APPLIED ECOLOGICAL STUDIES OF SHORELINE VEGETATION AT LAKES MANAPOURI AND TE ANAU, FIORDLAND

PART 3: VEGETATION OF THE LAKE TE ANAU SHORELINE

A. F. MARK, J. R. CRUSH & C. D. MEURK

Department of Botany, University of Otago

SUMMARY: Approximately 44 per cent of the forested mainland shoreline of Lake Te Anau appears to be vulnerable to high water tables maintained for unnaturally long periods. Results of 22 traverses across representative sites suggest a delicate ecological balance between natural lake level variation, shoreline relief and vegetation. Root distribution of beech trees along the shoreline confirms their general intolerance of prolonged inundation although diameter growth of trees growing on unconsolidated material showed a significant decline during a drought season rather than in an exceptionally wet one.

INTRODUCTION

Lake Te Anau, with a surface area of 133 sq miles (344km²) and 197 miles (317km) of shoreline has a natural variation in its level of 11.5ft (3.5m)—from a maximum of 670.5ft (204.3m) to a minimum of 659.0ft (200.8m) above mean sea level (based on daily records since 1933).

Since the more recent proposals for control of Lake Te Anau do not involve exceeding its natural maximum but instead will maintain high levels for unnaturally long periods, two lines of investigation were followed. The first assessed the tolerance of individual lake-shore species to both submergence and emergence, as was done for Lake Manapouri (Johnson 1972b). The second line involved defining those areas where water tables would be affected and assessing the possible extent of damage. Four aspects were considered. Three of these are presented here in separate sections while the fourth, dealing with composition of the lake-shore forest, will be published later.

Datum levels for the study were those recorded at Te Anau township, ranging from 660.8 to 661.6ft (201.4-201.6m). We assume a negligible error in applying these levels to sites around the lake since winds were light and rain was confined to the first two days when we were working near the township.

SECTION 1:

PARENT MATERIAL OF THE SHORELINE IN TERMS OF ITS ABILITY TO DEVELOP A WATER TABLE

Evidence from both Lake Monowai and the Upukerora Valley near Te Anau, indicates that mountain beech trees (*Nothofagus solandri* var. *cliffortioides*)* growing on pervious substrates may be killed within nine months by a permanent rise in the water table (Lister, Mark & Dodd 1970, Newhook 1970). Moreover, it was established by Newhook (1970) that depth of the water table beneath affected trees may vary from 1 to 6ft (0.3-1.8m).

With Lake Te Anau maintained at its control level for several months (Mark & Johnson 1972) a water table could be expected to develop at this level along any section of the shoreline composed of loose, unconsolidated materials.

Method

The entire western and northern shoreline between the lake outlet and Eglinton River mouth was examined and those sections formed by unconsolidated materials were plotted on to an aerial mosaic of the lake—scale 1: 63,360 (Lands & Survey Dept Map 526A). Shoreline lengths were later determined with a "Derby" cartometer.

* Nomenclature follows that used by Johnson (1972b).

