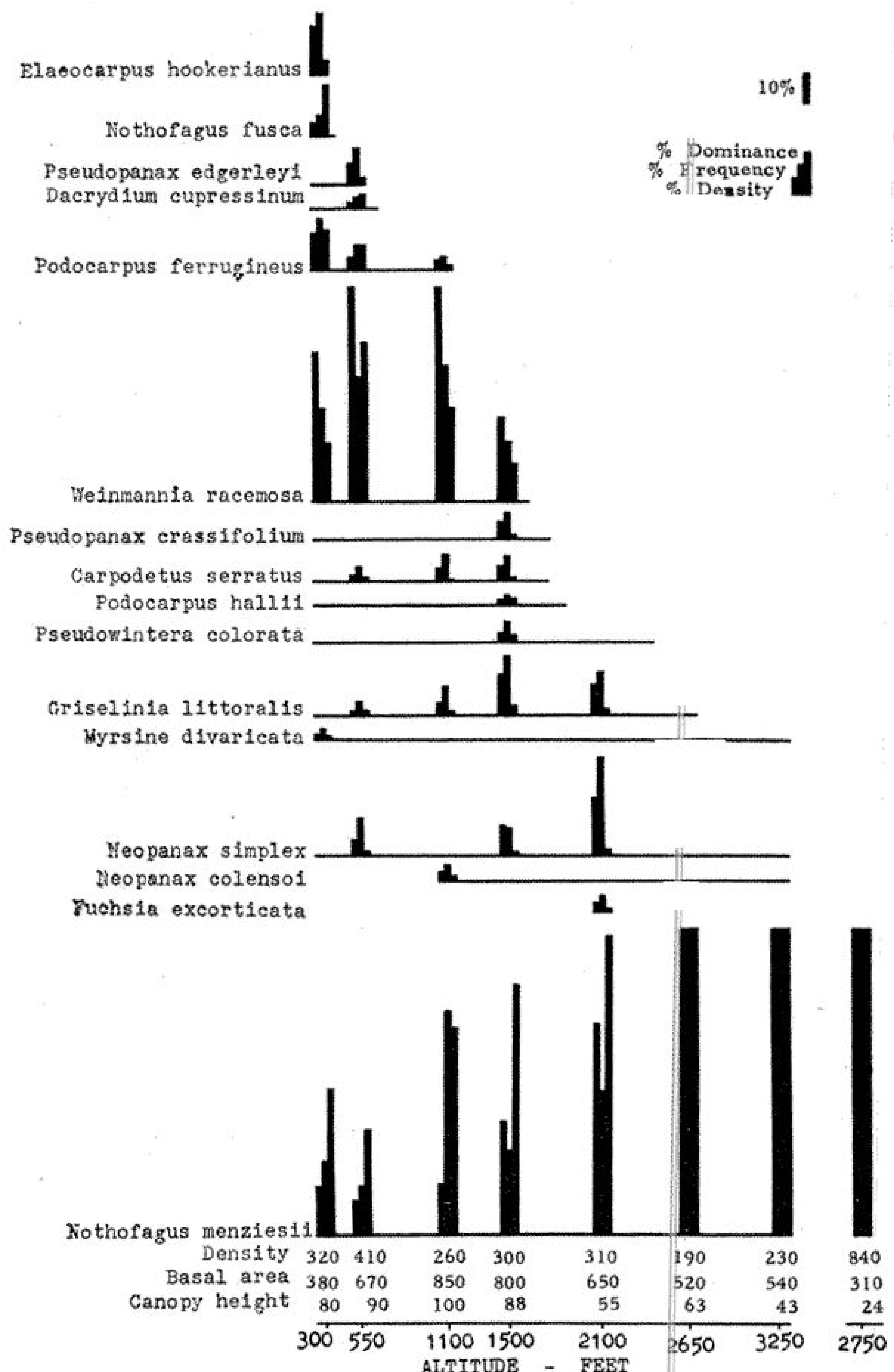


FIGURE 1. *Distribution of trees along an altitudinal gradient in the Hollyford Valley. The horizontal lines indicate presence and thus the altitudinal range of the species. Totals for density (no. of stems) and dominance (basal area in sq. ft.) per acre, together with tree canopy height (ft.) at each site are given at the base of the diagram.*

RESULTS AND DISCUSSION

Figures 1 to 4 present distribution data for the trees (16 species), small-trees (17 species), shrubs (35 species) and herbs (25 species), respectively. The total number of species represented is only 67 as some contribute to more than one category. The horizontal lines in these diagrams indicate presence so that the length of line represents the altitudinal range of the species.

