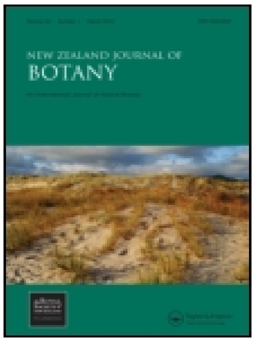

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Native vegetation and soil patterns in the Marlborough Sounds, South Island, New Zealand

G. Y. WALLS
Botany Division, DSIR
Private Bag, Havelock North
New Zealand

M. D. LAFFAN
NZ Soil Bureau, DSIR
Private Bag, Nelson
New Zealand

Abstract The Marlborough Sounds is a convoluted system of land and waterways formed by partial submergence of the prehistoric landscape. It has considerable geological, topographical, and climatic complexity and a long history of human settlement. Much of the original native vegetation still remains, and its patterns and groupings, along with those of the soils, are described. The vegetation is clearly influenced by topography, altitude, and local climate, and is categorised accordingly. In addition, the zone of ultramafic rocks and soils in the west has its own distinctive vegetation. The marked differences in soil morphology and nutrient status are attributed mainly to topography, parent material, and climate (mean annual rainfall and degree of summer droughtiness), and soil groupings reflect that. The clear links between the vegetation and soils allow reconstruction of vegetation patterns in the Marlborough Sounds before human arrival.

Keywords Marlborough Sounds; vegetation; soils; patterns; topography; climate; ultramafics

INTRODUCTION

The Marlborough Sounds is a partly drowned river valley system dominated by steep hill and mountain slopes rising from sea level to over 1000 m. A thousand years ago, before human arrival, virtually all of the land was covered in forests. Most would have been dominated by beeches (*Nothofagus* spp.), but in gullies and in moister or warmer and relatively fertile places at low altitudes there were lush broadleaved forests. Tall podocarp stands grew on most valley and coastal flats.

Maori settlement in the Marlborough Sounds began soon after their arrival in New Zealand around 1000 years ago (Prickett 1982). Remains of their middens, dwelling sites, defensive earthworks, storage pits, and gardens are abundant throughout the area, and stone material for implement-making, from the ultramafic zone in the western Marlborough Sounds, was traded all over the country. During Maori settlement, some forest was cleared, largely by burning, particularly in the gentle heads of bays and on headlands. Subsequent European logging and farming activities have caused most modification to the landscape, resulting in the clearance of considerably more than half of the area of native forest.

This paper outlines the native vegetation and soils of the region, and shows the broad relationship existing between major plant communities and soil groups. It is designed to bring together some major results from two separate but concurrent field surveys: one, a biological survey of reserves (Walls 1984), the other, a soil survey to map and assess soil resources (Laffan unpublished). The Marlborough Sounds region is defined here as the land north of a line following major ridges from Cape Soucis in the west to Rarangi in the east (Fig. 1). This corresponds exactly with the D'Urville, Sounds, and western Cook Strait Ecological Districts as defined in NZMS 242D, Second Edition, 1983, except that it does not include the small portion of coast southwest of Cape Soucis.

FACTORS AFFECTING VEGETATION AND SOILS

Although plant growth and succession and soil formation and distribution are somewhat interdependent, the environmental factors that most strongly influence vegetation and soils in the Marlborough Sounds are topography, climate, and parent materials. For the vegetation, the history of modification is also important.

Topography

Landform, slope, aspect, and altitude vary widely throughout the region. The region is dominated by hills and mountains, with much land above 600 m

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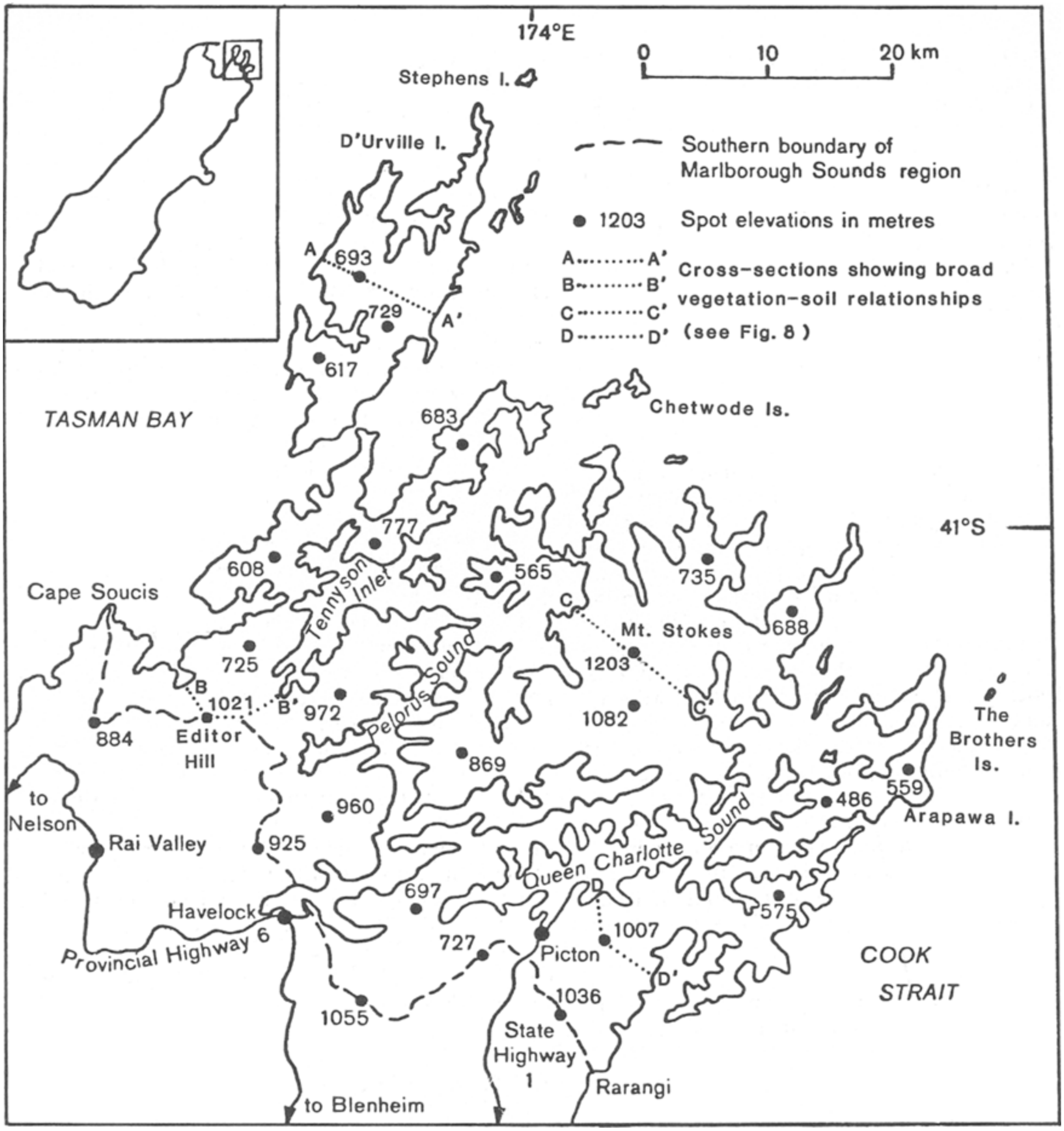

Fig. 1 Location of Marlborough Sounds region and the cross-sections illustrated in Fig. 8.

a.s.l. The highest peak is Mt Stokes (1203 m). Major ridges trend NE–SW, forming a landscape with pronounced aspect differences between sunny north-west-facing slopes and shady south-east-facing slopes. Slopes are mainly moderately steep to steep (13–30°) and steep (30–38°), with some very steep (> 38°) land on mountains and coastal cliffs. Flat and rolling land (slopes 0–12°) comprise only about 5–10% of the total area and occur mainly as alluvial flats and fans at the heads of larger bays and shallow inlets. Typical Marlborough Sounds topography is shown in Fig. 2.