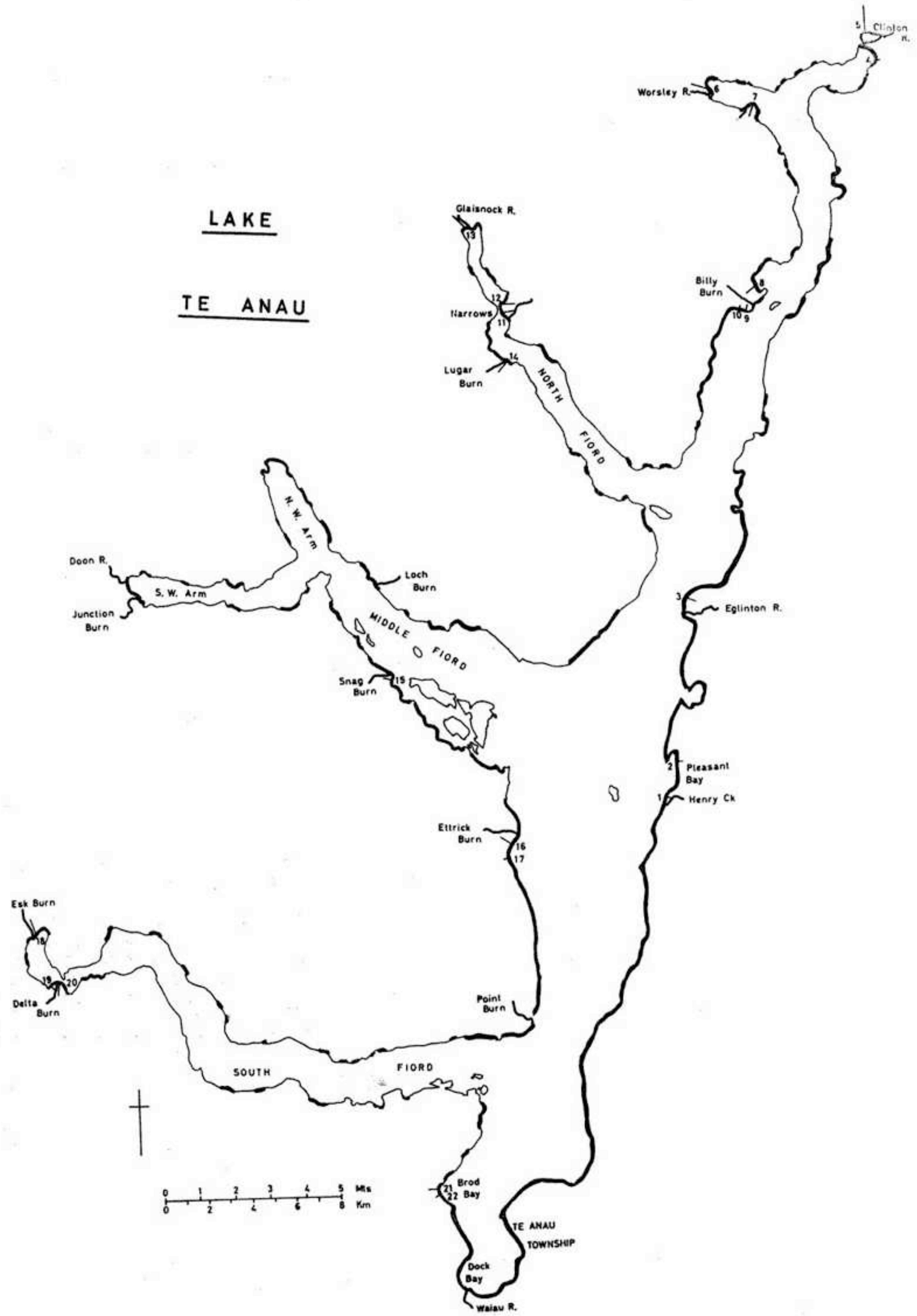

FIGURE 1. *Lake Te Anau shoreline showing sections formed of loose, unconsolidated material (thick line) and solid rock (thin line). Only the eastern shoreline between the Eglington River mouth and the lake outlet is largely without forest. Locations of the 22 study sites are numbered.*

Results

Sections of forested lake shore apparently susceptible to water-table effects amount to 66 miles (106km). This represents 44 per cent of the 150 mile (241km) forested mainland shoreline (Fig. 1). These sections consist mostly of stream, beach and morainic deposits, but also of areas where micaceous and feldspathic sandstones are sufficiently disintegrated to be included. The remaining 26 miles (42km) of mainland shoreline, between the Eglinton and Waiau Rivers, are composed of loose gravels but only small stretches are forested. Much of the 21 miles (34km) of island shoreline consists of hard rock.

SECTION 2:

SHORELINE PROFILES ON UNCONSOLIDATED MATERIAL

Having determined those sections of shoreline where woody vegetation might be damaged by sustained high water tables (Section 1), a total of 22 traverses were made. Most were on deltas which constitute an important feature of the shoreline while five were on other shoreline materials (for location see Fig. 1).

Method

Using 100ft tapes, a surveyor's staff and a "Watts" Autoset Level, a traverse perpendicular to the lake shore was continued, usually to el. 680ft (207.3m). Distance from the lake edge of each 1ft (30cm) rise or fall in elevation was measured and plants growing within a 6ft (1.8m) wide strip centred on the tape were noted (Fig. 2). The traverses are illustrated with the horizontal scale reduced to one-tenth of the vertical scale. Only major components of the vegetation can be shown and these are not to scale (Figs 3 & 4). Three types of shoreline situation are shown in more detail (Fig. 5).

Results

Rivers entering the heads of the lake's six arms (Fig. 1) are associated with broad, flat deltas, usually of fine alluvium, most of which rise very gently from below present lake level.

At the four fiord-head sites studied (Esk Burn, Glaisnock River, Worsley Stream and Clinton River) there is a distinct zone of mixed scrub—chiefly of manuka (*Leptospermum scoparium*) and small-leaved coprosmas (especially *C. propinqua*)—which contains several prominent trees of pokaka (*Elaeocarpus hookerianus*) and, at the Worsley Stream and Clinton River, a number of tall kahikatea (*Dacrycarpus dacrydioides*). As the diagrams (Figs 3 and 4) indicate, rushes and sedges are associated with more open or lower lying areas of scrub. A distinct "lichen line", the lower edge to the pale green lichen (*Usnea* sp.), which is prominent on these shrubs (Fig. 3), was measured at 669ft (203.9m), somewhat below the high lake level, as at Lake Manapouri (Johnson 1972b).

In addition to the heads of the main arms of the lake, deltas are also developed where the larger streams enter: Tutu Burn, Delta Burn, Point Burn, Ettrick Burn, Snag Burn, Loch Burn, Lugar Burn, Narrows, unnamed stream opposite Lugar Burn, Billy Burn, Sandfly Point, Nurse Creek and Eglinton River. These deltas are all more exposed than the four already considered and their alluvium is generally coarser. All are covered with forest and some occupy extensive areas since they rise only gradually away from

FIGURE 2. *Conducting the traverse on the extensive delta of the Lugar Burn. Pegs marking the 1ft and 2ft elevations above lake level near the edge of the turf and manuka scrub respectively. Silver beech dominates the forest behind the zone of manuka scrub.*

the lake shore (Fig. 2). However, no estimations of areas were made.

Vegetation between high and low water levels on these deltas varies from site to site, often over short distances, related to differences in exposure, slope and the nature of the substrate. At only one site (No. 10; S.W. end of Billy Burn delta) did the ground surface rise steeply to a level well above 680ft (207.3m) within a short distance (<300ft—90m) from the lake shore. Here, a near-vertical face cut down from the main surface of the delta at 707ft (215.5m) is probably the result of erosion when the lake was previously at a level of *ca.* 674ft (205.4m) as indicated by the prominent wave-cut platform shown in the profile (Fig. 4). Further out towards the tip of this delta, on both its south (site 9) and north (site 8) sides, as for all of the remaining seven deltas studied, the change in slope away from the water line is extremely gradual.