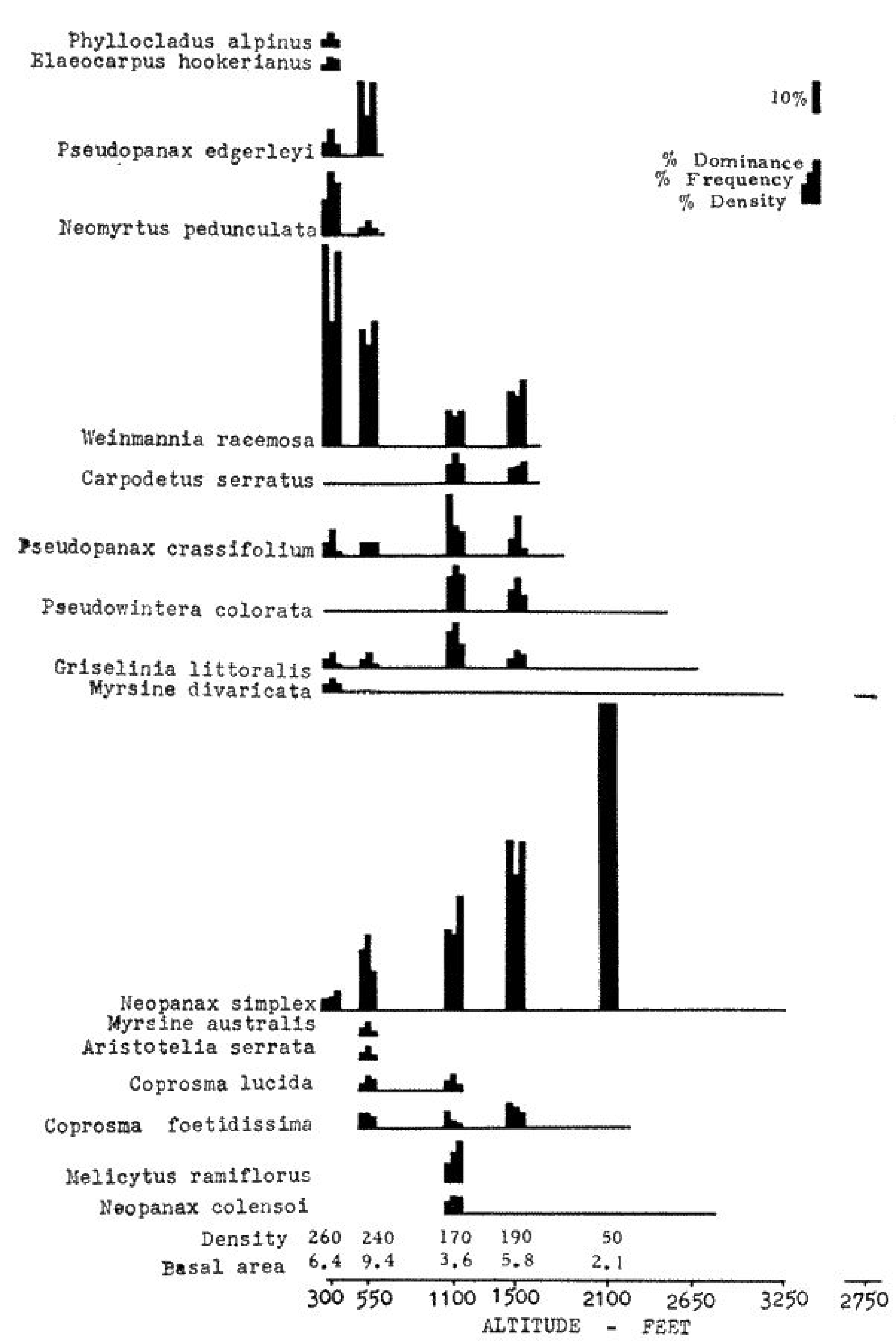


FIGURE 2. *Distribution of small-trees along the altitudinal gradient.*

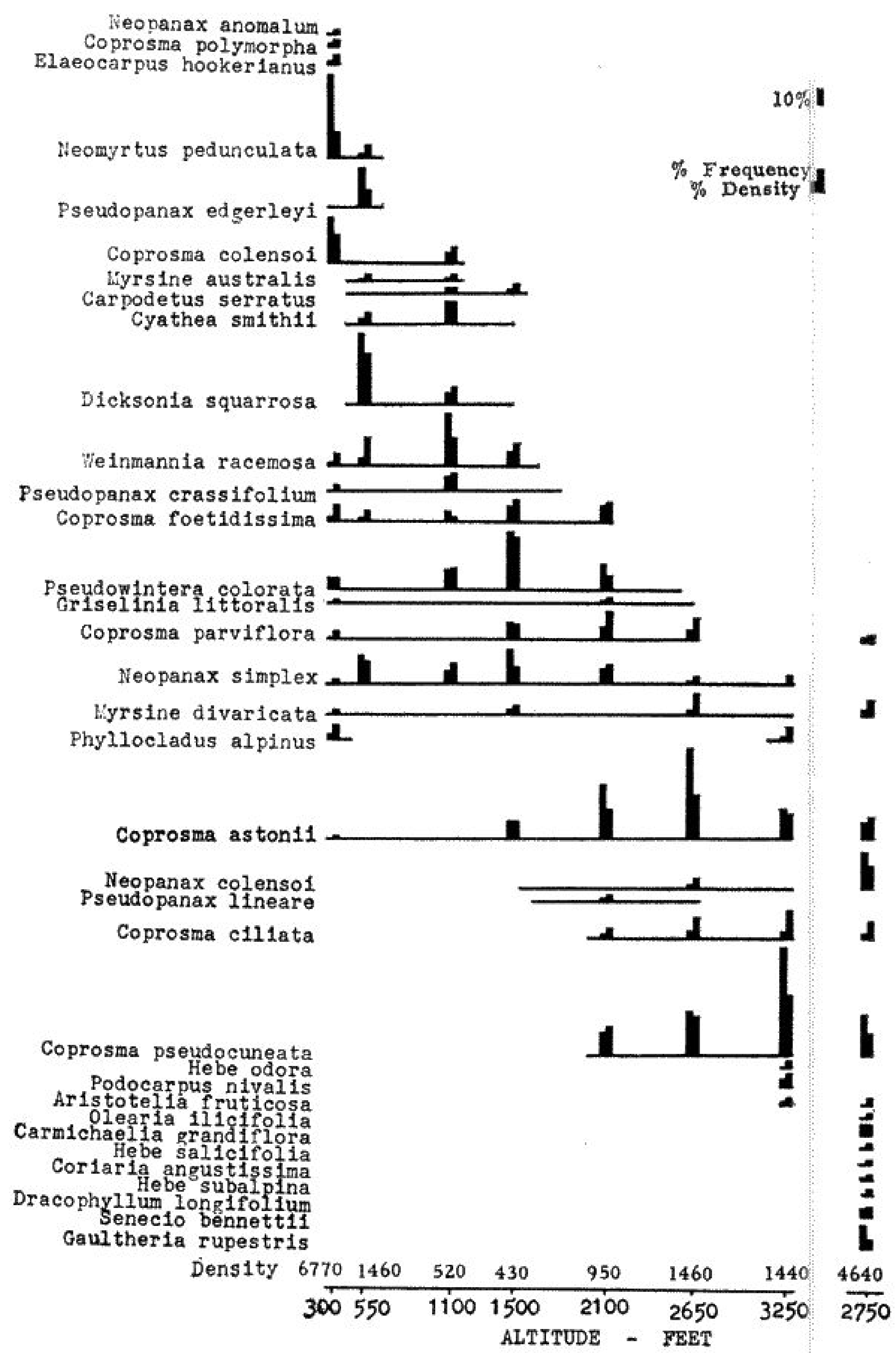


FIGURE 3. *Distribution of shrubs along the altitudinal gradient.*

TABLE 2. *Importance values for two species in each of the four layers of vegetation analysed, along an altitudinal gradient in the Hollyford Valley.*

Altitude (ft.)	300	550	1100	1500	2100	2650	3250
TREES							
Weinmannia racemosa	97	162	144	58	—	—	—
Nothofagus menziesii	85	59	116	146	214	300	300
SMALL-TREES							
Neopanax simplex	16	58	86	155	300	—	—
Weinmannia racemosa	174	113	31	56	—	—	—
SHRUBS							
Coprosma astonii	2	0	0	19	54	87	36
C. pseudocuneata	—	—	—	—	35	52	107
HERBS							
Blechnum discolor	133	81	96	85	43	—	—
B. minus	24	40	28	44	98	63	0

