FACTORS INFLUENCING VEGETATION DISTRIBUTION ON A SLOPE IN SOUTH WESTLAND, NEW ZEALAND

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CERTIFICATE

The work in this thesis was planned and executed by Mark Lieffering under my supervision.

per Mitchell Andrews.

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Abstract of a Thesis by Mark Lieffering on:

FACTORS INFLUENCING VEGETATION DISTRIBUTION ON A SLOPE IN SOUTH WESTLAND, NEW ZEALAND.

The vegetation of a slope consisting of two surfaces- a late Otira Glaciation moraine overlaying an early Otira outwash surface is reported. The study area was located between the Omoeroa and Waikukupa Rivers in Westland National Park. Three transects, from the bottom of the slope (on the outwash surface), up the slope to the top of the moraine were established. A total of 43 plots were assessed primarily for vacsular species abundance and tree species basal area. Classification of species abundance along these transects using the TWINSPAN procedure resulted in seven vegetation types. These showed an orderly grouping from pakihi and 'heath forest' (pink pine/manuka) vegetation on the older surface, to rimu/kamahi/rata forest on the younger moraine. These vegetation type boundaries were reinforced by establishing the distribution of the basal areas of the major tree species found along one of the transects.

The soils of the vegetation types found along one of the transects were characterized. No distinct differences in the measured chemical properties were found between the soils; however, slope position influenced the moisture regime and hence the soil profile morphologies.

The main factors influencing the distribution of the vegetation appeared to be the difference in the age of the two surfaces, differences in the soil moisture regimes and the presence of fire on the oldest surfaces.

KEYWORDS: South Westland, pakihi, heath/bog forest, rimu/rata/kamahi forest, Otira Glaciation, moraine, fluvio-glacial outwash, slope, natural fires, gley podzol, classification, TWINSPAN.

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1.0 INTRODUCTION

Over the last thirty years much has been learned about the glacial stratigraphy/chronology, and pedology of North Westland. Work on the glacial geomorphology has established the spatial and temporal relationships between the landforms which have resulted from various glacial episodes (eg. see Suggate, 1965, 1985). Pedological studies have set out the profile morphologies and the physical/chemical properties of some of the 'type locality' soils of the intermediate and high terraces (see Lee, 1980a). Soil maps at scales of up to 1:50,000 have been produced for a number of areas (eg. Mew, 1980a, b). Attempts have been made to elucidate the genesis of and relationships between the wet soils of the intermediate and high fluvio-glacial terraces (eg. Farmer et al, 1984; Mew and Lee, 1988).

In South Westland the situation is very different. Most pedological and geomorphological studies carried out in this region have been less detailed than those in North Westland. The Geological Map of New Zealand at a scale of 1:250,000 (Sheet 17- Hokitika) (Warren, 1967), the General Survey of the Soils of the South Island at a scale of 1:253,440 (Soil Bureau (N.Z.), 1968), the chronosequence work of Stevens (1963, 1968) and Sowden (1986), a number of unpublished reconnaissance surveys, some casual accounts in vegetation studies and National Park handbooks are the only sources of geomorphological and pedological information on South Westland. Hence, in both the quantity and detail of the available information, there is very little specific knowledge of the chronology/stratigraphy of the glacial landforms, or of their associated soil profile morphologies, physical/chemical characteristics and distributions of soil types in this area. This lack of 'in depth' knowledge of the soils and landforms of South Westland makes any plant ecological study much more difficult to carry out and interpret.

The pedology and geomorphology of North Westland has been studied in detail due to the economic development and accessibility of this region. This development has involved the logging of indigenous forest, and the clearing of lowland vegetation for mining and agriculture. These activities have decreased considerably the area of unmodified indigenous vegetation in North Westland. In particular, there are almost no fluvio-glacial surfaces with natural plant communities on them such as pakihis and heath/bog forests. This has limited the amount of research that has been carried out on these types of plant communities.

In South Westland, because of the lack of economic development, there are large tracts of vegetation unmodified by humans, including that of the oldest fluvio-glacial surfaces. Certain aspects of the indigenous vegetation of South Westland have been studied in some detail. In particular, in Westland National Park, the nature of the successional communities and relationships between the different communities on the glacial surfaces dating from the last stadial of the Otira Glaciation are known (eg. Stevens, 1963, 1968; Wardle, 1977, 1980). Sowden (1986) studied similar types of communities on tectonically uplifted terraces near the Wanganui River. However, little is known of the floristic nature and successional development of the plant communities found on the oldest fluvio-glacial surfaces. These are the surfaces left behind by the penultimate stadials of the Otira Glaciation (i.e. older than approximately 20,000 years). The general nature of vegetation is known but there has been no intensive study of the developmental relationships between this vegetation type and the communities found on the younger surfaces. The plant communities found on these older glacial surfaces are predominantly heath/bog forest and the treeless pakihi vegetation.

There has been much discussion on the mechanisms responsible for the development of vegetation types on the oldest glacial surfaces, particularly pakihis (see Mew, 1983). Pakihi is a name for both a landscape feature in Westland and the type of vegetation that occurs at these sites. Pakihis are usually flat areas of poorly drained, very infertile land with a treeless vegetation. The plants that grow at these sites are usually considered to be tolerant of the wet and infertile conditions. One of the reasons put forward for pakihi development is that there has been a deterioration, over long periods of time, in both the soil physical and chemical conditions. This is then thought to lead to the establishment of plants tolerant to very wet and infertile conditions, as are found in pakihi sites (eg. Stevens, 1968; Wardle, 1980). Another proposal is that changes in the regional climate led to wetter conditions and consequently the replacement of species intolerant of these conditions by more tolerant species (Rigg, 1962). Natural fires have been proposed as a secondary factor in the development of the pakihis (eg. Mew, 1983), but they have never been considered as a primary cause due to the high rainfall of the West Coast. Some workers have shown that forest species are colonising pakihi sites (Holloway, 1954; Wardle, 1977), confounding the idea that pakihi development is a 'permanent degradation' change. Mew (1983) tried to reconcile these opposing processes by proposing that regional climate change, microclimate change, and local topographic effects could account for the changes observed in both situations.

The study presented here utilized a site, the 'Omoeroa Plateau', on the Westland National Park piedmont to quantitatively assess the vegetation of a slope made up of two surfaces of different ages. The piedmont is the area of land between the Southern Alps and the coast. The landforms are predominantly of glacial origin, consisting of moraines and outwash surfaces. The slope's older surface is a fluvio-glacial outwash surface which has been partially overlayen by a younger moraine. A preliminary investigation was also made of the soils under the different plant communities found on the two surfaces. The objectives of this study were: (1) to establish the nature of the vegetation types on the slope; (2) to examine the floristic relationships between the vegetation types. In addition, the discussion will put forward some ideas as to the development of the vegetation types found on the slope.

2.0 LOCATION, CLIMATE, AND TOPOGRAPHY OF THE OMOEROA PLATEAU

Outlined below is the location, climate and topography of the study area. The geology, soils, and vegetation of the area will be described in the review of literature (Section 3.0).

2.1 LOCATION

The study was carried out on the 'Omoeroa Plateau', located between Franz Josef and Fox Glacier townships, on the Western side of the Southern Alps in Westland National Park (centred at N.Z.M.S S71 737716). The Omoeroa Plateau is bounded by the Waikukupa and Omoeroa Rivers (Figures 2.1 and 2.2).

The Plateau is about 9 km from the coast, 3 km from the Alpine Fault, and 17 km from the Main Divide. The plateau has an area of approximately 500 hectares and an altitude ranging from 430 to 450 m a.s.l. The surrounding moraines range in altitude from 430 to 500 m a.s.l. There are no higher landscape features between it and the coast. Figure 2.3 shows a general view of the Plateau and the surrounding moraine.

The study was sited near the south-east corner of the Omoeroa Plateau, as indicated in Figure 2.1 (N.Z.M.S. S71 746712). The Omoeroa Plateau was chosen because it contained pakihi vegetation that had supposedly not been logged or burnt and was accessible. Transects were placed for their accessibility and proximity to the road- this made it easier to set up a base camp.

2.2 CLIMATE

Franz Josef and Fox Glacier are the closest meteorological stations to the Omoeroa Plateau, both being approximately 8 km in a straight line from the study area. Franz Josef (ENE of study area) is at approximately 150 m a.s.l and 20 km from the coast. The following meteorological data are derived from New Zealand Meteorological Service (1983?).

The climate of the West Coast is characterized by wide variations over short distances. The greatest single factor affecting the climate of the area is the presence of the Main Divide, which intercepts the prevailing westerly airflow across the Tasman Sea (Hessell, 1982). This gives rise to a gradient of increasing precipitation from the coast to the Southern Alps (Griffiths and McSaveney, 1983).

The following meteorological data comes from N.Z.M.S (1983?). The mean annual rainfall (measured between 1926 and 1980) at Franz Josef is 4971 mm. Over this period the highest annual rainfall was 7500 mm and the lowest 3500 mm. On average, there are 177 raindays (>1.0 mm rain per day). South Westland experiences a spring maximum and a winter minimum distribution of rainfall. Franz Josef, in the wettest month (October) receives on average 491 mm of rain, compared to 291 mm in June, the driest month. Annual rainfall on the Omoeroa Plateau can only be estimated using the data from Franz Josef. Because of its higher elevation, it is estimated that the rainfall is between 5,000-6,000 mm per year.

The mean annual temperature at Franz Josef is 11.1^{o}C. Annual variation is not great. The average temperature of the warmest month (February) is 15.3^{o}C, while that of the coldest month (July) is 6.7^{o}C. The mean daily maximum and minimum temperatures are 15.7^{o}C and 6.5^{o}C respectively. Ground temperatures can drop below freezing at any time of year. However, the average minimum temperature is below zero only in the winter months. Given that air temperatures decrease approximately 0.5^{o}C per 100 m rise in altitude (Coulter, 1967), the Omoeroa Plateau could be expected to experience temperatures 1.5^{o}C lower than Franz Josef.

Franz Josef experiences, on average, 73 days with ground frosts and 22 days with air frosts a year. The study area, being at a higher altitude, could be expected to have a higher incidence of frosts.

No sunshine data are recorded at Franz Josef. The nearest recording stations are at Hokitika and Haast. Average annual sunshine hours for these two stations are 1883 hours and 1918 hours respectively. Hence, despite the high rainfall on the West Coast, these figures compare favourably with the sunshine received on the east coast of the South Island (eg. Christchurch- 1974 hours). Hessell (1982) showed that spring was the only season when Westland had significantly less sunshine than Christchurch. This is due to the maximum of westerly winds which cause orographic cloud during this season.

Snow rarely falls at Franz Josef. Because of its higher altitude, snow may occur to a limited extent during the winter on the Omoeroa Plateau. The most conspicuous ‘special’ weather phenomena at Franz Josef and its environs is thunder, which is heard approximately 12 days of the year. Thunder is often accompanied by lightning and/or hail.

2.3 TOPOGRAPHY

The study area can be divided into two distinct landforms: the Omoeroa Plateau and the surrounding moraines (see Fig. 2.2).

The plateau has a varied topography due to the presence of different landforms. The exact nature of the landforms is difficult to discern due to the extensive low forest cover which makes travel and visual assessment difficult. The most prominent features on the Plateau are a number of small hills presumably made of bedrock. Enveloping the bedrock hills is the dissected outwash surface. This has a rolling topography with many small streams cutting through it. Some of the rolling topography may relate to the underlying bedrock. There are small (up to 100 m by 100 m) areas of relatively flat land.

The topography of the surrounding moraines can be divided into four main land units. These are:
1) the lower slopes, possibly colluvial deposits, having slopes of 5^{o} to 15^{o}.
2) the mid-slopes, generally having slopes of approximately 15^{o} to 20^{o}. There are areas of relatively flat land within this unit.
3) the upper slopes, having steep gradients (up to 30^{o}) near the top of the moraines.
4) the ridge top, is relatively flat, and is up to 20 metres wide.

All the slopes are interspersed by hump/hollow systems and dissected by ephemeral stream channels. With heavy rainfalls, both of these contain water. Water may pond for some time in the hollows.

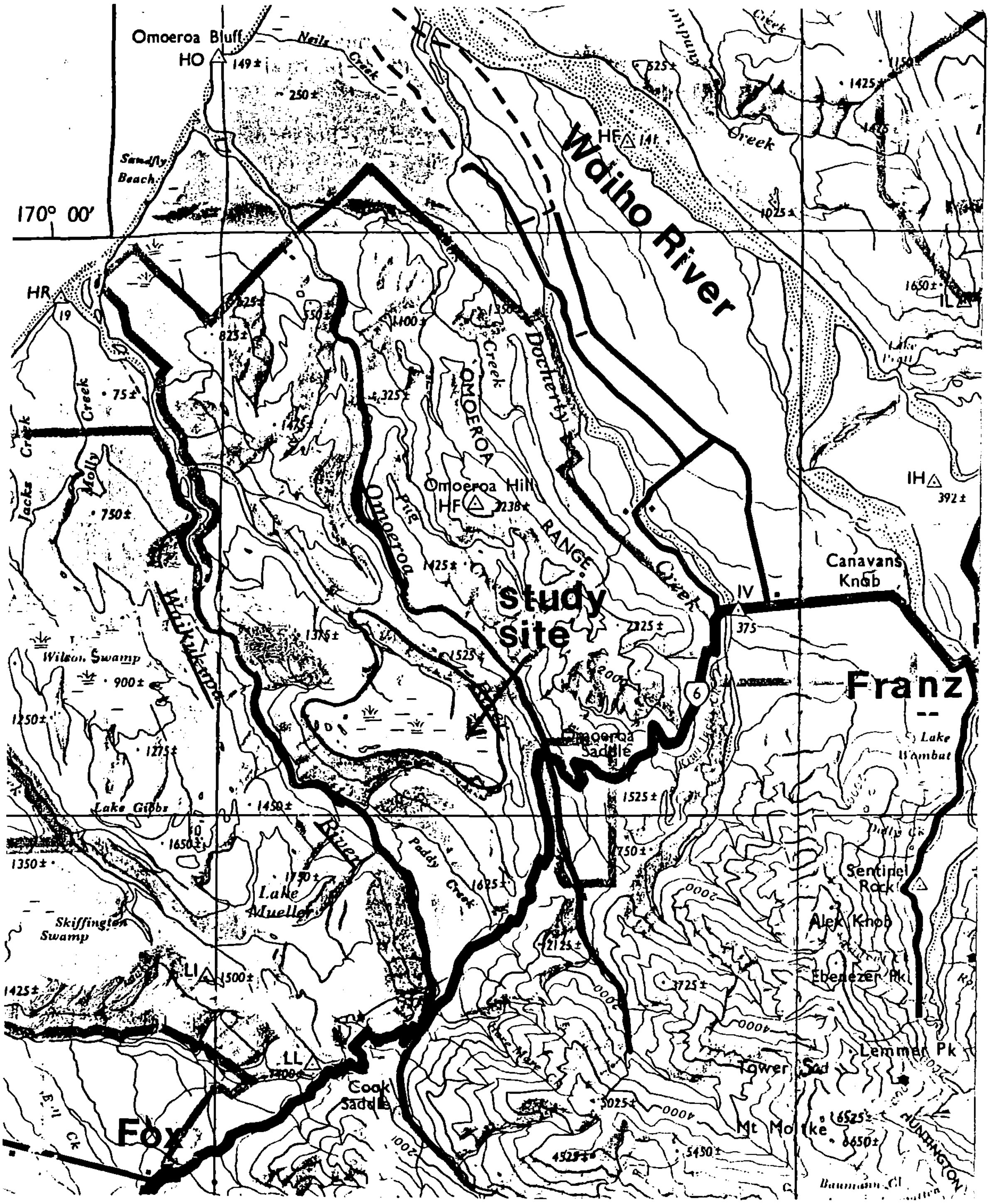

Figure 2.1 Location of the Omoeroa Plateau. (Adapted from N.Z.M.S 180 'Mount Cook and Westland National Parks'; scale approx. 1:100,000)

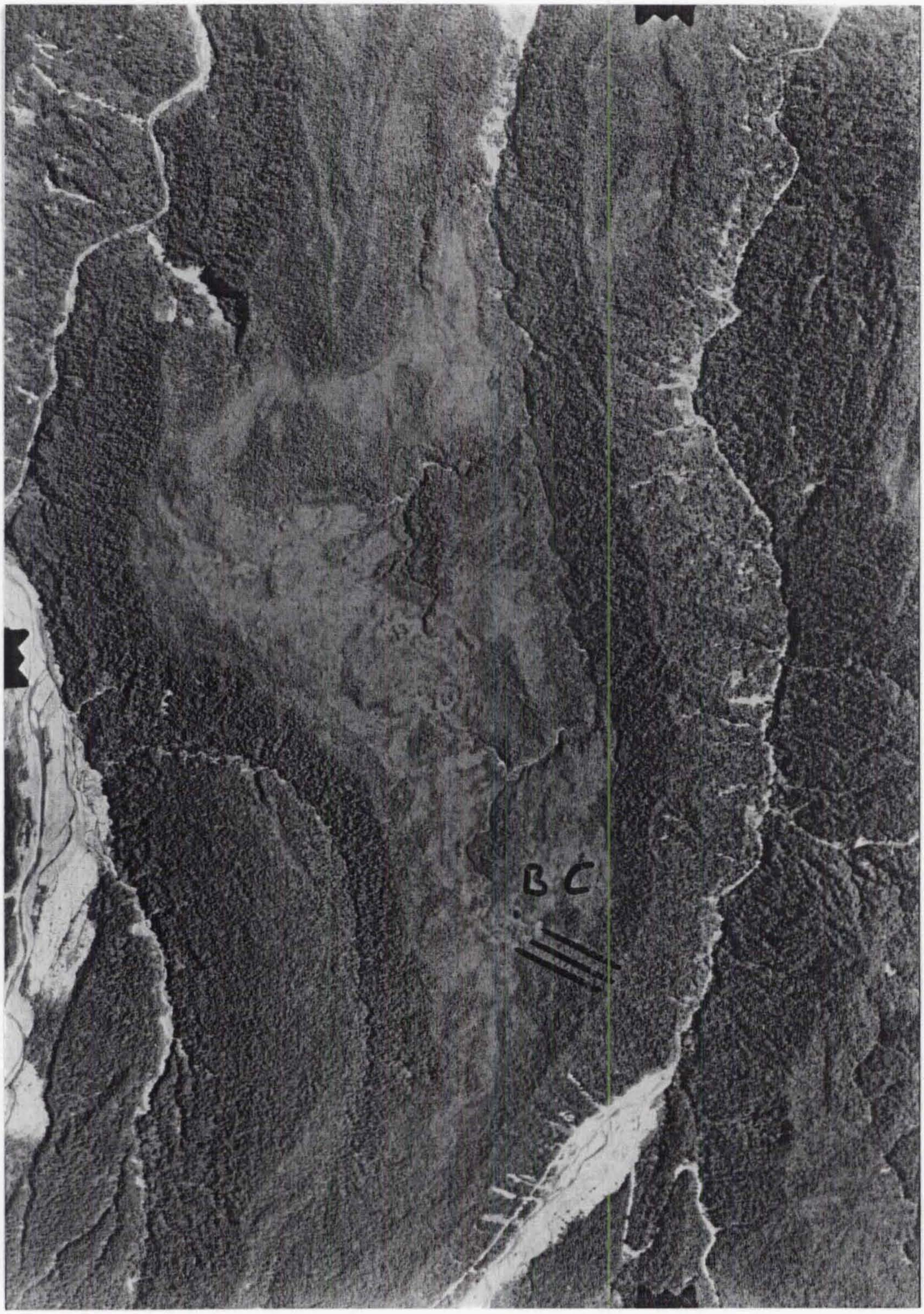

Figure 2.2 Aerial photograph of the Omoeroa Plateau (approximate scale- 1:30,000. Postition of the three transects and base camp shown)

Figure 2.3 General view of the Omoeroa Plateau, looking towards the Omoeroa Range. (Note Plateau surface and moraine ridge.)

3.0 LITERATURE REVIEW

3.1 GLACIAL GEOLOGY OF THE SOUTH WESTLAND PIEDMONT

The landscape of the area around the Omoeroa Plateau reflects the dominant influence of glacial activity. During the Pleistocene, South Westland experienced a series of climatic warmings and coolings. Associated with each of the cooling phases was some degree of glacial activity. These glacial activities left behind sets of glacial and fluvio-glacial landforms such as moraines and outwash surfaces. The landforms consisted of material, predominantly greywacke, argillite, and schist, eroded and brought down from the Southern Alps by the glaciers. The moraines and outwash surfaces were modified during the succeeding warmer interglacials, primarily through the action of water. The next glacial episode, depending on its extent, then either wholly or partially destroyed these landforms or covered them with their own depositions. Hence a series of glacial and fluvio-glacial landforms of different ages can be found in South Westland. The most recent glacial stage in Westland was the Otira Glaciation. It is also the most conspicuous in that it left large areas of landsurfaces visible today. It is estimated that the overall duration of this episode was from 70,000 to 14,000 years B.P (Suggate, 1978). During this glacial stage there were a number of stadials and interstadials. The last major advance was from approximately 25,000 to 14,000 years B.P (Suggate, 1978).

Compared to North Westland, the glacial chronology/ stratigraphy of South Westland has not been well documented. Extensive work has been carried out on the glacial landforms of North Westland (eg. see Suggate, 1965, 1978, 1985). Tentative correlations between events in North Westland and South Westland can be made. The New Zealand Geological Survey (Warren, 1967) mapped two major landsurfaces formed in Westland National Park during the Otira Glaciation, the younger Moana Formation and the older Okarito Formation. The former consists of tills and outwash gravels which flank the main valleys such as the Waiho, Omoeroa, Waikukupa, and Cook Rivers. These deposits were correlated by Warren (1967) to the Moana Formation of North Westland, which was laid down by the 'Kumara-3' (K3) glacial advance (Suggate, 1978). There are pulses evident during this advance- 17,000 to 14,000 years B.P and 14,500 to 14,000 years B.P (Suggate, 1978). The Okarito Formation surfaces mapped by Warren (1967) were laid down by the earlier piedmont ice sheet advances of the Otira Glaciation (Suggate, 1978). In North Westland, Suggate (1965) named these surfaces the Loopline Formation (Kumara-2 advance). Suggate (1985) divided this Loopline formation into the Larrikins Formation (younger Kumara-2 advance, $K2_2$) and the Loopline Formation (older Kumara-2 advance, $K2_1$). In Westland National Park the Okarito Formation landforms are found predominantly between the Cook and Waiho Rivers (Warren, 1967). Both Warren (1967) and

Suggate (1978) suggested that these surfaces may include remnants of pre-Otira (Waimea or Waimaunga) glaciations. Suggate (1987) stated that the Larrikins and Loopline Formations are "confidently assigned to Stages 2 and 4 of the deep-sea oxygen isotope record". The age of the Loopline Formation ($K2_1$ advance) was estimated as 50,000 to 70,000 years B.P and that of the Larrikins Formation ($K2_2$advance) of 17,000 to 25,000 years B.P (Suggate, 1987).

