New Zealand Journal of Botany

ISSN: 0028-825X (Print) 1175-8643 (Online) Journal homepage: http://www.tandfonline.com/loi/tnzb20

Vegetation and soils of North Island, Foveaux Strait, New Zealand

P. C. Kennedy

Vegetation and soils of North Island, Foveaux Strait, New Zealand

P. C. KENNEDY

Department of Botany, Victoria University of Wellington, Private Bag, Wellington, New Zealand

(Received 15 March 1978)

ABSTRACT

The vegetation and soils of North Island, in the north-east group of muttonbird islands in Foveaux Strait, are described. The flora consists of 10 ferns, 6 monocotyledons, 35 dicotyledons, and 8 adventives (59 species). The main community types are coastal ledge and rock communities, cliff communities of herbaceous plants, coastal shrubland of *Hebe elliptica, Olearia angustifolia,* and *Senecio reinoldii* encircling the island and giving way to *Myrsine chathamica* low forest on the plateau and with *Myrsine australis* low forest in the centre of the island. Scattered over the island are patches of *Muehlenbeckia australis* and *Histiopteris incisa*.

The island is capped with a loess deposit some metres deep which appears to have been largely derived from Foveaux Strait during episodes of low sea level during the Pleistocene. The soils contain many seal gastroliths and have also been strongly influenced by the large colonies of petrels. Chemical analysis of one soil profile under *Myrsine australis* low forest showed very high carbon and nitrogen concentrations, extremely high Truog phosphate and total phosphorus concentration, high cation-exchange capacity values, and high exchangeable potassium and sodium values.

The island is slightly modified by the actions of muttonbirders but there are no introduced mammals or predators.

INTRODUCTION

North or Pikomamuku Island (lat. 46° 49′S, long. 168° 14′E) is the outermost of the north-east muttonbird islands in Foveaux Strait (Fig. 1). The 8-ha island, composed of intrusive rocks, is nearly 40 m high at its peak, marked by a trig established by the Department of Lands and Survey surveyor A. E. Christian in 1950. Three hundred metres to the north-east of North Island is Zero Rock, a small stack some 25 m high (Fig. 2).

At Oban, the closest meteorological station, rainfall averages 1 455 mm per year and the mean annual temperature ranges from 7.5 to 10°c (av. 9.3°c). The climate at North Island is probably drier than at Oban due to some shelter that Stewart Island provides from southerlies.

The muttonbird islands were probably visited as far back as the thirteenth century by the Moa hunters, hunting on Stewart Island, and then by the Murihiku tribes who visited the islands seasonally for muttonbirds (Piper 1961).

North Island is a "beneficial island" administered by the Department of Lands and Survey. The island supports a large population of sooty shearwaters (*Puffinus griseus*) and is "muttonbirded" by permit. The muttonbirders have built a small hut and store at the south-east end and although the island is well tracked it is relatively unmodified. There is no natural water supply except for a few seepages. A total of 28 bird species have been observed (Nilsson 1975). The common gecko (*Haplodactylus granulatus*) has been recorded on Zero Rock (Adams & Cheyne 1968) but has not been seen on North Island.

Previous visits to the island were made by R. T. Adams and J. W. Cheyne in December 1968, and by D. Merton in February 1972, who liberated South Island saddlebacks (*Philesturnus c. carunculatus*) on North and Womens Islands. North Island was later visited by R. J. Nilsson in May 1973 and January 1975 and also by R. Russ during April 1976 (all of Wildlife Service, Department of Internal Affairs). I visited the island with a party from Victoria University of Wellington and officers of the Department of Lands and Survey from 20 to 23 September and from 28 to 31 October 1976.

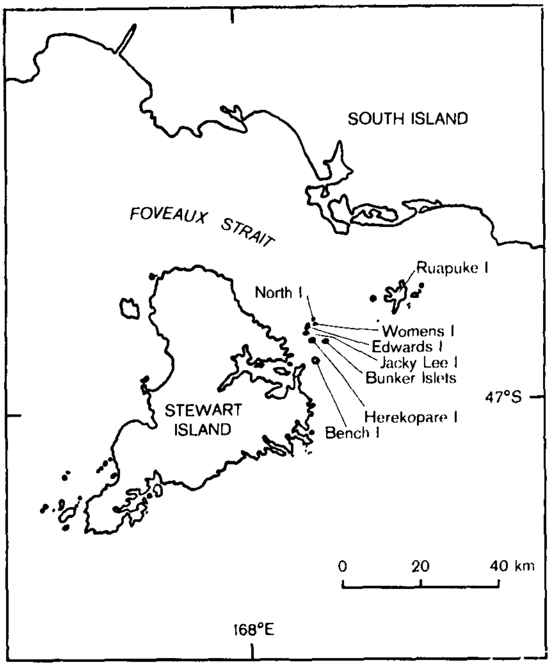

Fig. 1 Location of North Island in Foveaux Strait.

METHODS

Vegetation

The vegetation of the island is described below and is mapped in Fig. 2. The main community types on the island were also described in 8 × 2-m plots. Density, estimated % cover, canopy position, vigour, and distribution in the plot were determined for all the species present (*see* Table 1). The species in a 1-m area around the plot were also recorded. A soil profile was described in each of the first three plots and samples from soil horizons were taken for analysis from the profile under the *Myrsine australis* forest (plot 2). Species recorded are listed in Appendix 1.

Soils

Soil chemical analyses were determined as in Blakemore *et al.* (1972); except for total nitrogen which was determined by the modified indophenol blue method of Searle (1975) using a Technicon AutoAnalyzer II, after 0.5 g of finely ground soil from the < 2-mm soil fraction was digested with 3.25 ml sulphuric acid and a BDH Kjeldahl catalyst

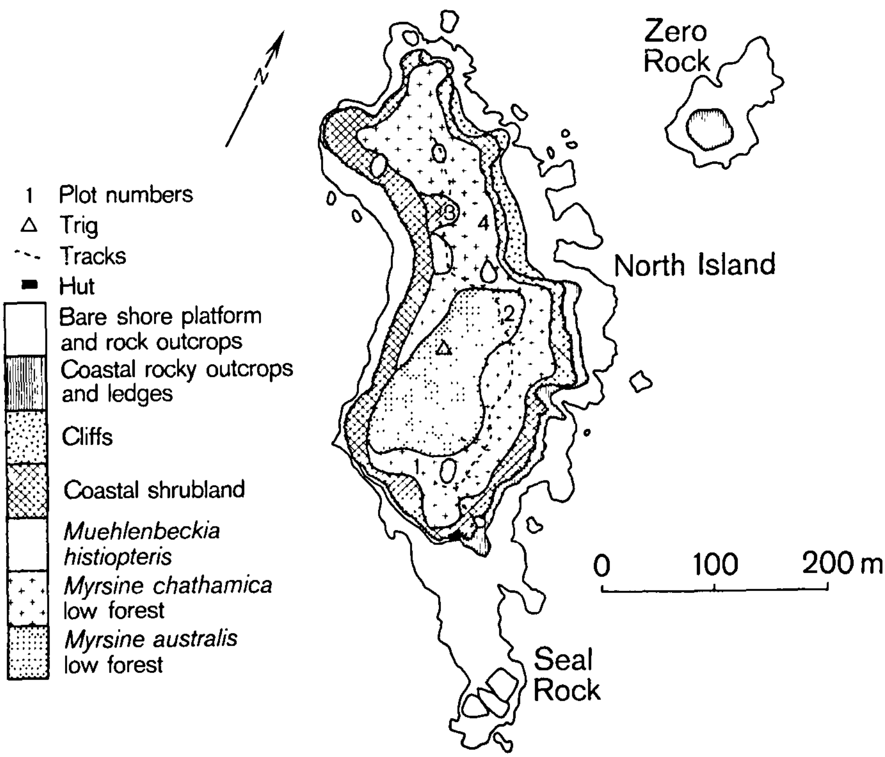

Fig. 2 Vegetation map of North Island.