A conspicuous and important feature of several deltas is a storm beach which forms a natural levee at or near the top of the beach. They show clearly in the profiles for sites 3 (Eglinton River), 7 (Sandfly Point), 8 (Billy Burn), 11 (Narrows), 14 (Lugar Burn), 15 (Snag Burn), 16 (Ettrick Burn) and 20 (Delta Burn). The relatively low storm beaches on the deltas of the Eglinton River (Fig. 5), Narrows, Sandfly Point and Delta Burn (site 20) are breached when the lake is high. On the delta of the Lugar Burn (site 14) a small storm beach at 667ft (203.3m) is still being breached, whereas a higher one at 670ft (204.2m) apparently is not. Where a storm beach is well developed, swamp or semi-swamp vegetation may extend back as far as the water ponded by the natural levee. At the Snag Burn (site 15 in Fig. 4) there is an extensive swamp of flax (*Phormium tenax*), niggerheads (*Carex secta, C. virgata*), scattered shrubs, especially of manuka and *Cop-*

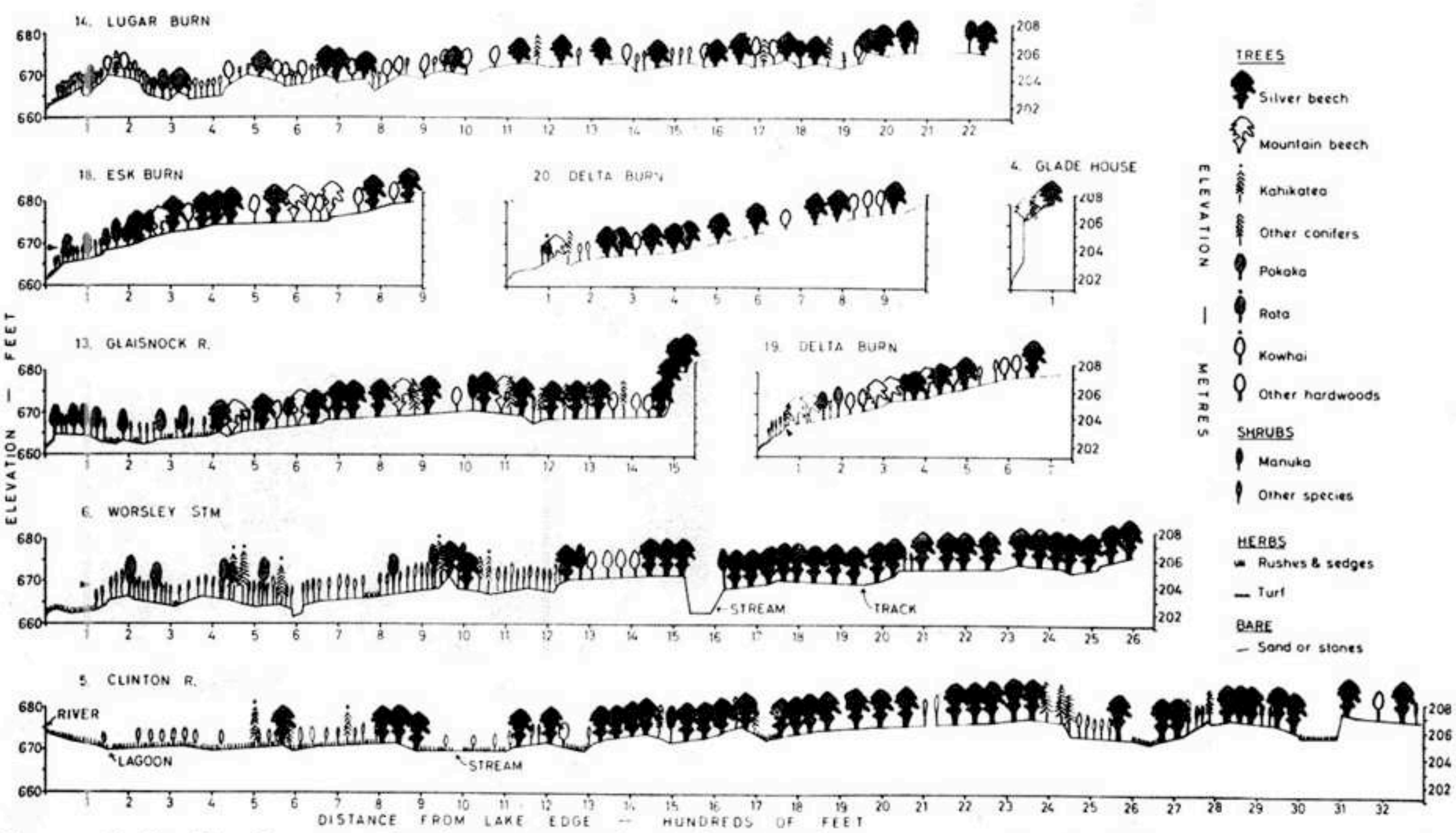

FIGURE 3. *Profile diagrams showing topography and vegetation pattern along eight transects at points around the Te Anau shoreline. Maximum penetration of driftwood (↖) and the "lichen line" (→) are shown for some profiles. (See Fig. 1 for locations of points). Note that the vertical scale exceeds the horizontal by a factor of ten. Elevations above sea level are given both in feet (left) and metres (right).*

rosma propinqua, and isolated trees of pokaka, kahikatea and *Pennantia corymbosa* (Fig. 5). Free water was present at el. 665.5ft (202.8m) despite a protracted drought which had kept the lake below this level for the previous five months.

On the south side of the Narrows (site 11) an open swamp of pokaka and kahikatea with associated shrubs, rushes and sedges, extends for