In North Westland, palynological work substantiates these dates. Moar and Suggate (1979) concluded that in North Westland the $K2_2$ advance of the Otira Glaciation began before 22,300 years B.P and that it ended about 18,000 years B.P. Their data also provided evidence that the $K2_2$ / $K2_1$ interstadial began before 31,600 years B.P and ended 26,000 years B.P.

The ages of the surfaces of the Omoeroa Plateau may be estimated using the information in Warren (1967) and the tentative correlations with North Westland. The prominent moraines surrounding the Omoeroa Plateau, shown as Moana Formation by Warren (1967) would have been laid down between 14,000 and 17,000 years B.P Nathan (1987, pers. comm.) concurred with this. The plateau floor, mapped as Okarito Formation by Warren (1967), is correlated with either the Larrikins Formation (17,000 - 25,000 years B.P) or the Loopline Formation (50,000 - 75,000 years B.P). However, Wardle (1979,1980) presented a different picture. Wardle (1980) stated that the geological map of Warren (1967) seemed inconsistent. Wardle (1979, p.113) showed the prominent moraines to pre-date the last major advance of the Otira Glaciation (ie. the Kumara-3 advance). This concurs with the map of Suggate (1978) which shows the ice limits during this stadial. The Kumara-3 advance (Moana Formation) is represented by a smaller moraine plastered onto the side of the side of the prominent moraine. Using the concept of analogous vegetation suites (in North Westland, Western Nelson and South Westland) and radio-carbon dating, Wardle (1980) felt that the ages of the older glacial surfaces have been under-estimated. Taking the ideas of Wardle into account it is suggested that the prominent moraines surrounding the plateau could be correlated to the Larrikins Formation (of Suggate, 1985; 17,000 to 25,000 years B.P) of North Westland. The plateau 'floor' could then be considered as correlated to the Loopline Formation, containing fluvio-glacial surfaces 50,000 - 70,000 years old.

Despite the tentative nature of the correlations with the glacial events in North Westland, the recent Pleistocene glacial history of South Westland can divided into two distinct, main events: the older Piedmont episodes and the younger Valley advances. The moraines of the Omoeroa Plateau were deposited during the latter, while the outwash surface was laid down during the former.

3.2 SOILS

3.2.1 SOIL SURVEY OF THE SOUTH WESTLAND PIEDMONT

Over the years, the spatial distribution of soils in Westland has been studied by a number of workers. Chavasse (1971) outlined the general relationships between the soils, landforms and vegetation types. Gley podzols, such as Okarito soils, were found on the highest and oldest terraces. The General Survey of the Soils of the South Island (Soil Survey (N.Z.), 1968) mapped the distribution of Westland soils at a very broad scale- 1:253,440. This survey is the only available information on the soils of the Omoeroa Plateau. The survey was carried out as a reconnaissance of the soils of the South Island to provide basic information for predicting future land use and broad fertility needs. It only provided a general soil pattern.

The South Westland part of the General Survey of the Soils of the South Island was probably carried out using aerial photographs and a limited amount of field work. The nature of the country and the presence of thick bush would make photo-interpretation difficult. The survey was carried out prior to the publication of the general geological map of Warren (1967). Thus, an inadequate knowledge of the types of landforms and bedrocks present in many areas of South Westland may have led to some erroneous delineations of soil sets.

The 'floor' of the Omoeroa Plateau appears to be mapped by the General Survey as Okarito 'lowland podzolized yellow brown earths'. The Okarito soils have generally been regarded as gley podzols, although there has been and still is a lot of argument among pedologists regarding the genesis and classification of the wet soils of Westland (see Section 3.2.3). These soils were derived from greywacke and schist alluvium with some loess deposits. This seems in accordance with what could be expected in this area.

The soils of the moraine area of the Omoeroa Plateau have been mapped by the General Survey as Matiri 'upland podzolized yellow brown earths'. These soils are formed from sandstone and conglomerates. However, it is believed that this is an example of an erroneous soil set assignment. The moraine is made up of greywacke and schist debris and hence the General Survey soil set which would probably best describe these soils would be the Waiuta 'lowland podzolized yellow brown earths'.

Only a few other soil surveys have been carried out on landforms similar to the Omoeroa Plateau. Mew (1981) presented an interim report on an advanced reconnaissance of soils in the Wanganui, Ianthe, and part of the Kakapotahi State Forests. Almond (1986) established the relationships between the glacial landforms laid down during the last stadial of the Otira Glaciation and soils of Saltwater State Forest. Palmer et al (1986) described the soils found on traverses made across landforms representative of the coastal lowlands and hill country between Karangarua and Haast. Doyle et al (1985) (cited by Palmer et al (1986)) mapped the soils found on moraines near Jacobs River. In all these studies gley podzol type soils are found on the oldest fluvio-glacial terraces.

3.2.2 SOIL DEVELOPMENT

Following on from the early Russian workers (see Rode, 1961), Jenny (1941) set out and popularized the factors of soil formation as:

$$s = f(cl, o, r, p, t, ...)$$

where 's' denotes the soil or any soil property, 'cl' is the climate, 'o' are the organisms, 'r' is the relief, 'p' is the parent material, 't' is the time since the start of soil formation, and '...' represents any locally important factors. Strictly, the factors are independent of each other, but in the 'real world' this is often not so. The factors can be regarded as variables that define the soil system (Birkeland, 1984). In South Westland the two main factor that influence the nature of the soil are time and relief.

3.2.2.1 CHRONOSEQUENCES

The temporal aspect of soil distributions may be referred to as the study of chronosequences. In such studies, sites are selected where the soil forming factors of parent material, relief, climate, and biota are considered to be similar or ineffectively varying for each site. Hence the major difference between sites is the duration of soil development. Moraines or outwash surfaces of differing age resulting from retreating glaciers or sites on river valley terraces are commonly used in chronosequence studies.

There have been a number of soil chronosequence studies in South Westland. Stevens (1963, 1968) investigated soil development in the Franz Josef Valley. Sowden (1986) investigated the soil development on tectonically uplifted terraces near the Wanganui River, while Basher (1986) looked at soil development on different aged landforms under high rainfall in the Cropp River catchment. Smith and Lee (1984) examined a soil sequence on terraces in the Arawata Valley. These studies were all carried out at sites with very high annual rainfalls - from 2,000 mm to 10,000 mm. The higher the rainfall the greater the weathering and leaching losses and hence the faster the rate of soil development. From the studies cited above, Tonkin et al (1985) summarized the chemical losses and mineralogical transformations that occur in Westland chronosequences. These include:

1) loss of 'base cations' (exchangeable Ca, Mg, K, Na) together with associated anions (eg. nitrate) and organic ligands.
2) progressive acidification and the saturation of exchange sites on soil colloids with aluminum and hydrogen.
3) dissolution of earlier formed oxides and hydroxy-oxides of aluminum and iron, and allophanic clays in the surface soil horizon, as pH falls. The result is the formation of an eluviated ('E') horizon.
4) reprecipitation of aluminum and iron oxides, and allophanic clays (with pH's greater than 5.0) resulting in the development of Bs horizons.
5) a variety of clay mineralogical transformations.
6) loss of total phosphorus and the transformation of primary phosphorus forms to secondary organic and inorganic forms (eg. see Walker and Syers, 1976).

Other changes in the soil that are apparent from these Westland studies are: increases in the amounts of soil organic matter, decreasing rates of carbon and nitrogen accumulations, the initiation of depth gradients of soil properties such as pH, cation exchange capacity, and percent base saturation. In addition to these chemical changes are changes in soil physical characteristics such as greater bulk densities with depth, loss of soil structure and the formation of impermeable horizons.

Molloy (1988) summarized Stevens' (1968) chronosequence study and provided correlations of the soils found on the different surfaces with those found in North Westland (eg. Mew, 1980a, b). On surfaces aged between 25-50 years, Molloy correlated Stevens' soils with Hokitika recent soils; 500 year old surfaces- Ikamatua yellow-brown earths; 5,000 year old surfaces- Waiuta podzols; 11,000 year old surfaces- Kumara gley podzols; and on the oldest, 22,000 year old surfaces, Okarito gley podzols.

3.2.2.2 SOILS ON SLOPES

Following on from the equation of Jenny (1941), a toposequence is a series of related soils that differ from each other primarily as a result of the effect of topography (r) on soil development. Topography can be defined as the aspect, slope contour, and relief of a site. The toposequence idea is closely linked to the concept of the soil catena. Each soil along a slope bears a distinct relationship to the soils above and below it. The catena provides a model of soil development on hillslopes, integrating the geomorphological processes of erosion, transport and deposition, hydrological processes of overland flow and through flow, with pedological processes (Tonkin, 1984). The catena "is a soil landform system in which there is a sequential change in soil profile form, including soil chemical, physical, and biological properties, from the summit of slopes to adjacent depressions or drainage ways" (Tonkin, pers comm.).

Of all these processes that relate soils to landscape geometry, the movement of water from the top of a slope to the bottom, by various pathways, is the most important. Differences in site hydrology affects the processes and chemistry of the soils. In general terms, the higher slopes are well drained and the toeslopes poorly drained. The latter are usually rich in clay and organic matter, and show varying degrees of gleying. These differences may be apparent at both micro- and macroscopic levels.

Numerous studies have shown that many soil properties are related to the gradient of the slope as well as the position on a slope (see Birkeland, 1984). Differences in soil properties with regard to position on a slope could be due to pedogenesis in-place, resulting from differences in moisture, leaching, or vegetation. In this case the various parts of the landscape are assumed to be of approximately the same age and differences are due to the topographic factor. However, this may not be true in many instances because the material at the foot of the slope may have been derived from upslope erosion. Hence, the soils differ in both the parent material and time of development. This illustrates the usefulness of the catena concept, compared to the toposequence concept. The time factor in discriminating soils on a slope is also true for slopes made up of differently aged deposits, as in a moraine laid on an older surface.

3.2.3 GLEY PODZOLS

From the soil survey work and the chronosequence studies reviewed above, it is apparent that the soils of the oldest fluvio-glacial surfaces of South Westland are, as conventionally classified, predominantly gley podzols. What follows is a short review of the literature pertinent to gley podzols.

Gley podzols have been defined by Cowie (1980) as

> "... a zonal group of very strongly leached soils occurring in superhumid areas where rainfall is above 2,000 mm. They consist of A horizons which are often peaty, overlying pale grey coloured and massive subsurface horizons which rest in iron or iron/humus cemented coarse textured materials, generally gravels. The structureless and impermeable subsurface horizon and underlying cemented materials hold up the downward movement of rainwater so that a perched watertable is present and the soils are waterlogged for most of the year."

There has been a lot of difficulty in classifying the wet soils of the high and intermediate terraces of Westland into groups according to the New Zealand Genetic Classification (eg. see Lee, 1980a; Mew and Lee, 1988). Attempts to classify the gley podzols in terms of the "Soil Taxonomy" (Pollock, 1980) and the FAO/UNESCO (Miller, 1980) systems have also met with limited success. In the most recent paper on the classification of the gley podzols Mew and Lee (1988) concluded that none of the wetland soils fitted precisely into all appropriate subgroups of any of the overseas soil classification systems.

The difficulty in classifying the gley podzols is due in part to an incomplete knowledge of the processes responsible for the development of these soils. There has been much debate on the genesis of the gley podzols. Until the mid 1970's, it was thought by most workers that under the high rainfall of the West Coast the soil podzolization process resulted in the formation of an iron/humus pan. This then inhibited drainage, leading to gleying conditions. Hence, the term 'gley podzol' was intended to imply gley conditions superimposed on a podzol soil (Ross and Mew, 1975). Mew and Lee (1988) commented that profile features strongly reflect both the effects of gleying and podzolization. They stated that while it is difficult to estimate the relative roles of these processes in the evolution of the soils, gleying processes in a perched water environment currently dominate.

Mew (1980c) outlined the site characteristics that are usually found with gley podzols. The landforms are usually intermediate and high terrace remnants with little or no slope. Altitudes of the sites are between 30 to 700 m above sea level. Annual rainfall ranges between 1,500 to 5,000 mm. The drainage of the sites ranges from imperfectly to very poorly drained. The vegetation of the sites varies considerably. At some sites gley podzols can be found under mature forest, at others under pakihi vegetation. In many cases, particularly in North Westland, this pakihi vegetation has been induced by humans.

Over the last 10 years there has been a lot of work carried out on the wet soils of the intermediate and high terraces of Westland. Most of this work has been presented in a special publication on podzols and gley podzols (Lee, 1980a). The information in this publication has also been written up in individual papers. Lee (1980b) and Mew and Lee (1981) set out the type localities, profile morphologies, and chemistry of eight West Coast soils of the low, intermediate, and high terraces. The locations of the type localities of these soils were in North Westland. Chemically, all soils showed characteristics of intense leaching and were extremely acid. Nutrient levels were low. Jackson (1984) presented data on physical aspects of the soil types set out by Mew and Lee (1981). The physical characteristics of the soils showed very large variations of properties with depth. These were associated with organic content and particle size distribution. The H and Ah horizons of all profiles were important for plant growth in that they contained sufficient readily available water to meet likely soil water deficits. In addition, they were the only parts of the profiles to be well aerated for much of the year.

The physical nature of the gley podzols is important in discussions on their genesis. The manner in which water is impeded in the profile has been the centre of much debate. As mentioned above, the occurrence of iron pans is often cited as a cause. However, the soils with gley podzol features (ie. massive grey horizon) are also those with a major texture contrast present between the upper and lower horizons. The profile morphologies of a number of West Coast wetland soils were set out by Mew and Lee (1981). The soils with fine textured material in the upper horizons all had parent materials consisting of loess with some glacial alluvium and are generally considered as gley podzols. The textures of this horizon were mainly silt loams. The soils without fine textured materials in the upper horizons had parent materials of glacial outwash alluvium, moraine, sandstone, and granite/gneiss alluvium. These soils are not generally regarded as gley podzols.

Young (1967) showed the presence of loess over outwash gravels in soils of the West Coast. Later work by Robertson and Mew (1981) confirmed this, by establishing the presence of volcanic ash in the fine textured material. Young (1967) made the point that the low permeability of the loess contributed significantly to the poor drainage of these soils rather than the presence of an iron pan below the loess. Jackson (1984) suggested that his investigations were inconclusive as to which horizons limit vertical water movement in most of the profiles. Jackson pointed out that horizons at a shallow depth will be poorly aerated even if a watertable is not present because they have pore size distributions that limit their air content under the high rainfalls and low evaporation of the West Coast.

3.2.4 SOILS: SUMMARY

In summary, the following points can be made. The Omoeroa Plateau has been mapped by the General Soil Survey of the South Island as having two main soil types. The placement of these soil types appears to approximate the areas occupied by the two surfaces of different ages set out in Section 3.1. From this survey, and chronosequence studies, it is apparent that the dominant soils of the Plateau are gley podzols. These soils are generally very wet and nutrient poor, providing difficult conditions for plant growth.

3.3 VEGETATION

3.3.1 VEGETATION OF THE SOUTH WESTLAND PIEDMONT: GENERAL

From the above literature, it can be concluded that the piedmont of Westland National Park consists primarily of two surfaces of different ages: older fluvio-glacial surfaces and younger moraines. On these surfaces there are a number of different vegetation types. Cockayne (1921) provided the first description and general classification of the vegetation of South Westland in his book "Vegetation of New Zealand". Communities described by Cockayne which are relevant to this study included rimu associations, southern rata - kamahi forest, Sphagnum - Gleichenia bog, manuka bog, and pakihis. A systematic vegetation assessment of what is now Westland National Park was carried out as part of the National Forest Survey of New Zealand. A summary of the results was published by Masters et al (1957). Though the survey concentrated on timber species, some indications of community trends were presented. The majority of forest types were found on "Westland gravel" hills, terraces and moraines. These were dominated by rimu, miro, and Hall's totara, with an understorey of rata, kamahi, and quintinia. It was noted that the terrace rimu communities graded into communities of silver pine - rimu, silver pine - kaikawaka, or silver pine - manuka. The latter community was found marginal to the open bogs of the wettest terrace soils. Variation in vegetation type was attributed to the degree of podzolization of the forest soils, freedom of drainage, age of the "forest crop", and the nature of the underlying material.

A detailed vegetation survey of the Westland National Park piedmont was carried out in 1984-85 by the New Zealand Forest Service as part of the South Westland Management Evaluation Programme. This survey assessed the vegetation between State Highway 6 and the coast on a regular 460 m by 900 m grid basis. The results have not been published.

From vegetation surveys carried out by between 1964 and 1975, a list containing nearly 800 species and descriptions of over 120 vegetation communities in Westland National Park were published by Wardle (1975, 1977). In addition, Wardle (1979, 1982) described and mapped the plant community and landscape relationships.

Published information specific to the vegetation of the Omoeroa Plateau and its surrounding moraines is scarce. Wardle (1982) mapped three main vegetation types in the study area based on the survey and papers cited above. These were tall forest, heath/bog forest, and pakihis. The vegetation types mapped for the prominent moraine ridge were forests with a main canopy of tall hardwoods, especially kamahi or rata, with or without a conifer overstorey of podocarps or kaikawaka. The vegetation types mapped for the plateau are: heath-scrub and heath-forest ie. manuka, pink pine and yellow-silver pine; and mires, swamps, bogs and pakihis. Between these two types of plateau vegetation were ill defined transitions. There were also transitions between the tall podocarp forest and the heath forest. Using the information of Wardle (1977, 1982) the main vegetation types of the study area may be surmised using the plant community groupings and descriptions of Wardle (1977) as follows:

a) Moraine ridge- community code 'B3a': rimu/kamahi/Blechnum forest.
This forest grows on steep slopes. Three layers are usually recognized. The upper layer has rimu and miro as large scattered trees. The middle layer contains kamahi, Hall's totara and rata. The lower story is a mixture of small trees and shrubs such as *Pseudopanax simplex, Coprosma foetidissima* and *Myrsine australis. Blechnum discolor* is the dominant ground cover.

- community code 'B5a': rata/kamahi/Blechnum forest.
This is the upland equivalent of the previous community. Rata and kamahi are dominant, with Hall's totara also important. The under story is a mixture of small trees and shrubs such as *Pseudopanax simplex, Coprosma foetidissima* and *Griselinia littoralis. Blechnum discolor* and *Astelia nervosa* dominate the ground vegetation.

- community code 'B3e': rimu/kamahi-quintinia forest
This forest type grows on gleyed podzolized yellow-brown earths with a cemented B horizon. Its canopy is three storied, the upper being dominated by rimu trees, which tend to be more numerous and smaller than in community 'B3a'. Hall's totara is always present, as is miro, and both can be abundant. The second storey is dominated by kamahi and quintinia; rata is usually present, and can be co-dominant. *Myrsine australis* and *Phyllocladus alpinus* are consistently common.

b) Plateau floor- community code 'J1a': piedmont heath-forest on wet ground. This forest occupies the poorly drained ground on the piedmont moraines. The canopy is uneven, up to 12m high. The main trees are *Halocarpus biformis* (more abundant above 300 m), *Lagarostrobus colensoi* (more abundant below 300 m), *Phyllocladus alpinus* and *Leptospermum scoparium*.

- community code 'J2a': 'Dacrydium' scrub of the piedmont moraine crests. This community is found on the moraine crests with little organic matter. The scrub consists of manuka, *Lagarostrobus colensoi*, and *Halocarpus biformis*. The trees are usually small, up to 2.5 m in height. The understorey is made up of *Gleichenia circinnata, Empodisma minus* and *Lepidothamnus intermedium X Lepidothamnus laxifolium*. Other plants in this vegetation type reflect the intermediate nature of this community with respect to communities 'J1a' and 'K3a'.

- community code 'K3a': natural pakihi. The main species are *Empodisma minus* and *Gleichenia circinnata*. Woody plants- *Leptospermum scoparium, Halocarpus bidwillii* and *Dracophyllum palustre*; are very stunted.

Phytosociological classification of the New Zealand flora, by such methods as the Braun-Blanquet system, has rarely been attempted. Recently however, Reif and Allen (1988) presented a phytosociological classification of the conifer-broadleaved hardwood forests of South Westland. Though the study incorporated only the forests of the steep mountainlands, a number of the communities recognized have counterparts on the South Westland piedmont. In a number of cases Reif and Allen (1988) compared their communities with the vegetation types set out by Wardle (1977).

3.3.2 VEGETATION DEVELOPMENT: SUCCESSION

The most comprehensive investigation on the plant successions of the Westland National Park area is by Wardle (1980). Wardle emphasized the importance of topography and the textural nature of the soil parent material as the dominant factor in determining successional pathways. On the moraines, the succession progresses through *Raoulia spp.*and moss communities through to open shrubland, low seral forest, rata-kamahi forest, kamahi and podocarp forest, to a community of rimu, kamahi and quintinia. This succession is usually considered to take up to 20,000 years. Hence, the successional development of plant communities on the surfaces dating from the last major stadial of the Otira Glaciation (11,000 - 14,000 years B.P.) is fairly well known. However, the development of plant communities on the older surfaces (early Otira Glaciation; greater than approximately 20,000 years B.P.) has not been well studied. The communities on these older surfaces are usually composed of plants that are adapted to extreme waterlogging and low nutrient status soils. They are variously referred to as heath forest, bog forest, and where there are very few trees- pakihi vegetation. The heath/bog forest consists of low stunted trees of the genera *Halocarpus, Lepidothamnus, Phyllocladus, Lagarostrobus* and *Leptospermum.* Pakihis are characterized by low ground vegetation of the genera *Gleichenia, Empodisma, Chionochloa, Dracophyllum* and others adapted to living in extremely nutrient poor environments (see Section 3.3.3 for more information).

3.3.3 VEGETATION DEVELOPMENT: PAKIHIS AND HEATH FOREST

There has been much debate on the mechanisms responsible for the development of the vegetation of the oldest fluvio-glacial surfaces. Wardle (1980) was of the opinion that the heath and pakihi communities were unlikely to represent the end point of a direct, linear succession from the earlier successional communities described above. Mew (1983) reviewed the hypotheses that have been put forward to explain the distribution and possible dynamics of pakihi vegetation. In considering the dynamics/ distribution of pakihis two opposite processes can be considered- the change from forest to pakihi and the change from pakihi to forest. In addition, it should be noted that the heath/bog forest is very important as an intergrade between tall forest and the pakihi communities. This community contains floristic elements of both types of contrasting vegetation.