Climate

Climate varies from mild and humid to cool and superhumid. Mean annual rainfall increases from

Figure 2 View of Tennyson Inlet and outer Pelorus Sound showing typical Marlborough Sounds landforms and forests. The altitudinal forest sequence, from sea level to over 900 m, contains hard beech (*Nothofagus truncata*) forests on ridges and coastal broadleaved forests in gullies and moist or fertile places below 500 m, red beech (*N. fusca*) forests between 500 m and 700 m, and silver beech (*N. menziesii*) forests above 700 m. In the foreground is a low forest of mountain beech (*N. solandri* var. *cliffortioides*) and southern rata (*Metrosideros umbellata*) which caps the higher-altitude ridges in this part of the Marlborough Sounds. Photo: Q.R. Christie.

c. 1000 mm in areas adjacent to Cook Strait and Tasman Bay, to over 2000 mm in the area adjacent to Mt Stokes and inner Pelorus Sound (New Zealand Meteorological Service 1973a). Rainfall also increases markedly with altitude, and moist northerly or easterly air flows occasionally produce rainfalls of high intensity and amount (New Zealand Meteorological Service 1973a), usually causing scouring of channels, landsliding (Laffan 1980), and flooding. Gales, often damaging to vegetation, occur frequently throughout the year, and prevailing steady winds cause marked striated sculpturing of forest and scrub canopies, especially on exposed hillsides, ridge crests, and saddles. In summer soil moisture deficits are common in the lower rainfall areas, and during these periods broadleaved trees and shrubs and ferns often wilt, and may even die. Vegetation adjacent to exposed coastlines is frequently subject to salt damage during strong winds.

At altitudes above 550 m, condensation of fog on vegetation, particularly dense forests, probably comprises a substantial proportion of the total precipitation. At altitudes above 1000 m light snow may fall several times per year, but generally does not persist for longer than 2–3 days.

The nearest climate stations are Rai Valley, some 12 km south-east of the region, Stephens Island, 3 km north-east of D'Urville Island, and The Brothers islands, 4 km east of Arapawa Island (Fig. 1). Although none of these stations really typify the Marlborough Sounds, their information gives guidelines. At Rai Valley, mean annual air temperature is 11.3°C with a mean July (coldest month) temperature of 5.9°C, and a mean February (hottest month) temperature of 16.0°C (New Zealand Meteorological Service 1973b).

Soil parent materials

The geology of the region is dominated by siliceous rocks; mainly greywacke which merges eastwards into schist. Along the western side of the region bands of basic rocks (mainly basalt and basaltic sediments, but also including serpentinitic greywacke) and ultramafic rocks (mainly serpentinite) occur. The ultramafic rocks form a northern extension of the Nelson "mineral belt".

On stream margins, terraces, and fans, soil-forming parent materials are mainly alluvial deposits. On the hill country and mountain land, parent materials are commonly formed from thick slope deposits derived from underlying rocks, although shallow parent materials formed directly over bedrock occur on spurs, ridge crests, and on very steep slopes (greater than 38°).

At altitudes below about 200 m, parent materials generally comprise strongly weathered bedrock and derived slope deposits. On some promontories and lower spurs the rock has been deeply and very strongly weathered, and often occurs as very soft, red rock. This weathering probably occurred during warm interglacial stages of the Quaternary period. At altitudes above about 200 m, parent materials are derived mainly from weakly or moderately weathered rocks, and they include extensive areas of relict periglacial deposits, particularly where the underlying rock is greywacke. They occur as both stratified 'fossil screes' and other non-stratified deposits of angular gravels and stones overlying planed bedrock. Thickness is highly variable but fossil screes more than 10 m thick comprising alternate layers of gravels and fine textured materials have been observed in road cuttings near Opouri Saddle, just SW of Tennyson Inlet. The origin of the deposits is attributed to periglacial weathering (mainly freeze-thaw) of exposed rock during cold glacial stages of the Quaternary period. The discovery of volcanic glass belonging to the Kawakawa Tephra Formation (20 000 yrs BP) buried within relict periglacial deposits (Laffan 1980) at several sites in the region suggests that substantial accumulation occurred during the last glaciation (c. 70 000 yrs to c. 10 500 yrs BP). It is probable that reworked loess has been incorporated into most parent materials on hilly and mountain land, particularly in the upper 1 m profile where finer textures predominate.

History of modification

The onset of periglacial conditions during the last glaciation undoubtedly would have affected the pattern of vegetation, particularly at altitudes above about 200 m. It is likely that the forest cover would have been patchy, if not entirely absent from areas with relict periglacial deposits, although there may have been a partial cover of tussocks, hardy shrubs, and herbaceous plants. At altitudes below the influence of periglacial weathering it is probable that refugia of many forest species occurred, particularly in relatively warmer coastal sites.

Since the beginnings of human settlement in the Sounds, the fluctuations in activities brought about by internal and world wars, economic changes, invasions and migrations have imposed many different conditions on the land. During the last 140 years the economics of traditional farming have fluctuated widely and for this period, in particular, fire has been the major tool employed in removal of forest and scrub. Frequency and time of burning have radically affected the nature of the regenerating vegetation. Much timber has been extracted from most valleys, coastal flats, and lower hillslopes. The depredations of domestic stock (mainly cattle and sheep) and feral introduced herbivorous mammals (pigs, goats, red deer and possums) have led to the damage and modification of much of the native vegetation.

The present-day vegetation is a complex mosaic of original forest tracts and remnants, regenerating native vegetation, pasture, exotic forests, and other communities. Much, but not all, of this variation is represented in an extensive system of reserves. Present day generalised vegetation and land use patterns are shown in Fig. 3.

THE FIELD SURVEYS

From late 1981 to mid 1983, G.Y.W. visited all 96 scenic and allied reserves in the Marlborough land district north of the Wairau River. Each reserve in this area — which covers most of the Marlborough Sounds — was walked over and scrutinised from vantage points. Vegetation patterns, plants, landforms, animals, modifying influences, and processes of change were noted. Vegetation maps were drawn from aerial photographs, and the material was subsequently published (Walls 1984). Much of the rest of the Marlborough Sounds was visited or seen during the survey, or on other occasions. In this way, a comprehensive knowledge of the entire area was acquired.

The soils have been recently mapped by M.D.L. at a scale of 1:75 000 as part of a regional survey of soil resources. The soil pattern was determined from numerous observations of soil profiles covering a wide range of parent materials, topography, climate, and vegetation. Representative soils were also sampled for laboratory analysis.

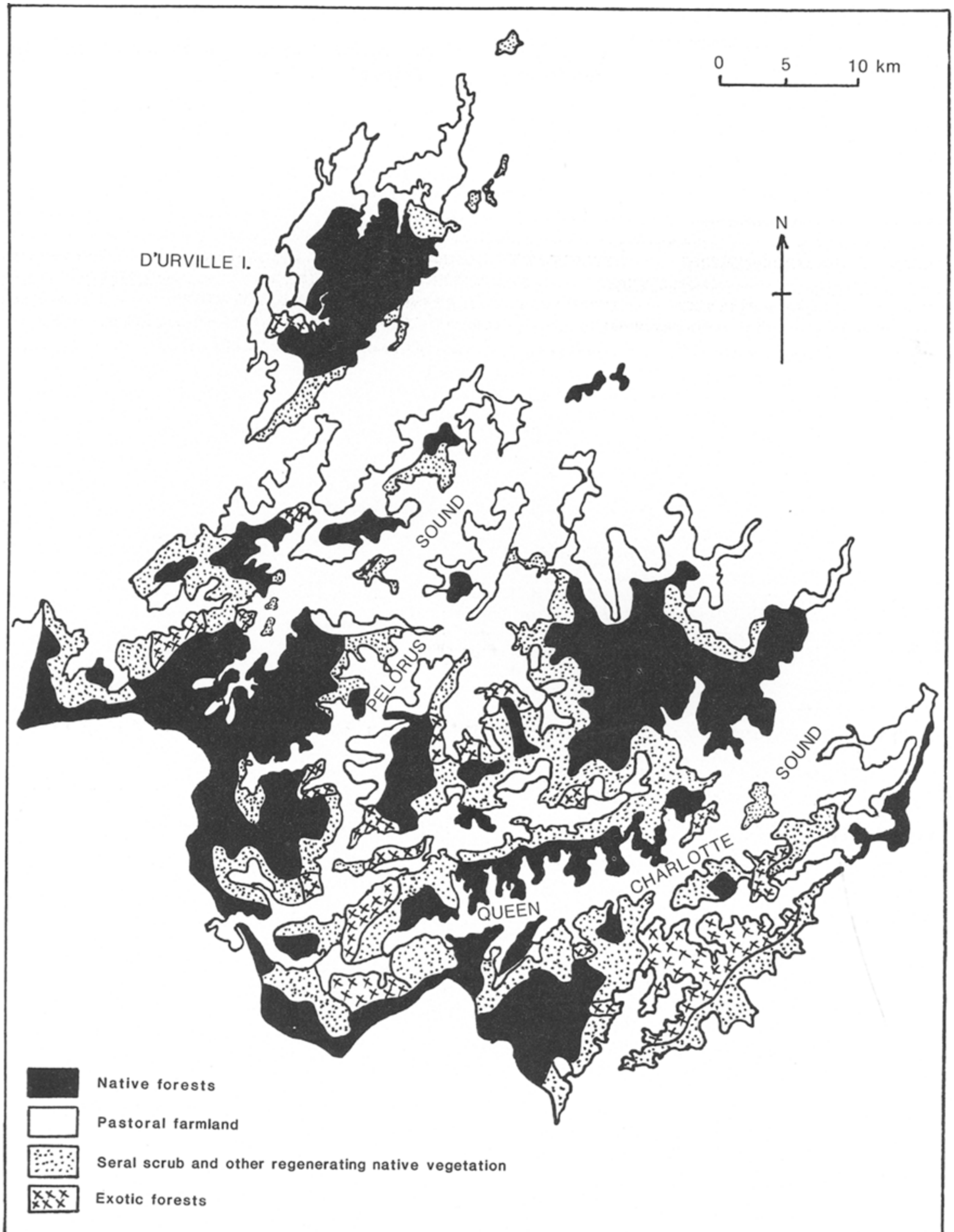

Fig. 3 Present-day generalised vegetation and land use patterns of the Marlborough Sounds.