tablet for 1 hr in a preheated aluminium block (B. Daly, pers. comm.). Exchangeable and soluble calcium and magnesium were analysed by atomic absorption spectrophotometry using a Varian Techtron AA4 Spectrophotometer. Potassium and sodium were analysed by flame emission using a Gallenkamp FH 500 flame analyser. Major element analysis was carried out by X-ray fluorescence spectroscopy (X.R.F.) according to Norrish & Hutton (1969).

Particle size distribution was determined as in Thomas (1973). For mineralogy, <2 mm whole soil was treated with 100 vol. hydrogen peroxide to remove organic matter, then with sodium citrate, sodium bicarbonate with heating, followed by sodium dithionite and continued heating for 10 min to remove iron oxides. Supernatant liquid was rejected after centrifuging, with each treatment. Fine sand was separated from whole soil by sieving. Clay was separated from silt by repeated sedimentation for 5 hr and the mineralogy was determined by X-ray diffraction (X.R.D.). Dried suspensions on glass slides (air dried, glycolated, and heat-treated) and powder mounts were used and a Philips PW 1352 X-ray diffractometer (Cu Kα radiation, 40 Kv, 20 Ma, and a 1-sec-time constant). Allophane was identified using the spot test method of Fieldes & Perrott (1966).

Results of the clay mineral analysis were verified by differential thermal analysis (D.T.A.), carried out using a chrome-alumel thermocouple sited in the centre of the sample, and a standard alloy block; aluminium oxide was used as the standard and a 1°c/min rise in temperature was used.

Fine-sand mineralogy was determined optically and by X.R.D. after magnetic separation of the sample by hand magnet and using a Franz isodynamic separator.

VEGETATION

(Species recorded are listed in Appendix 1)

Coastal rocky outcrops and ledges

Blechnum durum and *Poa astonii* were the commonest plant species along the coast. *Olearia angustifolia* seedlings and small plants of *Hebe elliptica* were found in deeper crevices in which the plants are able to find better anchorage. Other species include *Asplenium obtusatum* subsp. *obtusatum*, *Apium australe*, and occasional *Stilbocarpa lyallii* seedlings.

On the much wider ledges there has been considerable accumulation of peaty soil, here *Carex trifida* forms dense patches, excluding other species except occasional plants of *Senecio biserratus* and *Cirsium vulgare* (Fig. 3). *Senecio sterquilinus* and *Disphyma australe* were discovered on a few wider ledges. *Tetragonia trigyna* was common on such sites.

At the most northerly corner of the island there was a small area of exposed, sloping rocky ledges where *Myosotis rakiura*, *Gentiana saxosa*, and *Salicornia australis* could be found, with scattered plants of *Blechnum durum*, *Olearia*,* *Apium*, and *Poa astonii*.

Close to the hut *Apium*, *Tetragonia*, *Poa astonii*, *Carex*, *Plantago major*, and a *Rumex* species were growing on the small pebble beach. On the shore platform very small specimens of *Asplenium obtusatum* subsp. *obtusatum* and *Olearia* were growing in sheltered crevices and *Tillaea moschata* grew in the shallow soil-filled depressions in the rocks just above the high-tide mark.

Cliffs

High steep cliffs occur on the north-west to north-east sides of the island. Those at the north-west end are very steep and vegetated only on small ledges with plants mentioned for this type of site in the previous section (Fig. 4). The two bays along the north-east side of the island near Zero Rock have cliffs of 40–50° slope covered in part by loose soil held in place by mat plants. The northerly bay is vegetated on the upper portion of the cliff, the lower part being exposed rock. At the top of the cliff *Olearia* gives way to a low (1 m) fringe of *Hebe*, below this mats of *Disphyma* extend down the face. On the gentle slopes near the cliff top species include *Poa astonii*, *Apium*, *Asplenium obtusatum* subsp. *obtusatum*, *Salicornia australis*, and *Theleophyton billardieri*.

The cliff face in the southern bay (Fig. 5) is covered in extremely loose soil which is extensively burrowed. Small shrubs of *Hebe* and *Olearia* grow on the face, as well as many of the common coastal herbs. Along the base of the cliff are small patches of *Salicornia* growing on fallen mounds of soil, while at the southern end of the bay *Salicornia* covers the cliff in extensive hanging mats. Zero Rock appears to be vegetated on its upper half with *Disphyma* and a grass (probably *Poa astonii*). Adams & Cheyne (1968) recorded *Carex trifida* on the upper half, *Disphyma* covered a little of the northern face, and *Carex* and *Poa* were found on the south and east faces. There is very little vegetation on the northern side.

*In view of the limited flora, a generic epithet alone is used after the first citation of a species in the text.

Table 1 North Island vegetation and site data.

Plot	N.I. 1	N.I. 2	N.I. 3	N.I. 4
Vegetation	*Myrsine chathamica* low forest	*Myrsine australis* low forest	*Senecio reinoldii-Myrsine chathamica* low forest	*Myrsine chathamica* low forest
Slope °	20	10	15	0
Total veg. cover %	87	89	73	78
Ground cover soil %	60	5	50	70
Ground cover stones %	0	0	20	0
Ground cover veg. %	10	15	10	10
Ground cover litter %	30	80	20	20
Burrowing intensity	petrels moderate	petrels weak	penguin occasional	petrels moderate