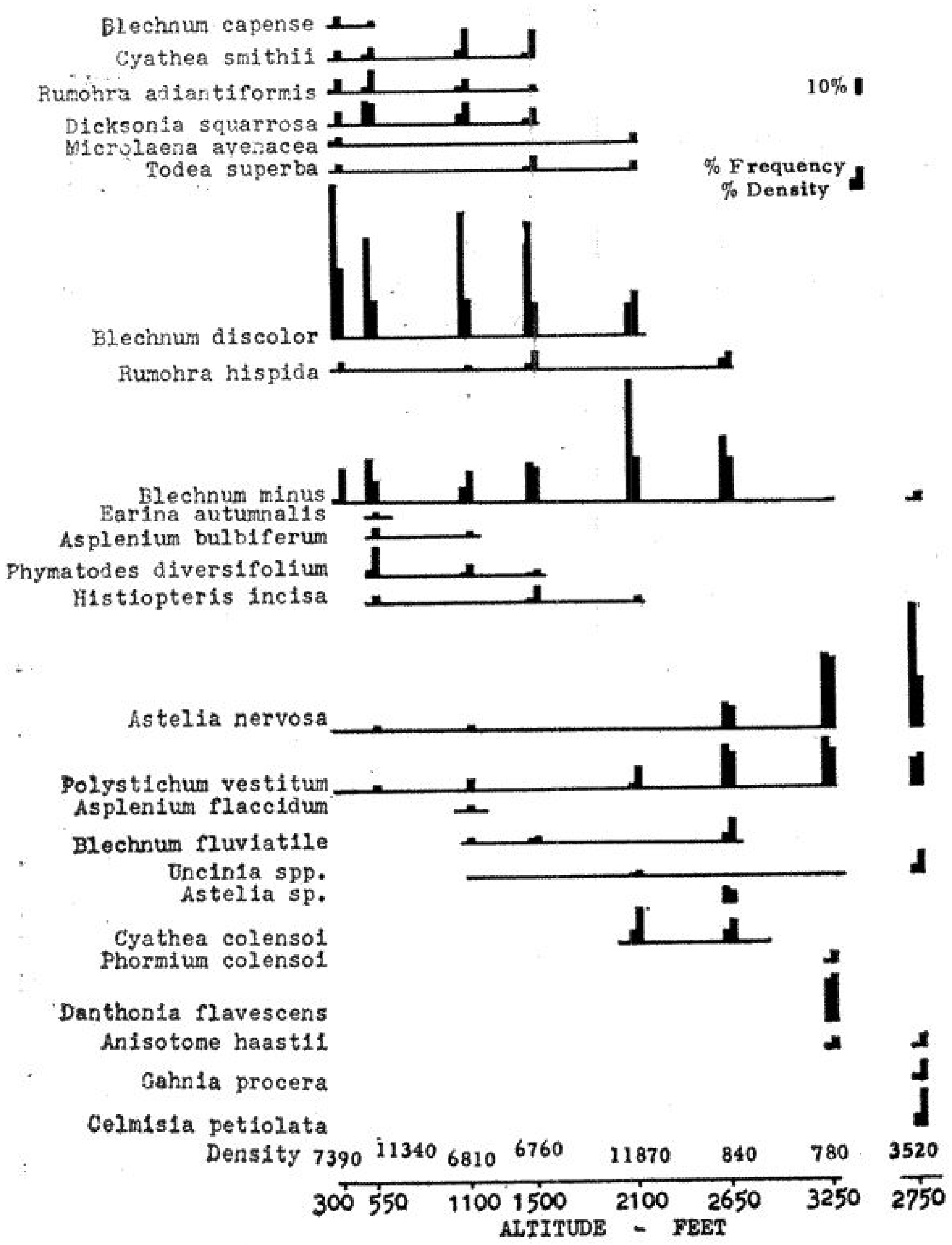


FIGURE 4. *Distribution of herbs along the altitudinal gradient.*

There are clearly altitudinal gradients both of composition and structure. Importance values of wide-ranging species in each of the four layers (Table 2) show the effects of altitude on these species.

Despite this gradient, rather abrupt changes both in composition and structure of the various strata are apparent just above the 1500 ft. contour. The forest may be regarded as changing from a lowland mixed beech-podocarp-kamahi forest to an upland pure silver beech forest.

Tree canopy height (Fig. 1) decreases with altitude only above 1000 ft. No consistent trend in total tree density with altitude is apparent. Total basal area decreases both above and below 1100 ft. where silver beech trees reach their maximum size (Fig. 6).

Small-tree density decreases with altitude until this layer becomes pure *Neopanax simplex* at about 2000 ft., and is virtually absent above about 2500 ft. except for silver beech poles which are numerous above 2000 ft. (Fig. 5). Total basal area of small-trees also tends to decrease with altitude.

Shrub densities are very high on the valley floor and also in the treeline stand in the upper Hollyford Valley where several subalpine species enter the forest. Densities are relatively low between 1100 ft. and 1500 ft. where deer faeces become most abundant (Table 3).

Herbs are abundant everywhere up to 2100 ft. (upper altitudinal limit of *Blechnum discolor*), and in the upper Hollyford *Astelia nervosa* is plentiful even at treeline.

Patterns of regeneration of the beech and podocarp species at each of the sites are shown in Figure 5. Miro (*Podocarpus ferrugineus*) seedlings are exceedingly numerous, and established regeneration of this species and also of thin-barked totara (*P. hallii*) appear to be sufficient for maintenance of their present status in the tree layer, at least at the sites studied. However, this may not be the case with rimu (*Dacrydium cupressinum*) above the valley floor. Kahikatea (*Podocarpus dacrydioides*) was represented by small seedlings only, at two sites. Seedlings of red beech (*Nothofagus fusca*) are about as abundant as mature trees, but no saplings or poles were recorded at the one site where this species occurs.

The earlier stages of silver beech regeneration are generally abundant throughout the forest, especially above the limits of kamahi and the podocarps. At 550 ft. and 1100 ft., the sites of maximum abundance of deer faeces (Table 3), saplings and poles are rare or absent.

The distribution of the stem diameter classes of kamahi and silver beech along the gradient is shown in Figure 6. The figure emphasises the consistently small diameters of beech stems in the upper Hollyford Valley treeline forest. The high proportion of large beech trees at the 1100 ft. site is also apparent. The largest diameter recorded (102 in.) was at this site.