Table 1 Major native plant communities of the Marlborough Sounds according to topography and soil parent materials.

1. Shore communities
   a) Sparse shrub–herbfields of steep rocky shores.
   b) Sequences including rushes, sedges and low herbs, scrub and low forests of sheltered gentle shores.
2. Valley flat, beach flat and fan communities
   a) Tall broadleaved forests where warmer and more fertile.
   b) Podocarp-beech-broadleaved forests where cooler and less fertile.
3. Gully and streamside communities
   Broadleaved forests (with or without tall podocarps and tree ferns).
4. Hill slope communities
   a) Lower slopes (below c. 500 m a.s.l.)
      i) Seral scrub of manuka, kanuka, tauhinu, broadleaved species, bracken, and introduced shrubs.
      ii) Communities of tree ferns.
      iii) Broadleaved forests, with or without tall podocarps, on warmer and more fertile sites.
      iv) Black beech forests on headlands and dry ridges.
      v) Hard beech forests with rimu on slopes and ridges.
      vi) Kamahi forests with beeches and tall podocarps, on some slopes.
   b) Mid slopes (c. 500–700 m a.s.l.)
      i) Seral scrub of broadleaved species, beeches, tree ferns, manuka, and kanuka.
      ii) Red beech forests with kamahi, silver beech, etc.
   c) Upper slopes (above c. 700 m a.s.l.)
      i) Silver beech forests.
      ii) Mountain beech forests on some wetter peaks and ridge crests.
5. Alpine zone communities
   Tussock grasslands, herbfields, and cushion bog.
6. Ultramafic zone communities
   a) Hard beech forests, with Hall's totara, southern rata, rimu, kamahi, black beech, etc.
   b) Low forest of mountain beech, toatoa, and cedar at high altitude.
   c) Induced scrub or heathland of manuka, coastal or mountain flax, and inaka.
   d) Herbs, grasses, rushes, sedges, ferns, and shrubs on open boulderfields and rock outcrops.
7. Outer island communities
   a) Herbfields of seabird colonies.
   b) Coastal broadleaved forests.
   c) Shrublands and *herbfields of cliffs and rocky shorelines.

*flax is treated as a herb here

THE NATIVE VEGETATION

The best early account of the vegetation of the Marlborough Sounds was by Martin (1932), who provided descriptions enabling a reconstruction of the vegetation in the areas he visited. Walls (1983) has brought together more recent information, and detailed descriptions and maps of the vegetation in reserves are published (Walls 1984). Table 1 outlines the major native plant communities, grouped largely according to topography, and more details are supplied in the following descriptions.

1. *Coasts*

Steep rocky shores support sparse vegetation of small hardy trees and shrubs, mainly broadleaved species, coastal flax (*Phormium cookianum*) and a variety of herbs, ferns, and grasses. Zonation sequences occur on gentler shores which include (running inland) rushes, sedges, and low herbs, backed by scrub and low forests of both broadleaved and small-leaved species.

2. *Valley flats, beach flats, and fans*

Few examples of the forests of these areas now exist but large podocarps (kahikatea, (*Dacrycarpus dacrydioides*), rimu (*Dacrydium cupressinum*), totara (*Podocarpus totara*), matai (*Prumnopitys taxifolia*), and miro (*P. ferrugineus*)) are usually emergent above a lower canopy of broadleaved species, mainly kohekohe (*Dysoxylum spectabile*), tawa (*Beilschmiedia tawa*), pukatea (*Laurelia novae-zelandiae*), and hinau (*Elaeocarpus dentatus*). In exposed coastal places, the broadleaved species are completely dominant. Understoreys of dense entanglements of ferns, vines, and broadleaved shrubs exist in the absence of prolonged browsing.

3. *Gullies and streamsides*

Most of the plants of flats and fans are found in these places, although broadleaved species (particularly mahoe (*Melicytus ramiflorus*), tawa, pukatea, kamahi (*Weinmannia racemosa*), kohekohe, tree fuchsia (*Fuchsia excorticata*), wineberry (*Aris-

totelia serrata), and tutu (*Coriaria arborea*)) and tree ferns are predominant. There is normally a profusion of small ferns, seedlings, and vines. In many places the tall trees, including podocarps, have been logged and subsequent regeneration has usually resulted in a dense lower stature forest of pole trees.

4. *Hill slopes*

Distinct altitudinal changes in forest composition allow recognition of three main divisions:

a) Lower slopes (below about 500 m a.s.l.)
Where there are forests, hard beech (*Nothofagus truncata*) is generally dominant in the canopy, with emergent rimu and fairly open understoreys. Black beech (*N. solandri* var. *solandri*) occurs on most headlands and some dry ridges, where it can form exclusive stands. In warm, relatively fertile sites, broadleaved species (tawa, hinau, and kohekohe mainly) can be dominant. In local areas, kamahi, red beech (*N. fusca*), and large podocarps are present where hard beech would otherwise be expected.

The main native species in scrub and low forest regenerating after forest clearance are manuka (*Leptospermum scoparium*), kanuka (*Kunzea ericoides*), tauhinu (*Cassinia leptophylla*), bracken (*Pteridium esculentum*), broadleaved species (especially mahoe, putaputaweta (*Carpodetus serratus*), wineberry (*Aristotelia serrata*), kamahi, and fivefinger (*Pseudopanax arboreus*)), and tree ferns.

b) Mid slopes (about 500–700 m a.s.l.)
Red beech is the dominant forest tree and kamahi is common. Soft tree fern (*Cyathea smithii*), horopito (*Pseudowintera colorata*), silver beech (*Nothofagus menziesii*), tree fuchsia (*Fuchsia excorticata*), broadleaf (*Griselinia littoralis*), and crown fern (*Blechnum discolor*) form moist, rather dense understoreys. Southern rata (*Metrosideros umbellata*), Hall's totara (*Podocarpus hallii*), and mountain toatoa (*Phyllocladus aspleniifolius* var. *alpinus*) often grow on ridge crests. It is generally too high for rimu, which rarely grows above 500 m a.s.l. In regenerating scrub, kamahi, fivefinger, heketara (*Olearia rani*), horopito, tree fuchsia, beeches, tree ferns, manuka, and kanuka are the main species.

c) Upper slopes (above about 700 m a.s.l.)
Relatively intact (unmodified) and structurally quite simple forests of silver beech prevail. They are very mossy and, probably due to browsing mammals, have little understorey vegetation. Southern rata and Hall's totara are common on ridges. In the western Sounds, mountain beech (*Nothofagus solandri* var. *cliffortioides*) forms low forests on some ridge crests where soils are shallow.

5. *Alpine zone*

Only above c. 1100 m a.s.l. on Mt Stokes is there true alpine vegetation. It was once lush herbfield, scrubland, and tussockland, with snowgrass (*Chionochloa pallens*, *C. flavescens* and hybrids) dominant, and an abundance of alpine daisies (*Celmisia* spp.), gentians (*Gentiana* spp.), eyebrights (*Euphrasia* spp.), buttercups (*Ranunculus* spp.), speargrass (*Aciphylla ferox*), and other herbs. Below this was a fringe of leatherwood (*Olearia colensoi*). Feral goats and pigs have intensively browsed, trampled, and rooted the area in recent decades though, and now there is a scattering of leatherwood and snowgrass, with mountain flax (*Phormium cookianum*) and *Coprosma* sp. (affinities with *parviflora*) in depressions, and a variety of low herbs forming a sparse ground cover. A cushion herbfield of *Donatia novae-zelandiae* and *Oreobolus pectinatus*, bordered by leatherwood and silver beech scrub, grows on wet peat in the saddle north of the summit.