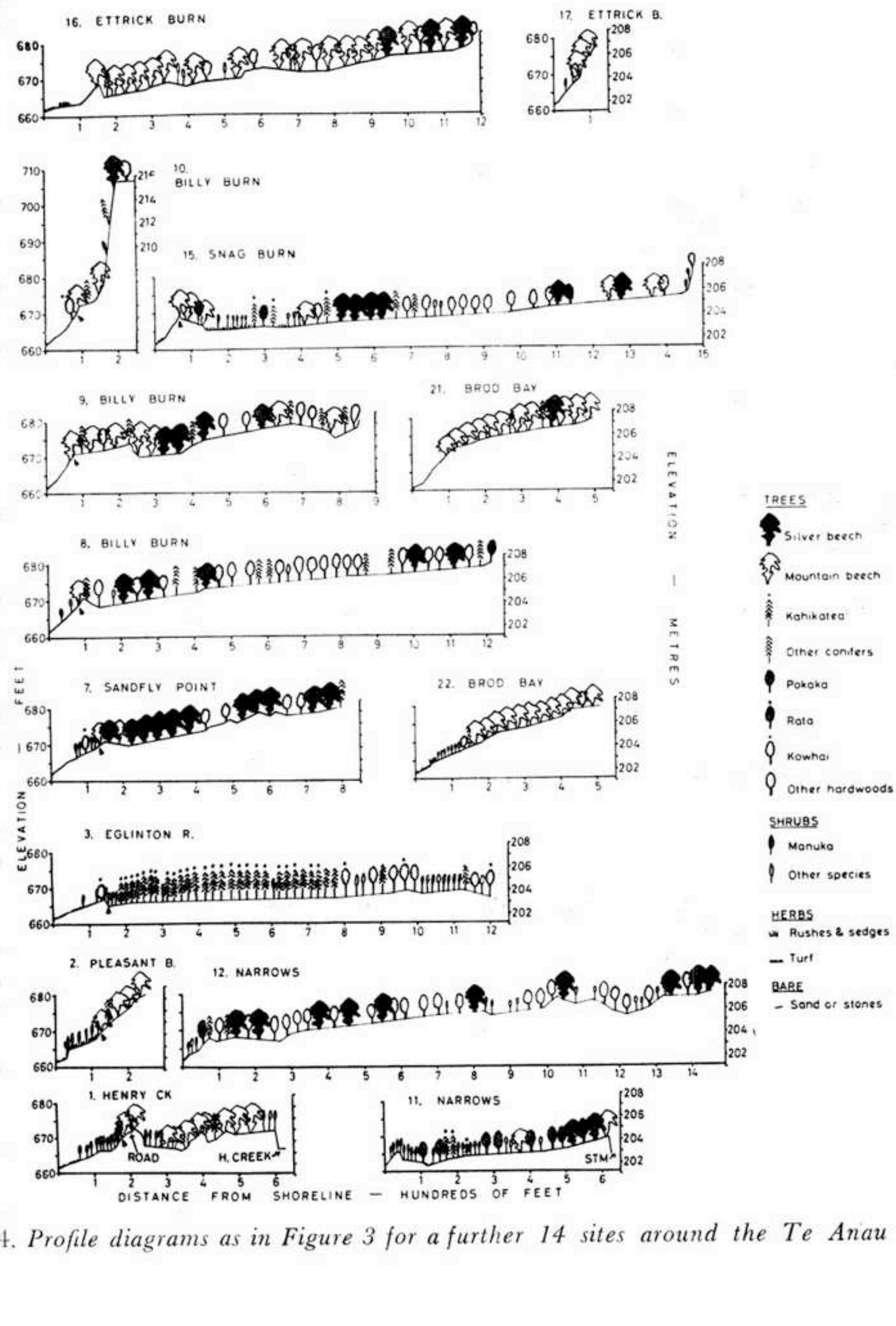

FIGURE 4. *Profile diagrams as in Figure 3 for a further 14 sites around the Te Anau shoreline.*

about 450ft (140m) behind a levee, which at 665.5ft (202.8m), is being breached. The most extensive swamp forest associated with a storm beach is on the Eglinton River delta (site 3 in Fig. 4) where driftwood indicates that the relatively low (667ft—203.3m) levee is occasionally breached. Behind this levee is an impressive kahikatea stand of dense, chiefly small trees. These have established in a stand of manuka which, as the diagram shows, still borders it on low-lying ground at either end of the transect. There are scattered large stems of cabbage tree (*Cordyline australis*) and kowhai (*Sophora microphylla*), together with occasional overtopped stems of manuka, some dead but others still persisting among the kahikatea trees (Fig. 5).

Both mountain and silver beech (*N. menziesii*) enter the vegetation sequence on the deltas wherever the ground surface rises above *ca.* 668ft (203.6m). At several sites isolated trees of mountain beech occur down to 667ft (203.3m) and on the delta of the Glaisnock River continuous beech forest develops at this level while isolated trees of both species occur down to 665ft (202.7m). A similar anomaly occurs nearby at the Narrows and is discussed later (p.152).

In addition to deltas there are long sections of shoreline, especially outside the three fiords, formed of unconsolidated materials. None of the five transects on such sites extended back from the shore more than 600ft (180m). At Brod Bay, on beach deposits, two transects (21 and 22) differed chiefly in the type of cover below high lake level. Around much of the bay, the beach consists of fine loose sand but towards the south (site 22), a stable mixture of silt and large stones is covered by a low turf up to *ca.* 663ft (202.1m), with jointed rush (*Leptocarpus similis*) beyond to *ca.* 665ft (202.7m). As Figure 5 shows, this is replaced in turn by manuka scrub which continues to the forest margin at *ca.* 669ft (203.9m). Generally similar patterns occur at Pleasant Bay (site 2) and Henry Creek (1) on forested sections of the eastern shoreline except that increased exposure apparently causes the forest margin to be about one foot (30cm) higher.

The site (17) south of the Ettrick Burn delta (Fig. 4) is typical of extensive sections of the western shoreline in that the ground rises to 680ft (207.3m), i.e. beyond the predicted future water table effect, within 100-200ft (30-60m) of the lake edge. Isolated patches of turf and rushes, together with scattered shrubs of manuka, occupy a rather bouldery beach which extends up to the forest at *ca.* 669ft (203.9m). Scattered trees of kowhai and southern rata (*Metrosideros umbellata*) occur along the forest edge on these and most other shorelines formed of unconsolidated materials.

Where solid rock forms the shoreline, forest usually extends down to the high lake level and with few exceptions is similar to that around Lake Manapouri (Johnson 1972a). Southern rata is particularly common beyond the entrance to North Fiord near the head of the lake but yellow-silver pine (*Dacrydium intermedium*), a conspicuous feature on thin soils in higher rainfall areas at Manapouri, is quite rare.