Evidence that there have been changes from forest to pakihi and vice versa comes from a number of sources. Rigg (1951, cited in Burrows et al, 1979) suggested that because some pakihi soils contain buried wood, there had been several cycles of forest succession and retrogression. Moar and Suggate (1979) showed that forest was dominant throughout most of the Holocene on certain central Westland sites which at present support pakihi vegetation.

There are a number of mechanisms which could explain the historical change from forest vegetation to pakihi vegetation. Contemporaneously, human beings can be shown to be responsible for the formation of pakihi vegetation through the action of logging and/or fire. This has been well documented in North Westland where the vegetation has been disrupted for timber extraction or agricultural purposes. Rigg (1962), who described the floristic components, vegetation development, and soils of pakihis near Westport, commented on the use of fire to maintain these communities treeless since the time of European settlement.

The possibility that natural fires can create pakihi vegetation sites by destroying the forest has rarely been credited. Natural fires are regarded as an unlikely cause of pakihi formation due to the very wet conditions which are usually prevalent on the West Coast. However, Burrows et al (1979) cited a radio-carbon date for a *Lagarostrobus colensoi* stump of 5950 +/-70 years B.P. from a pakihi near Westport. From this evidence they inferred that this pakihi may have had a fire influence before human settlement.

Changes in the physical characteristics of the soil as a direct cause of change from forest to pakihi have never been examined. McDonald (1955) looked at the physical properties and moisture contents of soils at sites in Westland where natural forest and cleared land carrying pakihi vegetation occurred on the same soil type. He concluded that there were no significant differences in the soils beneath the pakihi and forest vegetation. This conclusion does not preclude the idea that changes in soil physical status influences the development of natural pakihi vegetation communities. Park (1972) investigated the 'pakihi gaps' in the *Nothofagus* forests of the Tararua Ranges. He came to the conclusion that the development of pakihis was due to increasing soil water and decreasing air content of the soils.

The idea that changes in the chemical characteristics of a soil could lead to the formation of pakihi vegetation for forest, has been put forward, but seldom on its own. Both Stevens (1968) and Wardle (1979) thought that a decline in forest vigour could result from the decline in soil fertility. Degradation of both the soil physical characteristics and chemical fertility have been cited as the reason for pakihi development (Rigg, 1962; Wardle, 1980).

Changes in the regional climate have been postulated to have led to a deterioration of the forest to pakihi vegetation (Rigg, 1962). This change presumably included an increase in rainfall which could have accelerated the physical and chemical deterioration of the soil and hence favoured the spread of pakihi vegetation.

Changes in climate have also been put forward as a possible mechanism for forest replacing pakihi. Chavasse (1971) suggested that boggy areas become firmer with time. Together with periodic drying, this led to forest colonization of the pakihi sites. Holloway (1954) suggested that a change in climate, around 800 years ago, restricted forest regeneration. He felt that the forests have only recently started to regenerate and only the "most recalcitrant pakihi soils remain unforested". Cockayne (1928) and Mark and Smith (1975) all expressed the idea that forest was advancing into pakihi vegetation but did not state reasons supporting these assumptions. In some instances it has been shown that cleared sites may reforest in the absence of fire (Hughes, 1975; Wardle, 1977).

Mew (1983) tried to reconcile the opposite processes of forest declining into pakihi vegetation and pakihi being invaded by forest. He felt that the main governing factor which influences the direction of vegetation development is the rise and fall of the watertable of a particular site. This could be caused by:

a) regional climatic changes, either short or long term, leading to increased rainfall and soil water;
b) local microclimate changes, leading to either increased or decreased amounts of surface and/or subsurface water;
c) local topographic effects, for example blockage or partial impedance of drainage outlets of a hollow within a moraine, leading to a local rise in the watertable.

Mew (1983) felt that these mechanisms seem best to explain the present pattern of the relative distribution of natural pakihi and forest vegetation in South Westland. He also stressed that the generally low nutrient fertility of the soils also influences the vegetation succession. Mew (1983) considered that topography and natural fires were of secondary importance.

Norton (1989) examined the floristics and vegetation dynamics across two ecotones between a raised ombrogenous mire and forest in Saltwater State Forest, South Westland. He concluded that the position of the mire-forest ecotone was relatively stable, because it was determined primarily by the underlying sediments. The floristics and structure of the ecotones were dynamic, responding to a variety of disturbances such as natural fires and stand replacement.

3.3.4 VEGETATION DISTRIBUTION: SUMMARY

There are a number of factors which can influence the distribution of vegetation on the Westland National Park piedmont. As stressed above, the piedmont is made up of two glacial surfaces deposited by different episodes of the Otira Glaciation. Time acts through the process of plant succession to discriminate between plant communities on surfaces of different ages. The floristic development of plant communities through time is molded by both vegetative and pedological processes. There is a close link between soil development over time and plant succession. The interaction between the input of different species' propagules and their survival in the existing environment shape the course of succession at a particular site. The environment includes both abiotic components such as soil conditions and biotic components such as competition. Hence, changes in the soil over a period of time will lead to changes in the vegetation. These changes include a loss of chemical and physical fertility. In South Westland, with its very high rainfall, the chemical changes in the soil over time are relatively quick (within approximately 10,000 years). Hence for surfaces that are older than this, the chemical nature of the soil may not be important in differentiating between soils of a different age.

As noted above, the nature of the soil will differ along a slope. The effect of soil drainage on vegetation patterns in New Zealand has been noted (Cockayne, 1928; Wardle, 1974, 1980; Mew, 1975; Smith and Lee, 1984). In an investigation of the soils and *Nothofagus* forests of the Inangahua Depression, Mew (1975) found that soil fertility was less important in determining forest pattern than soil drainage. Another factor to be considered is that of erosion: on steeper slopes this phenomenon is likely to occur on a more regular basis. This will affect the nature of the plant communities at that site. Hence, superimposed upon the effects of time on vegetation and soils is the effect of the overall relief of a site.

Other factors can also be important in influencing vegetation distribution. The climate of an area may be important, depending on the variations within the area. Altitude is an important site characteristic that will change the climatic regime across an area. Another factor that may influence the vegetation of an area is the occurrence of fires. As stated above, human induced fires have been shown to be important in perpetuating pakihi type vegetation, especially in North Westland. Natural fires may also be important in the initiation of pakihis and heath forests.

4.0 METHODS OF VEGETATION ASSESSMENT, SOIL SAMPLING AND STATISTICAL ANALYSIS

4.1 VEGETATION ASSESSMENT

The vegetation of the Omoeroa Plateau and the surrounding moraines was quantitatively assessed in plots along three parallel transects. Each plot was 10 m X 20 m in size and orientated with the longest side perpendicular to the direction of the transect. The transects, which were approximately 60 m apart, started on the Plateau floor and proceeded up to the moraine crests (Fig. 2.2). The plots were 50 m apart. However, where vegetation types were under-represented along the transects, for example in pakihi clearings and their margins, additional plots were established.

A total of 43 main plots were assessed. In each of these main plots all trees (woody plants >5 cm diameter at breast height (dbh)) were counted and their diameters measured. At the centre of this main plot a 4 m X 4 m sub-plot was established. In this area all saplings (woody plants <5 cm dbh and higher than 50 cm) were counted. Percentage ground cover type was estimated in five randomly placed 0.1 m^2 rings. Classes of cover type were- vascular plants, bryophyte, litter, rock and bare ground.

In the main plot the cover score of all species in six tiers (where present) was estimated. The tier heights were:

tier 1 .... <0.3 m
tier 2 .... 0.3 m - 2 m
tier 3 .... 2 m - 5 m
tier 4 .... 5 m - 12 m
tier 5 .... 12 m - 20 m
tier 6 .... >20 m

The assigned cover score values were:

1 ···· <1%
2 ···· 1 - 5%
3 ···· 5 - 25%
4 ···· 25 - 50%
5 ···· 50 - 75%
6 ···· 75 - 100%

The relative wetness (on a scale of 1 to 10) and slope, together with signs of windthrow and burning were also noted to aid later interpretation.

4.2 VEGETATION ANALYSIS

The vegetation data were analysed using the PC-ORD multivariate analysis package (McCune, 1987). The package summarizes data and performs various methods of community classification and ordination. Before analysing the data, species were given an overall abundance value in each plot. This was obtained by summing transformed species abundance values across transformed tier heights in which the species occurred (see Tables 4.1 and 4.2). The transformations were made to give final species abundance ratios (lowest transformed abundance: highest transformed abundance) of 1:30 in forest plots, 1:20 in scrub/heath plots, and 1:10 in pakihi plots, as recommended by Leathwick (1987).

TABLE 4.1 Abundance value transformations

Abundance value	Cover score range	'Average' cover score	standardized $\log_{10}(x20)$
1	<1%	0.5%	1.00
2	1 - 5%	3.0%	1.78
3	5 - 25%	15.0%	2.48
4	25 - 50%	37.5%	2.88
5	50 - 75%	62.5%	3.10
6	75 - 100%	87.5%	3.24

TABLE 4.2 Tier transformations/weightings

Tier	Height range	'Average' height	standardized $\log_{10}(x10)$
1	<0.3 m	0.3 m	1.00
2	0.3 - 2 m	2.0 m	2.71
3	2 - 5 m	3.0 m	3.08
4	5 - 12 m	8.5 m	4.02
5	12 - 20 m	16.0 m	4.58
6	20 - 25 m	22.5 m	4.90

4.2.1 VEGETATION CLASSIFICATION

Classification is the assignment of entities to classes or groups. Classification methods are defined by two main features: the strategy- how the arrangements which yield the final groupings are made; and the numerical basis upon which the strategy works (Causton, 1988).

Divisive polythetic procedures are probably the most commonly used methods of classification (DeVelice, 1985). These methods subdivide the total number of plots on the basis of more than one species or plot attribute. During the 1970's, several divisive polythetic classification methods were developed. These methods involve different strategies of dividing the plots or species after initial ordering along the first axis of an ordination. One of these methods- indicator species analysis, is currently one of the more widely used computer based classification procedures. This method is incorporated into a program called TWINSPAN (Two Way INdicator SPecies ANalysis), which was developed at Cornell University.

Reviews of the TWINSPAN procedure and comparisons with other classification techniques can be found in Gauch (1982), Kershaw and Looney (1985) and Causton (1988). Gauch and Whittaker (1981) compared two divisive and three agglomerative techniques and found TWINSPAN to be "usually more informative" when analysing field data. TWINSPAN also has the advantages of simultaneously classifying species and plots, and producing a floristic table in which both plots and species are sorted along the principal axis of floristic gradient.

The TWINSPAN procedure has been used in New Zealand with apparent success by Clarkson (1984), Sowden (1986), Leathwick (1987), Norton (1989), and DeVelice and Burke (1989). DeVelice (1985) considered the classification produced by TWINSPAN as ecologically sound and recommended the use of this technique in phytosociological classification in New Zealand.

The beneficial attributes of TWINSPAN are partly due to the technique incorporating both ordination and classification procedure to achieve the end result. Over the years there has been much discussion on the best way of 'modelling' the distribution of vegetation. Ordination uses the gradient and continuum concepts in analysing vegetation patterns. Classification tries to assign measured plots to several groups. Hence, classification may be most suitable in situations where the vegetation has marked changes. Therefore TWINSPAN, in using both ordination and classification procedures, partially overcomes the conflict with regard to the underlying mechanisms of vegetation distribution.

In this study TWINSPAN was used to classify the plots. TWINSPAN uses the reciprocal averaging ordination technique to establish the major variation in a data set. The ordination is divided at its middle to produce a dichotomy of the samples. Differential species that are preferential to either side of the dichotomy are established. The dichotomy is refined by constructing a second ordination based on the differential species. This second ordination determines the dichotomy. The process of making dichotomies by dividing ordinations is continued until the classification is complete. Classification of the species proceeds in the same way as that of plots with the exception that species have attributes relating to preferences to either side of plot divisions.

Indicator species analysis, the procedure on which TWINSPAN is based, is essentially a technique for classifying qualitative data. In order to classify quantitative data the concept of pseudospecies was introduced by Hill et al, (1975). The basis of the concept is to introduce extra 'species', which are derived from an actual measured 'base' species. These pseudospecies have the same name as the base species but are differentiated by numbers which represent the abundance of the base species. The number of pseudospecies required for any one species in a plot is directly proportional to the abundance of that species. For example, consider a plot which contained two species- species A with a total abundance of 4 and species B with a total abundance of 37. If the designated pseudospecies abundance classes (termed 'cut levels') were 0-2 (class 1), 3-10 (2), 11-20 (3), 20-40 (4), and 40 plus (5), then species A would be represented in the analysis by pseudospecies classes (1) and (2), whereas species B would be represented by four pseudospecies- classes (1) to (4).

Except for the pseudospecies cut levels (as described above), the default parameters specified by the PC-ORD - TWINSPAN program were used. The cut levels used were 0, 2, 5, 10, 20, and 40.

4.3 SOIL DESCRIPTION AND ANALYSIS

Soil descriptions and samplings were carried out at each vegetation type, as classified by the TWINSPAN procedure (see above). Soil pits were dug along the first transect at a representative site of each vegetation type. The pits were approximately 1 m X 1 m in area. Their depth varied between 50 cm and 80 cm, depending on the nature of the underlying horizons. In each pit, horizons were defined and assessed for texture, mottling and concretions, consistency and colour. From each horizon samples were taken for chemical analysis.

Between each soil pit, augering was carried out approximately every 12 m to establish where soil boundaries occurred. At the same time, approximate ground surface heights were assessed along the first transect using a 'human Abney level' technique. This technique involved two people proceeding along the transect with a tape measure and at short intervals (10 m to 15 m) estimating the altitude difference between themselves. It is believed that due to the difficult nature of the ground surface, this technique gave as good a result as would have been obtained by conventional surveying techniques.

Chemical analyses of the soil samples (carried out by the Soil Science Department, Lincoln College) were pH(H_2O), pH(KCl), levels of organic carbon and organic nitrogen, levels of oxalate extractable iron and aluminium, levels of exchangeable aluminium, and the amount of acid extractable phosphorus. Duplicate samples were analysed for each horizon. The standard Soil Bureau methods, with minor changes were used.

5.0 RESULTS

5.1 VEGETATION CLASSIFICATION

Table 5.1 presents the abundance values for all the species in the plots of the first transect. A change in the species and their abundances occurs moving up the slope. There is also an increase in the species richness. The other two transects showed similar patterns.

TABLE 5.1 - Abundance values of the species in the plots of the first transect.

Vegetation type of each plot is indicated, letters as defined in Figures 5.1 and 5.2, names as defined by the TWINSPAN dendrogram- Figure 5.3 and Section 5.1

Sample Unit: plot3 'K - PAKIHI'

Value	Code	Species	Code Name
1.00	72	CELMISIA SPECIES	CELSP.
7.72	1	CHIONOCHLOA RUBRA	CHIRUB
1.00	8	CYATHODES EMPETRIFOLIA	CYAEMP
2.48	4	DRACOPHYLLUM PALUSTRE	DRAPAL
3.10	5	EMPODISMA MINUS	EMPMIN
1.00	81	GENTIANA SPECIES	GENSP.
7.30	3	GLEICHENIA CIRCINNATA	GLECIR
9.58	2	HALOCARPUS BIDWILLII	HALBID
1.00	6	LEPIDOTHAMNUS LAXIFOLIUM	LEPLAX
1.00	79	OREOBOLUS PECTINATUS	OREPEC
1.00	71	PENTACHONDRA PUMILA	PENPUM

Sample Unit: plot4 'K -PAKIHI'

Value	Code	Species	Code Name
1.00	7	ANISOTOME AROMATICA	ANIARO
1.00	76	CARPHA ALPINA	CARALP
1.00	72	CELMISIA SPECIES	CELSP.
10.18	1	CHIONOCHLOA RUBRA	CHIRUB
4.49	4	DRACOPHYLLUM PALUSTRE	DRAPAL
3.10	5	EMPODISMA MINUS	EMPMIN
6.60	3	GLEICHENIA CIRCINNATA	GLECIR
5.82	2	HALOCARPUS BIDWILLII	HALBID
1.78	6	LEPIDOTHAMNUS LAXIFOLIUM	LEPLAX
1.00	77	LIPAROPHYLLUM GUNNII	LIPGUN

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Sample Unit: plot5  'J - PAKIHI'

   Value   Code   Species            Code Name

    1.00    68   ASTELIA LINEARIS VAR. LINEARIS ASTLIN
    1.00    72   CELMISIA SPECIES        CELSP.
    7.72     1   CHIONOCHLOA RUBRA        CHIRUB
    1.00     8   CYATHODES EMPETRIFOLIA     CYAEMP
    1.78     4   DRACOPHYLLUM PALUSTRE      DRAPAL
    1.00    11   DROSERA SPATHULATA        DROSPA
    3.10     5   EMPODISMA MINUS         EMPMIN
    2.48     3   GLEICHENIA CIRCINNATA      GLECIR
    7.30     2   HALOCARPUS BIDWILLII       HALBID
    1.78     9   HEMIPHUES SUFFOCATA       HEMSUF
    1.00     6   LEPIDOTHAMNUS LAXIFOLIUM    LEPLAX
    1.00    10   LEPTOSPERMUM SCOPARIUM     LEPSCO
    1.00    71   PENTACHONDRA PUMILA       PENPUM
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Sample Unit: plot6  'K - PAKIHI'

   Value   Code   Species            Code Name

    1.00    70   APOROSTYLIS BIFOLIA      APOBIF
    1.00    72   CELMISIA SPECIES        CELSP.
   10.28     1   CHIONOCHLOA RUBRA        CHIRUB
    1.78     4   DRACOPHYLLUM PALUSTRE      DRAPAL
    1.00    12   DROSERA ARCTURI         DROARC
    1.00    11   DROSERA SPATHULATA        DROSPA
    3.10     5   EMPODISMA MINUS         EMPMIN
    1.00    81   GENTIANA SPECIES        GENSP.
    2.88     3   GLEICHENIA CIRCINNATA      GLECIR
    2.88     2   HALOCARPUS BIDWILLII       HALBID
    1.00     6   LEPIDOTHAMNUS LAXIFOLIUM    LEPLAX
    1.00    14   LYCOPODIUM RAMULOSUM      LYCRAM
    1.00    71   PENTACHONDRA PUMILA       PENPUM
    1.00    13   THELYMITRA VENOSA        THEVEN
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Sample Unit: plot1  'H - FIRST MARGIN'

   Value   Code   Species            Code Name

    1.00    70   APOROSTYLIS BIFOLIA      APOBIF
    1.00    76   CARPHA ALPINA          CARALP
    6.60     1   CHIONOCHLOA RUBRA        CHIRUB
    1.00     8   CYATHODES EMPETRIFOLIA     CYAEMP
    1.78     4   DRACOPHYLLUM PALUSTRE      DRAPAL
    1.00    12   DROSERA ARCTURI         DROARC
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   1.00   11   DROSERA SPATHULATA          DROSPA
   1.00   19   DROSERA STENOPETALA         DROSTE
   2.88    5   EMPODISMA MINUS             EMPMIN
   6.60   17   GAHNIA PROCERA              GAHPRO
   1.78    3   GLEICHENIA CIRCINNATA       GLECIR
   1.00    2   HALOCARPUS BIDWILLII        HALBID
  13.98   15   HALOCARPUS BIFORMIS         HALBIF
   9.58   16   LAGAROSTROBUS COLENSOI      LAGCOL
   7.30   18   LEPIDOTHAMNUS HYBRID        LEPHYB
   1.00    6   LEPIDOTHAMNUS LAXIFOLIUM    LEPLAX
  16.36   10   LEPTOSPERMUM SCOPARIUM      LEPSCO
   1.00   79   OREOBOLUS PECTINATUS        OREPEC
   1.00   71   PENTACHONDRA PUMILA         PENPUM
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Sample Unit: plot2  'G - SECOND MARGIN'

  Value   Code   Species                   Code Name

   1.00   70   APOROSTYLIS BIFOLIA         APOBIF
   1.00   25   ASTELIA NERVOSA             ASTNER
   1.00   28   COPROSMA COLENSOI           COPCOL
   1.00    8   CYATHODES EMPETRIFOLIA      CYAEMP
   7.30   22   CYATHODES JUNIPERINA        CYAJUN
   1.00   26   DACRYDIUM CUPRESSINUM       DACCUP
   1.00    4   DRACOPHYLLUM PALUSTRE       DRAPAL
   1.00   11   DROSERA SPATHULATA          DROSPA
  10.81   20   ELAEOCARPUS HOOKERIANUS     ELAHOO
   1.00    5   EMPODISMA MINUS             EMPMIN
   5.82   17   GAHNIA PROCERA              GAHPRO
   1.00   29   GRISELINIA LITTORALIS       GRILIT
  27.34   15   HALOCARPUS BIFORMIS         HALBIF
   1.00   27   HYMENOPHYLLUM SPECIES       HYMSP.
   1.00   18   LEPIDOTHAMNUS HYBRID        LEPHYB
   1.00    6   LEPIDOTHAMNUS LAXIFOLIUM    LEPLAX
  26.31   10   LEPTOSPERMUM SCOPARIUM      LEPSCO
   9.68   31   PHYLLOCLADUS ALPINUS        PHYALP
  10.81   21   PODOCARPUS HALLII           PODHAL
   3.71   23   PSEUDOPANAX SIMPLEX         PSESIM
   1.00   24   UNCINIA SPECIES             UNCSP.
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Sample Unit: plot7  'G - SECOND MARGIN'

  Value   Code   Species                   Code Name

   1.00   70   APOROSTYLIS BIFOLIA         APOBIF
   1.00   25   ASTELIA NERVOSA             ASTNER
   2.71   28   COPROSMA COLENSOI           COPCOL
   1.00    8   CYATHODES EMPETRIFOLIA      CYAEMP
   7.30   22   CYATHODES JUNIPERINA        CYAJUN
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1.00	26	DACRYDIUM CUPRESSINUM	DACCUP
3.71	4	DRACOPHYLLUM PALUSTRE	DRAPAL
1.00	11	DROSERA SPATHULATA	DROSPA
7.16	20	ELAEOCARPUS HOOKERIANUS	ELAHOO
4.49	5	EMPODISMA MINUS	EMPMIN
6.60	17	GAHNIA PROCERA	GAHPRO
1.00	81	GENTIANA SPECIES	GENSP.
1.00	44	GLEICHENIA CUNNINGHAMII	GLECUN
27.19	15	HALOCARPUS BIFORMIS	HALBIF
1.00	27	HYMENOPHYLLUM SPECIES	HYMSP.
13.95	16	LAGAROSTROBUS COLENSOI	LAGCOL
2.48	18	LEPIDOTHAMNUS HYBRID	LEPHYB
19.16	30	LEPIDOTHAMNUS INTERMEDIUM	LEPINT
1.00	6	LEPIDOTHAMNUS LAXIFOLIUM	LEPLAX
25.61	10	LEPTOSPERMUM SCOPARIUM	LEPSCO
1.00	36	LUZURIAGA PARVIFLORA	LUZPAR
12.08	31	PHYLLOCLADUS ALPINUS	PHYALP
2.71	23	PSEUDOPANAX SIMPLEX	PSESIM