6. *Ultramafic zone*

The vegetation is distinct in appearance and structure from that on adjacent land, although most of the plants are also found in non-ultramafic areas. Considerable areas of the natural climax vegetation of most of the ultramafic zone — low forest of hard beech, black beech, Hall's totara, southern rata, rimu, kamahi, manuka, and lancewood (*Pseudopanax crassifolius*) — still remain at high altitudes. The forests of mountain beech, mountain toatoa, and cedar (*Libocedrus bidwillii*) on Editor Hill in the western Sounds are also associated with ultramafic soils. On land burnt in the past, as shown in Fig. 4, there is a tight scrub or heathland of stunted manuka, coastal or mountain flax (*Phormium cookianum*), and inaka (*Dracophyllum longifolium*), with protruding rock outcrops and open boulderfields in which grow many herbs, grasses, rushes, sedges, ferns, and shrubs. The presence of plants characteristic of low open vegetation, a few of which are confined to the "mineral belt", suggests a long history of open vegetation in places.

7. *Islands*

The vegetation of the larger islands and those within the shelter of the Sounds' waterways, resembles that of the mainland, although in many cases their freedom from introduced mammals allows denser vegetation and the persistence of some plants now rare on the mainland. Almost without exception, the outer islands are breeding grounds for seabirds, and the soils are enriched and conditioned by their activities. Lush coastal vegetation, including broadleaved forests, fields of the annual groundsel *Senecio sterquilinus*, and shrublands and herbfields of cliffs and rocky shorelines, grow on them. Distinctive plants which occur include the prostrate Cook Strait kowhai (*Sophora microphylla*), large-leaved milk tree (*Paratrophis banksii*), Cook's

Fig. 4 View of the Marlborough Sounds landscape inland from Tennyson Inlet. The left-hand high point is Lookout Peak (1005 m). Mid-altitude hard beech (*Nothofagus truncata*) and red beech (*N. fusca*) forests can be seen, and above these are forests of silver beech (*N. menziesii*), with mountain beech (*N. solandri* var. *cliffortioides*) on the high ridge crests. The foreground is an outrider of the ultramafic zone, showing large rock outcrops and the distinctive heathland of stunted manuka (*Leptospermum scoparium*), inaka (*Dracophyllum longifolium*), and small herbs, grasses, rushes, sedges, ferns, and shrubs which is the result of regeneration following past burning. There is another small ultramafic area, supporting forest of mountain beech, toatoa (*Phyllocladus aspleniifolius* var. *alpinus*) and cedar (*Libocedrus bidwillii*) on the slopes of Editor Hill (1021 m) on the right-hand skyline. Photo: Q.R. Christie

scurvy grass (*Lepidium oleraceum*), and fierce lancewood (*Pseudopanax ferox*).

THE SOILS

The region was previously mapped at 1:253 440 scale as part of a reconnaissance soil survey of the South Island (New Zealand Soil Bureau 1968), while the soils of Stephens Island and Maud Island have been described by Ward (1961) and Webb & Atkinson (1982), respectively. Recent soil resource data are given in Laffan (1980), Laffan & Daly (in press), and Laffan et al. (in press).

Soil patterns

Soil differences due to topography are marked, particularly between soils of the alluvial flats and fans, and soils of the hill country and mountains. Within these major topographic groups, parent material and climate are the dominant factors determining soil properties and distribution. Mean annual rainfall and the presence or absence of summer droughtiness are the main factors affecting leaching of the soils and ultimately their morphological properties and natural nutrient status. In the drier coastal areas (mean annual rainfall range about 1000–1800 mm) summer droughtiness is common, whereas in the higher rainfall areas (greater than 2000 mm mean annual rainfall) and at altitudes above about 150–250 m in drier areas, summer droughtiness is uncommon or negligible. At altitudes above 550 m droughtiness is rare, and cooler mean temperatures result in slower plant growth and a shorter growing season than at lower altitudes. On the basis of these findings, the soils of the region have been subdi-

Table 2 Major soil-physiographic units of the Marlborough Sounds according to topography, climate, and parent materials.

1. Soils of the alluvial flats and fans
   - (a) with drier climate
     - (i) from siliceous parent materials
   - (b) with wetter climate
     - (i) from siliceous parent materials
2. Soils of the lowland hill country (altitude < 550 m)
   - (a) with drier climate
     - (i) from siliceous parent materials
     - (ii) from basic parent materials
     - (iii) from ultramafic parent materials
   - (b) with wetter climate
     - (i) from siliceous parent materials
     - (ii) from basic parent materials
     - (iii) from ultramafic parent materials
3. Soils of the upland hill country and mountains (altitude > 550 m) with cooler, wetter climate
     - (i) from siliceous parent materials
     - (ii) from ultramafic parent materials

vided into three major soil-physiographic units based on landform and altitude:

(1) Soils of the alluvial flats and fans, generally occurring near sea level.
(2) Soils of the lowland hill country, occurring at altitudes below 550 m.
(3) Soils of the upland hill country and mountains, occurring at altitudes above 550 m.

The soils have been further subdivided into two main climatic groups, based on mean annual rainfall and susceptibility to drought, and a third subdivision has been made on parent material. Soils with a drier climate are normally weakly droughty in summer (i.e., soil moisture below wilting point for 1–2 months) and they cover most of the coastal areas (about 45% of the region) apart from high rainfall coasts such as Tennyson Inlet and the western side of inner Pelorus Sound. Droughtiness is negligible or uncommon in soils with a wetter climate, which cover about 55% of the region. The major soil-physiographic units according to topography, climate, and parent materials are outlined in Table 2. Their approximate distributions are shown in Fig. 5 and 6.

Soil morphological properties

1. *Soils of the alluvial flats and fans*

Most soils are well drained although some low-lying sites are imperfectly or poorly drained, and a few peat soils are very poorly drained. Somewhat excessively drained soils formed from coastal sand dunes also occur locally, but they cover only a minor area. For well drained soils, profile morphology typically shows thin, dark grey A horizons overlying yellowish brown B horizons. Imperfectly drained and poorly drained soils are characterised by greyish and reddish mottles or grey base colours throughout the profile. Soil texture and stoniness are highly variable, but stony silt loams or stony clay loams occur widely on the alluvial flats and fans.

2. *Soils of the lowland hill country*

Soils formed from siliceous parent materials are generally well drained with very dark greyish brown or dark brown A horizons overlying yellowish brown B horizons. The thickness of A horizons is highly variable but is strongly related to native vegetation type; under beech forests profiles typically have very thin A or AB horizons or accumulations of organic matter directly overlying B horizons, whereas under coastal broadleaved forests A horizons are thicker and more strongly developed. In areas with drier climate, subsoil structures are usually blocky with firm consistence, whereas soils with wetter climate generally have nut-structured, friable to very friable subsoils. Soil profiles with well developed podzol features characterised by distinct, greyish coloured eluvial horizons overlying yellowish brown illuvial horizons also occur sporadically in areas with wetter climate.

In areas with drier climate, soils formed from basic parent materials are generally well drained and profiles are characterised by dark brown A horizons overlying brown or reddish brown, firm, blocky-structured B horizons. In areas with wetter climate, the soils are often imperfectly drained with greyish-mottled, friable, nut-structured B horizons.

Textures of soils formed from siliceous and basic parent materials are predominantly silty clays or silty clay loams with few to many stones throughout the profile. Soil depth is highly variable, but on average, soils are deeper than 75 cm. Shallow

Fig. 5 Distribution of major soil-physiographic units in the Marlborough Sounds according to topography and climate.