Exposed rocky sites with characteristic rupestral vegetation are similar to those on Manapouri (Johnson 1972a) but are much less common.

A feature of both lake shores since February 1971 is the death, on rocky areas with thin soils, of many tree and other forest species: mountain beech, manuka, southern rata, juvenile and adult lancewood (*Pseudopanax crassifolium*), *P. lineare,* broadleaf (*Griselinia littoralis*), *Coprosma lucida,* inaka (*Dracophyllum longifolium*), tree tutu (*Coriaria arborea*), mingimingi (*Cyathodes juniperina*), *C. empetrifolia, Gaultheria rupestris* and *Cassinia fulvida.* Clumps of *Notodanthonia setifolia, Lycopodium varium* and *L. scariosum* have also died but even fully exposed orchids (*Earina* spp. and *Dendrobium cunninghamii*) and mosses looked unharmed. These deaths occurred during the prolonged drought of the 1970-71 growing season. Losses decrease towards the western sides of both lakes but they occur to well above the shoreline. Death of mountain beech trees up to 12in. (30cm) diameter and manuka up to 8in. (20cm), noted on Holmwood Island in Lake Manapouri, suggests that the severity of this drought exceeds any during the past century or so.

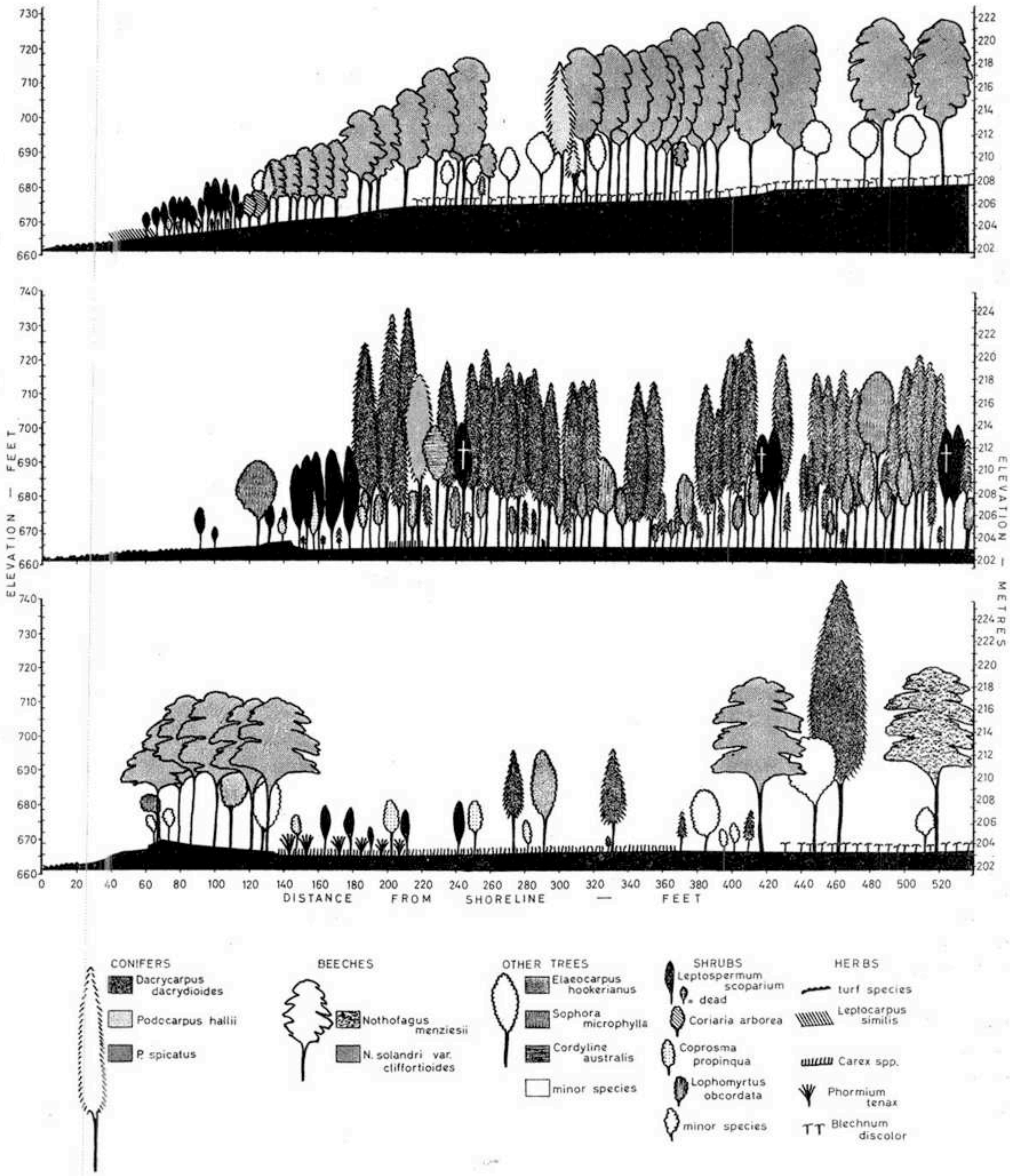

FIGURE 5. *Detailed profile diagrams of three contrasting types of shoreline vegetation at Lake Te Anau (top is at Brod Bay, site 22 in Fig. 1; centre is Eglinton River delta, site 3; bottom is Shag Burn delta, site 15).*

SECTION 3.

ROOT DISTRIBUTION AND GROWTH RATES OF BEECH TREES ALONG THE LAKE TE ANAU SHORELINE

With evidence that mountain beech trees are vulnerable to prolonged raising of a water table (p.143) it was considered that root distribution patterns of shoreline trees should indicate their tolerance to inundation. Diameter growth rates were also studied to assess the growth response of lake-shore beech trees to exceptionally wet or dry growing seasons.