	N.I. 1 D	C	S	V	d	N.I. 2 D	C	S	V	d	N.I. 3 D	C	S	V	d	N.I. 4 D	C	S	V	d
Myrsine chathamica																				
adult	6	30	um	v	r	1	1	u	n	o	1	2	u	n	o	4	40	u	v	r
sapling						1		m	n	o	15	20	m	n	r					
seedling											10	1	*l*	v	r					
M. australis	10	40	u	v	r	20	60	u	v	r						6	10	u	n	*l*
Coprosma areolata																				
adult						1	2	u	n	o										
seedling & saplings	3	2	m	s	o	6	2	m	n	r						5	5	m	n	o
C. lucida	1	2	m	n	o	+					1	1	m	n	o					
Hebe elliptica											1	1	m	n	o	3	5	m	n	r
Senecio reinoldii											8	30	u	v	r	3	5	u	s	r
Pittosporum tenuifolium											3	2	m	n	o					
Muehlenbeckia australis	2	1	*l*	s	o						2	5	m	n	o					
Tetragonia trigyna	1	1	*l*	s	o						1	1	*l*	n	o	1	<1	*l*	n	*l*
Senecio biserratus	3	1	*l*	n	o															
Stellaria parviflora	1	1	*l*	n	o															
Stilbocarpa lyallii						+					10	3	*l*	n	o	5	5	*l*	n	*l*
Hydrocotyle moschata											2	3	*l*	n	o	1	<1	*l*	n	*l*
Melicytus lanceolatus						+														
Solanum laciniatum											+									
Carex trifida						+										1	<1	*l*	n	*l*
Asplenium obtusatum	14	8	*l*	v	r	16	5	*l*	v	r	5	2	*l*	v	r	10	2	*l*	n	*l*
A. polyodon											+									
Blechnum durum						55	15	*l*	v	r	4	1	*l*	n	o	5	2	*l*	n	*l*
Histiopteris incisa	3	1	*l*	s	o	6	2	*l*	v	*l*						1	<1	*l*	n	*l*
Hypolepis tenuifolia						+														
Phymatodes diversifolium	+					1	2	*l*	n	*l*										
Polystichum vestitum											1	1	*l*	n	o					

D = density/plot (clumps, trees, mats); C = cover %; S = strata, u = upper, m = middle, *l* = lower; V = vigour, v = vigorous, n = normal, s = suppressed; d = in-plot distribution, o = peripheral, r = regular, *l* = local; + = species in 1-m plot surround.

Coastal shrubland

The coastal shrubland consists of a wide zone of *Olearia angustifolia* on the south-west to south-east slopes of the island and a narrower zone at the top of the cliffs at the north-west end and along the north-east side of the island. *O. angustifolia* is the dominant tree, forming a close canopy, 4–7 m high in most areas. *Senecio reinoldii* remains scattered among the *Olearia* except in the area surrounding plot 3 (Fig. 6), where *S. reinoldii* forms a small, nearly pure stand. *Hebe elliptica* is common as a sub-canopy shrub where enough light penetrates the canopy; *Hebe* occurs as a pure fringe outside the *Olearia* at the cliff edges and as a dominant species in patches among the *Olearia* on the more broken slopes at the southern end of the island (Fig. 7). All of this zone is burrowed to some extent, but at the northern end of the island there are much greater quantities of *Olearia* litter on the ground, probably indicating lower petrel numbers. The coastal scrub at the most northerly tip of the island contains an isolated patch of *Coprosma repens* and *Solanum laciniatum*. *Lepidium oleraceum*, *Sonchus oleraceus*, and *Poa annua* were also found here. *Scirpus nodosus* and *Myosotis rakiura* occur in rocky areas near the outer edge of the *Olearia* zone.

Fig. 3 A large ledge on the eastern side of the island covered in *Carex trifida* and *Poa astonii*. *Hebe elliptica* occurs in the upper left.

Fig. 4 Steep cliffs at the north end of the island. Above them lies a narrow band of *Poa astonii,* then low plants of *Olearia angustifolia* grading into taller *Olearia* and *Senecio reinoldii* forest. Kelp beds occur at the base of the cliff.

Fig. 5 The southern bay on the east side of the island. The cliff sides are covered in mats of *Salicornia australis* and *Disphyma australe.*

In several places the *Olearia* is broken by patches of *Carex trifida, Hierochloë redolens, Poa astonii,* and *Tetragonia trigyna,* with occasional patches of *Stellaria parviflora* under the dense *Carex.*

Myrsine chathamica low forest

Away from the coastal fringe *Myrsine chathamica* low forest covers most of the plateau on the island (Fig. 8). *Coprosma areolata* is the most abundant shrub or small tree associated with *Myrsine,* whose canopy varies from 4 to 7 m in height. Both species produce abundant seedlings which form thickets in places. *Coprosma lucida, Myrsine australis,* and *Pittosporum tenuifolium* var. *colensoi* are frequent with occasional *Melicytus lanceolatus* growing up to 4 m high. A few small trees of *Aristotelia serrata* grow on the plateau in this zone. *Myrsine chathamica* appears to be more wind tolerant than *M. australis,* the apparent climax tree on North Island. *Myrsine chathamica* is less erect, more deeply rooted, and more wind tolerant than *M. australis,* and replaces *M. australis* where it has been toppled by wind or burrowing. *Stilbocarpa lyallii* (in flower on 22 September) was common over all of the plateau.

Myrsine australis low forest

This community occurs in the central portion of the island towards the southern end surrounding the trig station. The forest has a canopy of up to 8 m in places and dwindles to < 3 m at the trig station where trees are heavily windshorn (Fig. 9). *Coprosma lucida, C. areolata, Melicytus lanceolatus, Hebe elliptica, Aristotelia serrata,* and *Griselinia littoralis* are common canopy trees among the *Myrsine australis.* Other tree species include *Pittosporum tenuifolium* var. *colensoi, Myrsine chathamica,* one plant of *Fuchsia excorticata,* and rare plants of *Coprosma foetidissima. Clematis paniculata* scrambles over the *Myrsine* canopy beside the trig. On the plateau under *M. australis* the fern cover is extensive; *Phymatodes diversifolium* is abundant, and occurs with *Asplenium obtusatum* subsp. *obtusatum, Blechnum durum,* and rare plants of *A. polyodon.* At the highest point on the island large boulders form an outcrop which protrudes from the canopy (Fig. 6). *Pyrrosia serpens* and *Asplenium flaccidum* subsp. *flaccidum* occur among these rocks.

Fig. 6 View from the trig to the north end of the island. *Olearia angustifolia* forms a band around the shore to the left and dark *Myrsine chathamica* shows in the canopy in the centre and to the right. Plot 3 of *Senecio reinoldii* shows at the upper centre as the slightly lower uneven patch in the canopy.

Fig. 7 View from the trig towards the south end of the island, showing the wind-shorn canopy. Womens Island is to the immediate left, with the Bunker Islands behind. Herekopare Island is at the upper right with Bench Island to the left of it.

Fig. 8 *Myrsine chathamica* low forest (plot 1). Large clumps of *Asplenium obtusatum* subsp. *obtusatum* and some *Blechnum durum* occur in the foreground.

Fig. 9 *Myrsine australis* low forest (plot 2). There is an extensive ground cover of *Blechnum durum*. Shrubs of *Coprosma areolata* occur in the foreground and *Myrsine chathamica* at the upper right.