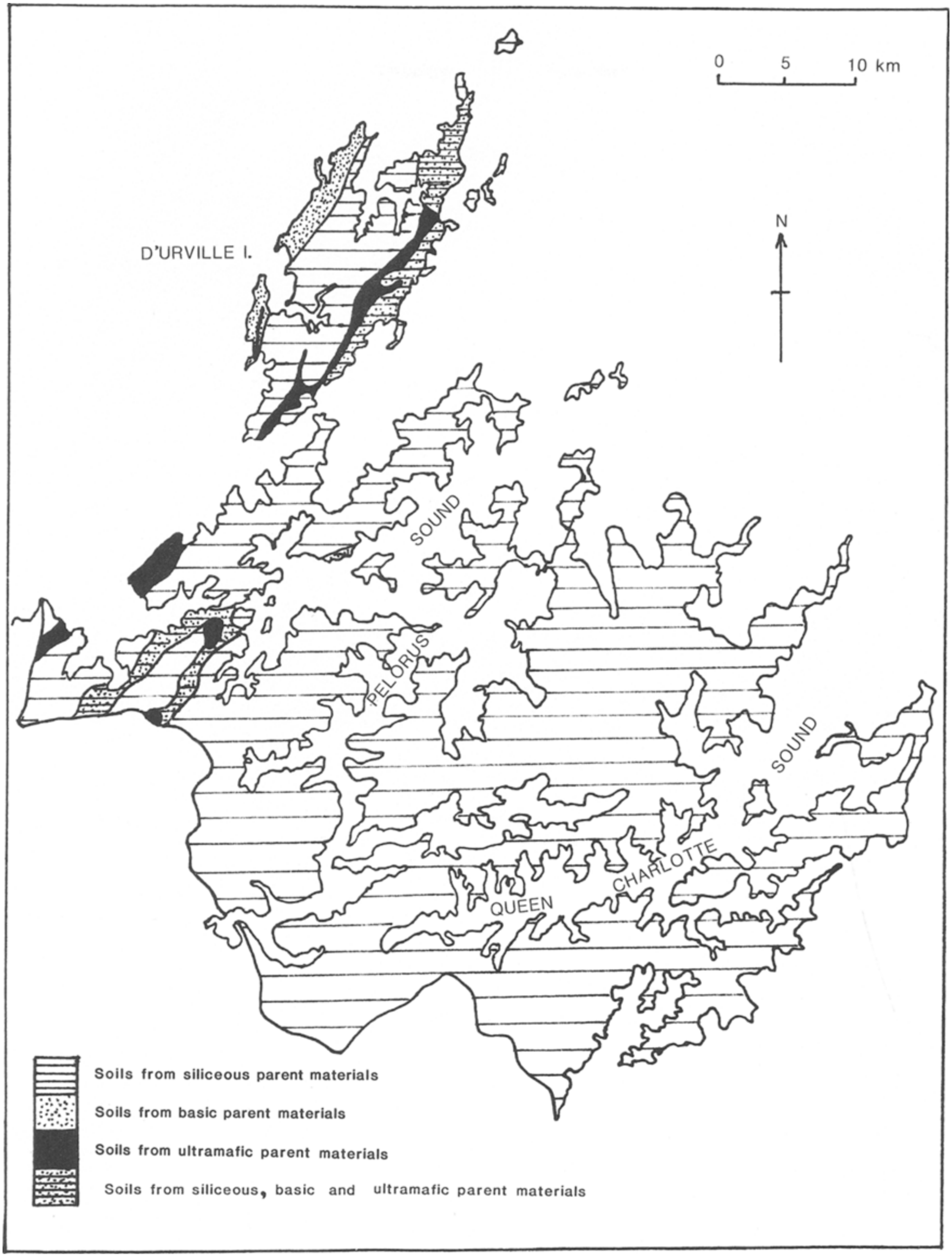

Fig. 6 Distribution of major soil–physiographic units in the Marlborough Sounds according to parent materials.

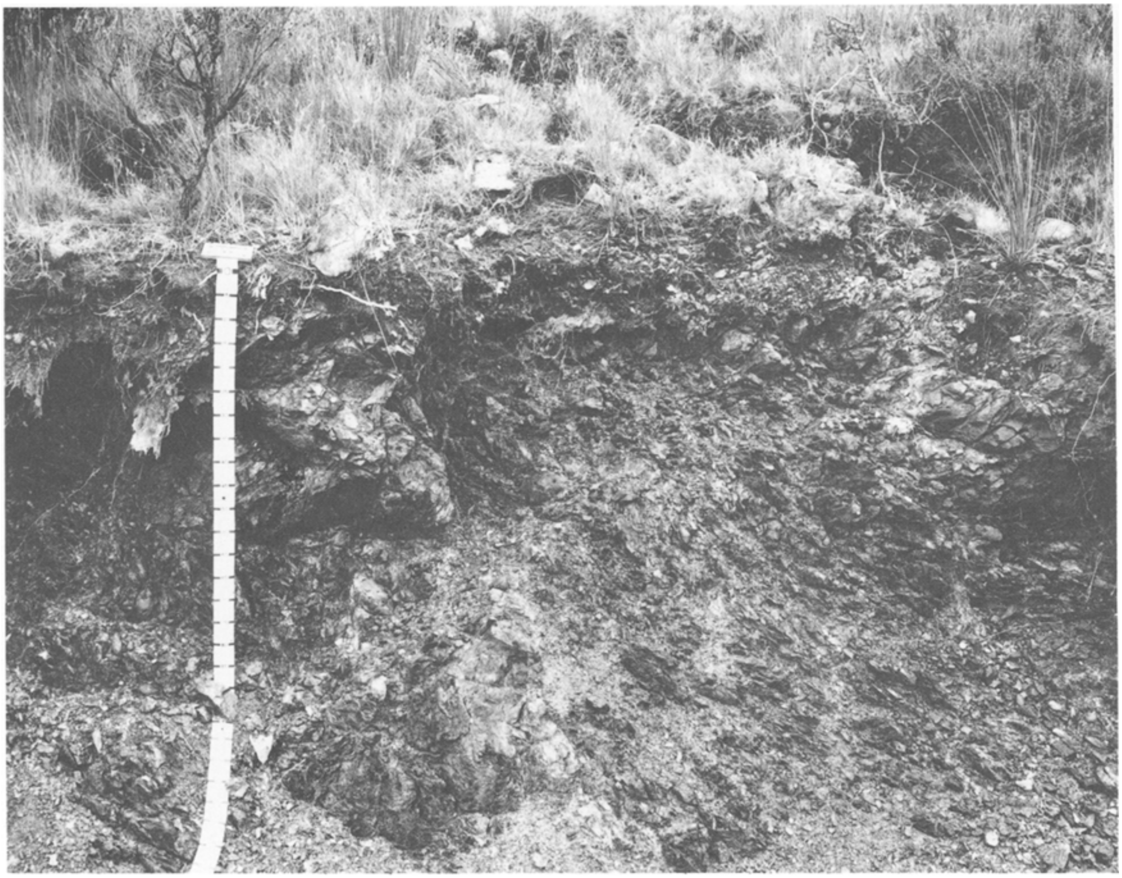

Fig. 7 Road cutting through ultramafic vegetation, soil, and rock above Croisilles Harbour. The soil is very shallow and stony, resting on flaky, weakly weathered serpentinite rock and supporting dwarfed vegetation of manuka (*Leptospermum scoparium*), sedges, rushes, small grasses, and small herbs after having been burnt in the past. Photo: Q. R. Christie.

(less than 50 cm deep) and stony soils occur extensively in association with rock outcrops on ridges, spurs, and very steep (> 38°) slopes.

Soils formed from ultramafic parent materials are extremely variable, particularly in stoniness, soil depth, and drainage characteristics. In areas with drier climate, the soils range from shallow (less than 50 cm deep) to moderately deep or deep and they are generally well drained or somewhat excessively drained with brown, stony clay loam or clay textured subsoils. In areas with wetter climate, the soils are predominantly shallow, stony, and imperfectly drained with greyish and rusty coloured mottles. An example is pictured in Fig. 7. The soils usually occur in association with numerous rock outcrops and surface boulders.

3. *Soils of the upland hill country and mountains*
Soils formed from siliceous parent materials are generally strongly podzolised, and profiles are characterised by thin, dark reddish brown organic layers and friable, dark brown A horizons overlying very friable, often slightly greasy, yellowish brown or strong brown B horizons. Subsoils generally contain appreciable amounts of illuvial amorphous material (allophane and mineral-organic complexes, generally produced during podzolisation processes) which imparts a greasy feel to subsoil materials (Laffan et al., in press).

Textures are generally silty clays or silty clay loams with few to many stones throughout the profile. Well developed podzols occur more frequently than in the lowland hill country, and some profiles also have a thin, hard iron pan at the interface of the greyish coloured eluvial horizon and underlying yellowish brown, illuvial horizon. Shallow, greyish coloured soils overlying massive bedrock also occur extensively on narrow ridge crests.

In the alpine zone at altitudes above 1100 m, soils are generally shallow (less than 50 cm deep), stony, and imperfectly drained. In sites where the vegetation cover is still intact, profiles characteristically have relatively thick (20–22 cm) dark greyish brown A horizons overlying thin greyish eluvial horizons resting on bedrock. Thin, hard, reddish iron pans also occur on and in the underlying bedrock. A significant area of soils has been severely eroded due to disturbance and depletion of the vegetation cover by feral animals. In downslope sites where thicker slope deposits have accumulated, profiles are characterised by thick A horizons, greyish eluvial horizons, thin, reddish iron pans and greasy yellowish brown subsoils. The relatively thick A horizons formed under the influence of grassland and herbfield vegetation are a major feature distinguishing soils of the alpine zone from forested soils at lower altitudes.