Methods

Sites with sand or gravel beaches were selected as their water table is probably the most responsive to lake level variation and trees could be selected whose roots were not confused with those of accompanying shrubs. Thirty trees were examined at eleven localities around the lake. For each tree a series of trenches was dug 1m apart down the beach, beginning at the tree base. The trenches varied from 0.3m to 1.5m in depth depending on the root system. Height above lake level of each trench, depth of the rooting zone, distance from the tree base and number and dimensions of roots were all recorded.

Wood cores were extracted with an increment borer from mountain beech trees both along the lake shore and from higher elevations beyond the lake's influence. Four cores were removed at breast height from each tree, one from the side facing the lake and the others at 90 degree intervals around the trunk. Either five or ten trees were sampled at each site. The cores were subsequently mounted on hardboard and finely sanded for examination under a binocular microscope. Widths of each of the 21 outermost growth rings were measured.

Results

The vertical distribution limits of mountain beech roots (Table 1) are not usually lower than 666ft (203m). Generally the root profile is similar on the forest and beach sides of a marginal tree, consisting of a surface zone of fibrous roots above a zone of scattered thicker roots. Excavations on all sides of isolated trees showed that the density of roots is much lower on the beach than within the forest at points equidistant from the base. Moreover, no large (>2cm diam.) roots found on the lake side of marginal trees ever advanced down the beach but grew either parallel to the forest margin or turned back towards it (Fig. 6).

TABLE 1. *Height above mean sea level of the lowermost roots of individual beech trees growing along the forest margin of Lake Te Anau. One to four samples per site.*

Locality	Species	Height of Lowermost Roots (Feet A.S.L.)			
Brod Bay	Mountain Beech	670.6	668.0	663.3	
Esk Burn	Mountain Beech	665.8	665.8	664.6	
Delta Burn	Mountain Beech	666.8	666.3	666.1	
Ettrick Burn	Mountain Beech	666.6	666.6	666.6	
Snag Burn	Mountain Beech	666.8	666.6	665.8	665.6
Lugar Burn	Mountain Beech	666.6	665.1		
Narrows	Mountain Beech	665.8	665.3	666.1	
Glaisnock River	Silver Beech	665.8	665.6		
Billy Burn	Mountain Beech	666.6	666.3	666.1	
Sandfly Point	Mountain Beech	666.6	666.1	666.1	
Worsley Stream	Mountain Beech	665.6			

Mean value 666.3ft (203.1m)
Standard deviation 1.0ft (0.3m)

TABLE 2. *Comparison of diameter increment for the 1957-58 and 1970-71 growing seasons with the mean annual value for a 21 year period. Five or ten samples per site from both lake-shore trees and sites above the lake's influence.*

		Locality	Elevation ft	Elevation m	Mean annual diameter growth for 21 years up to 1970-71 (μm)	Mean diameter growth 1957-58 (μm)	Mean diameter growth 1970-71 (μm)
A	(Shoreline sites)	Brod Bay	672	204.8	1027	1097	606*
		Brod Bay	668	203.6	1236	1321	612*
		Esk Burn	672	204.8	1933	1666	1727N.S.
		Delta Burn	670	204.2	1066	1454	430**
		Snag Burn	669	203.9	1182	1330	485*
		Sandfly Point	669	203.9	2745	2915	1424*
B	(Sites above lake influence)	Brod Bay	680	207.3	870	1015	497**
		Brod Bay	702	214.0	1257	1157	636**
		Henry Creek	700	213.4	1285	1509	636**

Significance of differences: *P<0.05 **P<0.01

FIGURE 6. *A mountain beech tree from the lake-front forest of the south side of Billy Burn delta. This example demonstrates the absence of any supporting roots on the lake-front side of the tree and the consequences of undercutting.*

Mean annual diameter increments of each tree at nine localities were compared with their values for (a) the 1970-71 growing season, an extended drought period, and (b) the exceptionally wet growing season of 1957-58 when the lake maintained a high level throughout the summer (mean daily value = 666.3ft or 203.1m). Significant reductions in growth associated with the drought season were found both at the shoreline and elevated sites (Table 2). The one exception was at the Esk Burn, at the head of South Fiord—the most westerly and therefore probably the least drought-affected site.

By contrast there are no significant differences at any site between the diameter increment for an exceptionally wet season and the mean annual value (Table 2). However, the lake did not reach its maximum level until December, by which time most diameter growth was probably completed (Bussell 1965). No effect was apparent in the following season.

DISCUSSION AND CONCLUSIONS

Vegetation patterns along the 197 mile (317km) shoreline of Lake Te Anau show the same relationship to the natural fluctuations in lake level as at Lake Manapouri (Johnson 1972b). We believe that the pattern of woody vegetation along those sections of the Te Anau shoreline composed of unconsolidated material largely reflects the tolerances of the various species to either inundation or periodic development of high water tables.

With the exception of two sites, distribution limits of species were consistent in the many areas studied. On the deltas of the Glaisnock River and the Narrows, both near the head of North Fiord, however, values for the lower elevation limits of several species are 1-2ft (30-60cm) below those recorded from similar sites elsewhere. Data from both the zonation study (Johnson 1972b) and from the traverses were consistent in this respect.

Operating proposals for Lake Te Anau indicate that possible damage to woody vegetation along the shoreline would be confined largely to the effects of a high water table maintained for unnaturally prolonged periods. Approximately 66 miles (106km) of shoreline forest overlies unconsolidated material in which such water table effects could be expected, although variation in the texture and degree of compaction would affect the rate of response to lake level fluctuation. Along much of this distance the ground surface rises steadily away from the lake shore so that a strip of scrub and forest less than 100-200ft (30-60m) wide might be affected. However, it is important to realise that the loss of even a narrow fringe of lake-shore scrub and forest would cause replacement of its natural protective edge (Fig. 7) by an abrupt edge of relatively tall trees. Not only would this look unnatural but ecologically it would be unstable because such tall trees become vulnerable to damage and uplifting by wind.