Muehlenbeckia australis — Histiopteris incisa community

This association can be found as small isolated patches over the island and appears to be the result of clearing for gardens by the muttonbirders. The *Muehlenbeckia* and *Histiopteris* form an extremely dense entanglement with *Muehlenbeckia* scrambling over the *Histiopteris* to a height of 2 m. Regrowth of scrub species is considerable in most patches. Seedlings of *Senecio reinoldii*, along with occasional *Hebe elliptica*, *Griselinia littoralis*, and *Myrsine chathamica* are present, many with *Muehlenbeckia* scrambling all over them. Occasional plants of *Blechnum durum*, *Asplenium obtusatum* subsp. *obtusatum*, and *Pteridium aquilinum* var. *esculentum* occur beneath the *Histiopteris*. At the northern end of the island there is a small clearing around the track, which still contained potatoes and sow thistle (*Sonchus oleraceus*).

SOILS

The Foveaux Strait islands near North Island have accordant plateau surfaces which were probably marine planed during the higher sea level of the Oturian (Suggate 1965) interglacial. The soils of Bench Island are placed in the Rakiura soil set (Leamy 1974). The soils have been mapped as being derived from potassic diorite (N.Z. Department of Scientific and Industrial Research Soil Bureau 1973).

On North Island soils were examined in the vegetation plots NI1, NI2, and NI3 (descriptions in Appendix 2). All upper horizons are dark friable organic silts or silt loams and rest on compact yellow-brown clay loams that grade into clays. Some bleached sand grains occur in the upper B horizon under *Senecio reinoldii* but not under *Myrsine australis* despite acid conditions (pH 3.0). The three soil profiles characterise most of the soil pattern except for a small area at the northern tip of the island which has a layer of slightly organic sand resting on base rock. The sand appeared to have been blown up from the well weathered rocks below.

One of the most noticeable soil features is the abundance of small, coloured, well rounded pebbles, < 3 cm diameter (reds, greens, greys, and cream) on the surface and through the soil profile. The pebbles were found in low numbers in plot 1 and 2 but in much larger numbers in the soil under *Senecio reinoldii* (plot 3). Most were small, but several > 3 cm diameter were found deeper in the profile. Four pebbles collected from the profile in plot 3 were blackened on one half, possibly as the result of a fire. The stones from plot 3 included medium- to fine-grained granites, veined quartz, sandstone, cherts, argillites, and minor quantities of andesites. Pre-Pleistocene and Pleistocene gravels cover most of the Foveaux Strait floor. The pebbles within the soils are similar to those taken from the bed of Foveaux Strait near North Island (D. J. Cullen, pers. comm.) where most pebbles belonged to the Porphyrite–diorite and Granite–gneiss assemblages of Cullen (1967).

Burrows (1972) described gastroliths in the soils of Taumaka Island off Westland. These stones were also of a diverse geological origin and appeared to have been voided by southern fur seals. Very few seals were observed around North Island and those seen were confined to the area around Seal Rock. It is probable that the island was a more important seal colony in the past. The extent to which penguins may have contributed to the many small stones on the island is unknown. In all three profiles examined, gastrolith abundance appeared to decrease with depth (*see* Fig. 10).

At the top of the cliff in the large bay on the north-east side of the island (Fig. 5) the soil was exposed *in situ*. Within the exposure the presence of (presumed seal) gastroliths as several diffuse and discrete bands seems to suggest that intense burrowing has disrupted these bands in the other profiles examined (Fig. 10). The cliff exposure with its bands of gastroliths appears to have a low organic matter content in its lower section which suggests that differing intensities of seal occupation have occurred in the past on an island with an extremely sparse vegetation. Seal occupation may also have been continual and the discrete layers of pebbles may have formed as a result of wind winnowing the soil away and concentrating pebbles from a diffuse distribution through the profile into bands (D. Cullen, pers. comm.). This latter hypothesis suggests alternating periods of accumulation and erosion. The sequence of aeolian accumulation observed in this profile could represent two stadial/interstadial episodes since the end of the Oturian interglacial.

Soil chemistry

The soils on North Island are influenced by the many nesting petrels, which have probably been adding nutrients to the soil for some thousands of years.

The Rakiura soils on Stewart Island are moderate to strongly acidic, have very low Truog phosphate values, medium carbon and nitrogen values, low to high cation exchange capacity, and low base saturation. Exchangeable calcium is very low, magnesium medium, potassium low, and sodium is low to high (L. C. Blakemore, pers. comm.).

On North Island very high nitrogen values were found in the upper horizons on the plateau. Loss on ignition was high and decreased with depth. Very

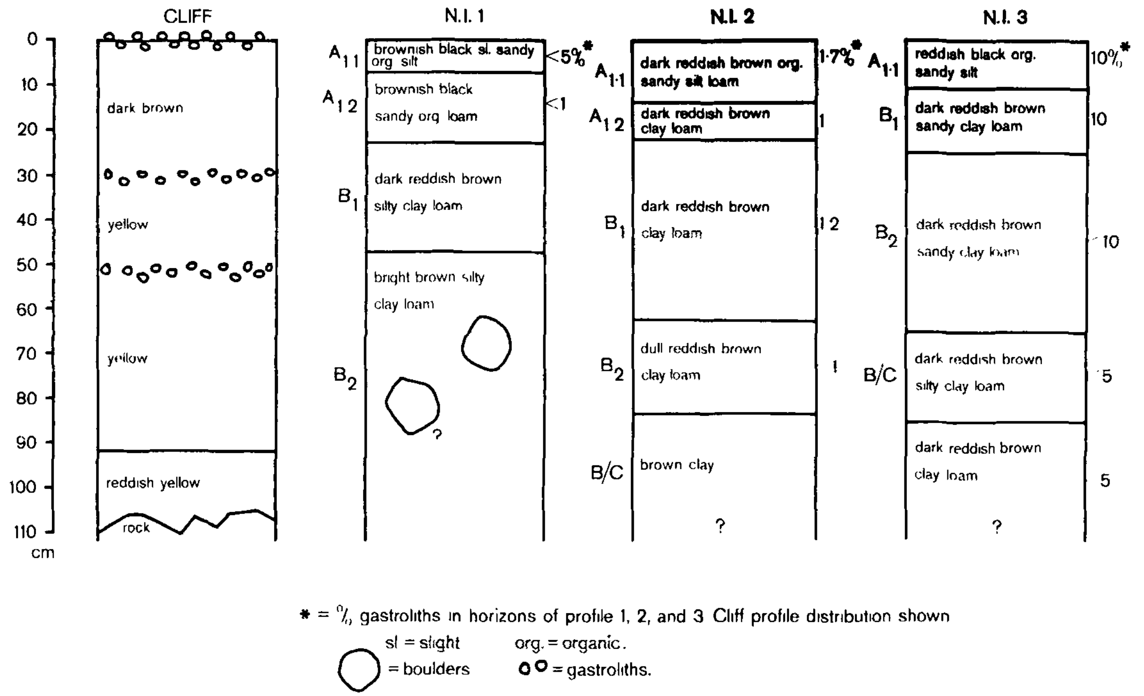

Fig. 10 Vertical sections comparing the cliff section with the three soil profiles examined on North Island.

high organic carbon values were recorded, producing high C/N ratios for the upper horizons (Table 2). High carbon values in the lower, 2/3 and 2/4, horizons are associated with the incorporation of organic matter into the subsurface soil by past burrowing by birds. The downward movement of soluble nitrogen forms (nitrate) may account for high nitrogen values in lower horizons. Truog phosphate concentrations were extremely high throughout the profile (Table 2). On islands inhabited by sea birds, the citric acid-P concentration in the surface horizons has been found to rise with bird numbers (Ward 1961). The high values in lower unburrowed horizons may be attributable to the mobility of phosphorus at high concentrations in upper horizons (Cox *et al.* 1967).