Sample Unit: plot8 'F - SECOND MARGIN'

Value	Code	Species	Code Name
1.00	70	APOROSTYLIS BIFOLIA	APOBIF
1.00	68	ASTELIA LINEARIS VAR. LINEARIS	ASTLIN
3.71	28	COPROSMA COLENSOI	COPCOL
3.71	34	COPROSMA FOETIDISSIMA	COPFOE
7.30	22	CYATHODES JUNIPERINA	CYAJUN
3.71	26	DACRYDIUM CUPRESSINUM	DACCUP
1.00	4	DRACOPHYLLUM PALUSTRE	DRAPAL
13.21	20	ELAEOCARPUS HOOKERIANUS	ELAHOO
5.82	17	GAHNIA PROCERA	GAHPRO
1.00	81	GENTIANA SPECIES	GENSP.
1.00	37	GRAMMITIS BILLARDIERI	GRABIL
39.25	15	HALOCARPUS BIFORMIS	HALBIF
1.00	27	HYMENOPHYLLUM SPECIES	HYMSP.
21.10	16	LAGAROSTROBUS COLENSOI	LAGCOL
1.00	18	LEPIDOTHAMNUS HYBRID	LEPHYB
34.79	30	LEPIDOTHAMNUS INTERMEDIUM	LEPINT
22.22	10	LEPTOSPERMUM SCOPARIUM	LEPSCO
1.00	47	LIBERTIA PULCHELLA	LIBPUL
1.00	36	LUZURIAGA PARVIFLORA	LUZPAR
1.00	14	LYCOPODIUM RAMULOSUM	LYCRAM
1.00	41	LYCOPODIUM VOLUBILE	LYCVOL
1.00	39	METROSIDEROS UMBELLATA	METUMB
3.71	35	MYRSINE DIVARICATA	MYRDIV
6.79	32	PSEUDOPANAX COLENSOI	NEOCOL
1.00	38	NERTERA DICHONDRAEFOLIA	NERDIC
21.14	31	PHYLLOCLADUS ALPINUS	PHYALP

2.71	42	PITTOSPORUM CRASSIFOLIUM	PITCRA
26.11	21	PODOCARPUS HALLII	PODHAL
3.71	23	PSEUDOPANAX SIMPLEX	PSESIM
1.00	40	QUINTINIA ACUTIFOLIA	QUIACU
1.00	24	UNCINIA SPECIES	UNCSP.
3.71	33	WEINMANNIA RACEMOSA	WEIRAC

Sample Unit: plot9 'D - LOWER MID-SLOPE'

Value	Code	Species	Code Name
3.71	25	ASTELIA NERVOSA	ASTNER
3.71	48	BLECHNUM CAPENSE	BLECAP
3.71	28	COPROSMA COLENSOI	COPCOL
3.71	34	COPROSMA FOETIDISSIMA	COPFOE
6.60	22	CYATHODES JUNIPERINA	CYAJUN
6.79	26	DACRYDIUM CUPRESSINUM	DACCUP
2.71	80	DRACOPHYLLUM TRAVERSII	DRATRA
10.81	20	ELAEOCARPUS HOOKERIANUS	ELAHOO
7.72	17	GAHNIA PROCERA	GAHPRO
3.71	44	GLEICHENIA CUNNINGHAMII	GLECUN
1.00	37	GRAMMITIS BILLARDIERI	GRABIL
20.36	15	HALOCARPUS BIFORMIS	HALBIF
13.95	30	LEPIDOTHAMNUS INTERMEDIUM	LEPINT
16.06	10	LEPTOSPERMUM SCOPARIUM	LEPSCO
1.00	47	LIBERTIA PULCHELLA	LIBPUL
1.00	36	LUZURIAGA PARVIFLORA	LUZPAR
1.00	14	LYCOPODIUM RAMULOSUM	LYCRAM
3.71	39	METROSIDEROS UMBELLATA	METUMB
6.79	32	PSEUDOPANAX COLENSOI	NEOCOL
3.71	66	NEOMYRTUS PEDUNCULATA	NEOPED
20.36	31	PHYLLOCLADUS ALPINUS	PHYALP
21.27	21	PODOCARPUS HALLII	PODHAL
3.71	23	PSEUDOPANAX SIMPLEX	PSESIM
3.71	40	QUINTINIA ACUTIFOLIA	QUIACU
18.46	33	WEINMANNIA RACEMOSA	WEIRAC

Sample Unit: plot10 'D - LOWER MID-SLOPE'

Value	Code	Species	Code Name
1.00	25	ASTELIA NERVOSA	ASTNER
1.00	48	BLECHNUM CAPENSE	BLECAP
3.71	28	COPROSMA COLENSOI	COPCOL
3.71	34	COPROSMA FOETIDISSIMA	COPFOE
1.00	43	CTENOPTERIS HETEROPHYLLA	CTEHET
1.78	22	CYATHODES JUNIPERINA	CYAJUN
24.31	26	DACRYDIUM CUPRESSINUM	DACCUP
10.81	20	ELAEOCARPUS HOOKERIANUS	ELAHOO

5.82	17	GAHNIA PROCERA	GAHPRO
1.00	81	GENTIANA SPECIES	GENSP.
1.00	37	GRAMMITIS BILLARDIERI	GRABIL
18.96	15	HALOCARPUS BIFORMIS	HALBIF
27.39	30	LEPIDOTHAMNUS INTERMEDIUM	LEPINT
5.82	10	LEPTOSPERMUM SCOPARIUM	LEPSCO
1.00	47	LIBERTIA PULCHELLA	LIBPUL
1.00	36	LUZURIAGA PARVIFLORA	LUZPAR
22.17	39	METROSIDEROS UMBELLATA	METUMB
16.10	66	NEOMYRTUS PEDUNCULATA	NEOPED
23.30	31	PHYLLOCLADUS ALPINUS	PHYALP
29.82	21	PODOCARPUS HALLII	PODHAL
4.02	46	PSEUDOPANAX CRASSIFOLIUS	PSECRA
15.32	23	PSEUDOPANAX SIMPLEX	PSESIM
6.60	40	QUINTINIA ACUTIFOLIA	QUIACU
36.69	33	WEINMANNIA RACEMOSA	WEIRAC

5/

Sample Unit: plot11 'D - LOWER MID-SLOPE'

Value	Code	Species	Code Name
3.71	25	ASTELIA NERVOSA	ASTNER
3.71	48	BLECHNUM CAPENSE	BLECAP
6.79	28	COPROSMA COLENSOI	COPCOL
6.79	34	COPROSMA FOETIDISSIMA	COPFOE
3.71	22	CYATHODES JUNIPERINA	CYAJUN
30.82	26	DACRYDIUM CUPRESSINUM	DACCUP
15.39	20	ELAEOCARPUS HOOKERIANUS	ELAHOO
5.82	17	GAHNIA PROCERA	GAHPRO
1.00	81	GENTIANA SPECIES	GENSP.
3.71	44	GLEICHENIA CUNNINGHAMII	GLECUN
1.00	37	GRAMMITIS BILLARDIERI	GRABIL
7.10	29	GRISELINIA LITTORALIS	GRILIT
13.17	15	HALOCARPUS BIFORMIS	HALBIF
5.82	10	LEPTOSPERMUM SCOPARIUM	LEPSCO
1.00	47	LIBERTIA PULCHELLA	LIBPUL
1.00	36	LUZURIAGA PARVIFLORA	LUZPAR
1.00	14	LYCOPODIUM RAMULOSUM	LYCRAM
33.22	39	METROSIDEROS UMBELLATA	METUMB
3.71	35	MYRSINE DIVARICATA	MYRDIV
10.81	32	PSEUDOPANAX COLENSOI	NEOCOL
3.71	66	NEOMYRTUS PEDUNCULATA	NEOPED
23.82	31	PHYLLOCLADUS ALPINUS	PHYALP
37.49	21	PODOCARPUS HALLII	PODHAL
1.00	45	PRUMNOPITYS FERRUGINA	PRUFER
6.79	23	PSEUDOPANAX SIMPLEX	PSESIM
15.39	40	QUINTINIA ACUTIFOLIA	QUIACU
1.00	49	TRICHOMANES RENIFORME	TRIREN
34.26	33	WEINMANNIA RACEMOSA	WEIRAC

EL

Sample Unit: plot12 'B - UPPER MID-SLOPE'

Value	Code	Species	Code Name
3.71	25	ASTELIA NERVOSA	ASTNER
3.71	48	BLECHNUM CAPENSE	BLECAP
3.71	28	COPROSMA COLENSOI	COPCOL
8.90	34	COPROSMA FOETIDISSIMA	COPFOE
24.28	26	DACRYDIUM CUPRESSINUM	DACCUP
15.39	20	ELAEOCARPUS HOOKERIANUS	ELAHOO
1.00	37	GRAMMITIS BILLARDIERI	GRABIL
10.81	29	GRISELINIA LITTORALIS	GRILIT
1.00	16	LAGAROSTROBUS COLENSOI	LAGCOL
3.71	30	LEPIDOTHAMNUS INTERMEDIUM	LEPINT
1.00	47	LIBERTIA PULCHELLA	LIBPUL
1.00	36	LUZURIAGA PARVIFLORA	LUZPAR
19.09	39	METROSIDEROS UMBELLATA	METUMB
6.79	35	MYRSINE DIVARICATA	MYRDIV
12.92	32	PSEUDOPANAX COLENSOI	NEOCOL
1.00	38	NERTERA DICHONDRAEFOLIA	NERDIC
27.39	31	PHYLLOCLADUS ALPINUS	PHYALP
35.24	21	PODOCARPUS HALLII	PODHAL
3.71	45	PRUMNOPITYS FERRUGINA	PRUFER
10.81	46	PSEUDOPANAX CRASSIFOLIUS	PSECRA
3.71	23	PSEUDOPANAX SIMPLEX	PSESIM
1.00	24	UNCINIA SPECIES	UNCSP.
33.41	33	WEINMANNIA RACEMOSA	WEIRAC

LE

Sample Unit: plot13 'B - UPPER MIDSLOPE'

Value	Code	Species	Code Name
3.71	25	ASTELIA NERVOSA	ASTNER
3.71	48	BLECHNUM CAPENSE	BLECAP
1.00	50	BLECHNUM DISCOLOR	BLEDIS
6.79	28	COPROSMA COLENSOI	COPCOL
15.32	34	COPROSMA FOETIDISSIMA	COPFOE
1.00	53	COPROSMA LUCIDA	COPLUC
30.89	26	DACRYDIUM CUPRESSINUM	DACCUP
6.79	20	ELAEOCARPUS HOOKERIANUS	ELAHOO
5.82	17	GAHNIA PROCERA	GAHPRO
3.71	44	GLEICHENIA CUNNINGHAMII	GLECUN
1.00	37	GRAMMITIS BILLARDIERI	GRABIL
6.79	29	GRISELINIA LITTORALIS	GRILIT
1.00	27	HYMENOPHYLLUM SPECIES	HYMSP.
1.00	47	LIBERTIA PULCHELLA	LIBPUL
1.00	51	LINDSAEA TRICHOMANOIDES	LINTRI
1.00	36	LUZURIAGA PARVIFLORA	LUZPAR
37.46	39	METROSIDEROS UMBELLATA	METUMB

6.79	35	MYRSINE DIVARICATA	MYRDIV
12.92	32	PSEUDOPANAX COLENSOI	NEOCOL
1.00	38	NERTERA DICHONDRAEFOLIA	NERDIC
2.71	52	PHORMIUM COOKIANUM	PHOCOO
15.32	31	PHYLLOCLADUS ALPINUS	PHYALP
36.65	21	PODOCARPUS HALLII	PODHAL
6.79	45	PRUMNOPITYS FERRUGINA	PRUFER
3.71	46	PSEUDOPANAX CRASSIFOLIUS	PSECRA
1.00	49	TRICHOMANES RENIFORME	TRIREN
29.42	33	WEINMANNIA RACEMOSA	WEIRAC

Sample Unit: plot14 'B - UPPER MID-SLOPE'

Value	Code	Species	Code Name
1.00	56	ASPLENIUM FLACCIDUM	ASPFLA
3.71	25	ASTELIA NERVOSA	ASTNER
1.00	48	BLECHNUM CAPENSE	BLECAP
3.71	50	BLECHNUM DISCOLOR	BLEDIS
3.71	28	COPROSMA COLENSOI	COPCOL
11.30	34	COPROSMA FOETIDISSIMA	COPFOE
3.71	55	CYATHEA SMITHII	CYASMI
36.65	26	DACRYDIUM CUPRESSINUM	DACCUP
18.28	20	ELAEOCARPUS HOOKERIANUS	ELAHOO
1.00	37	GRAMMITIS BILLARDIERI	GRABIL
6.79	29	GRISELINIA LITTORALIS	GRILIT
1.00	27	HYMENOPHYLLUM SPECIES	HYMSP.
1.00	47	LIBERTIA PULCHELLA	LIBPUL
1.00	51	LINDSAEA TRICHOMANOIDES	LINTRI
1.00	36	LUZURIAGA PARVIFLORA	LUZPAR
38.76	39	METROSIDEROS UMBELLATA	METUMB
3.71	65	MYRSINE AUSTRALIS	MYRAUS
5.82	35	MYRSINE DIVARICATA	MYRDIV
9.68	32	PSEUDOPANAX COLENSOI	NEOCOL
1.00	38	NERTERA DICHONDRAEFOLIA	NERDIC
27.39	31	PHYLLOCLADUS ALPINUS	PHYALP
30.20	21	PODOCARPUS HALLII	PODHAL
9.07	45	PRUMNOPITYS FERRUGINA	PRUFER
10.81	46	PSEUDOPANAX CRASSIFOLIUS	PSECRA
9.68	23	PSEUDOPANAX SIMPLEX	PSESIM
1.00	58	RUMOHRA ADIANTIFORMIS	RUMADI
1.00	24	UNCINIA SPECIES	UNCSP.
35.57	33	WEINMANNIA RACEMOSA	WEIRAC

EL

Sample Unit: plot15 'A - RIDGE'

Value	Code	Species	Code Name
3.71	25	ASTELIA NERVOSA	ASTNER
3.71	48	BLECHNUM CAPENSE	BLECAP
7.30	50	BLECHNUM DISCOLOR	BLEDIS
11.30	34	COPROSMA FOETIDISSIMA	COPFOE
3.71	55	CYATHEA SMITHII	CYASMI
11.86	26	DACRYDIUM CUPRESSINUM	DACCUP
1.00	60	DICKSONIA LANATA	DICLAN
1.00	62	DICKSONIA SQUARROSA	DICSQU
1.00	20	ELAEOCARPUS HOOKERIANUS	ELAHOO
3.71	17	GAHNIA PROCERA	GAHPRO
1.78	44	GLEICHENIA CUNNINGHAMII	GLECUN
1.00	37	GRAMMITIS BILLARDIERI	GRABIL
5.48	29	GRISELINIA LITTORALIS	GRILIT
1.00	27	HYMENOPHYLLUM SPECIES	HYMSP.
1.00	61	LEPTOPTERIS SUPERBA	LEPSUP
1.00	51	LINDSAEA TRICHOMANOIDES	LINTRI
1.00	36	LUZURIAGA PARVIFLORA	LUZPAR
15.86	39	METROSIDEROS UMBELLATA	METUMB
1.00	63	MICROLAENA AVENACEA	MICAVE
9.19	65	MYRSINE AUSTRALIS	MYRAUS
3.71	35	MYRSINE DIVARICATA	MYRDIV
8.90	32	PSEUDOPANAX COLENSOI	NEOCOL
3.71	66	NEOMYRTUS PEDUNCULATA	NEOPED
1.00	38	NERTERA DICHONDRAEFOLIA	NERDIC
23.21	31	PHYLLOCLADUS ALPINUS	PHYALP
23.45	21	PODOCARPUS HALLII	PODHAL
25.13	45	PRUMNOPITYS FERRUGINA	PRUFER
1.00	85	PSEUDOWINTERA COLORATA	PSECOL
6.79	46	PSEUDOPANAX CRASSIFOLIUS	PSECRA
3.71	23	PSEUDOPANAX SIMPLEX	PSESIM
3.71	59	RIPOGONUM SCANDENS	RIPSCA
1.00	24	UNCINIA SPECIES	UNCSP.
34.79	33	WEINMANNIA RACEMOSA	WEIRAC

In summary, the dominant species in the vegetation types were:

1) pakihi vegetation -

Chionochloa rubra
Empodisma minor
Gleichenia circinnata
Halocarpus bidwillii

2) first margin vegetation -

Phyllocladus alpinus
Gahnia procera
Halocarpus biformis
Leptospermum scoparium
Lagarostrobus colensoi

3) second margin vegetation -

Halocarpus biformis
Leptospermum scoparium
Gahnia procera
Lepidothamnus intermediu~~*m*~~ s
Phyllocladus alpinus
Elaeocarpus hookerianus
Podocarpus hallii

4) lower mid-slope vegetation -

Metrosideros umbellata
Dacrydium cupressinum
Weinmannia racemosa
Podocarpus hallii
Elaeocarpus hookerianus
Phyllocladus alpinus
Halocarpus biformis
Leptospermum scoparium

5) upper midslope and ridge top vegetation -

Coprosma foetidissima
Prumnopitys ferrugine~~*us*~~ a/
Metrosideros umbellata
Dacrydium cupressinum
Weinmannia racemosa
Podocarpus hallii
Elaeocarpus hookerianus
Phyllocladus alpinus

The two-way ordered table (Fig. 5.1) is an interaction between all the classified plots and the classified species produced as a result of four divisions of the data set by the TWINSPAN procedure. Four divisions were carried out as this gave a 'usable' number of plot groups; more divisions would have given too many groups. Species abbreviations are arranged along the left hand side of the table, and plot numbers are along the top. For a list of the species abbreviations and their species names refer to Appendix 1. The pattern of zeros and ones on the bottom and right hand side define the classification groupings of the plots and species. The interior of the table contains the highest abundance class of each species in each plot. These classes are defined by the pseudospecies cut levels, as set out in Section 4.2.1.

The four divisions of the TWINSPAN procedure produced 11 plot groupings, as indicated by the letters 'A' - 'K' above the plot numbers at the top of the two-way table. The plot group boundaries have been shown on a schematic map (Fig. 5.2) of the three transects. The plot numbers only indicate the relative positions of the plots, they are not to scale. For example, the true distance between plot 15 and plot 14 is 50 m, while that between plot 6 and plot 1 is only 17 m. The letters on the periphery are the plot groupings as defined by Figure 5.1.

The schematic map shows that there is a well ordered sequence of plot groupings from the plateau up onto the moraine ridge. The vegetation types along the transects are (moving up the slope): the pakihi vegetation (groupings I, J, and K), the first 'margin' vegetation type (group H), the second 'margin' vegetation type (groupings E, F, and G), the lower 'mid-slope' vegetation type (group D), the upper 'midslope' vegetation type (groups C and B), and the ridge top vegetation type (group A).

The two-way table and the resultant vegetation map do not provide any indication of the importance of each TWINSPAN division. To get this information, it is possible to construct a classification dendrogram using the TWINSPAN divisions and their eigen values (Causton, 1988). Figure 5.3 is the dendrogram of the plot groupings as produced by four divisions in the TWINSPAN procedure. The dichotomies are based on the patterns of zeros and ones at the bottom of the TWINSPAN two-way table (Fig. 5.1). The eigen values on the left hand side of the diagram are those of the first axis of the reciprocal averaging ordination technique, as carried out as a preliminary step in the TWINSPAN procedure. These eigen values define at what level a division is to be carried out. The species abbreviations at each dichotomy are the 'indicator species' used by TWINSPAN. The numbers at each dichotomy define each division and split in order to clarify later discussion. For example, the numbers 3/2 indicate that that dichotomy is the second split within TWINSPAN's third division.

```
                a     b    c     d   e f g    h  i  j    k
                 |        |  |       ||  |   |   ||      |
                1414112244222 11233323 3  12 1233133 123
                5331247802456901378926852771169029145803346

  8    BLEDIS   3311-212-----------------------------------  000000
 16    COPLUC   -31-----1----------------------------------  000000
 21    CYASHI   22---2-------------------------------------  000000
 23    DICLAN   11-----------------------------------------  000000
 24    DICSQU   12-----------------------------------------  000000
 49    LEPSUP   11-----1---------1-------------------------  000000
 51    LINTRI   111--1-1-1---------------------------------  000000
 57    MICAVE   11-----------------------------------------  000000
 58    MYRAUS   32-1-2-2-2---------------------------------  000000
 69    PRUFER   5635232542--2--1-2-22----------------------  000000
 70    PSECOL   11-----1-----------------------------------  000000
 75    RIPSCA   2------------------------------------------  000000
  3    ASPBUL   -----1-------------------------------------  000001
  4    ASPFLA   -----1-1-----------------------------------  000001
 39    GRILIT   333243-12331---3--12----1------------------  000001
 65    PHOCOO   --2----------------------------------------  000001
 76    RUMADI   -----1-------------------------------------  000001
  7    BLECAP   2-22212222121212122211---------------------  000010
 15    COPFOE   44443444443332232333222---1----------------  000010
 17    CORSP.   ---1------------1--------------------------  000010
 18    CTEHET   ---1----------1----------------------------  000010
 71    PSECRA   3323444441-24-2-33-11----------------------  000010
 80    TRIREN   -11---1--11----1--11-----------------------  000010
 59    MYRDIV   223-33-133222--22-22212--------------------  000011
 22    DACCUP   415555545555535555555-211111---------------  000100
 30    EARAUT   ------------1------------------------------  000101
 56    METUMB   455545555565625555565-1--------------------  000101
 73    PTESP.   ------------1------------------------------  000101
 74    QUIACU   ---4---533-5523431-32-1--------------------  000101
 79    THEELO   ------1-----------1-1----------------------  000101
 26    DRATRA   -------------2-----22----------------------  00011
 61    NEOPED   23----23-3--224222-2-2---------------------  00011
 37    GLECUN   1223--------32-2-222-1---1-----------------  00100
  6    ASTNER   2222221122221212121112--11-----------------  001010
 38    GRABIL   11111111111111111111111--------------------  001010
 60    NEOCOL   344443--333--32433443-33--1----------------  001010
 82    WEIRAC   55555555555554555555552----2---------------  001010
 14    COPCOL   -3322233232222232332222112-2---------------  001011
 68    PODHAL   5555555556556555555655524-33---------------  001011
 72    PSESIM   23-2234443-432432223-22-22-2---------------  001011
 31    ELAHOO   143-443455-4444423343443431----------------  001100
 43    HYMSP.   1111-11111-1----111111111111---------------  001100
 50    LIBPUL   -11111111111111111111111--11---------------  001100
 53    LUZPAR   111111111111111111111111-111---------------  001100
 62    NERDIC   111111-1---1----------11-------------------  001100
 66    PHYALP   5445555353555555555555543444-3-3-----------  001101
  9    BULMOD   --------------------------1----------------  00111
 46    LEPINT   ---52-2---2--45-5-554-55-4-1---------------  00111
 55    LYCVOL   ----------1---------1-1--------------------  00111
 67    PITCRA   ----------------------2----2---------------  00111
 34    GAHPRO   2-33--3--32-333333233333333333-3-----------  01
 35    GENSP.   ----------11--1111111111-1-----1--------1-1  01
 81    UNCSP.   11--11-11--1----11----111-11-1-------------  01
 20    CYAJUN   ----------1--312222233333333-3-3--1--------  100
 41    HALBIF   --------2233-5445555-556555545454233-------  1010
 48    LEPSCO   -------------433444345555555444431111-11---  1010
 54    LYCRAM   -------------1-11---1111---1--1--1--------1  1010
 29    DROSTE   -----------------------1---11--------------  1011
 44    LAGCOL   ----1-----------1---5155-42-3144-3-1-------  1011
  2    APOBIF   ----------------------1-11--11111---------1  110
  5    ASTLIN   ----------------------1---11--1--111111----  110
 25    DRAPAL   ----------------------121221112311111111221  110
 45    LEPHYB   ----------------------13121133331-11-------  110
 19    CYAEMP   ------------------------11--11111--111-11--  1110
 28    DROSPA   ---------------------1--111-111-11111111--1  1110
 47    LEPLAX   -----------------------1111-11111111-111111  1110
 32    EMPHIN   ------------------------121-222222222222222  11110
  1    ANIARO   --------------------------------1--------1-  111110
 10    CARALP   ----------------------------1-1--111-111-1-  111110
 11    CELSP.   ------------------------------1-11--1111111  111110
 12    CENCIL   -------------------------------------1-----  111110
 13    CHIRUB   ----------------------------3-3-33333333344  111110
 27    DROARC   ----------------------------1---11--------1  111110
 33    EUPDIS   --------------------------------1----1-----  111110
 36    GLECIR   ----------------------------113222222222332  111110
 40    HALBID   ----------------------------1----1123221332  111110
 42    HEMSUF   ------------------------------1--1111111---  111110
 52    LIPGUN   --------------------------------------1--1-  111110
 63    OREPEC   ----------------------------1-1--1---1111--  111110
 77    RYTGRA   --------------------------------1------1---  111110
 78    THEVEN   ------------------------------1111-1-111--1  111110
 64    PENPUM   ----------------------------1111-11111111-1  111111

                0000000000000000000000000000011111111111111
                0000000000000000000000111111100001111111111
                00000000000111111111110111111    0000000111
                00111111111000111111111 001111    0111111
                  00111111    00000001           0001111
```