On the deltas associated with most of the main water courses entering the lake, slopes away from the shoreline are extremely gradual. Thus in ten such traverses an elevation 10ft (3m) above the high lake level was not reached within 1000ft (300m) of the shoreline while in three of these the distance exceeded 2000ft (600m). The longest traverse (3200ft—970m) was on the very extensive flat alongside the Clinton River opposite Glade House at the head of the lake. Although no estimation of total area of these deltas was made, they are up to one mile (1.6km) in width.

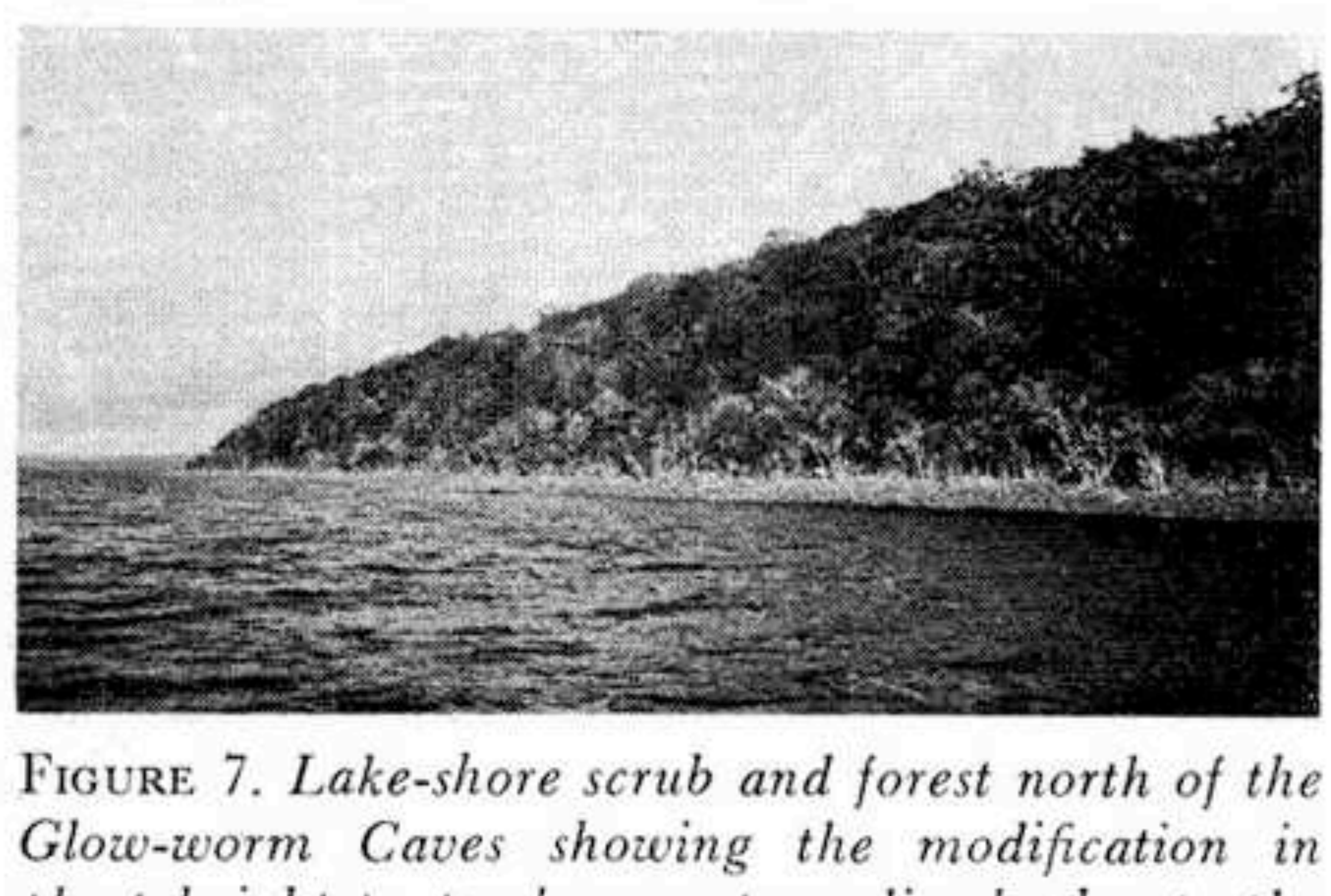

FIGURE 7. *Lake-shore scrub and forest north of the Glow-worm Caves showing the modification in plant height to produce a streamlined edge to the vegetation.*

On the fine sediments of very low-lying deltas at the heads of most arms of the lake a swamp vegetation of rushes, sedges, scrub and scattered trees of kahikatea and pokaka may extend from about high lake level down to an elevation for the shrubs of *ca.* 664ft (202.4m). Here they must tolerate flooding for periods of up to 250 days. Generally similar swamp vegetation is associated with often extensive depressions that have been produced locally on several deltas by the formation of storm beaches or natural levees, at or somewhat below the high lake level. Periodic inundation that does not exceed some critical maximum period is probably necessary for the maintenance of these swamp communities. On the Snag Burn delta, presence of free water in the swamp up to an elevation of 665.5ft (202.8m), which the lake had not reached within five months, implies that water exchange across the storm beach may be impeded at least below a certain level. This could be a critical factor in both development and maintenance of the swamp communities on deltas.

Beech forest is developed on sites that are sufficiently elevated to receive no more than about 50 days of continuous flooding to the level of their trunk bases. Root distribution of beech trees along the lake shore indicates that they avoid areas inundated for periods exceeding about 50 days. Indeed, the roots make such little use of the lakeshore side that marginal trees are prone to undercutting by wave action and may eventually collapse on to the beach (Fig. 6). High levels maintained for long periods could seriously affect the stability of marginal trees.