Soils from ultramafic parent materials are mainly shallow, stony, and imperfectly drained with greyish mottles.

Soil nutrient status

The natural nutrient status of the soils is determined primarily by the effects of parent material and climate, and, to a lesser degree, by type of vegetation. In areas with drier climate, soils formed from basic parent materials generally have a high nutrient status, resulting from the accumulation of nutrients from the base-rich parent material in association with a relatively low degree of leaching. However, in areas with wetter climate, soils formed from basic parent materials have a medium to low nutrient status resulting from the depletion of nutrients from the soil caused by much stronger leaching.

The natural nutrient status of soils formed from siliceous parent materials is generally low in areas with drier climate and very low in areas with wetter climate, reflecting the generally lower inherent nutrient levels in siliceous parent materials. Lowest nutrient levels occur in soils at altitudes above 550 m, where leaching is strongest. Exceptions are soils formed from recent alluvium or poorly drained soils which have medium nutrient status, and soils on many of the outer islands which have medium to high nutrient status resulting from enrichment by seabird activity and the inputs from salt spray.

Soils formed from ultramafic parent materials have an unusual nutrient status dominated by very high levels of magnesium and trace elements (Lyon et al. 1970). Although pH values are often near optimum, the soils have severe nutrient imbalances and some also have toxic levels of chromium and similar elements which are inimical to normal growth in most plants. Soils formed from ultramafic parent materials are less influenced by climate than are soils formed from siliceous or basic parent materials.

Vegetation effects on nutrient status are suggested by slightly higher pH and nutrient levels in soils with coastal broadleaf forest than in adjacent soils with beech or beech–podocarp forests. Studies by Wassilieff (1983) verify this apparent trend.

In the Marlborough Sounds, soils with high nutrient status are characterised by slightly acid to near neutral pH, high levels of most exchangeable bases (calcium, magnesium, potassium, sodium), high to very high percentage Base Saturation (%BS), medium to high available (Truog) phosphorus (P), low P retention, and adequate sulphur (S) and reserve potassium (K) levels. Conversely, soils with very low nutrient status have strongly acid pH, low to very low levels of exchangeable bases, very low %BS, very low available P, medium to high P retention and marginal levels of reserve K. Soils with medium and low nutrient status are intermediate between these two extremes.

Representative chemical analyses (pH, %BS, exchangeable Ca, Mg and K, and 0.5M H_2SO_4P) for the major soil–physiographic units are given in Table 3, together with New Zealand Soil Bureau ratings (Blakemore et al. 1977). Most of the soils analysed are from unfertilised sites. Results of pH, %BS and exchangeable bases reflect the leaching status of soils, whereas P extracted by 0.5M H_2SO_4 indicates reserves of P some of which may be available for plant uptake. The exchangeable bases also indicate levels of Ca, Mg, and K readily available to plants. Most soils have low levels of total nitrogen (N) and available P in topsoils, and very low levels of both N and P in subsoils (Laffan & Daly, in press). However, some soils on the outer islands have high to very high levels of N and P resulting from seabird enrichment (Ward 1961). Table 4 shows the relative nutrient status for major soil–physiographic units based on New Zealand Soil Bureau ratings for chemical properties.

RELATIONSHIP BETWEEN NATIVE VEGETATION AND SOIL PATTERNS

Table 4 outlines the broad relationships occurring between the native vegetation and soil groupings. Vegetation–soil relationships are also shown diagrammatically as cross-sections through D'Urville Island, Editor Hill, Mt Stokes, and Port Underwood (Fig. 8). Clearly apparent are the strong correlations between vegetation and soils according to topography, parent materials, altitude, and climate.

Table 3 Representative chemical analyses for major Marlborough Sounds soil–physiographic units.

Soil–physiographic unit	No. of profiles analysed	pH ts[1]	pH ss[1]	BS% (profile)	Exchangeable (me%) Ca ts	Ca ss	Mg ts	Mg ss	K ts	K ss	0.5M H_2SO_4 P(mg%) ts	ss
Soils of the alluvial flats and fans												
with drier climate												
— from siliceous PM[2]	1	5.0	5.1	24 L	6.2 M	1.5 VL	1.9 M	0.5 L	0.55 M	0.59 M	16 M	10 M
with wetter climate												
— from siliceous PM	2	4.4	5.2	8 VL	3.5 L	0.4 VL	1.5 M	0.3 VL	1.03 H	0.16 VL	21* H	8 L
Soils of the lowland hill country (altitude < 550 m)												
with drier climate[3]												
— from siliceous PM	7	5.2	5.3	28 L	4.3 L	1.4 VL	3.4 H	1.7 M	0.67 M	0.23 VL	4 VL	4 VL
— from basic PM	2	5.3	6.3	71 H	7.5 M	6.7 M	4.9 H	5.6 H	0.65 M	0.44 L	9 L	5 L
with wetter climate												
— from siliceous PM	11	4.8	5.1	9 VL	2.3 L	0.5 VL	1.6 M	0.4 VL	0.38 L	0.17 VL	5 L	5 L
— from basic PM	3	5.3	5.3	29 L	9.6 M	0.93 VL	5.4 H	2.4 M	0.60 M	0.11 VL	3 VL	3 VL
— from ultramafic PM	2	6.1	6.7	82 VH	2.4 L	1.2 VL	11.8 VH	16.9 VH	0.24 VL	0.16 VL	3 VL	1 VL
Soils of the upland hill country and mountains (altitude > 550 m)												
with wetter, cooler climate[3]												
— from siliceous PM	6	4.6	4.9	6 VL	1.8 VL	0.5 VL	1.1 M	0.2 VL	0.32 L	0.11 VL	4 VL	4 VL

(1) ts = topsoil (A and AB horizons).
(1) ss = subsoil (B horizons 20–50 cm depth).
(2) PM = parent materials.
(3) Soils from ultramafic parent materials were not analysed, but they are likely to be similar to ultramafic soils of the lowland hill country with wetter climate.
Ratings: (Blakemore et al. 1977) VL = very low, L = low, M = medium, H = high, VH = very high.
*This value is anomalously high as one profile has been topdressed with phosphatic fertiliser.

Table 4 Relationship between major native vegetation groups and soil–physiographic units in the Marlborough Sounds.

Major native vegetation groups	Relative plant species and community diversity[1]	Major soil–physiographic units	Relative soil nutrient status[2]
1. Valley and beach flats and fans		Soils of the alluvial flats and fans	
in warmer and more fertile sites		with drier climate	
◇ podocarp–coastal broadleaved forests	high	◇ from siliceous parent materials	low to medium
in cooler and less fertile sites		with wetter climate	
◇ podocarp–beech forests	medium	◇ from siliceous parent materials	low to very low
2. Hillslopes on lower slopes (< 500 m a.s.l.)		Soils of the lowland hill country (< 550 m a.s.l.)	
in warmer and more fertile sites		with drier climate	
◇ coastal broadleaved–podocarp forests, broadleaved scrub*, tree ferns, black beech forests	medium to high	◇ from siliceous parent materials and basic parent materials	low high
in cooler and/or less fertile sites		with wetter climate	
◇ scrub of small-leaved species, hard beech–rimu forests, kamahi–beech–podocarp forests	medium	◇ from siliceous parent materials, and basic parent materials	very low medium
on midslopes (500–700 m a.s.l.)		Soils of the upland hill country and mountains (> 550 m a.s.l.)	
◇ broadleaved scrub† red beech forests	low to medium	◇ from siliceous parent materials	very low
on upper slopes (700–1100 m a.s.l.)			
◇ silver beech, mountain beech forests	low	◇ from siliceous parent materials	very low
3. Alpine zone (> 1100 m a.s.l.)		Soils of the mountains (> 1100 m a.s.l.)	
◇ herbfield, scrub, tussockland	medium	◇ from siliceous parent materials	very low
4. Ultramafic zone		Soils of the lowland and upland hill country and mountains	
◇ beech–podocarp–etc.‡ low forests, heath-like scrub, boulderfields	medium	◇ from ultramafic parent materials	severe imbalances
5. Outer Islands		Soils of the lowland hill country (< 550 m a.s.l.) with drier climate	
◇ coastal broadleaved forests, shrublands, herbfields	medium to high	◇ from siliceous parent materials (enriched by seabirds)	medium to high

1 Relative to each other within the Marlborough Sounds.
2 Based on national ratings for chemical properties (Blakemore et al. 1977).
* Scrub of coastal broadleaved species.
† Scrub of upland broadleaved species.
‡ etc. = mainly kamahi, lancewood, manuka, and southern rata.