Analysis of the diameter growth rates of silver beech trees is shown in Figure 7. These results show (a) relatively small diameter

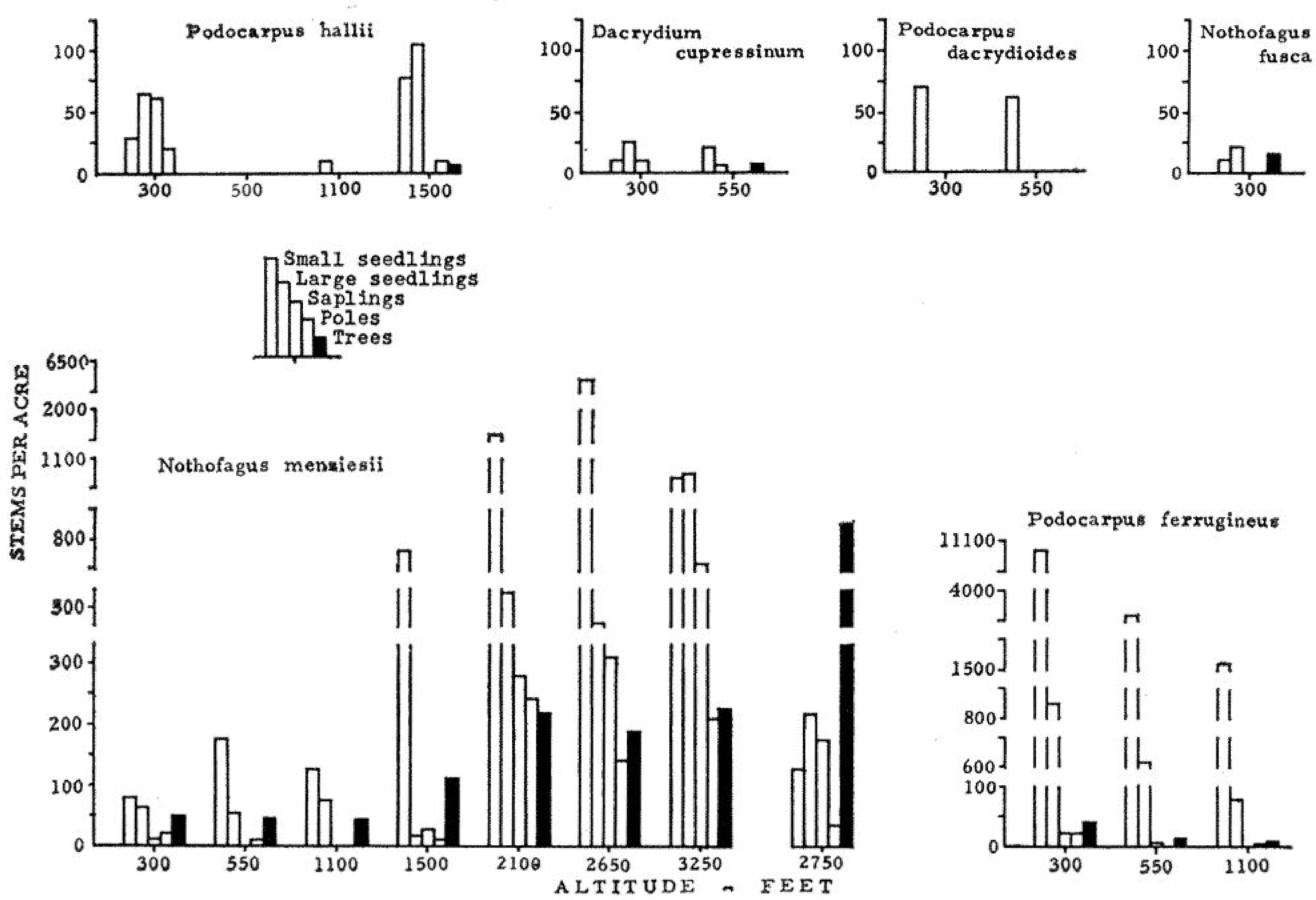


FIGURE 5. *Distribution of trees and regeneration classes of the beech and podocarp species along the altitudinal gradient. Each group of vertical columns represents total densities (no. of stems per acre) of four regeneration classes and trees (black column) at each of the sampling points. Isolated columns can be identified by their location relative to the projection on the base line (see key).*