Figure 5.1 The two-way table output from the TWINSPAN procedure

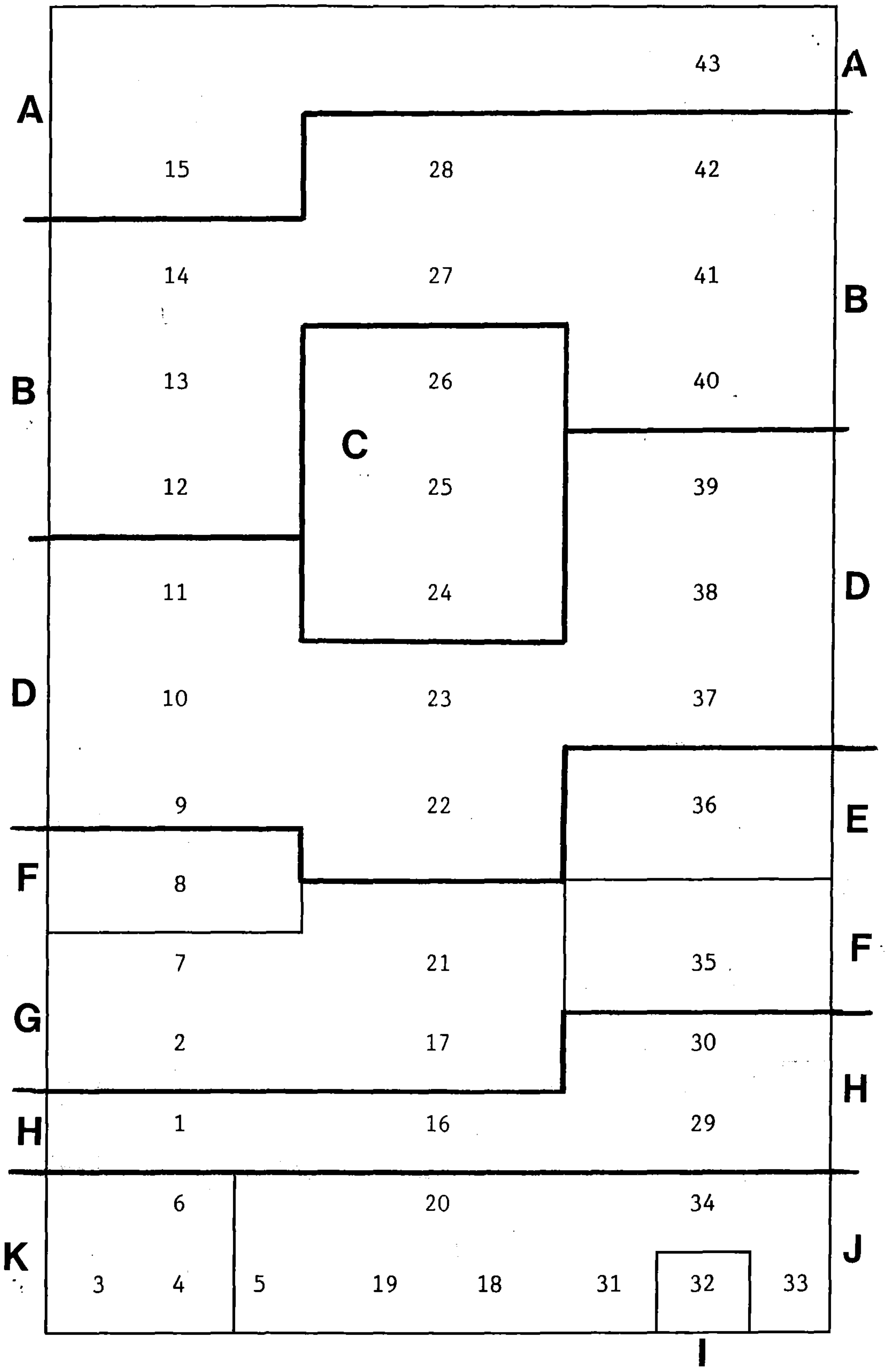
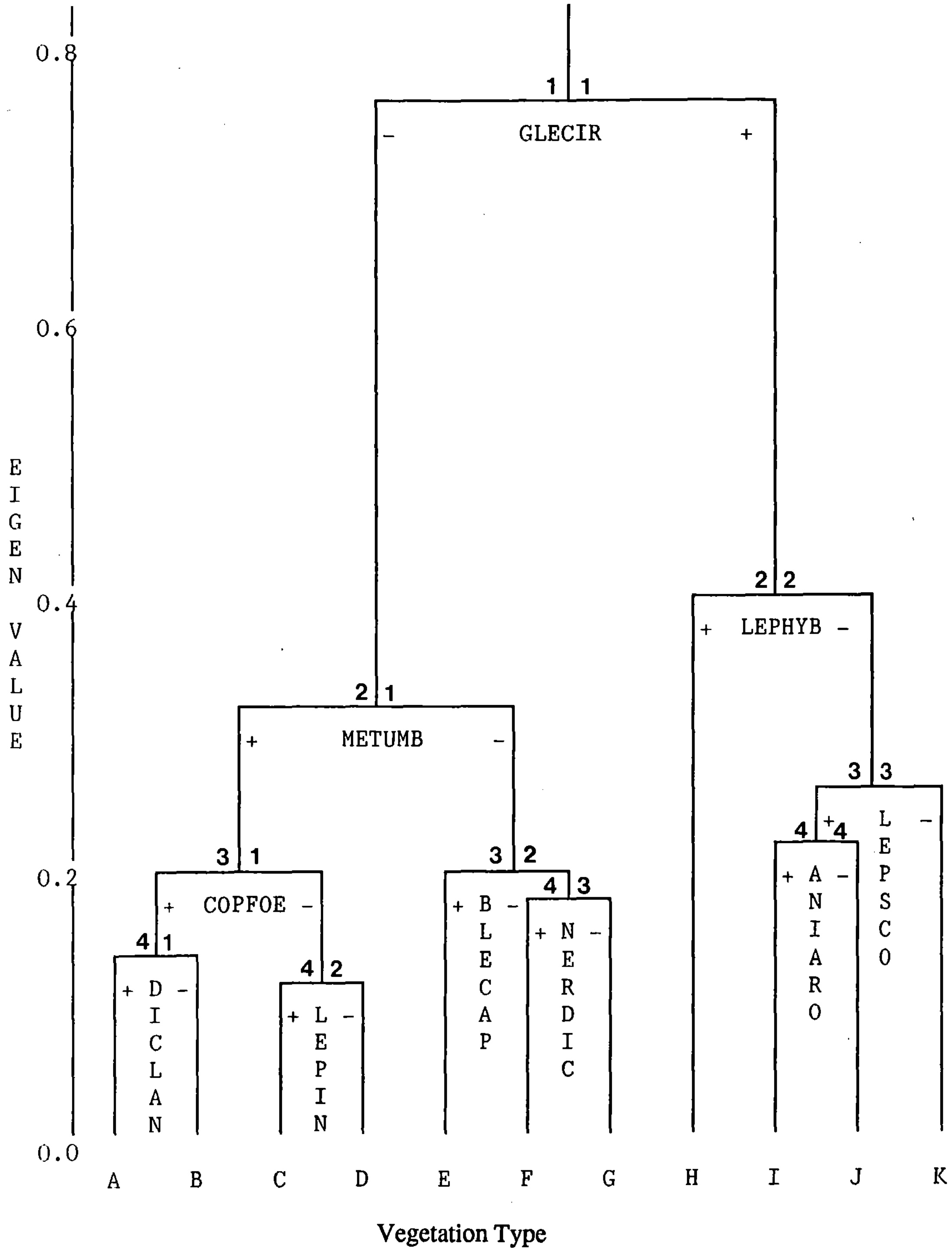


Figure 5.2 Schematic map of the three transects;
Letters indicate indicate plot groups;
red lines are boundaried based on
the dendrogram (Fig. 5.3)

X



Type	Plot numbers	Type	Plot numbers
A	15 43	G	2 7 17 21
B	12 13 14 27 28 40 41 42	H	1 16 29 30
C	24 25 26	I	32
D	9 10 11 22 23 37 38 39	J	5 18 19 20 31 33 34
E	36	K	3 4 6
F	8 35		

NOTE - Eigenvalues are those of the first RA ordination axis of each division.
- indicator species shown at each division

Figure 5.3 Dendrogram drawn from the TWINSPAN output.

The eigen values used were those from the first axis of the reciprocal averaging ordination technique at each dichotomy- the first step in the TWINSPAN procedure. The dendrogram shows the relative importance of each dichotomy to the dichotomy previous to it. For example, the third division created six clusters of plot groupings: A/B and C/D (eigen value of the division- 0.201); E and F/G (eigen value 0.199); K and I/J (eigen value 0.244) (plot group H was created at the second division). However, division 4/split 3, which divides groupings F and G, has an eigen value of 0.195, which is 98% (ie. nearly the same) of the previous dichotomy's (division 3/split 2) eigen value. Hence the division 4/split 3, which divided F and G, can be regarded as relatively unimportant when compared to the previous division (division 3/split 2- E from F/G). A similar approach can be applied to the division 4/split 4 which splits I and J (eigen value 0.223) compared to the previous division (division 3/split 3- K from I/J- eigen value 0.244). Division 4/split 4 has an eigen value approximately 91% of that of division three/split 3 hence could be considered as relatively unimportant. The same can not be said for the division 4/split 1 which divided A and B (eigen value 0.142) in relation to division 3/split 1 (splitting A/B from C/D- eigen value 0.201). Division 4/split 1's eigen value was 71% of division 3/split 1's eigen value hence could be seen as important.

On the basis of these empirical workings, it is proposed that the plot groupings E, F, and G should be considered as one vegetation type, as well as the plot groupings I, J, and K. Hence, the eleven plot groupings resulting from four divisions of the TWINSPAN procedure have been condensed into seven groupings. This is shown on the schematic map of the transects by the red boundary lines.

An interesting feature of the two-way table produced by TWINSPAN (Fig. 5.1) is the collection of numbers inside the columns of species and rows of plots. These numbers are the highest abundance class of every pseudospecies in every plot. The abundance classes are defined by the pseudospecies cut levels, as set out in Section 4.2.1. The resulting pattern is an interaction between the species and plot classification. There is an orderly gradation of species from those that are found predominantly near the top of the transects/ moraine down to those that are found predominantly at the pakihi sites.

The altitudinal/ground surface profile of all of the plots of the first transect is represented in Figure 5.4. All plots except plots 3, 4, and 5 are represented- because these plots all contain pakihi vegetation, these plots can be regarded as 'replicates' of plot 6. The vertical height axis has been exaggerated 4.5 times that of the horizontal distance axis. By stereoscopically viewing aerial photographs of the area (eg. Fig. 2.2) it can be seen that the diagram is an accurate representation of the ground surface topography.

The ground surface profile can be divided into a number of land units. The first, from 0 m to 90 m along the transect, is the older fluvio-glacial outwash plateau. This area is relatively flat (slopes are less than 3^{o}) with little relief. From 90 m onwards along the transect is the younger moraine. This area has a number of distinct surfaces within it. There are three steeply sloping areas: 90 m to 140 m; 270 m to 320 m; and from 360 m to approximately 470 m at the top of the ridge. Between these areas there is one major flat surface- from 140 m to 270 m. The slopes of the steep sections, as measured in the field and from an 'unexaggerated' ground surface profile diagram, range between 15^{o} and 20^{o}. From stereoscopic examinations of aerial photographs it appears that the steep slope from 270 m to 320 m along the transect is a subsidiary ridge leading off the main ridge.

The vegetation boundaries, shown as vertical green lines in Figure 5.4, are mapped from the TWINSPAN output (Figs. 5.1, 5.2, 5.3). Hence the profile diagram provides a 'sideways' view of the vegetation distribution (eg. Fig. 5.2) in relation to the topographical features of the first transect. The vegetation boundaries have been placed half-way between the plots that were classified into different plot groupings. Because of this there may be an error (of up to plus or minus 20 m) in a mapped boundary from where the inferred boundary presumably lies. The plot grouping F of Figure 5.2 is mapped together with plot grouping G, because of the reasons related to the eigen value of the dichotomies, as set out above.

The concept that there are a number of different vegetation types on the slope is reinforced by plotting the basal areas of the major tree species. The plots of transect 1 are presented in Figure 5.5. The graph shows that a tree species' basal area correlates with the abundance a species has in that plot (Fig. 5.1). Some of the minor discrepancies near the baseline are due to the curve fitting procedure used and have no bearing on the overall result. Use of the curve fitting procedure also means that for each plot the absolute basal area of each species may not be reflected.

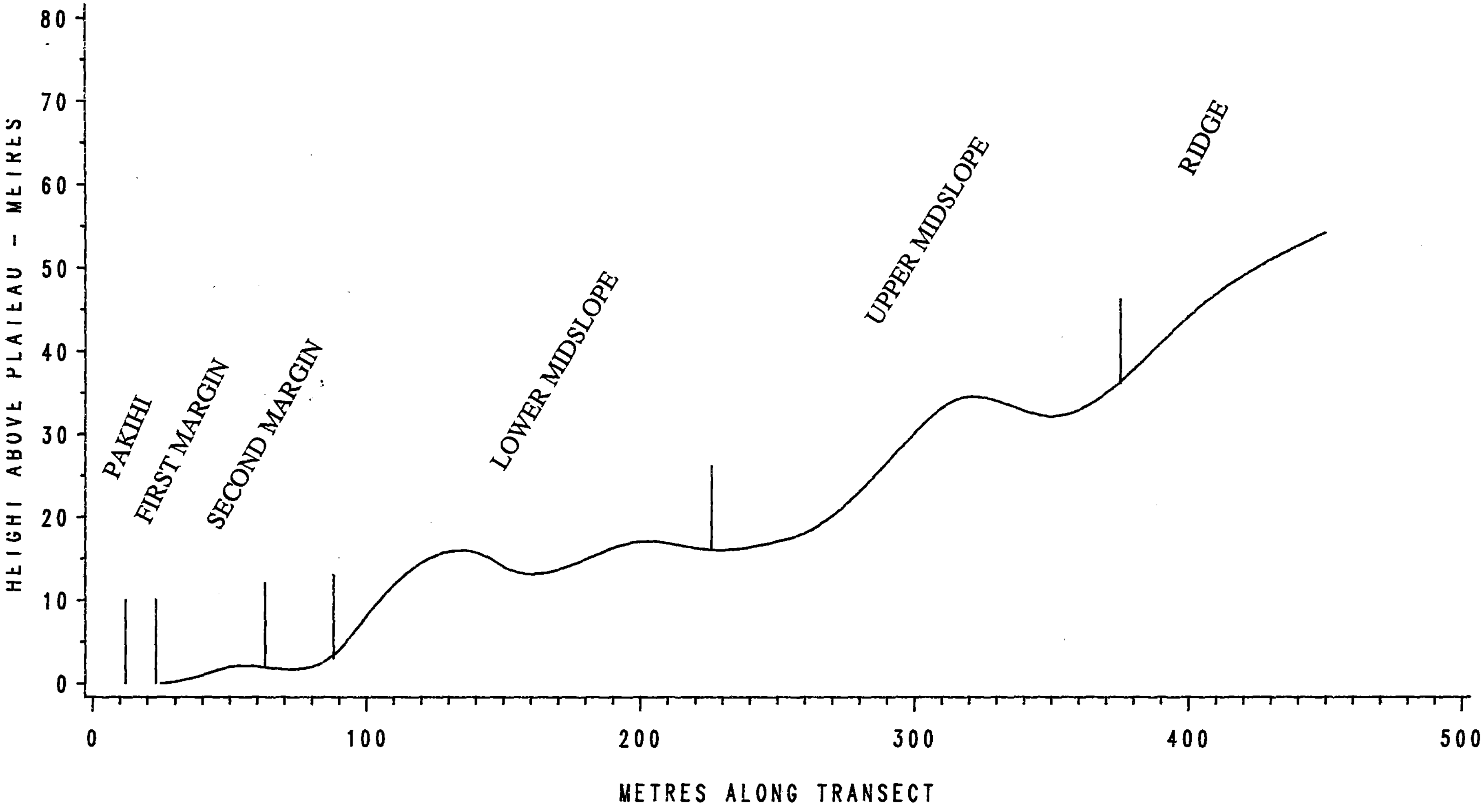


Figure 5.4 Topographical profile of the first transect showing the vegetation boundaries as vertical green lines.

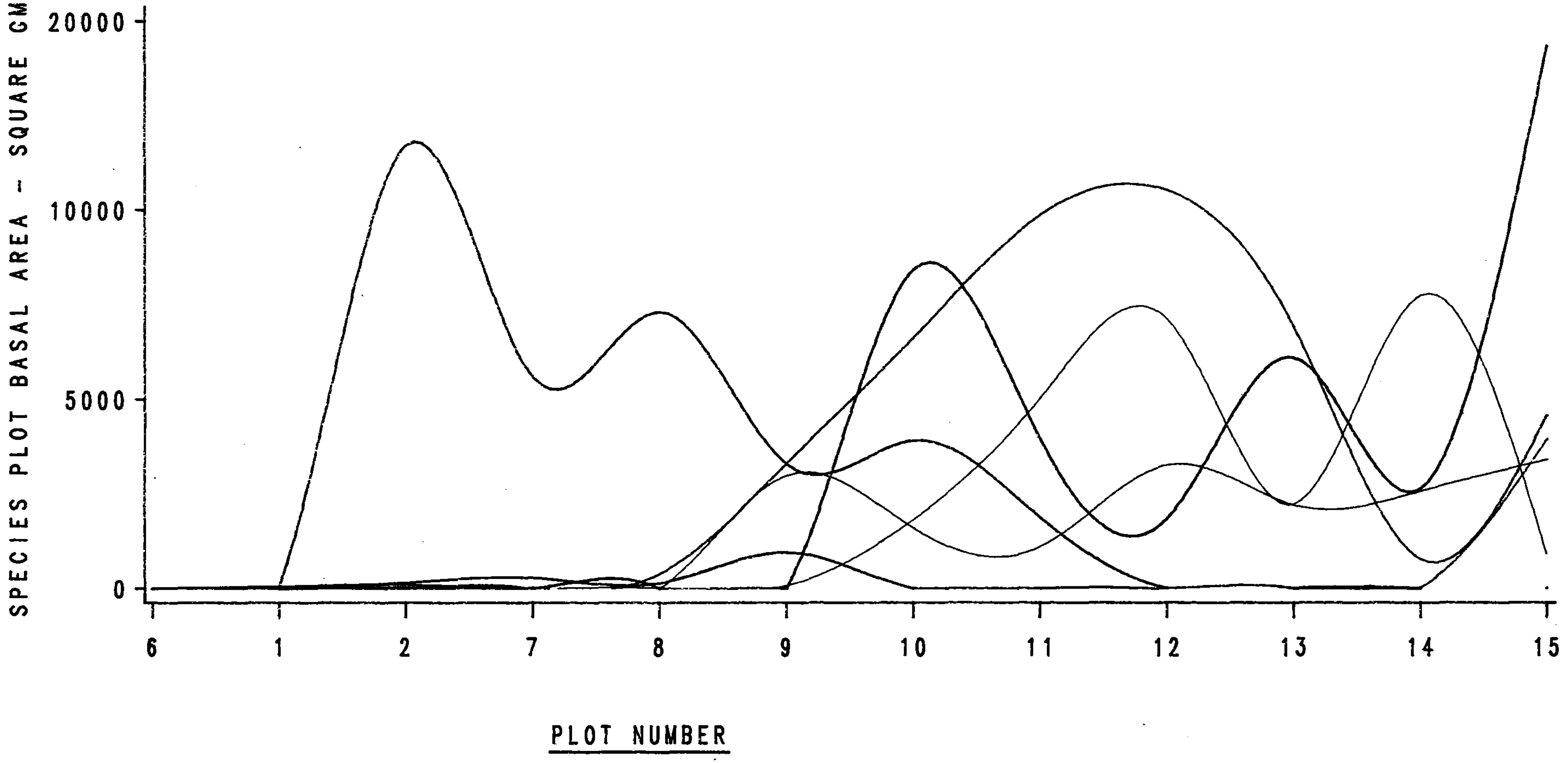


Figure 5.5 Basal areas of the major tree species of the first transect.