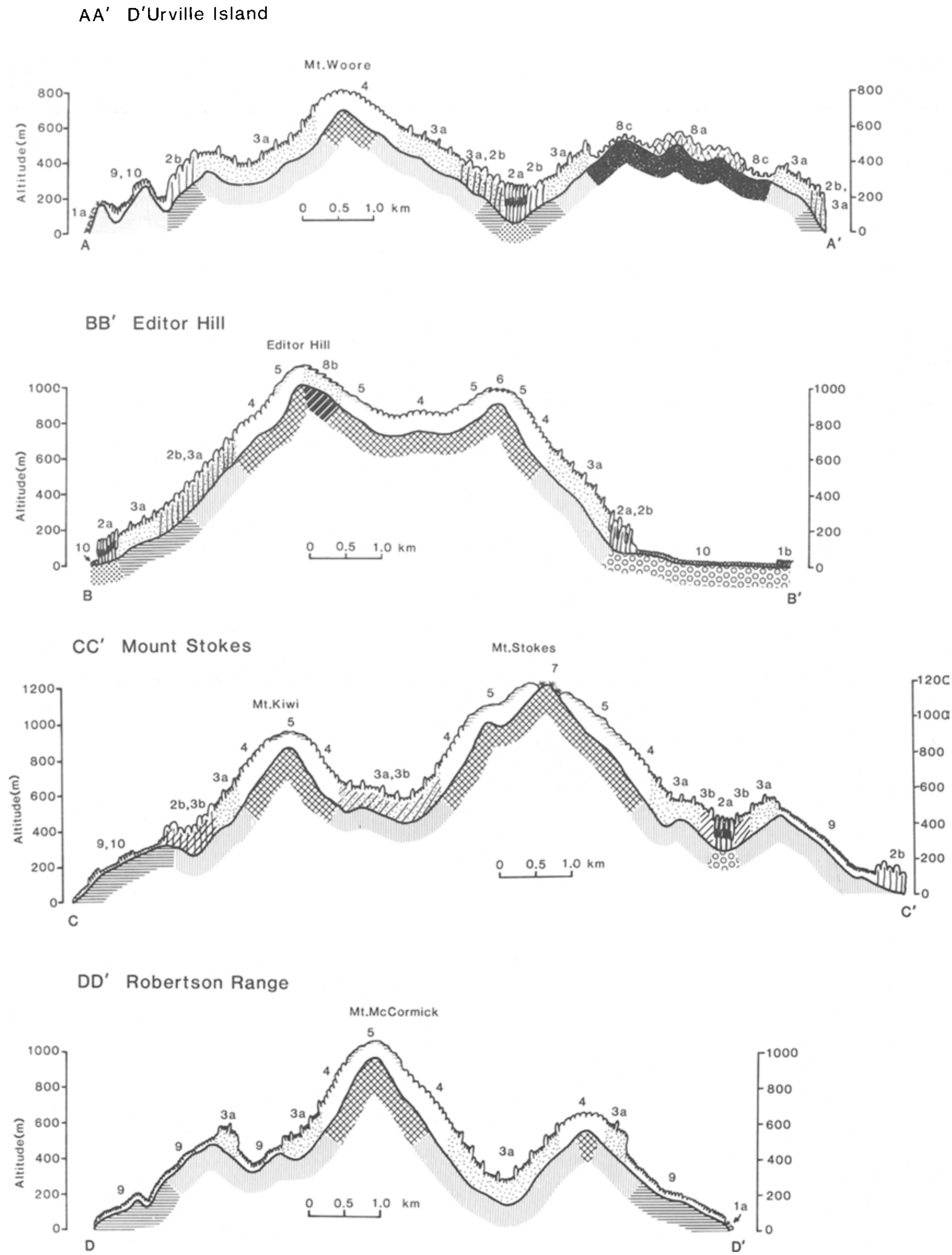

Fig. 8 Four cross-sections of the Marlborough Sounds showing major vegetation and soil groups. Vertical exaggeration ×2.5. For locations see Fig. 1.

Key to Fig.8

Major vegetation groups

Shore, valley flat and fan communities

1a Sparse shrub-herbfield on coastal cliffs
1b Rushland on estuary margins
2a Podocarp -broadleaved forest

Hillslope and alpine zone communities

2b Coastal broadleaved-podocarp forest
3a Hard beech -(black beech) forest with emergent rimu (< 500m asl)
3b Kamahi forest with beeches and podocarps (< 500m asl)
4 Red beech forest (450-700m asl)
5 Silver beech forest (> 700m asl)
6 Mountain beech forest (> 800m asl)
7 Alpine herbfield,scrub and tussock (> 1100m asl)

Ultramafic zone communities

8a Beech-podocarp-etc. mixed low forest
8b Mountain beech-toatoa-cedar low forest
8c Heath-like scrub and boulderfields

Modified/induced vegetation

9 Regenerating native scrub,low forest,tree ferns,bracken,etc.
10 Grazed pasture

Major soil groups

Soils of the alluvial flats and fans

From siliceous PM with drier climate
From siliceous PM with wetter climate

Soils of the lowland hill country (< 550m asl)

From siliceous PM with drier climate
From basic PM with drier climate
From siliceous PM with wetter climate
From ultramafic PM with wetter climate

Soils of the upland hill country and mountains (> 550m asl)

From siliceous PM with cooler,wetter climate
From ultramafic PM with cooler,wetter climate

1. *Topography*

Both the vegetation and soil groupings are separated into similar broad topographic and landform units; of flats and fans, lower hillslopes (lowland hill country) and midslopes, upper slopes and alpine zone (upland hill country and mountains).

2. *Parent material*

The relative diversity of plant species and communities appears to be strongly related to soil nutrient status. The greatest diversity, which is mostly within vegetation dominated by broadleaved species, occurs where soil fertility is highest and climate most favourable for plant growth: broadleaved species are dominant in areas with drier climate where soil nutrient status is relatively high, but they also occur to a lesser extent in areas with wetter climate. Podocarp species are also more prevalent in soils with higher nutrient status, particularly those formed from basic parent materials in areas with wetter climate. Conversely, the simpler communities dominated by beeches occur mostly on soils with low or very low nutrient status, but they also occur on exposed coastal headlands and low-lying spurs, where the soils are relatively shallow and drier. In soils formed from ultramafic parent materials, the vegetation is lower in stature and more sparse than that occurring in soils formed from siliceous or basic parent materials, and has a distinctly different assemblage of species.

3. *Altitude*

The change in beech forests at about 500 m a.s.l. (as low as 350 m and as high as 600 m) from hard beech dominance to red beech is consistent and very marked. The 500–550 m altitudinal zone also represents the upper limit at which rimu occurs. The change from lowland hill country soils to upland hill country and mountain soils at about the same altitude is just as distinct. Although marked changes in vegetation occur at altitudes of 700 m where red beech forests give way to silver beech, corresponding major differences in soil properties were not observed.

The abrupt change in vegetation at 1100 m a.s.l. from woody forest to non-woody herbfield, scrub and tussock land is reflected in the corresponding, though less pronounced, change in soil pattern already described.

4. *Climate*

The effects of climate on soil properties are most pronounced for soils formed from siliceous and basic volcanic parent materials. Nutrient status is highest in soils with drier climate and lowest in soils with wetter climate. Climatic effects on soils and vegetation are also closely related to altitude, with mean annual rainfall and precipitation from fog condensation generally increasing with altitude, and mean temperatures decreasing with increasing height above sea level. The effect of wind is primarily on vegetation structure: gales cause canopy damage and/or salt burning, whilst canopies are kept low where exposed to prevailing winds.

DISCUSSION AND CONCLUSIONS

Although their responses to environmental factors are likely to differ, it is not altogether surprising that vegetation and soils should be related. The plants that grow depend on the nutrients available and the substrate structure, soils are conditioned and modified by plants, and both are influenced by climate and microclimate (which depends on slope, aspect, altitude, etc.).

The clear link between soil and vegetation in the Marlborough Sounds allows reconstruction of past vegetation patterns based on broad soil, topographic, and climatic groupings, and existing vegetation. Figure 9 shows the probable distribution of major vegetation types just before the first humans arrived, about 900 A.D., assuming little change in climate and landforms since then.