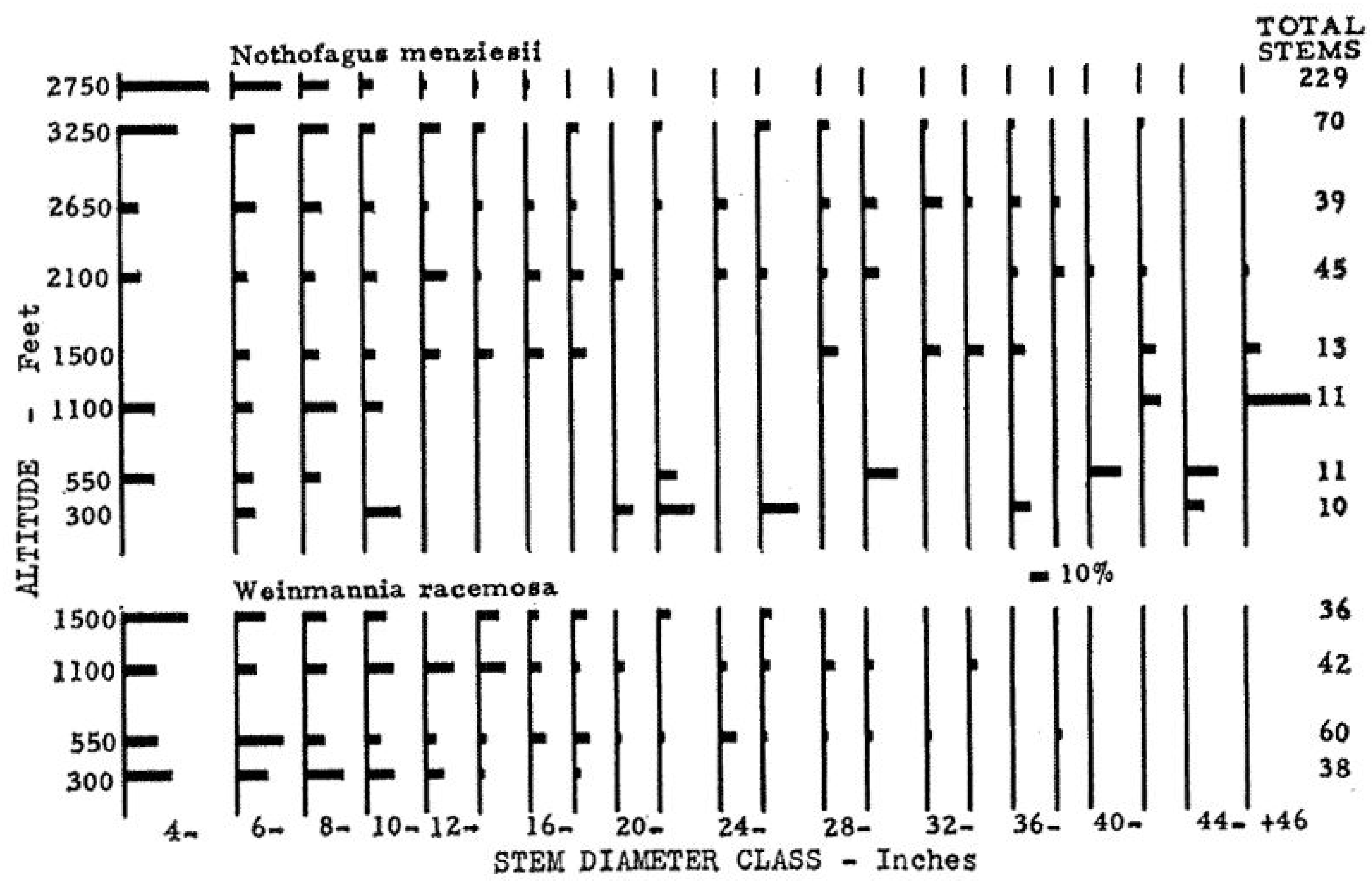


FIGURE 6. *Altitudinal distribution of stem diameter classes of silver beech and kamahi trees along an altitudinal gradient in the Hollyford Valley and at a treeline site (2750 ft.) in the upper Hollyford Valley. The horizontal columns represent the percentage distribution of the stem diameter classes within each species at each of the sampling points. The absolute values (total stems counted per site) are listed on the right.*

growth rates of silver beech trees above 1500 ft. (except "c" below); (b) no consistent trend in growth rates with time at the different sites; (c) relatively rapid diameter growth at the upper Hollyford Valley treeline site (2750 ft.). Growth rates at this site have been declining with time. This is typical of stands undergoing natural thinning. No trees had more than 70 growth rings.

The result of the deer faecal pellet-group counts is shown in Table 3.

TABLE 3. *Estimated number of deer faecal pellet-groups per acre along an altitudinal gradient in the Hollyford Valley*

Altitude (ft.)	*Pellet groups/acre*
300	41
550	184
1100	512
1500	113
2100	58
2650	0
3250	111
2750*	24

* Upper Hollyford Valley treeline site.