There is insufficient information on the texture and permeability of the deltas to draw conclusions regarding either rates or extent of penetration of water tables from the shoreline. The material is obviously variable in a way that would affect these factors, but a water table coinciding with the present lake level was recorded in sandy material 2.6ft (80cm) below the surface at a point 310ft (94m) in from the shoreline on the delta of Worsley Stream. We are indebted to Mr D. H. Inch for lake and water table levels measured for one year by Ministry of Works engineers on the coarse delta of the Upukerora River in Te Anau township. Several interesting features are revealed by these data but their relevance to the generally finer sediments of the forested deltas remains unclarified. Water table levels at all sites were invariably higher than the lake, even during the prolonged dry period between early January and early September, 1971, when the lake remained below its mean level. At the two most elevated sites, also most distant from the shoreline, the water table averaged *ca.* 13ft or 4m and 28ft or 8.5m above the lake level during this period. Our predictions of water table effects along the forested shoreline based on horizontal projections of lake level values beneath the forest, could therefore under-estimate the effect. As might be expected, the water table response to changes in lake level generally decreased with distance from the shoreline except that during the period of steadily falling lake level following initiation of the project in September, 1970, lowering of water tables was most rapid (up to 0.6-0.9ft or 18-28cm per day) at the two highest sites. Comparable data are needed from a representative series of forested lake-shore deltas.

Both the shoreline vegetation and topography, especially the storm beaches, indicate that lake level variation probably has not significantly exceeded its recorded range during the several centuries involved in the life span of the present forest trees, though according to Mr C. M. Bambery (N.Z. Electricity Dept, pers. comm.) the lake level rose to *ca.* 674ft (205.4m) during the floods of 1878. Evidence from the Henry Creek site for a possible storm beach at el. 673ft (205.1m) is not sufficient in itself although the distinct wave cut platform at a similar elevation on the south side of Billy Burn delta is more convincing. There is evidence (McKellar and Atkinson 1970) in the Brod Bay-Dock Bay region for a post-glacial lake level at 710ft (216.4m). However, neither of these higher levels bears any relevance to the present vegetation.

In view of the apparently close relationship between the pattern of shoreline vegetation and the natural variation in lake level we conclude that the graph indicating the longest flood recorded at each level above the mean value (see Johnson 1972b, Fig. 1) should indicate the maximum tolerance to flooding of the woody vegetation. This graph thereby provides the basis for our recommended control of the lake level so as to conserve the natural features of at least the woody shoreline vegetation (Mark & Johnson 1972).

The magnitude of damage should depend on the extent to which the lake level was allowed to exceed the predicted tolerance values. Most of those sections of the forested shoreline highlighted in Figure 1 probably would be affected. An additional factor to consider, however, is the frequency of flooding at any particular high level which the woody shoreline vegetation can tolerate. Some critical minimum interval between floods would be necessary to allow occasional exposure of the swamp forest and subsidence of a water table from unconsolidated material. Average duration between floods of any particular level can be calculated from the 38-year record of daily lake levels; but tolerance limits of the woody vegetation probably are most closely approximated by the mean interval between floods of any particular level for the wettest one year period on record. Values for October 1957-September 1958 are as follows: 670ft or 204.2m = 182 days; 669ft or 203.9m = 57 days; 668ft or 203.6m = 32 days; 667ft or 203.3m = 26 days; 666ft or 203.0m = 31 days. Being values for a particularly wet year, these intervals could be fairly close to the tolerance limits of the woody vegetation.

Without similar regard for the pattern of low lake levels (see Johnson 1972b, Fig. 1) some disdisturbance to the herbaceous plant communities is predicted, but such changes would be less obvious and therefore less objectionable.

REFERENCES

BUSSELL, W. T. 1965. Growth studies in a selection of New Zealand trees. *Ph.D. Thesis* University of Otago.

JOHNSON, P. N. 1972a. Applied ecological studies of shoreline vegetation at Lakes Manapouri and Te Anau, Fiordland; Part 1: Vegetation of Lake Manapouri shoreline. *Proceedings of the New Zealand Ecological Society* 19: 102-119.

JOHNSON, P. N. 1972b. Applied ecological studies of shoreline vegetation at Lakes Manapouri and Te Anau, Fiordland. Part 2: The lake edge flora—habitats and relations to lake levels. *Proceedings of the New Zealand Ecological Society* 19: 120-141.

LISTER, R. G., MARK, A. F. and DODD, J. N. 1970. *Submission to the Commission of Inquiry on Lake Manapouri by the Otago Branch of the Royal Society of New Zealand.* Unpublished 32pp. + appendices.

MCKELLAR, I. C. & ATKINSON, I. A. E. 1970. Report on the Lake Te Anau Shoreline. *Department of Scientific and Industrial Research. Unpublished Report.*

MARK, A. F. & JOHNSON, P. N. 1972. Applied ecological studies of shoreline vegetation at Lakes Manapouri and Te Anau, Fiordland. Part 4: Recommendations. *Proceedings of the New Zealand Ecological Society* 19: 155-157.

MANAPOURI COMMISSION OF INQUIRY. 1970. *Report on the proposal to raise the level of Lake Manapouri for the purpose of generating electricity.* Govt. Printer, Wellington.

NEWHOOK, F. J. 1970. Ecological aspects of the proposed scheme for Lakes Manapouri and Te Anau. *In: Submission of the Auckland Civic Trust to the Manapouri Commission of Inquiry.*

WARDLE, J. A. 1970. The ecology of *Nothofagus solandri* 4. Growth, and general discussion to Parts 1 to 4. *New Zealand Journal of Botany* 8: 609-46.

WARDLE, P. 1967. Biological Flora of New Zealand 2. *Nothofagus menziesii* (Hook.f.) Oerst. (Fagaceae) Silver Beech. *New Zealand Journal of Botany* 5: 276-302.

WOOD, B. L. 1962. Sheet 22, Wakatipu (1st Ed.) "Geological Map of New Zealand 1: 250,000". Department of Scientific and Industrial Research, Wellington.