Coastal cliffs of the outer Sounds probably supported sparse communities of shrubs, grasses, and herbs. It is most likely that lush broadleaved forests with podocarps would have occupied all lowland coastal flats, fans, gullies, beach heads, and more fertile hill slopes, as well as the smaller islands: tall forests of tawa, pukatea, kohekohe, matai, kahikatea, totara, rimu, and miro in coastal valleys and on coastal flats; tall forests of kahikatea, matai, totara, rimu, and hinau, with or without titoki, tawa, kamahi, black beech, and silver beech in valleys further inland; lower-stature broadleaved forests of kohekohe, tawa, mahoe and other species in sites with strong maritime influence.

Beech forests clothed most hillslopes: black beech dominant on dry headlands; hard beech dominant on hillslopes below 500 m a.s.l.; red beech dominant between about 500 and 700 m a.s.l.; silver beech dominant above 700 m a.s.l.; mountain beech dominant in isolated high-altitude sites in the southwest.

The vegetation on ultramafic soils, mainly low mixed forests as described, but also areas of scrub and open vegetation, would have been distinctive for its lower stature, relatively open form and sparseness compared with that on adjacent country. Alpine vegetation no doubt grew where it does now, but the herbfields, scrub, tussock-land, and cushion bogs, without mammals, had a much greater profusion of plants.

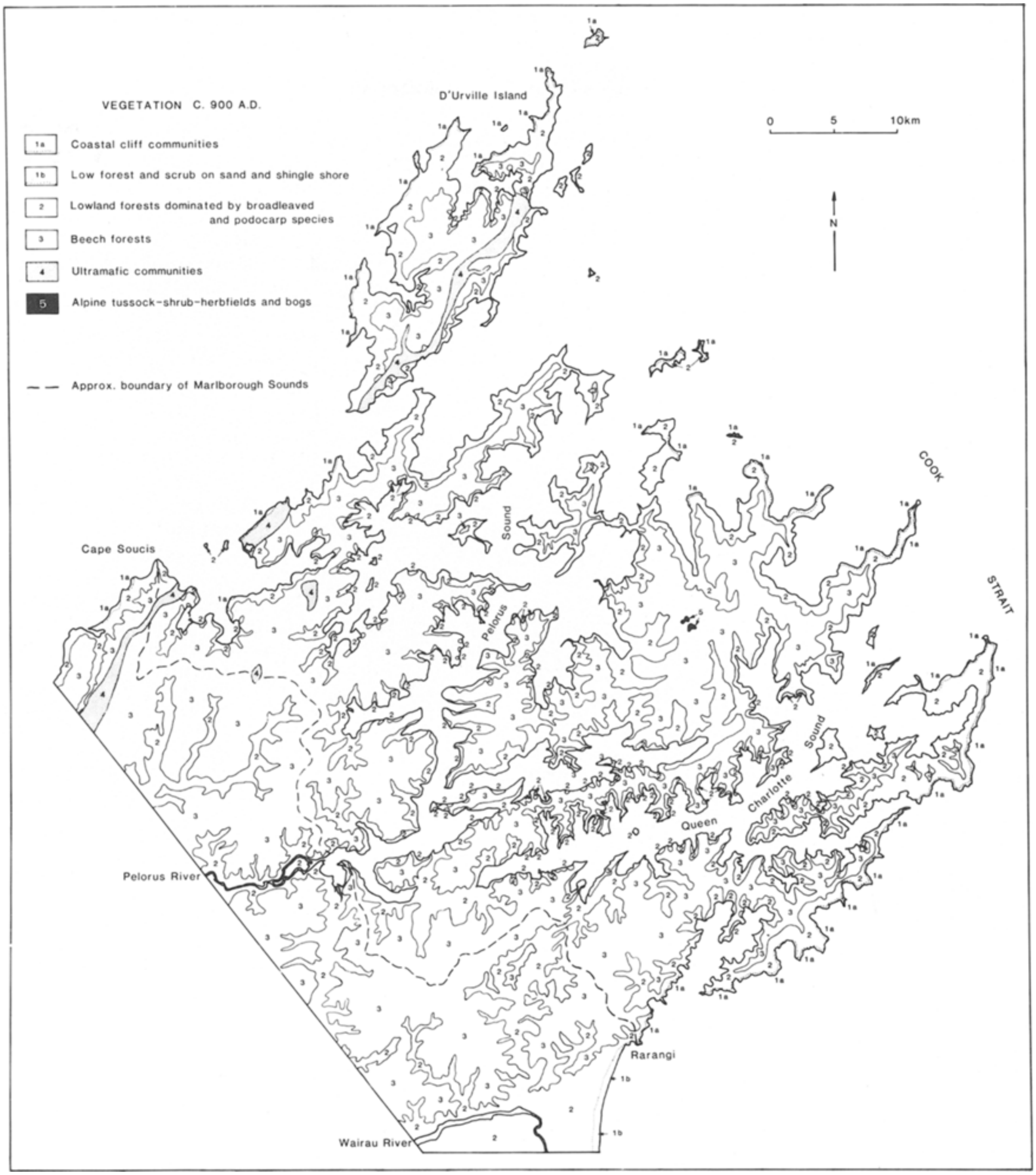

Fig. 9 Distribution of major vegetation types of the Marlborough Sounds just before human arrival.

The consistency in the altitudinal changes in and limits of major canopy trees throughout the Marlborough Sounds suggests a fairly simple climatic explanation, as described by P. Wardle (1964, 1971). Thus, it is probable that rimu and hard beech reach their effective altitudinal limit at 500–550 m a.s.l. and red beech at 700 m a.s.l. because they cannot competitively survive in the lower temperatures and higher precipitation at higher altitudes. Likewise, woody forest vegetation cannot grow above about 1100 m a.s.l. The wider occurrence of podzols and podzolised soils above 550 m a.s.l. is thought to result from the effects of both vegetation differences and greater effective precipitation, rather than that the soils directly affect vegetation patterns.

That broadleaved and tall podocarp plant species are dominant in the Marlborough Sounds at lower altitudes and where the soils are relatively more fertile, is presumably a reflection both of their relatively higher demand for nutrients and of the more favourable climate for plant establishment and growth there. In general, beech species seem able to grow in the sites that are less favourable, and mountain beech is probably most tolerant of adversity, in terms of both soil conditions and climate. At altitudes above about 700 m a.s.l. in the western Sounds, and near Mt Stokes, low forests of mainly mountain beech occur on the crests of ridges, while taller forests occur on the sides of ridges and mountain slopes. On the ridge crests the soils are grey coloured, stony and shallow (less than 50 cm thick), and their nutrient status is typically very low. They have been interpreted mainly as imperfectly drained, very strongly leached eluvial podzols resting directly on top of bedrock (Laffan et. al. in prep.). The occurrence of low forests on these high-altitude ridges is thought to result from the effects of both climatic exposure and shallow, impoverished soils. These patterns and interpretations support the more general conclusions of other observers in New Zealand such as P. Wardle (1964) and J. Wardle (1984).

Windthrow has occurred extensively in forests throughout the region, particularly in beech forests on exposed headlands, spurs, and ridges. Windthrow often causes locally severe soil disturbance resulting from exposure of the underlying substrate and mixing of soil materials attached to the roots of overturned trees. The dominance of beech on many coastal headlands and low altitude spurs possibly results from successful and exclusive regeneration following windthrow on such sites, which are generally more freely drained and drier than the adjacent gully sides, on which podocarp and broadleaved species are dominant. It may also reflect the greater tolerance of beeches to summer dryness on these drought-prone sites.

The local occurrence of forest areas dominated by kamahi, red beech, and large podocarps where hard beech could be expected is possibly the result of past land-sliding, wind or fire damage, or that they are relics of times when the climate was different. It is also a possibility, although untested, that in forests of the Marlborough Sounds, the component of these trees, and of broadleaved species in general, increases with increased depth of unconsolidated slope deposits, and that this leads to competitive exclusion of hard beech in some sites. J. Wardle (1984) has suggested that there is greater competition for establishment sites in lower-altitude moister areas, and that kamahi, with its annual production of seed and its ability to sucker or develop epicormic branches, would have a distinct advantage over beeches during the process of forest recovery following partial or total destruction. This would seem to provide sufficient explanation for these apparent forest anomalies in the Marlborough Sounds.

The dwarfing effects on the vegetation of ultramafic soils, and the possession of distinctive and alpine plant species on them, are undoubtedly the result of a nutrient composition inimical to normal plant growth (Lyon et al. 1970, Lee et al. 1983). Only plants tolerant of these conditions, mainly small-leaved or narrow-leaved, can grow in these soils.

On the outer islands, the effect of seabirds is to create soils which are deep, friable, and unusually high in plant nutrients, and it is only the physical effects of the seabirds themselves, the salt-laden winds, and summer dryness that prevent there being a greater profusion of vegetation.

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