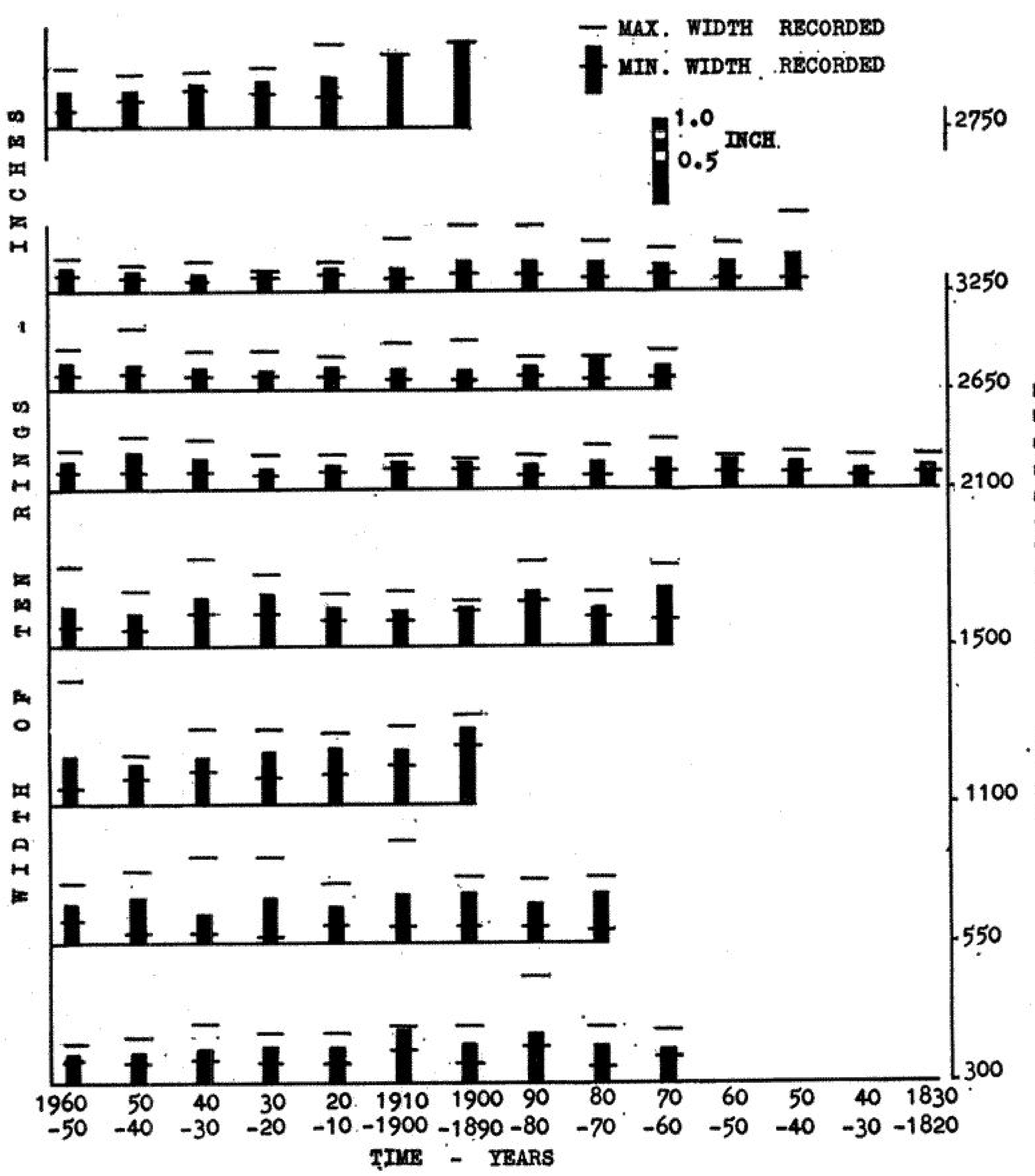


FIGURE 7. *Diameter growth rates of silver beech trees (mean of five trees) at seven sites along an altitudinal gradient in the Hollyford Valley and at a treeline site (2750 ft.) in the upper Hollyford Valley. Growth rates are presented as the maximum, minimum and mean width of groups of 10 growth rings. Assuming the rings to be annual, the time scale (in years) is shown on the abscissa.*

These results suggest that the deer browsing below treeline may be concentrated on the lower slopes of the valley between say 500 ft. and 1300 ft. Since the relationship between faecal abundance and deer population size is not yet known (Riney 1957), no estimate of deer abundance can be made.

CONCLUSIONS

There is little evidence of ecological interdependence among any of the species recorded. Competition may be a factor in eliminating species from some altitudinal zones, but otherwise it would seem that the range of each one is determined by its individual environmental tolerance. All the same, the data do suggest a division of many of the 67 species into two groups — those which do not venture above 1500 ft. (22) and those which occur only above that level (20). So, although the composition of the forest varies continuously with altitude, it is also possible to recognise two distinct forest types; beech-podocarp-kamahi forest below, and silver beech forest above.