Halocarpus biformis had a high basal area in plots 1, 2, 7, and 8- these are the margin plots. The basal area of *Halocarpus biformis* diminished in plots 9, 10 and 11. The species did not occur further up the slope. *Leptospermum scoparium* occurred in plot 1 to a limited extent and had higher basal areas in plots 2, 7, 8, and 9. It did not occur further up the slope.

All other species except *Prumnopitys ferrugineus* occurred as large enough trees to register basal areas from plot 9 upwards. *Podocarpus hallii* had its maximum basal area in plots 10, 11, and 12. The other major emergent trees *Dacrydium cupressinum* and *Metrosideros umbellata* had variable basal areas 'counterphasic' to each other in plots 10 and upward. *Weinmannia racemosa* and *Phyllocladus alpinus* had fairly constant basal areas up the transect form plot 10 upwards, except that the basal area of *Phyllocladus alpinus* decreased in the last three plots. *Prumnopitys ferrugineus* had a high basal area only in the last plot, near the top of the ridge.

5.2 SOILS

5.2.1 DRAINAGE STATUS

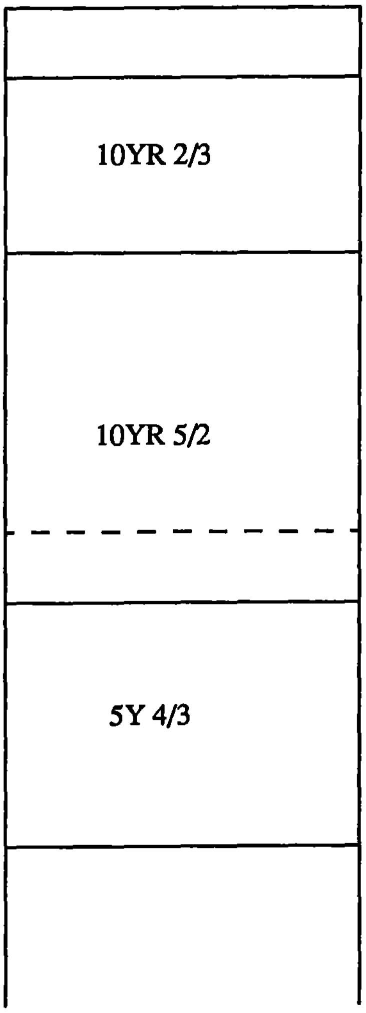
Figures 5.6 to 5.11 are the horizon descriptions of the six soil profiles. The probable parent materials of each profile and drainage status/wetness of each site are also recorded. The most obvious difference between the profiles is the wetness of their surfaces. Differences were associated with the slope of the site where the profile was dug (see Fig. 5.12 for pit/profile positions). The two wettest profiles, 1 and 2, were situated on flat sites at the bottom of the slope. The other lower lying site, profile 3, was on a slight slope relative to profiles 1 and 2 and was drier than these profiles. Of the three other profiles, profiles 5 and 6 were situated on sloping ground (up to 20^{o}) and were therefore quite well drained. Profile 4 was sited at the bottom of a small 'backslope' and had a wetter surface than profiles 5 and 6. Hence, the three wettest sites were found on the flatter ground, while the drier sites were found on slopes.

The way in which the water was contained within the profiles differed. At two of three wetter sites, profiles 2 and 4, the water was contained within the organic/litter horizon. On the other hand, at the other wet site, profile 1, a considerable amount of water was at the surface and flowed in small rivulets. This was due to the tussocky nature of the vegetation. However, the surface horizon was still very wet.

5.2.2 PROFILE MORPHOLOGIES

Landscape position, vegetation, drainage status of the site influenced the soil profile morphologies. The two soils with poor drainage and forest vegetation (profiles 2 and 4) also had the largest organic horizons. These two profiles also had top horizon colours with low Munsell hue values (profile 2- 5YR; profile 4- 7.5YR). Horizon colour was variable both within and between profiles. Only a few trends and generalizations can be made. The two sites at the bottom of the transect, profiles 1 and 2 had a greyish coloured horizon. For all the profiles olive and grey colours tended to increase with depth. In most profiles the colour change with depth was gradual. However, profile 2 had a distinct colour horizonation change. At 35 cm depth there was a sudden change from an organic reddish brown horizon to a silty clay olive grey horizon.

Fig. 5.6 - PROFILE 1



0cm
- litter

5
- brownish black; silt loam
- structureless, non-sticky
- very wet

15
- greyish yellow brown; silt loam
- massive, friable
- olive mottles, weathered stones
- dry

30
- few stones- surrounded by mottles

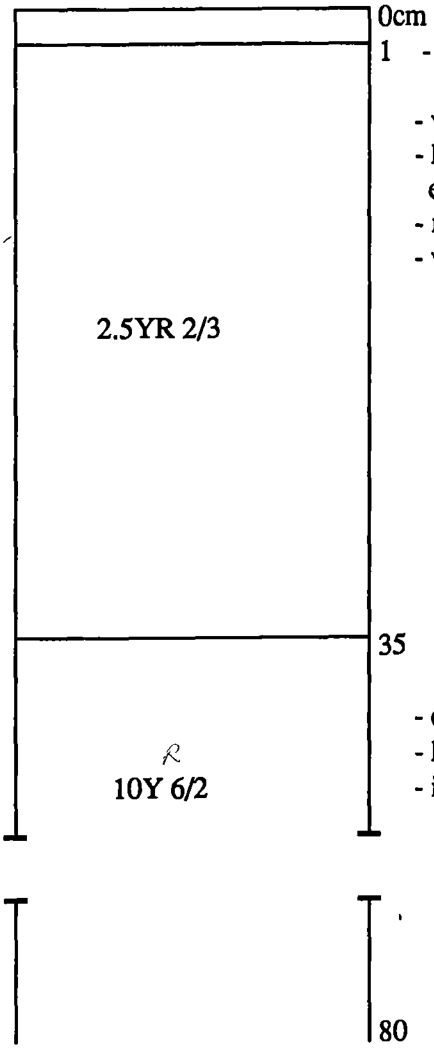
35
- dark olive; gravel with sandy matrix
- abundant stones
- dead roots
- dry

50
- impenetrable parent material

DRAINAGE STATUS/WETNESS: 9

PARENT MATERIAL: Felspathic quartzo-
sandstone

Fig. 5.7 - PROFILE 2



- dense roots

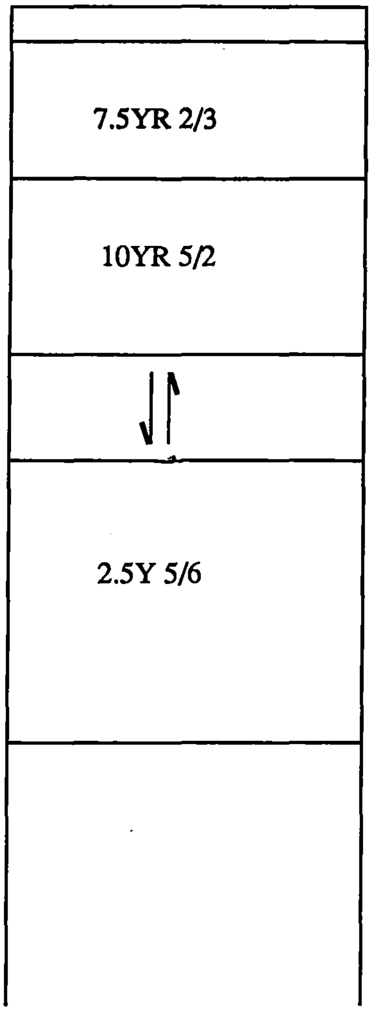
- very dark reddish brown;
- high organic matter content -hard to estimate texture
- rare fine sand particles
- very wet; over saturated; flowing water

- olive grey; silt loam
- heavy massive friable structure
- impermeable layer

DRAINAGE STATUS/WETNESS: 10

PARENT MATERIAL: Mixture of felspathic quartzo-sandstone, metamorphic schistose material, mica, greywacke, argillite, quartz; mostly sandstone material.

Fig. 5.8 - PROFILE 3



0cm
2 - litter

- very dark brown; silt loam
- large amount organic matter present

10 - small amount mineral matter

- greyish yellow brown; silt loam

20

- merging from grey with mottles to next horizon

25 - very common Fe concretions

- yellow brown; silt loam with common ghost parent material
- common reddish brown (2.5YR 4/8) concretions

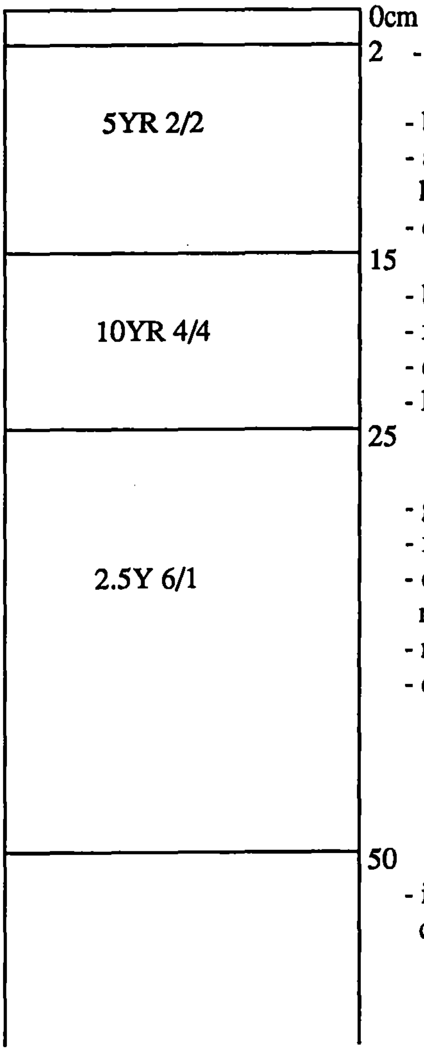
40

- weathered rocks

DRAINAGE STATUS/WETNESS: 6

PARENT MATERIAL: Mostly sandstone material; some argillite.

Fig. 5.9 - **PROFILE 4**



- litter

- brownish black; no mineral texture
- abrupt change down to next horizon
- damp

- brown; silt loam
- friable
- damp
- lots of organic matter, hard to texture

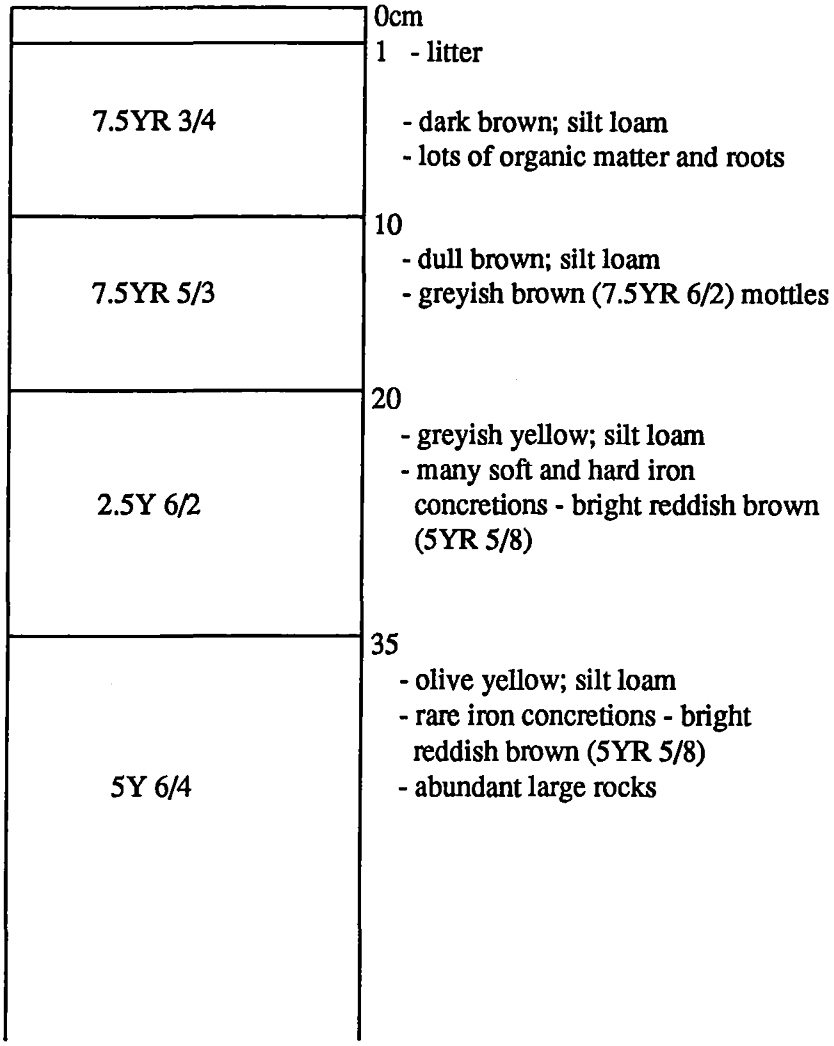
- grey; silt loam
- friable
- common bright brown (7.5 YR 5/8) mottles and iron concretions
- more stones to depth
- dry, but water seeping in from below

- inpenetrable stony horizon coated with a lot of iron

DRAINAGE STATUS/WETNESS: 7

PARENT MATERIAL: Mostly sandstone material, some metamorphosed argillite.

Fig. 5.10 - PROFILE 5



0cm

1 - litter

- dark brown; silt loam
- lots of organic matter and roots

10

- dull brown; silt loam
- greyish brown (7.5YR 6/2) mottles

20

- greyish yellow; silt loam
- many soft and hard iron concretions - bright reddish brown (5YR 5/8)

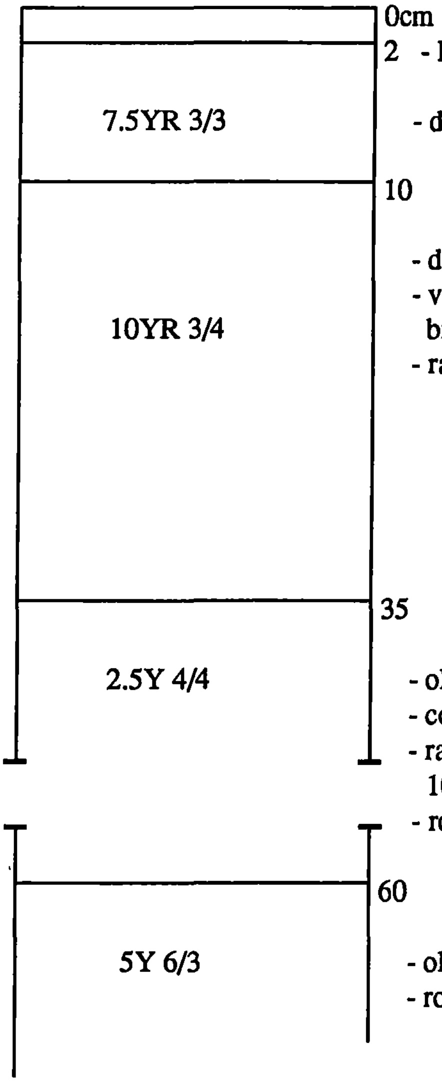
35

- olive yellow; silt loam
- rare iron concretions - bright reddish brown (5YR 5/8)
- abundant large rocks

DRAINAGE STATUS/WETNESS: 5

PARENT MATERIAL: Weathered sandstone, weakly metamorphosed sandstone.

Fig 5.11 - **PROFILE 6**



- litter

- dark brown; silt loam

- dark brown; silt loam
- very rare iron mottles - bright brown (7.5YR 5/6)
- rare gravels

- olive brown; silt loam
- common weathered stones
- rare bright brown mottles (7.5YR 5/6 - 10YR 6/2)
- roots to 60cm

- olive yellow; silty gravel
- rocks and weathering material

DRAINAGE STATUS/WETNESS: 3

PARENT MATERIAL: Micaceous and chlorite schist, some argillite.

In terms of soil texture, no general trends can be discerned. All profiles had organic matter in the surface horizons, of variable depth. Most upper mineral horizons had silt loam textures. In all profiles there was, with depth, more gravels and stones.

The type of gravels and stones and the underlying parent material of each profile was variable. All profiles had some feldspathic quartzo-sandstone, a variety of grades of greywacke and argillite, and metamorphosed, micaceous and chlorite schists. Most of the rock fragments were highly weathered. It may have been possible that there was more sandstone type material at the bottom of the transects (ie. on the plateau) than on the top; at the top of the ridge there appeared to be more schistose material. However, these statements are based on limited sampling.

The types of mottling and concretions within and between the six profiles varied. Mottles, ranging in colour from olive to bright red occurred in all profiles except profile 2. Profile 6 had the least amount of mottling. Iron concretions were noted in profiles 3, 4 and 5. Profile 3 also had a distinct iron pan.

5.2.3 PROFILE CHEMISTRY

The chemical analysis of the profiles is presented in Table 5.2. The pH(H_20) of all the profiles was low at the surface, ranging from pH 3.9 to 4.3. In all profiles pH(H_2O) and pH(KCl) increased with depth. The organic carbon and nitrogen content of all the profiles was highest in all surface organic horizons and decreased markedly with depth. Profiles 2 and 4 had very high organic carbon and nitrogen contents in the horizon immediately below the surface organic horizon.

For most profiles, the oxalate chemistry showed increases in oxalate extractable iron and aluminium with depth. The exceptions to this were profiles 2, 3 and 6. The latter two profiles showed initial increases with depth but in the bottom horizons the amount of oxalate extractable iron decreased.

The exchangeable aluminium values increased with depth for all profiles except profile 3. This profile showed increasing amounts of exchangeable aluminium up to 25 cm depth, then there was a decrease. The acid extractable phosphorus values were higher in the organic horizon than the next horizon for all the profiles except profile 4. In this profile the organic horizon had a slightly lower value. For profiles 1, 3, 5, and 6 there was a decrease in the amount of phosphorus down the profile, but the bottom horizon had a greater amount. This increase was very noticeable in profiles 3 and 6. In profile 2 the bottom of the second horizon was not reached, hence no complete statement can be made as to the depth trends in this profile. In profile 4 there was no increase in the amount of phosphorus in the bottom horizon.

Figure 5.12 shows the position of the soil boundaries (indicated by the vertical red lines) on the altitudinal profile of the transect. Seven soil types were delineated- three on the plateau and four on the moraine. The blue circles indicate the positions of the soil pits which were dug in each of the six vegetation groupings.

TABLE 5.2 - Chemical analyses of the soil profile horizons.

profile	horizon	depth (cm)	pH (H_2O)	pH (KCl)	org C (%)	org N (%)	oxalate		Exch Al	NH$_2$SO$_4$ P (ppm)
							Fe	Al (mg/g)		
1	1	5	-	-	34	0.68	-	-	-	19
	2	15	4.1	3.3	4.1	0.22	0.4	1.6	2.4	10
	3	35	4.4	3.6	1.1	0.06	1.4	1.9	6.6	2
	4	50	4.9	4.0	0.7	0.04	3.9	2.5	7.3	34
2	1	3	-	-	-	-	-	-	-	-
	2	35	3.9	3.0	18	1.03	1.2	3.3	2.6	36
	3	80	4.7	3.8	1.0	0.05	1.9	3.0	9.2	5
3	1	3	-	-	29	0.58	-	-	-	19
	2	10	4.3	3.0	5.7	0.29	0.5	0.0	2.1	11
	3	20	4.1	3.3	2.8	0.16	0.4	1.1	3.0	4
	4	25	4.4	3.6	1.3	0.08	2.4	9.6	10.6	23
	5	40	4.5	3.6	1.0	0.06	3.4	11.0	7.5	17
	6	40+	4.8	3.9	0.6	0.03	4.1	5.2	7.3	194
4	1	2	-	-	36	0.36	-	-	-	52
	2	15	4.0	3.1	28	0.90	0.4	0.5	0.2	62
	3	25	4.2	3.4	3.7	0.20	0.5	1.5	3.7	10
	4	50	4.5	3.6	0.9	0.06	2.0	8.7	5.5	10
5	1	1	-	-	31	0.67	-	-	-	53
	2	10	3.9	3.1	6.3	0.29	0.7	1.0	4.0	22
	3	20	4.1	3.3	3.3	0.17	0.8	1.8	4.9	10
	4	35	4.3	3.5	2.1	0.11	1.7	5.5	7.7	10
	5	35+	4.5	3.8	1.2	0.08	2.5	5.8	6.8	16
6	1	2	-	-	18	0.60	-	-	-	66
	2	10	4.1	3.2	6.7	0.23	1.0	2.6	4.5	27
	3	35	4.3	3.4	3.4	0.17	1.3	3.6	5.4	26
	4	60	4.4	3.6	2.3	0.10	2.5	5.6	5.8	45
	5	60+	5.0	4.6	0.4	0.02	7.3	1.3	8.1	700

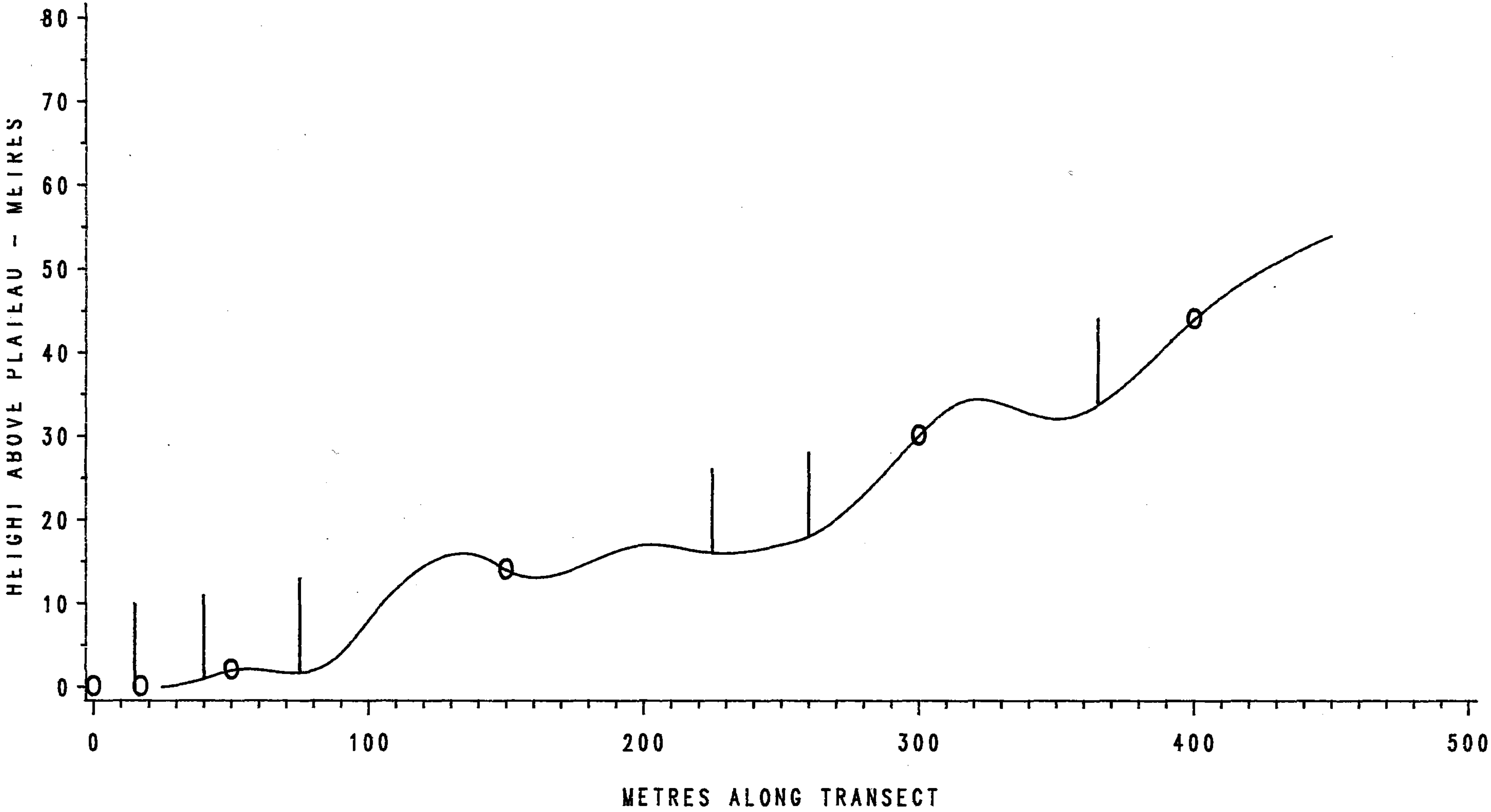


Figure 5.12 Topographical profile of the first transect showing the soil boundaries

6.0 DISCUSSION

6.1 VEGETATION ANALYSIS AND CHARACTERIZATION

The vegetation survey and analysis of the three transects on the Omoeroa Plateau showed that there were a number of different vegetation types along the slope.