Large quantities of organic matter and also appreciable clay content give the soil high cation exchange properties; but the extremely acid nature of the soil is linked with lower base saturation values. The soil is supplied with an excess of "soluble ions", except calcium; all showed accumulation in the subsoil, chloride reaching high concentration. Exchangeable calcium in this North Island soil is considerably lower than that in the Rakiura soils. Exchangeable magnesium is similar and exchangeable potassium and sodium are much higher.

Analyses of NI 2/4, 2/5, and 2/6 for total major elements by X.R.F. are shown in Table 3. Total phosphorus is high. The samples were also high in iron but low in aluminium and magnesium. Table 3 contains comparative data for four greywacke-derived loess samples from the South Island and a granite and a norite rock sample from Bluff.

Soil mineralogy

Clay minerals are dominated by quartz. Illite was common in all of the lower horizons and small quantities of feldspar (probably albite) were found in horizons 3, 4, and 5. Chlorite was found in all the horizons, with the largest quantity in horizon 6. Allophane was found both in horizon 3 and horizon 6 (Table 4). D.T.A. analysis of clays in all samples confirmed the presence of quartz, illite, and allophane, and an endothermic peak at 380°c which was present in all samples was possibly geothite. Clay minerals found in Rakiura soils of Stewart Island include quartz (abundant), kaolinite/halloysite (abundant), allophane (abundant), and gibbsite (low) (L. C. Blakemore, pers. comm.).

In the silt fractions, apart from quartz, feldspar minerals were the commonest mineral. A combination of feldspars was present. Albite was present in

Table 2 North Island, plot 2, soil analyses.

	Sample number 2/2	2/3	2/4	2/5	2/6
Depth cm	2–13	13–21	21–61	61–81	81–111
Horizon	$A_{1\cdot 1}$	$A_{1\cdot 2}$	B_1	B_2	B/C
Texture	sandy loam	clay loam	clay loam	clay loam	clay
>2 mm organic material %	2.3	0.9	0.5	0.5	0.0
>2 mm gravel %	1.7	0.2	1.2	0.1	0.0
<2 mm %	96	98.9	98.3	99.4	100
Coarse sand %	8	3	2	3	2
Fine sand %	54	30	18	17	11
Silt %	28	38	37	35	34
Clay %	10	29	43	45	52
pH (air dry)	3.10	2.90	2.90	2.90	2.95
C %	24	25	10	0.2	n.d.
Loss on ignition %	53	50	27	19	13
N %	1.56	1.3	0.65	0.32	0.15
C/N	15	19	15	1	1
Truog P mg %	142	134	182	142	179
Cation-exchange capacity m.e. %	91	94	67	56	41
Exchangeable, m.e. %					
Ca	0.4	0.3	0.1	0.1	0.03
Mg	2.1	1.3	0.5	0.6	0.2
K	2.1	1.4	2.1	2.1	0.9
Na	2.4	1.9	1.3	1.8	0.2
Base saturation %	8	5	6	8	1
Soluble Cl, m.e. %	1.2	0.8	0.5	1.1	1.8
Ca	n.d.	n.d.	n.d.	n.d.	n.d.
Mg	0.2	0.1	0.1	0.2	0.7
K	0.2	0.2	0.15	0.25	0.2
Na	1.1	0.9	0.6	0.5	0.7

n.d. = not detectable.

Table 3 Total element analysis of North Island soil samples.

	Fe_2O_3	MnO	T_1O	CaO	K_2O	P_2O_5	S_1O_2	Al_2O_3	MgO	Na_2O	L.O.I.‡	Total
North Island 2/4	12.55	0.04	1.34	1.37	1.18	4.77	43.98	6.80	0.31	0.60	17.14	100.08
2/5	11.91	0.05	1.31	1.58	1.35	4.76	48.83	8.22	0.44	0.75	19.81	99.01
2/6	13.94	0.05	1.32	1.60	1.47	4.54	49.12	11.47	0.49	1.54	14.12	99.66
Tautuku silt loam*	7.00	0.06	1.02	2.66	1.82	0.05	—	24.7	2.66	2.94	—	—
Wikiwi silt loam*	7.84	0.13	0.85	3.36	1.12	0.07	—	20.9	2.16	2.52	—	—
Timaru silt loam*	5.60	0.03	0.68	1.24	1.12	0.09	—	19.0	1.00	2.38	—	—
Tekapo silt loam*	4.20	0.03	0.62	2.10	1.40	0.03	—	10.9	1.83	3.22	—	—
Norite–Bluff†	13.08	0.24	1.51	8.98	0.93	1.22	51.46	15.43	4.53	3.41	—	100.8
Biotite–Muscovite Granite–Bluff†	1.80	0.05	0.28	1.35	4.99	0.63	72.55	13.88	0.43	3.46	—	99.4

*From N.Z. Department of Scientific and Industrial Research Soil Bureau (1968). Element % has been converted to oxide %. C horizons.
†Samples 241 and 13 *in* Challis & Newman (1971) respectively.
‡L.O.I. = Loss on ignition at 1 000°c.

all horizons, but commoner in 2 and 6. Andesine and oligoclase were common throughout. Small quantities of epidote occurred throughout (Table 4).

Quartz was the dominant fine-sand mineral. In horizon 2 the quartz grains were well rounded; some were strained, indicating some metamorphic derivation; others were clear, probably derived from granite (J. Gibb, pers. comm.). In horizons 3, 4, 5, and 6 the quartz grains were angular to sub-rounded, which indicates that some quartz was derived on site. No volcanic glass was seen in any sample. Magnetite was the most abundant heavy mineral. Piedmontite, augite (grains well rounded), sillimonite, and lithic fragments were present with traces of horneblende and

Table 4 Mineralogy, North Island, plot 2.

	Sample numbers 2/2	2/3	2/4	2/5	2/6
Clay*					
Quartz	Ab	Ab	Ab	Ab	++
Feldspar–albite	tr	++	+	+	
Illite	+	++	++	++	++
Chlorite	+	+	++	++	+++
Allophane		++			Ab
Silt*					
Quartz	Ab	Ab	Ab	Ab	Ab
Feldspar–albite	++	+	+	+	++
Andesine–oligoclase	++	++	++	++	++
Epidote group	+	+	+	+	+
Fine sand %†					
Quartz	74	70	68	80	59
Magnetite	14	17	26	11	23
Piedmontite	8	8	2	4	6
Augite	4	4	2	4	tr
Sillimonite		tr			6
Lithic fragments		tr	2		6
Hornblende		tr			
Epidote	tr				

* Estimated by peak heights.

† Magnetite was determined by weight, the remaining heavy minerals and quartz were estimated visually from the remaining material.