The floor and lower slopes of the valley up to an altitude of aboue 1600 ft. are occupied by beech-podocarp-kamahi forest, in which the subordinate layers are well developed. Beech and podocarp trees form a rather open canopy, the gaps in which are filled chiefly by kamahi. On the valley floor, red beech and pokaka (*Elaeocarpus hookerianus*) are characteristic, although silver beech, rimu, miro, thin-barked totara and kamahi are also present. These latter species are better developed on the lower valley sides. Silver beech and kamahi are the predominant species at both sites.

A small-tree layer, dominated by *Weinmannia racemosa, Neopanax simplex, Pseudopanax edgerleyi, P. crassifolium, Neomyrtus pedunculata, Griselinia littoralis, Pseudowintera colorata* and *Myrsine divaricata* is relatively well developed, together with both shrub and herb layers. Prominent shrubs in this lowland forest zone include *Neomyrtus pedunculata, Coprosma colensoi, C. foetidissima, Dicksonia squarrosa, Weinmannia racemosa, Pseudowintera colorata* and *Neopanax simplex*. The herb layer is dominated by *Blechnum discolor* and *B. minus*.

Seedlings of the dominant beech and podocarp species are present at all sites but saplings and poles are generally less numerous than mature trees.

Above the upper limits of the lowland mixed forest, a beech forest dominated by silver beech continues to treeline at about 3250 ft. This forest lacks a well-defined small-tree layer, although shrub and herb layers remain distinct. Shrubs increase in importance due to the incoming of *Coprosma pseudocuneata* and the increased abundance of *C. astonii*. Taking the shrub layer overall, it is clear that there are two classes of shrubs; those such as *Neomyrtus pedunculata, Coprosma colensoi* and *Dicksonia squarrosa* which are plentiful only at low levels, and those such as *Coprosma astonii, C. ciliata* and *C. pseudocuneata* which are plentiful only at the higher levels. There is thus a zone between 600 ft. and 2000 ft. in which the shrubs layer is weak although it contains at least nine species. This weakness may be related to the greater incidence of red deer. *Blechnum discolor* predominates in the herb layer up to 2100 ft., above which it is replaced by *B. minus, Polystichum vestitum* and *Astelia nervosa*, but nowhere are these as numerous.

Silver beech regeneration is generally satisfactory within the upland forest.

Diameter growth of silver beech trees reaches a maximum at about 1000 ft. and is generally higher in trees of the lowland forest than in those of the upland forest. Canopy height of the beech trees varies directly with the diameter growth rates.

Evidence from the forest structure and diameter growth rate analysis of the dominant (silver beech) trees in the treeline stand in the upper Hollyford Valley, indicates that this forest has probably developed within the last hundred years. Perhaps freedom from avalanches only within relatively recent times explains the presence of this young forest stand.

The deer population below treeline seems to be concentrated between 500 ft. and 1300 ft. No significant reduction in herb or regeneration densities, except perhaps for saplings and poles of silver beech, occurs within this zone, but shrub densities are relatively low.

Comparison of the Hollyford transect with a similar one in undisturbed forest at Blanket Bay, Secretary Island, shows differences which can scarcely be attributed to the presence of exotic animals in only one of these areas. These vegetational differences probably relate chiefly to innate environmental differences between the two areas, thus suggesting a natural complexity of vegetation patterns in the Fiordland region. This complexity must limit the usefulness of any one locality as a standard for comparison.

Some notable differences in floristic composition and also in the altitudinal distributions of certain species occur between the Hollyford Valley area and Blanket Bay, Secretary Island. Species recorded from the Hollyford area, but absent from the Blanket Bay transect include *Nothofagus fusca, Neopanax anomalum, Podocarpus nivalis, Aristotelia fruticosa, Olearia ilicifolia, Carmichaelia grandiflora* and *Coriaria angustissima,* while the reverse is true for *Olearia oporina, O. colensoi, Senecio reinoldii, S. scorzoneroides, Ascarina lucida, Dacrydium intermedium, D. biforme, Pittosporum colensoi, P. divaricatum, Leptospermum scoparium, Archeria traversii, Nothofagus solandri* var. *cliffortioides, Schefflera digitata, Dracophyllum menziesii, Ourisia macrocarpa* and *Danthonia* (*acicularis*)*. For a comparison of upper altitudinal limits of several species in these two areas see Mark (1963: Table 1).

* This undescribed snow-tussock is being described by Zotov (pers. comm.) as *Chionochloa acicularis.*

Despite differences in patterns of altitudinal distribution and also in floristic composition between these two areas, rather distinct changes in both composition and structure occur close to the 1500 ft. contour in both localities, allowing the recognition of distinct lowland and upland forest types. The canopy is up to 40 ft. taller in the Hollyford at equivalent altitudes. It is 23 ft. taller at treeline. The altitude of the treeline is about 300 ft. higher in the Hollyford 3250 ft.) than at Blanket Bay (2950 ft.).

The Hollyford and Blanket Bay forests are compared in some detail in the paper dealing with Secretary Island (Mark, 1963) and will not be repeated here.

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