Classification of the abundance values for each species in every plot was the main method of establishing the existence of the different vegetation types. The two-way table output from the TWINSPAN procedure (Fig. 5.1) gave the first impression that there was a definite trend in the distribution of the vegetation. Because TWINSPAN is based upon the combination of classification and ordination the diagonal structure of the pseudo-species abundance levels indicates that the vegetation was responding to an environmental gradient.

Drawing the dendrogram from TWINSPAN's two-way table showed the relationships in a graphical manner (Fig. 5.2). The application of the technique of using the eigen value of the initial reciprocal averaging ordination to define the level of the dichotomies (described in Section 5.1) does not appear to be widespread. The only other published occasion found where the method has been used was in a textbook by Causton (1988). Although the methodology or reasoning behind the technique was not adequately explained in the text, it made intuitive sense and hence was used. In all New Zealand papers that were examined in which TWINSPAN was used and a dendrogram constructed (see Section 4.2.1), no account or use was made for the 'explanatory power' (eigen value) of each dichotomy. In some of these papers grouping of the vegetation plots into vegetation types was based on the number of divisions; if the groupings did not 'make sense', the plot groupings of the previous division were used. In other papers, if the plots in two groups did not appear to be different from each other the two groups would be combined through empirical reasoning. It is believed that the method employed in this study is a valid and useful way to decide on whether a dichotomy is significant. Though the reasoning is also empirical, it is so in a mathematical sense. In the dendrogram of the 43 plots of the study, in all cases where all two groups of plots resulting from a division were empirically combined because of the small difference in the eigen value compared to the previous division's eigen value, the combination appeared to be ecologically sound.

The changing composition of the vegetation was also shown by the variation in the basal areas of the major tree species along the slope (Fig. 5.5). However, it must be pointed out that the 'size class distribution' of the trees is an important factor in the basal area value of a species in a plot; a total basal area value can be made up of many small trees or a few large trees. The basal area parameter is probably useful for monitoring purposes in the future, being of a more discrete nature compared to the assessed abundance values.

The vegetation types established and mapped in this study (Fig. 5.2) broadly corresponded to the communities set out by Wardle (1977, 1980, 1982). However, where Wardle (1982) mapped three vegetation types (at a scale of 1:100,000) on the slope incorporating the Omoeroa Plateau and moraine, this study found seven. Hence, this project can be regarded as a refinement of Wardle's survey and description of the vegetation of this one particular landscape unit.

The vegetation types found at the bottom of the slope (types I, J, and K) were floristically similar to pakihi vegetation described by other authors (eg. Wardle, 1977; Rigg, 1962; Burrows et al, 1979). The vegetation type was comparable to the 'K3a' pakihi community of Wardle (1977). In fact, Wardle used the Omoeroa Plateau pakihi vegetation as an illustrative example of 'natural pakihi'. As shown by Table 5.1, the pakihi vegetation had the lowest number of species; no more than 15 species were found in each plot. Pakihi vegetation is generally considered to consist of species which are tolerant of very wet and infertile conditions. Woody vegetation, when it occurred, consisted of stunted *Halocarpus* and *Dracophyllum*.

In this study, the margin or heath/bog forest (types E, F, G, and H) was an important vegetation type because it was found as an intergrade between two very different plant communities- the pakihi and forest vegetation. This vegetation type was similar to communities 'J1a and b' and 'J2a' of Wardle (1977). The heath/bog forest found in this study can be divided into two distinct zones: first margin (type H) and second margin (types E, F, and G) (see Fig. 5.2 and Section 5.1). Both vegetation types contained, as dominant trees, *Halocarpus biformis, Leptospermum scoparium* and to a limited extent *Lagarostrobus colensoi.* The low abundance of *Lagarostrobus colensoi* can be attributed to the altitude of the study site. Wardle (1977) stated that *Lagarostrobus colensoi* is more abundant below approximately 300 metres, with *Halocarpus biformis* more abundant at higher altitudes. The ground vegetation of most plots in both vegetation types contained *Cyathodes juniperina, Lepidothamnus laxifolium, Lepidothamnus intermedium* X *Lepidothamnus laxifolium*, and *Dracophyllum palustre*. However, there were distinct differences between the two vegetation types. The first margin vegetation (ie. immediately next to the pakihi clearing) contained many plant species characteristic of pakihi vegetation, which were not found in the second margin vegetation. Some of these species included *Pentachondra pumila, Thelimytra venosa, Oreobolus pectinatus, Gleichenia circinnata, Chionochloa rubra* and *Carpha alpina*. Conversely, the second margin vegetation contained species that occurred further up the slope but not in the first margin vegetation. These species included *Luziriga parviflora, Libertia pulchella, Hymenophyllum* species, *Elaeocarpus hookerianus, Pseudopanax simplex, Podocarpus hallii, Weinmannia racemosa,* and *Dacrydium cupressinum.* These observations are reinforced by the dendrogram drawn from the TWINSPAN procedure (Fig. 5.3): the first margin vegetation type 'splits off' from the pakihi plots while the second margin vegetation 'splits off' from the lower mid-slope vegetation. Hence it is inferred that the first margin vegetation type is related to the pakihi vegetation and the second margin vegetation is related to the upslope vegetation types. Another interesting feature of the dendrogram is that in splitting the second margin vegetation (vegetation types E, F, and G) from the upslope vegetation types (split 2/1) the TWINSPAN indicator species is *Metrosideros umbellata.* This indicates that southern rata occurs preferentially upslope, and not in the second margin vegetation. This makes ecological sense, *Metrosideros umbellata* preferring the better drained upslope sites.

Further up the slope there were a number of different vegetation types. They are comparable to communities 'B3e' and 'B5a' of Wardle (1977) near the bottom of the slope, and community 'B3a' near the top of the moraine ridge. Of the vegetation types, the tall forest had the most number of species, each plot having between 20 and 30 species. All vegetation types are dominated by either *Dacrydium cupressinum* or *Metrosideros umbellata.* As shown by Figure 5.5 there appeared to be a 'counterphasic' relationship between these two tree species. Where one is dominant, the other is suppressed. Compared to *Dacrydium cupressinum, Metrosideros umbellata* appeared to be found on the relatively drier sites. The canopy of the upslope vegetation was variously composed of *Weinmannia racemosa* and/or *Podocarpus hallii.* The latter had a high basal area in the midslope plots of transect 1, where the ground surface was relatively flat and wet (Figs 5.6 - 5.12). At the top of the ridge *Prumnopitys ferrugineus* became increasingly dominant. This was probably because of the better drainage at the top of the slope.

Another example of TWINSPAN's 'valid' choice of indicator species is in splitting the upper moraine plots (vegetation types A and B) from the lower moraine plots (vegetation types C and D) (split 3/1). The indicator species is *Coprosma foetidisima,* which probably prefers the upper slope sites better.

The vegetation types established in this study may be tentatively related to the phytosociological study of the steepland forests of central Westland by Reif and Allen (1989). These authors classified a number of vegetation types that were found in this study. In this study, the upslope forest on the moraine is comparable to various communities in the *Prumnopitys ferrugineus* community group of Reif and Allen (1989). Specifically, the mid-slope vegetation of the Omoeroa Plateau is similar to the *Dacrydium cupressinum* community/pure subdivision and the *Phyllocladus aspleniifolius subdivision* (pure type). The moraine ridge vegetation appears to be comparable to the *Prumnopitys ferrugineus* - *Coprosma lucida* community/pure subdivision. The margin vegetation of the Omoeroa Plateau appears to be similar to the *Halocarpus biformis* - *Gahnia procera* community. Reif and Allen (1989) recognized two subdivisions in this community- a pure subdivision and an *Empodisma minus* subdivision. The authors commented on the transition from these stunted shrubland communities through to pakihi vegetation and stated that this transition represented a change in a certain set of soil conditions, for instance a decrease in fertility. Reif and Allen thought that these *Halocarpus* communities represented the most advanced successional stage sampled in their study.

In summary, the analysis of the vegetation on the transects has shown that there were a number of different vegetation types on the slope. In some cases the boundary between the vegetation types was very discrete, such as between the pakihi and margin vegetations. Further up the slope the boundaries were more diffuse. However, in both situations, it was possible to detect the floristic relationships between the vegetation types. These will be discussed more fully later (Section 6.4).

6.2 SOIL CHARACTERIZATION

The pedological component of this study was carried out as a cursory examination of the soils of the slope. Definite conclusions could not be drawn because the investigation was not conducted in sufficient depth. The variability of soil necessitates the use of multiple sampling (spatial replication) in order to establish the nature of the soil of an area. Time did not permit this to be carried out.

Investigation of the soil profiles examined along the transect showed that there were differences in the soils under the different vegetation types on the slope. However, trends could only be established for the type of profile morphologies under the vegetation types, not in the profile chemistry. Profiles 1, 3, and 4 appeared to be, as conventionally classified, gley podzols. They generally showed the characteristics of gley podzols, as described for North Westland by Mew and Lee (1981). Profile 3 had a very definite iron pan. Profile 2, which had a very large (80 centimetre) organic horizon overlaying a very pale, massive silt horizon, has been described by other workers in South Westland as a peat or a 'muck' soil (D. Norton pers. comm.). Profiles 5 and 6 could be considered as gleyed/podzolized yellow brown earths (J. Adams, pers. comm.). However, no more definite correlations with other soils will be attempted due to the superficial nature of this study's soil survey.

No distinct trends relating most of the chemical parameters measured and either the age of the surfaces or the landscape position. This was probably because of the extreme age of the site. The chronosequence work carried out by Stevens (1963, 1968), Sowden (1986), and Basher (1986) indicated that under the high leaching environment of the West Coast, most of the chemical changes over time occur during the first 10,000 years of a soil development. Assuming the moraine was approximately 20,000 years of age means that most of the chemical changes would already have occurred in the soils of both surfaces. Any further aging of the surfaces would not make any appreciable differences in the soil chemistry. The only characteristic which might still be in the process of change is the amount of acid extractable phosphorus in the profile. This parameter, together with the other fractions of phosphorus in a soil profile, was considered by Walker and Syers (1976) to be a potential method of aging soils up to 25,000 years of age. Mew and Lee (1981) discussed the levels of acid extractable phosphorus in the West coast type locality wet soils in relation to the Walker and Syers (1976) model but noted that the inferences were largely conjectural. The acid extractable phosphorus values for the profiles in the study do not show any real definite trends, in terms of suspected age of the surface or the depth of the horizon. The values are comparable to the values obtained by Mew and Lee (1981) for other wet soils of Westland. However, the soil at the top of the moraine ridge (profile 6) had a very high level of acid extractable phosphorus, particularly in the bottom horizon which may be an indication of its relative youthfulness. The values for the other profiles, where they are unusually high, such as profile 3, may be a reflection of colluvial deposition of younger till from the moraine. Profiles 4 and 5 did not have high levels of acid extractable phosphorus because it is probable that the parent material was not sampled.

The only other chemical parameter that showed any obvious trend with site location was the amounts of organic matter in the Ah horizons of the profiles. The amount of organic carbon and nitrogen in these horizons seemed to be related to the wetness of the site and the nature of the vegetation. Profiles 2 and 4 had two of the wettest surfaces and they also had the highest organic matter in their surface horizons. The two profiles at the bottom of the slope, though both being very wet, had different amounts of organic matter. Profile 2, with the heath forest vegetation, had a lot more organic matter (and a much larger organic layer) than the soil under the pakihi vegetation.

With regards to the soil profile morphologies, there were trends and differences which could be attributed to the landscape position of the sites. All the sites were very wet but there were marked differences in the relative wetness of each site. The two soil profiles at the bottom of the slope were the wettest. Further up the slope, profile 4 was also wet, being sited at relatively flat landscape position. Profile 6 was the driest, being situated on a slope of approximately 15^{o}. As mentioned above, the wetness of the site and vegetation was reflected in the depth of the Ah horizon.

The two profiles at the bottom of the slope; profiles 1 and 2, were the only sites at which a massive, silty, pale horizon was found. This horizon may be derived from loess deposition during the long period of time that the soil has had to develop. All other profiles further up the slope had iron concretions and mottling. This indicates periodic oxidizing conditions. The two bottom profiles did not show evidence of mottling reflecting the more intense waterlogging conditions at these sites.

Profile 3 was of interest due to the fact that although it occurred at the bottom of the slope, it was relatively dry compared to profiles 1 and 2. Though it did have a greyish silty horizon, it also contained, further down the profile, a hard iron pan. The site was on a small rise up from the plateau, which might explain the observed conditions.

Hence, notwithstanding the cursory nature of the soil survey part of this study, it is possible that the water characteristics, rather than the chemistry of the soils are more important in influencing the distribution of vegetation on the slope.

6.3 PLATEAU SURFACES

The vegetation of any area is influenced by a number of factors which are directly related to the nature of the land surface on which it grows. These include the age and topography of the surface. The former is associated with the successional development of the vegetation; the latter determines the hydrological characteristics of the site. It is therefore important to establish the temporal and spatial relationships of the surfaces that make up the slope. The assumption that the slope is made up of at least two distinct surfaces- the plateau floor and the surrounding moraine, is based on aerial photographs (eg. Fig. 2.2), the altitudinal profile of the first transect (eg. Fig. 5.4), the available geological information and the vegetation/soil changes along the transects. The exact position of the boundary between the plateau proper and the moraine is difficult to establish without intensive geomorphological investigations. However, using the available information and data gathered in this study, it is possible to position the temporal and spatial boundary between the two surfaces.

The geological map of Warren (1967) shows, albeit at a small scale, that there are at least two surfaces of different ages in the area where the three transects were placed. These surfaces were laid down during two different stadials of the Otira Glaciation. Establishing the glacial chronology of the Omoeroa Plateau area has been problematic and only tentative correlations with the chronologies of North Westland can be made. As set out in Section 3.1, the Plateau floor could be correlated to the Loopline Formation in North Westland, laid down 50,000 to 70,000 years B.P. The surrounding moraines may therefore be correlated to the Larrikins formation of North Westland, laid down 17,000 to 25,000 years B.P.

Utilizing both the altitudinal profile of transect 1 (eg. Fig. 5.4) and the aerial photograph (Fig. 2.2), it is proposed that the boundary between the plateau and the moraine lies between 50 metres and 90 metres along the transects. The boundary is believed to be in this area because of the relatively sudden rise of the land surface of transect 1. Use of a stereoscope to examine aerial photographs of the area confirms this. The presumption can be backed up by both the soil survey carried out (Fig. 5.12) and the vegetation boundaries established (Fig. 5.4). The two soil types at the bottom of transect 1 (ie. from 0 m to 50 m) differed from the rest of the soil types further up the slope by having a horizon consisting of a massive, greyish, silty material. This may be a result of loess deposition over long periods of time. This would be expected if the plateau had been laid down up to 60,000 years B.P.

Compared to utilizing the soil, using changes in the vegetation (Figs. 5.2 and 5.4), to demarcate the boundary between the plateau and the moraine is more problematic. Due in part to the manner in which the survey was carried out, the vegetation boundaries have an error of up to 20 m in either direction in their position. The dynamic nature of vegetation also makes basing boundary positioning on this indicator less robust than when basing the decision on a less dynamic entity such as landscape and/or soil analysis. The dynamic nature of vegetation is due to niche and demographic differentiation within plant populations, disturbances imparted upon it by the environment, and its plastic response to these disturbances. However, despite these factors it is readily apparent that there is a definite vegetation change at about 90 m along transect 1- from the vegetation type dominated by *Halocarpus biformis* to that dominated by species such as *Dacrydium cupressinum, Metrosideros umbellata, Podocarpus hallii* and *Weinmannia racemosa* (Figs. 5.2 and 5.5). Again, using the aerial photographs and a stereoscope, this distinct change in the vegetation can be confirmed. This change in vegetation types also occurs on the other two transects.

6.4 FACTORS INFLUENCING VEGETATION DISTRIBUTION

From the presented above, it is apparent that the slope contains a number of different vegetation types. In addition, examination of Figure 2.3 shows a major change in the type of vegetation on the slope, in addition to the presence of pakihi vegetation on the Plateau floor. This section of the discussion puts forward a scenario which may explain the observed vegetation distribution.

In determining and hypothesizing which factors may have influenced the distribution of vegetation on the slope two approaches can be considered. Firstly, ideas that consider disturbance factors and vegetative processes such as succession can be utilized to account for the observed vegetation trends. This concept is associated with the second approach which considers that the long term landscape evolution of the Omoeroa Plateau has influenced the vegetation differentiation seen today on the slope.

Disturbance factors are an important mechanism in the development of the pakihi vegetation type found on the Plateau. Pakihis are conventionally thought to have formed as a result of physical degradation of the soil leading to wet soil conditions (see Section 3.3.3). However, in the case of some of the sites examined in this study, poor drainage might not have been the dominant factor of pakihi formation, as a number of the pakihi sites were on relatively steep slopes (up to 10^{o}). Other pakihi sites were of a circular nature, with no obvious drainage gradation in the surrounding vegetation. It is hypothesized that fire has been a major factor in the formation of pakihi clearings on the Omoeroa Plateau. This idea is based on the evidence of burning, both contemporary and historic, found at all pakihi sites. A number of the pakihi sites contained tree stumps which had been recently burnt, as evidenced by the presence of intact charcoal on the remaining trunks. These fires, though of a contemporary nature, can not be attributed with any certainty to human activity, as the area is not visited often. At the sites where intact charred stumps were found there occurred many juveniles of *Leptospermum scoparium*. This species is often associated with fire, being one of the first species to colonise recently burnt sites.

Circumstantial evidence was also found for ancient fires. All pakihi sites examined had buried wood within the soil profile, at approximately 15 to 25 cm depth. No evidence of charcoal was found on or around these pieces of wood. This is not unexpected, as in such a high leaching environment charcoal would not be expected to stay intact for too long. However, it is conceivable that fire was a factor in creating the clearings. The vegetation of the heath forest with its many resinous trees is very flammable. The pakihi vegetation, which has a lot of dead material in it, and burnable plant material, particularly *Chionochloa rubra, Empodisma minor* and *Gleichenia circinnata,* is also very burnable when dry. Even a few days without rain is enough to dry out the upper detritus layer. Norton (1989) stated that fast moving southerly fronts bring little rain but frequently have lightning associated with them. Hence it is believed that the conditions conducive to the initiation of natural fires commonly occur on the Omoeroa Plateau.

Fires have been, and are, important in the formation of pakihi type vegetation. Fire would destroy nearly all the existing vegetation and organic matter, making the regeneration of the forest very difficult. Regeneration through a *Leptospermum scoparium* scrub to the heath forest would take a considerable time. In addition, the vegetation would be prone to more fires, which would maintain the pakihi type vegetation.

In comparing the species composition of the pakihis of the Omoeroa Plateau examined in this study, which are inferred to have a burning history, there are important differences with the species cited by Wardle (1977) for fire induced pakihis. Species stated by Wardle to occur in burnt pakihis but not found in this study include *Baumea teretifolia, B. tenax, Halorogis micrantha, Pteridium aquilinum, Nertera scapanioides, Dianella nigra, Lepidosperma australe, Nothodanthonia gracilis, Schizaea fistuloa,* and *Urticularia novae-zelandiae.* Species found in the Omoeroa Plateau pakihis and mentioned by Wardle include *Gleichenia circinnata, Empodisma minus, Lycopodium ramulosum, Drosera binata, D. spathulata, Celmisia graminifolia, Gahnia rigida, Pterostylis venosa, Centrolepis ciliata,* and *Bulbinella modesta.* The differences noted may be due to the relatively high altitude of the Omoeroa Plateau, the local nature of some of the species cited by Wardle, or the limited geographic scope of the present study. In addition, the sites examined by Wardle were probably initiated by humans, and hence the species list would reflect this human influence.

The process of plant succession is also important in determining the types of vegetation found on the Plateau. It is possible that the first margin vegetation type is successional and occurred after a fire in the pakihi vegetation. The fire would have occurred in the pakihi vegetation and penetrated some distance into the surrounding heath forest. This idea is supported by the occurrence of the large number of small *Leptospermum scoparium* trees found in the margin, which is usually about 10 to 20 metres in width. The presence of many pakihi species in the first margin vegetation reinforces this idea. In addition, many stumps and pieces of wood (up to 30 centimetres in diameter) were found in the organic horizon of the first margin vegetation.

These were found at depths of up to 80 centimetres. This is an indication of a history of forest ? destruction and regeneration.