Ab = abundant, tr = trace, + = 5–10%, ++ = 10–20%, +++ = 20–60%.

epidote. X.R.D. analysis also showed the presence of some feldspar, probably anorthoclase (Table 4).

The fine soil on the island is well sorted and probably derived as loess from a variety of sources. In all three profiles there were no weathered diorite fragments, elsewhere on the island, where the soil rock contact could be seen, no weathered contact was observed. Much aeolian material is likely to have been derived from the Foveaux Strait area during periods of low sea level during glacial episodes. Higher proportions of fine sands are distributed in Foveaux Strait around the major river mouths and parallel to the submerged 35-fathom shore line east of Ruapuke Island (Cullen 1967). The fine- to medium-grade sands in Foveaux Strait contain much dark mica and magnetite (Cullen 1967).

Other material is likely to have been derived from beyond Foveaux Strait; the loess deposits of the nearby Southland plains are derived from rock types ranging from schists to the Southland greywackes (Raeside 1964). The long distance from Southland will have aided in sorting, particularly in the silts which are dominated by quartz and the feldspars andesine and oligoclase, and the fine sands dominated by quartz, magnetite, and piedmontite.

EFFECTS OF MAN AND SEA BIRDS ON THE VEGETATION

North Island is heavily burrowed by petrels. Fairy prions (*Pachyptilla turtur*), broad-billed prions (*P. vittata*), sooty shearwaters (*Puffinus griseus*), and diving petrels (*Pelecanoides urinatrix*) visit the island from late spring to early winter to breed in burrows dug in the soil. Broad-billed prions, fairy prions, and diving petrels have constructed burrows in most of the coastal fringe among *Olearia angustifolia* and *Hebe elliptica;* the most intense burrowing occurs on the medium slopes (30°) on the south-west and north-east sides of the island where the many diving petrels and fairy prions have completely burrowed large portions of the slope under *Olearia,* producing small screes of loose soil. On the coast, ground cover is often reduced to scattered *Poa* and *Tetragonia,* whereas on the plateau intense burrowing reduced the ground cover to scattered *Phymatodes diversifolium.* On the plateau and among the upper *Myrsine chathamica* there were burrows of sooty shearwaters, diving petrels, and white-faced storm petrels (*Pelagodroma marina*). The ground is kept bare of vegetation by the continual movement of the birds across the ground, their tendency to drag twigs and leaves into their burrows to line nests and the ejection of soil from the burrow during its excavation.

On the southern muttonbird islands Fineran (1973) found that burrows were chiefly distributed in the top 45 cm of peat in the horizon where tree roots were best developed. On North Island burrowing appeared to be limited to the more friable upper horizons.

Several pairs of yellow-eyed penguins (*Megadyptes antipodes*) were nesting on the plateau (10+ pairs, Nilsson 1975) among *Senecio reinoldii* and *Myrsine australis* and had made definite tracks from their nest sites to the shore. Many little blue penguins (*Eudyptula minor*) were breeding on the island and their continual movement up and down the slopes to court and breed must have a considerable effect on the ground cover.

Because of the sea birds the soil is extremely nutrient rich, particularly in phosphorus and nitrogen from guano and soluble salts from nasal secretions. The herbaceous *Senecio* species and the nitrophilous grass *Poa annua* (Gillham 1960) appear to benefit from this enrichment. However, the soil is deficient in calcium, a result of acidic conditions, and most of the species of the plateau in particular the *Myrsine* species must be rapid calcium cycling or low calcium demanding species.

South Island saddlebacks appear to be well established on the island (Nilsson 1975). When birds search for invertebrates, the birds are usually seen in the *Myrsine chathamica* scrub using the low-to-medium sized trunks and branches as perches. Saddlebacks are known to spend considerable time searching for wetas on the southern muttonbird islands. Several wetas and some cockroaches (*Celatoblatta subcorticaria*) were found near the hut. One pair of saddlebacks had formed a territory around the hut and could often be seen foraging for insects near the wood piles and drinking from the rainwater supply. *Muehlenbeckia australis* thickets may be important breeding sites (Nilsson 1975); territorial behaviour was observed near several of these thickets on the island. The mixture of vegetation types on this island is important in providing saddlebacks with their varied invertebrate and berry food supply.

Blue shags (*Stictocarbo punctatus steadi*) and Stewart Island shags (*Leucocarbo carunculatus chalconotus*) are nesting on the north-west side of Zero Rock where they produce much guano.

Visits by muttonbirders, who have made tracks and cut trees for firewood, have resulted in the vegetation being modified. There appears to be no evidence of recent fire on the island, but fragments of charcoal were found in plot 2 at a depth of 12–60 cm. Small areas of the island have been cleared for growing potatoes. Only one area still contained a few potatoes: all of the others are covered in *Muehlenbeckia australis* and *Histiopteris incisa.*

There are several plant species which have been either introduced or are adventive. Most appeared to have been introduced by visitors to the island; *Holcus lanatus, Plantago major,* and a *Rumex* species occur by the hut; *Solanum tuberosum* and *Sonchus oleraceus* in the abandoned garden. *Stellaria parviflora* is common beside tracks near the hut and appears to be introduced. An *Agrostis* sp. and *Poa annua* are confined to the northern corner of the island and *Cirsium vulgare* occurs on the north-east side of the island; they may have been blown from a neighbouring island. *Coprosma repens* and *Solanum aviculare* are also to be found on this corner of the island.

DISCUSSION

In general the vegetation of North Island resembles that on nearby Edwards Island (Motunui) rather than that found on Womens, Herekopare, and Jacky Lee Islands (Nilsson 1975). Cliff and shore vegetation appears similar to that on Womens Island (Johnson 1976), except that *Myosotis rakiura* and *Gentiana saxosa* were found on North Island but not on Womens; *Linum monogynum, Chenopodium ambiguum, Dichelachne crinita,* and notably *Poa foliosa* were found on Womens but not on North. The coastal halophytic herbs *Samolus repens* and *Selliera radicans,* although abundant on the nearby mainland, are not present on both islands (Johnson 1976).

The central plateau vegetation of the island contains more plant species than any other association on the island, 25 species compared to 21 in the *Myrsine chathamica,* 14 in the *Olearia angustifolia* scrub, 17 on the cliff, 20 on the rocks, and 10 in the *Muehlenbeckia* tangles. In these stands, vegetation is similar to the central stands on Bird Island (Fineran 1966) and the "coastal" vegetation seen by me on Bench Island. Species such as *Clematis paniculata, Fuchsia excorticata,* and *Pseudopanax colensoi* found in coastal forest near Oban were present as single specimens only. The rarity of mainland species on North Island is to be expected as most of these species are dispersed by forest birds; at North Island they probably depend on the occasional visits of native pigeons (*Hemiphaga novae-seelandiae*) and blackbirds (*Turdus merula*) for dispersal. Most of the other species on the island appear to be well adapted for wind dispersal, particularly the herbaceous *Senecio* species. The seeds of *Cardamine debilis* may have been introduced by sea birds. These central stands of greater species diversity have been noted on sheltered sites on some of the south-west muttonbird islands (Fineran 1973) and have been suggested as being relicts of larger stands when the islands were larger (Fineran 1966). These stands appear to be part of the normal succession on these islands: *Hebe elliptica–Olearia angustifolia–Senecio reinoldii* → *Myrsine chathamica* → *Myrsine australis* → *Weinmannia racemosa–Metrosideros umbellata;* with the successional stage being dependent on size of the island, disturbance, exposure from wind and salt, and distance from Stewart Island. *Myrsine chathamica* has a discontinuous distribution among the islands. It is abundant on Womens, Bird, and Edwards and there is a single specimen on Herekopare (Johnson 1976).

The small Foveaux Strait islands are particularly important because of the dominance of tree composites in their coastal vegetation and the mixed composition of its flora, containing elements of vegetation from the South Island, Stewart Island, the other offshore islands nearby, and the Subantarctic Islands. The islands are also inhabited by many breeding sea birds. North Island in particular has two species of penguin and six species of petrel breeding on it. A total of 14 species of sea bird and 14 land birds have been sighted, most resident on this small island. The land birds include healthy populations of both Stewart Island fern bird (*Bowdleria punctata stewartiana*) and South Island saddlebacks. The lack of predators (Nilsson 1975) such as wekas and rats, prevalent on nearby islands, and the wide variety of vegetation types on North Island makes this island and some of the smaller offshore islands extremely valuable in themselves and for the protection of endangered bird species.

ACKNOWLEDGMENTS

I sincerely thank the Department of Lands and Survey, Invercargill, for their considerable logistics assistance; Mr Bert Youngman and family for their hospitality on Stewart Island; Mr Herbie Hansen and the crew of *Kiwi* for their assistance; Dr D. R. McQueen and all the members of both expeditions for their field assistance.

Dr B. V. Sneddon (Department of Botany, Victoria University of Wellington), Mr A. P. Druce (Botany Division, DSIR, Taita), and Dr P. J. Brownsey (National Museum, Wellington) for their help in plant identification. Miss M. MacIntyre for her help in identifying the cockroach species.

I also thank Mr Bill Yardley and Mr Kerry Stevens for their invaluable help with X.R.D. and D.T.A. analysis, Mr A. Lauder for his assistance in examining the gastroliths, and Mr J. Gibb for his optical analysis of the fine sands (all of the Department of Geology, Victoria University of Wellington).

Margaret Macdonald, Dr Peter Harper, Mr C. G. Vucetich, and Dr D. R. McQueen read the manuscript and provided useful criticism.

I am grateful to Mrs Olga Vincent for typing the manuscript.

APPENDIX 1: PLANT SPECIES RECORDED ON NORTH ISLAND

Specimens have been deposited in the herbarium of the National Museum (WELT). Plant names are based on Allan (1961), Moore & Edgar (1970), Brownsey (1977) for the genus *Asplenium*, and Drury (1974) for the erechtitoid Senecios, except where otherwise noted.

Abundance and distribution are given by the symbols: A = abundant, F = frequent, O = occasional, R = rare, W = widespread, P = plateau only, S = summit only, C = coastal fringe, L = local only.

Pteridophytes		
Asplenium polyodon	PR	
A. flaccidum subsp. *flaccidum*	SR	WELT P 9220
A. obtusatum subsp. *obtusatum*	WF	WELT P 9222–5
Blechnum durum	WA	WELT P 9221
Histiopteris incisa	LPA	
Hypolepis tenuifolia	PR	WELT P 9218
Phymatodes diversifolium	WF	
Polystichum vestitum	PR	WELT P 9219
Pteridium aquilinum var. *esculentum*	PO	
Pyrrosia serpens	SR	
Monocotyledons		
Carex trifida	CA	WELT S 2061
Hierochloë redolens (Vahl) Roem. et Schult.	CF	WELT S 2060
Poa astonii Petrie	CA	WELT S —
Scirpus cernuus	CF	
S. nodosus	CO	
S. praetextatus	CF	WELT S 2063
Dicotyledons		
Apium australe	CF	WELT 52079
Aristotelia serrata	PF	
Clematis paniculata	SR	WELT 52077
Coprosma areolata	PF	WELT 52067, 69
C. foetidissima	PR	
C. lucida	PF	WELT 52066
C. repens	CR	WELT 52068
Cardamine debilis	PO	WELT 52085
Disphyma australe	CA	
Fuchsia excorticata	SR	WELT 52072
Gentiana saxosa	CO	WELT 52076
Griselinia littoralis	PF	
Haloragis erecta	WO	WELT 52080
Hebe elliptica	WA	
Hydrocotyle moschata	PF	WELT 52080
Lepidium oleraceum	WO	
Melicytus lanceolatus	PF	WELT 52071
Muehlenbeckia australis	LPA	
Myosotis rakiura	CO	WELT 52078
Myrsine australis	PA	
M. chathamica	PA	WELT 52070
Olearia angustifolia	CA	
Pittosporum tenuifolium var. *colensoi*	PF	WELT 52064
Pseudopanax colensoi	PR	WELT 52065
Salicornia australis	CA	
Senecio biserratus	WF	WELT 52087
S. minimus	PR	WELT 52088
S. reinoldii	CF	
S. sterquilinus	CO	WELT 52083
Solanum laciniatum	WO	
Stellaria parviflora	WF	WELT 52084
Stilbocarpa lyallii	PA	
Tetragonia trigyna	CA	
Theleophyton billardieri	CF	WELT 52075
Tillaea moschata	CF	WELT 52082
Adventive species		
Agrostis sp.	CR	
Cirsium vulgare (Savi) Ten.	CR	
Holcus lanatus L.	LCR	
Plantago major L.	CO	WELT 52081
Poa annua L.	CR	WELT 52062
Rumex sp.	CO	
Solanum tuberosum L.	PR	
Sonchus oleraceus	CO	WELT 52073–4

APPENDIX 2: SOIL PROFILE DESCRIPTIONS

North Island 1. *Myrsine chathamica* low forest

L	1–0 cm	Loose dry *Myrsine chathamica* leaves, fruit, and twigs.
$A_{1.1}$	0–5 cm	Very friable, brownish black (5YR 2/2*), slightly sandy organic silt with weak crumb structure, containing abundant fine and coarse roots. Less than 5% fine gravels. Diffuse boundary.
$A_{1.2}$	5–21 cm	Firm, brownish black (5 YR 2/2), organic "sandy" loam with a moderate to medium nut structure breaking to a crumb. Abundant roots and less than 1% fine gravel. Indistinct boundary.
B_1	21–46 cm	Massive, firm, dark reddish brown (5 YR 3/4), silty clay loam, occasional roots. Distinct boundary.
B_2	46 to below 74 cm	Firm, compact, bright brown (7.5 YR 5/6), silty clay loam. Massive, no roots and occasional boulders.

*Standard Munsell colour notation.