The relationship between heath forest and pakihi burning has also been noted by Wardle (1977). He stated that fire has modified pakihi in many places in and around Westland National Park and extended it over areas previously occupied by heath-scrub, heath-forest, rimu forest, and rimu/kamahi-quintinia forest. After a single fire, Wardle thought that the woody species may regenerate quite rapidly, but pakihi vegetation becomes entrenched after repeated burnings. If the pakihi is left unburnt (after one burning), Wardle stated that the manuka increased until it forms a dense thicket; this suppresses the pakihi species and acts as a nurse to tree seedlings, especially Hall's totara, celery pine, rimu, silver pine (and presumably at higher altitudes pink pine), and kamahi.

The importance of fire in the development of pakihi and heath forest was also noted by Mark and Smith (1975). The authors commented that the relatively sharp boundaries between the silver pine and manuka woodlands and the open and closed manuka stands along the margin of the pakihi in their study have resulted from fires which penetrated to various extents. They stated that the prevailing moisture conditions would determine the extent of the fires. In the case of this pakihi/heath forest the fires were directly attributable to humans; where the possible influence of humans was less, they stated that margins were less abrupt. Mark and Smith also found buried wood (up to 3 m depth) within 20 m of the pakihi - heath forest boundary; this they cited as evidence as that the margin had been subjected to disturbances prior to European settlement.

An interesting phenomenon was observed in the margin vegetation regarding *Halocarpus biformis*. This concerned the occurrence of adventitious root shoots in this species. Adventitious root shoots are relatively rare in coniferous species, the only New Zealand report found being by Moar (1955) for *Lagarostrobus colensoi*. In the present study, in numerous instances, clumps of even sized *Halocarpus biformis* were found. These saplings were nearly always joined together underground. They were up to 2 metres away from a parent tree. Moar (1955) stated that he found the incidence of adventitious shoots was higher at sites where disturbance, such as logging or fire, had occurred. Moar considered the adventitious roots of *Lagarostrobus colensoi* to be of an accessory nature, for the buds that occurred on the lateral roots did not form as a result of damage to the main stem and there was no evidence that their formation was due to root injury. Moar noted that because the shoots of *Lagarostrobus colensoi* developed in clumps around healthy plants, that there must have been localized factors stimulating the adventitious shoot growth. In the case of the present study, the occurrence of adventitious shoots may be a response to fire. They are therefore important in the possible successional development of the heath forest from the pakihi vegetation.

In terms of the landscape evolution of the Omoeroa Plateau, what factors have affected the distribution of the different vegetation types on the slope under study? Based on the data collected and the general information available on the plant species and geology of the area, a hypothesis can be put forward which may explain the observed vegetation trends. A number of assumptions need to be made, especially in quantifying the glacial chronology of the area. These assumptions are based on tentative correlations with the glacial chronology of North Westland, not on 'hard evidence' (see Section 3.1).

Based on the assumption that the Omoeroa Plateau originated during that stadial of the Otira Glaciation which resulted in the Larrikins Formation in North Westland (Section 3.1), it can be envisaged that the bottom of the slope was laid down about 60,000 years B.P. as a fluvio-glacial outwash surface. Concurrent with the formation of this surface was the initiation of primary plant succession. The plant communities that developed during this succession would probably have been similar to the communities that are thought to have developed on the successional surfaces of the Franz Josef/Waiho Valley, as outlined by Stevens (1968) and Wardle (1980). The successional sequence may have been modified to some extent by prevailing climatic conditions after the interstadial. However, by about 40,000 years B.P. (ie. 20,000 years of vegetation development on the outwash surface) it is probable that the plateau floor had a vegetation similar to the 'terrace rimu forest' of South Westland today ie. *Dacrydium cupressinum* emergents with a canopy of *Weinmannia racemosa* and *Quintinia acutifolia.*

The 'rimu terrace' type of forest might have been the vegetation type of the plateau floor for many thousands of years. However, it may be that the chemical and physical depauperation of the soil led to some degree of forest decline. This idea has been put forward by Stevens (1968) and Wardle (1979, 1980). Hence it may be possible that by about 25,000 years B.P. (ie. 35,000 years of soil and vegetation development) the vegetation of the plateau floor was of a heath/bog forest or at least a stunted rimu/quintinia/kamahi forest. In any case, whether or not any forest decline took place, approximately 25,000 years B.P. there would have been a major disturbance of the vegetation, in the form of the last major stadial of the Otira Glaciation.

It has been estimated that during the last major stadial of the Otira Glaciation there was a drop of $5^{O}C$ in average annual temperature (Willet, 1952). It is also probable that the annual rainfall decreased. These two environmental changes in themselves would have had a drastic effect on the vegetation of an area. It is most probable that any tall forest (eg. such as the 'terrace rimu' forest) would have developed into vegetation types better adapted to these new environmental conditions. Stunted heath forest as is found today on the Omoeroa Plateau, or tussock grassland might have been such vegetation types.

Another factor that may have accelerated any forest decline on the Omoeroa Plateau during the last stadial of the Otira Glaciation was the probable presence of a periglacial zone. This zone of colder air would have altered the environment immediately surrounding the glacier which flowed down the Omoeroa Valley. This periglacial environment would have had a marked effect on the plants of the Omoeroa Plateau through a further decrease in the air and soil temperatures. This would have led to the development of a wet heath or grassland vegetation. This idea concurs with that put forward by Wardle (1979). He believed that at the height of the Valley advance (ie. that which resulted in the deposition of the moraine) ice covered up to 70 percent of the Westland National Park area. Most of the rest was periglacial and covered by a continuous vegetation which at its tallest would have been scrub of subalpine character.

With the deposition of the moraines alongside the Omoeroa Plateau, primary plant succession would have been initiated on these new surfaces. What is seen today is the result of approximately 20,000 years of primary succession on this moraine. Over time, the communities that would have been found on the moraine, would have been those set out by Wardle (1980).

On the plateau during the last 20,000 years there would have been a maintenance of the heath forest together with the development of the pakihi vegetation through the action of fires, as outlined above. The heath forest may have developed on the plateau during this time if the vegetation of the plateau consisted of a grassland/shrubland type vegetation during the last stadial of the Otira Glaciation.

During the 20,000 years that the moraine has existed, a variety of geomorphic slope processes, such as erosion and deposition, would have taken place on it. This would have resulted in new surfaces on the slope, including colluvial deposits on the plateau, initiating secondary succession. In addition, disturbances, such as windthrow, would have affected the composition of the forest.

The vegetation types resulting from both the primary and secondary successions that have taken place on the moraine slope would have been influenced to a large extent by the vegetation that was already in place at the bottom of the slope. Propagules from the species growing on the outwash surface would have been a ready source of new plant material for the plant communities of the newly exposed surfaces. This is shown by the number of species shared by the vegetation types growing near the boundary between the two surfaces.

Palynological evidence from North Westland provides some support to the scenario outlined above. Again, as in making extrapolations from the North Westland glacial chronology work, caution must used in making the correlations with South Westland. Moar and Suggate (1973) considered that pollen data from near Hokitika indicated that the interstadial between the $K2_1$ and $K2_2$ glacial advances of the Otira Glaciation was temperate enough to allow the establishment of *Dacrydium cupressinum* and *Nothofagus* forest in North Westland. They dated the interstadial from some time before 30,000 years B.P to about 25,000 years B.P. This would fit in with the development of a 'terrace rimu' type forest on the plateau surface during this interstadial. Near Westport, the work of Moar and Suggate (1979) showed that grassland was dominant at this site from about 26,000 years B.P until about 12,000 years B.P. They inferred from this and other late Otiran sites that a grassland phase lasting thousands of years occurred at this time in many parts of the central and North of the South Island. This idea agrees with the proposed scenario of heath or grassland vegetation on the plateau while the Omoeroa Valley was glaciated.

Hence the main idea of the proposed hypothesis is that the difference in the age of the two surfaces is the dominant factor in differentiating the vegetation types that are seen today. It must be emphasized that although the scenario described above incorporated tentative dates to the glacial events relevant to the study's landscape, the absolute chronology of the events is not important to the main ideas of the hypothesis. What is important is that the surfaces were deposited during different stadials of the Otira Glaciation. The environmental perturbations that occurred during the glacial episode that deposited the moraines were severe enough to lead to the development of a stunted heath vegetation type. Successional development from this vegetation type led to the present plateau heath forest. Another important consequence of the time factor is that the longer time of existence also means that the vegetation would have had a longer time to develop, and be influenced by disturbances. The time factor would also have influenced the development of the soils, leading to differentiation along the slope, especially in their physical characteristics.

The changes in the drainage status of the surfaces along the slope would have influenced the vegetation through the development of the Plateau landscape. The slope was formed through the laying down of the moraine. Though the original plateau would have been very wet, the moraine would have served as a catchment, channelling run-off down onto the plateau. Incorporating these conditions into the scenario put forward above, means that with the deposition of the moraine, a heath type vegetation grew on a very waterlogged plateau surface. These wet conditions would have maintained the heath vegetation and 'driven' succession to a vegetation type tolerant of these conditions. The moraine on the other hand, composed of a relatively porous parent material and being a slope, would have supported the succession of vegetation types as found in the Franz Josef Valley and described by Wardle (1980).

An alternative hypothesis might be put forward to explain the distribution of the vegetation on the slope. This hypothesis considers the idea that change in the drainage status along the slope is the most important factor that influences the vegetation. To be valid this hypothesis would also consider that there was no difference in the ages of the two surfaces or that the difference in age was immaterial. This could mean that the two surfaces were deposited at approximately the same time. The plateau floor would then be a product of colluvial and alluvial erosion from the moraine. However, in many other sites in South Westland the rimu type forest found further up the slope is found on flat surfaces as poorly drained and wet as the plateau. Hence, if the surfaces were of a similar age and drainage status was the most important, why is the vegetation on the plateau not similar to that upslope ? It must be stressed that though it is proposed that drainage is not the dominant influence in determining the vegetation of the slope, this factor has influenced and is influencing the vegetation simultaneously with the age factor.

It could be proposed that the microclimatic factor of cold air drainage may influence the distribution of the vegetation on the slope. However, it is believed that the difference in height between the top of the moraine and the plateau floor is insufficient to create the necessary temperature differential for this phenomenon to occur. If this assumption were proved wrong, then the microclimatic effects of the cold air drainage would also be a factor in the development and maintenance of the heath and pakihi vegetation at the bottom of the slope.

In summary, the hypothesis put forward is that the major factor influencing the distribution of the vegetation on the slope is the difference in the ages of the two surfaces. The stadial of the Otira Glaciation which deposited the moraine was a major factor in the development of a heath or grassland/shrubland vegetation on the plateau. The primary effect of this stadial was to impose a climatic disturbance, in the form of decreased temperatures, on the existing vegetation. The vegetation would then have changed into a type more tolerant of these conditions ie. a stunted heath forest or tussock grassland. The heath forest which is found on the plateau floor today is a result of either development from a grassland vegetation since the end of the Otira Glaciation, or it has been maintained throughout this time period. A major factor in maintaining the vegetation types on the plateau would have been and still is the changes in the drainage status of the slope. The vegetation types found on the moraine are a product of succession over the time that this landform has been in existence. The successional pathways would have been altered by geomorphic processes on the slope. The occurrence of natural fires has been a major factor in the development of the pakihi vegetation and is still important today in maintaining this vegetation type. The heath forest is probably capable of re-establishing in the pakihi clearings, but this is a slow process due to the chemical and physical infertility of the soil. In addition, the occurrence of fires would set back this succession.

Though it is proposed that the main factor influencing the vegetation on the slope is the relative ages of the surfaces, it must be remembered that all the other environmental factors have been and are superimposed on this dominant influence. The combined influence of the ages of the surfaces, drainage, fires and other abiotic environmental factors interact with the biotic environment to provide a framework through which plant succession proceeds to produce the observed vegetation trends. The proposed successional vegetation types outlined in the scenario are a result of the inherent, ubiquitous factor of time interacting with environmental factors existing throughout the history of the slope's development. The intensity of the various factor's influences would differ through time. For instance, the climate has changed over the history of the slope's existence, as has the drainage status. This has resulted in a complex series of vegetation responses over time.

6.5 RELEVANCE OF THE STUDY

The study described has a number of implications which are relevant to the understanding of the plant communities of the South Westland piedmont. Firstly, it has shown the floristic relationships between the vegetation types growing on two of the oldest surfaces of the South Westland piedmont. Secondly, the study has provided an insight into the successional development of the vegetation types of the fluvio-glacial surfaces deposited during the penultimate stadial of the Otira Glaciation. These vegetation types include heath forest and pakihi. The importance of the climatic disturbance during the last major stadial in the development of these vegetation types has been stressed. In addition, the importance of natural fires in the development of pakihi vegetation has been emphasized.

Of a more general nature, the study has highlighted the importance of having a full understanding of all the potential environmental factors that may influence the development of vegetation. These factors include the geological, geomorphological, pedological and climatic history and processes of an area. In addition, a knowledge of the autecological responses of the plants present at a site and their interactions with each other is needed. If this full complement of influences, processes and plant reactions is known with a certain degree of confidence, pausible hypotheses regarding the development of vegetation types at a site can be generated. An inadequate knowledge of any of the factors outlined may mean that any hypotheses generated are, at the most, tentative. This study was hampered in that there is an incomplete knowledge of the glacial chronology/stratigraphy of the area, the nature of the soils are poorly understood and there is almost no information on the autecology of the plant species found on the South Westland piedmont.

A number of factors relevant to this study meant that some problems and constraints were faced. There was the need to study vegetation that had not been altered by human activity. This was to ensure that any differences that were observed in the vegetation could be attributed to natural causes. The site chosen, in Westland National Park, was considered by a number of sources to be the most northerly old fluvio-glacial surface not logged or burnt by humans. Nearly all sites of a similar nature in North Westland could not be guaranteed to have been been unaffected by humans. This created some problems. Firstly, the actual travelling time from Lincoln College was considerable, and secondly, the access to the site itself was by foot only. This limited the overall scope and extent of the study.

6.6 FURTHER RESEARCH

In the course of completing the project on the Omoeroa Plateau, a number of deficiencies in the available information about the South Westland piedmont's landforms and vegetation were identified.

1. there is a need for a detailed investigation of the chronology and stratigraphy of the glacial landforms of the South Westland piedmont.

2. the distribution and characteristics of soils on the piedmont needs to be studied. Correlations with landform need to be made, incorporating catenary sequences. In addition the short range variation due to geomorphic processes and windthrow needs investigating.

3. once more information on the landforms and soils has been gathered, canonical ordination techniques could be applied to the vegetation data in order to ascertain which environmental factors are important in influencing the distribution. For example, it is envisaged that a canonical ordination constrained to the ages of the surface and drainage status would be a useful exercise to assess which of these factors is more important in determining the nature of the vegetation on the slope. It would hopefully reinforce the conclusions of this study that age was more important - a preliminary attempt to use this method on the data of the first transect did find that age was more important.

3. studies need to be conducted on the autecology of the plant species of the area. This is also true for much of New Zealand's flora. Knowledge of the responses of species to environmental influences would aid interpretation of observed vegetation distributions. Important studies would include nutrient, light, and temperature responses, and tolerance to waterlogging.

4. radiocarbon techniques could be used to establish the age of the intact charred stumps together with the various buried wood pieces found under the pakihis and heath forest. This would provide information on the dates of the fires.

5. work needs to be carried out on the phenomenon of adventitious root shoots in *Halocarpus biformis*. Investigations could find out what type of disturbance bring about the development of shoots and their growth rates. This knowledge would be useful in establishing mechanisms and timeframes for the re-establishment of the heath forest after being destroyed by fire.

7.0 CONCLUSIONS

The following conclusions can be made from the study of the vegetation, soils, and landforms of the Omoeroa Plateau:

1. the slope was made up of two surfaces of different age: the Plateau floor, at the bottom of the slope, and the moraine up the slope.

2. absolute dating of the surfaces is problematic because of the lack of detailed knowledge of the glacial and stratigraphy of the glacial landforms of South Westland. However, it is possible to assess the relative dates of the deposition of the landforms and make tentative correlations with the relatively well studied glacial events of North Westland. On the basis of these correlations it is proposed that the floor of the Omoeroa Plateau was deposited during the $K2_1$ stadial of the Otira Glaciation, approximately 50,000 to 60,000 years B.P and the moraine was deposited during the $K2_2$ stadial of the Otira Glaciation, approximately 20,000 years B.P. Regardless of the validity of these assumptions, the important point is that the surfaces were deposited during different stadials of the Otira Glaciation and there was an interstadial between the deposition events.

3. the vegetation survey and classification analysis of the data showed that there were differences in the types of vegetation found on the slope. The classification procedure used, TWINSPAN, appeared to provide a good separation of the vegetation types. A total of seven distinct vegetation types were established. They included pakihi and heath forest at the bottom of the slope, with rimu-kamahi and rata-kamahi forest further up the slope on the moraine. The differences in the vegetation were also expressed in the changes in the basal areas of the dominant tree species found on the slope.

4. the main hypothesis generated proposed that the main factor influencing the distribution of the vegetation types was the difference in the ages of the surfaces which made up the slope. The pakihi and heath forest vegetation were found on the older fluvio-glacial outwash Plateau floor while the 'tall forest' vegetation was found on the younger moraine.

5. the scenario put forward to explain the observed distribution envisaged the succession of vegetation on the Plateau floor over approximately 20,000 years to a rimu dominant forest not unlike that found today on surfaces of a similar age in South Westland. Further forest development over the next 10,000 years may have led to the development of a stunted rimu-quintinia-kamahi forest or even a heath forest. This vegetation experienced a major disturbance in the form of the $K2_2$ stadial of the Otira Glaciation. Glacial climatic conditions, including a periglacial environment, would have led to the development of a heath or tussock grassland vegetation type. This stadial also resulted in the deposition of the moraine part of the slope; on this surface succession has led to the forest vegetation type present today.

6. the changing drainage status along the slope has accentuated and maintained the differences in the vegetation types. Due to the extreme ages of both the surfaces no differences in the measured soil chemical parameters were found.

7. the importance of both contemporary and historic natural fires in the development of pakihi vegetation was established. Evidence for fires was the presence of burnt stumps and buried wood. Both the heath forest and the pakihi vegetation are prone to fire, especially after dry spells. The fires would act to maintain the pakihis and enlarge their area. However, it is believed that the heath forest is capable of slowly re-establishing in the pakihis. An important phenomenon in this process is the use of adventitious root shoots by the most dominant tree species of the heath forest- *Halocarpus biformis*.

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APPENDIX 1

List of species names, abbreviations, and codes:

Code	Abbrev.	Species name
7	ANIARO	*Anisotome aromatica*
70	APOBIF	*Aporostylis bifolia*
57	ASPBUL	*Asplenium bulbiferum*
56	ASPFLA	*Asplenium flaccidum*
68	ASTLIN	*Astelia linearis var. linearis*
25	ASTNER	*Astelia nervosa*
48	BLECAP	*Blechnum capense*
50	BLEDIS	*Blechnum discolor*
69	BULMOD	*Bulbinella modesta*
76	CARALP	*Carpha alpina*
72	CELSP.	*Celmisia species*
78	CENCIL	*Centrolepis ciliata*
1	CHIRUB	*Chionochloa rubra*
28	COPCOL	*Coprosma colensoi*
34	COPFOE	*Coprosma foetidissima*
53	COPLUC	*Coprosma lucida*
67	CORSP.	*Corybas species*
43	CTEHET	*Ctenopteris heterophylla*
8	CYAEMP	*Cyathodes empetrifolia*
22	CYAJUN	*Cyathodes juniperina*
55	CYASMI	*Cyathea smithii*
26	DACCUP	*Dacrydium cupressinum*
60	DICLAN	*Dicksonia lanata*
62	DICSQU	*Dicksonia squarrosa*
4	DRAPAL	*Dracophyllum palustre*
80	DRATRA	*Dracophyllum traversii*
12	DROARC	*Drosera arcturi*
11	DROSPA	*Drosera spathulata*
19	DROSTE	*Drosera stenopetala*
86	EARAUT	*Earina autumnalis*

20	ELAHOO	*Elaeocarpus hookerianus*
5	EMPMIN	*Empodisma minus*
73	EUPDIS	*Euphrasia disperma*
17	GAHPRO	*Gahnia procera*
81	GENSP.	*Gentiana species*
3	GLECIR	*Gleichenia circinnata*
44	GLECUN	*Gleichenia cunninghamii*
37	GRABIL	*Grammitis billardieri*
29	GRILIT	*Griselinia littoralis*
2	HALBID	*Halocarpus bidwillii*
15	HALBIF	*Halocarpus biformis*
9	HEMSUF	*Hemiphues suffocata*
27	HYMSP.	*Hymenophyllum species*
16	LAGCOL	*Lagarostrobus colensoi*
18	LEPHYB	*Lepidothamnus hybrid*
30	LEPINT	*Lepidothamnus intermedium*
6	LEPLA	*Lepidothamnus laxifolium*
10	LEPSCO	*Leptospermum scoparium*
61	LEPSUP	*Leptopteris superba*
47	LIBPUL	*Libertia pulchella*
51	LINTRI	*Lindsaea trichomanoides*
77	LIPGUN	*Liparophyllum gunnii*
36	LUZPAR	*Luzuriaga parviflora*
14	LYCRAM	*Lycopodium ramulosum*
41	LYCVOL	*Lycopodium volubile*
39	METUMB	*Metrosideros umbellata*
63	MICAVE	*Microlaena avenacea*
65	MYRAUS	*Myrsine australis*
35	MYRDIV	*Myrsine divaricata*
32	NEOCOL	*Pseudopanax colensoi*
66	NEOPED	*Neomyrtus pedunculata*
38	NERDIC	*Nertera dichondraefolia*
74	NERSCA	*Nertera scapanioides*
79	OREPEC	*Oreobolus pectinatus*
71	PENPUM	*Pentachondra pumila*
52	PHOCOO	*Phormium cookianum*

31	PHYALP	*Phyllocladus alpinus*
42	PITCRA	*Pittosporum crassicaule*
21	PODHAL	*Podocarpus hallii*
45	PRUFER	*Prumnopitys ferrugineus*
85	PSECOL	*Pseudowintera colorata*
46	PSECRA	*Pseudopanax crassifolius*
23	PSESIM	*Pseudopanax simplex*
87	PTESP.	*Pterostylis species*
40	QUIACU	*Quintinia acutifolia*
59	RIPSCA	*Ripogonum scandens*
58	RUMADI	*Rumohra adiantiformis*
75	RYTGRA	*Rytidosperma gracile*
13	THEVEN	*Thelymitra venosa*
64	TMEELO	*Tmesipteris elongata*
49	TRIREN	*Trichomanes reniforme*
24	UNCSP.	*Uncinia species*
33	WEIRAC	*Weinmannia racemosa*