North Island 2. *Myrsine australis* low forest

L	2–0 cm	Loose *Myrsine australis* litter and twigs.
$A_{1\cdot1}$	0–11 cm	Very friable, dark reddish brown (2.5 YR 2/2), organic sandy silt loam with weak crumb structure, abundant fine roots. 1.7% fine-coarse gravel. Diffuse boundary.
$A_{1\cdot2}$	11–19 cm	Friable, dark reddish brown (2.5 YR 2/2), clay loam with moderate nut structure and 1% fine gravels, occasional roots. Indistinct boundary.
B_1	19–59 cm	Firm, moist, dark reddish brown (5 YR 3/2), clay loam containing 1.2% fine and medium gravels, and occasional charcoal fragments, occasional roots. Indistinct boundary.
B_2	59–79 cm	Massive wet, dull reddish brown (5 YR 5/4), clay loam, containing occasional roots and one piece of fine gravel. Distinct boundary.
B/C	79 to below 109 cm	Massive, wet, brown (7.5 YR 4/4), clay, no roots or gravels.

North Island 3. *Senecio reinoldii/Myrsine chathamica* low forest

L	2–0 cm	Loose decaying *Senecio reinoldii* litter.
$A_{1\cdot1}$	0–8 cm	Very friable, reddish black (2.5 YR 2/1), organic (sandy) silt with very weak, fine crumb structure. Abundant roots. 10% gastroliths consisting of coarse gravels. Diffuse boundary.
B_1	8–22 cm	Firm, very dark reddish brown (2.5 YR 2/2), sandy clay loam with moderate nut structure containing bleached sand grains and frequent roots. 10% gastroliths, both coarse gravels and small stones. Indistinct boundary.
B_2	22–62 cm	Very friable, sandy clay loam, colour as above, with strong nut structure, containing occasional bleached sand grains and occasional roots. Less than 10% gastroliths. Distinct boundary.
B/C	62–82 cm	Firm, silty clay loam, very dark reddish brown (10 YR 2/2), with moderate large nut structure, rare roots. Less than 5% gastroliths. Distinct boundary.
	82 to below 98 cm	Firm, massive, dark reddish brown (2.5 YR 3/3), clay loam.

Gastroliths decreasing down profile.

REFERENCES

ADAMS, R. T.; CHEYNE, J. W. 1968: Muttonbirding. Colonies, Habitats, reports on etc. Stewart Island Group. File of the Department of Internal Affairs. WIL 18/4/6.

ALLAN, H. H. 1961: "Flora of New Zealand". Vol. I. Government Printer, Wellington. 1 085 pp.

BLAKEMORE, L. C.; SEARLE, P. L.; DALY, B. K. 1972: A. Methods for chemical analysis of soils. *In* Soil Bureau laboratory methods. *N.Z. Department of Scientific and Industrial Research Soil Bureau Scientific Report 10.*

BROWNSEY, P. J. 1977: A taxonomic revision of the New Zealand species of *Asplenium. N.Z. Journal of Botany 15:* 39–86.

BURROWS, C. J. 1972: The Flora of the Open Bay Islands. *Journal of the Royal Society of New Zealand 2:* 15–42.

CHALLIS, G. A.; NEWMAN, M. 1971: Chemical analysis of New Zealand rocks and minerals with C.I.P.W. norms and petrographic descriptions 1917–57. Part 1: Igneous and Pyroclastic rocks. *N.Z. Department of Scientific and Industrial Research. N.Z. Geol. Survey Bulletin n.s. 84.*

COX, J. E.; TAYLOR, R. H.; MASON, RUTH 1967: Motunau Island, Canterbury, New Zealand. An ecological survey. *N.Z. Department of Scientific and Industrial Research Bulletin 178:* 1–109.

CULLEN, DAVID J. 1967: The submarine geology of Foveaux Strait. Ibid. *184:* 1–67.

DRURY, D. G. 1974: Illustrated and annotated key to the erechtitoid Senecios in New Zealand (Senecioneae–Compositae) with a description of *Senecio diaschides. N.Z. Journal of Botany 12:* 513–40.

FIELDES, M.; PERROTT, K. W. 1966: The nature of allophane in soils Part 3–Rapid field and laboratory test for allophane. *N.Z. Journal of Science 9:* 623–9.

FINERAN, B. A. 1966: The vegetation and flora of Bird Island, Foveaux Strait. *N.Z. Journal of Botany 4:* 133–46.

——— 1973: A botanical survey of seven muttonbird islands, south-west Stewart Island. *Journal of the Royal Society of New Zealand 3:* 475–525.

GILLHAM, MARY E. 1960: Vegetation of tern and gannet colonies in northern New Zealand with a comparative note on colonies in the Bass Strait, Tasmania. *Transactions of the Royal Society of New Zealand 88:* 211–34.

JOHNSON, P. N. 1976: Vegetation and flora of Womens Island, Foveaux Strait, New Zealand. *N.Z. Journal of Botany 14:* 327–31.

LEAMY, M. L. 1974: Soils of Stewart Island (Rakiura), New Zealand. *N.Z. Department of Scientific and Industrial Research Soil Bureau Soil Survey Report 22.*

MOORE, LUCY B.; EDGAR, ELIZABETH 1970: "Flora of New Zealand". Vol. II. Government Printer, Wellington. 354 pp.

NILSSON, R. J. 1975: Survey of Womens and North Islands and an investigation on the 1972 liberation of South Island saddlebacks. 4 January 1975–11 January 1975. File of the Department of Internal Affairs. WIL 33/5/30, Wildlife, Saddleback, North and South Island.

NORRISH, K.; HUTTON, J. T. 1969: An accurate X-ray spectrographic method for the analysis of a wide range of geological samples. *Geochimica et Cosmochimica Acta 33:* 431–53.

N.Z. DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH SOIL BUREAU 1968: Soils of New Zealand. Part 3. *N.Z. Department of Scientific and Industrial Research Soil Bureau Bulletin 26(3).*

——— 1973: Map of parent rocks of New Zealand soils 1:1 000 000. *N.Z. Department of Scientific and Industrial Research Soil Bureau Soil Survey Report 5.*

PIPER, K. E. 1961: Stewart Island, a geographical study. M.A. Thesis. University of Canterbury, New Zealand.

RAESIDE, J. D. 1964: Loess deposits of the South Island, New Zealand, and soils formed on them. *N.Z. Journal of Geology and Geophysics 7:* 811–38.

SEARLE, P. L. 1975: Automated colorimetric determination of ammonium ions in soil extracts with 'Technicon AutoAnalyser II' equipment. *N.Z. Journal of Agricultural Research 18:* 183–7.

SUGGATE, R. P. 1965: Late Pleistocene geology of the northern part of the South Island, New Zealand. *N.Z. Department of Scientific and Industrial Research Geological Survey Bulletin (n.s.) 77:* 1–91.

THOMAS, R. F. 1973: E. Test methods for soil engineering. *In* Soil Bureau laboratory methods. *N.Z. Department of Scientific and Industrial Research Soil Bureau Scientific Report 10.*

WARD, W. T. 1961: Soils of Stephens Island. *N.Z. Journal of Science 4:* 493–505.