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Stratigraphy and landsnail faunas of Late Holocene coastal dunes, Tokerau Beach, northern New Zealand

F. J. Brook*

At least four depositional episodes, each involving cycles of dune instability and sand accumulation followed by stabilisation and soil formation, are represented in a Holocene dune sequence at Tokerau Beach. The first depositional episode followed the maximum post-glacial sea level rise at 6500 years BP, probably with formation of a narrow dune belt landward of the present coastline. The second depositional episode resulted in extensive progradation of the dune belt to about the present coastline from c. 3000–2000 years BP, followed by dune stabilisation and soil formation from c. 2000–900 years BP. The third depositional episode involved vertical dune accretion at c. 900–600 years BP, followed by stabilisation and soil formation after c. 600 years BP. The fourth depositional episode, after 240 years BP, resulted in further vertical dune accretion and localised extensive erosion and reworking of pre-existing dune deposits. Fossil landsnail faunas indicate that there was patchy sandfield and shrubland vegetation on the dune belt from c. 3000–2000 years BP, followed by a mosaic of shrubland and forest from c. 2000–900 years BP. After 900 years BP there was a progressive reversion to patchy shrubland vegetation, but an extensive shrubland cover again became established at c. 600 years BP and persisted until c. 450 years BP, when it was replaced by patchy shrubland and sandfield vegetation.

Dune progradational phases in the first two depositional episodes correlate with and probably developed primarily in response to changes in sea level, whereas subsequent alternating phases of dune stabilisation and build-up are inferred to have resulted in part from the influence of long term cyclical variation in prevailing local wind and wave regimes in Doubtless Bay.

Two stratigraphically distinct, exotic, sea-rafted pumice units are represented in the Tokerau dune sequence. Tokerau pumice (new), which has a primary depositional age of c. 3000 years BP, and Loiseles pumice, which has a primary depositional age between 881 and 516 years BP.

Keywords landsnails, coastal dunes, Holocene, extinction, sea-rafted pumice, Loiseles pumice, Tokerau pumice, northern New Zealand

INTRODUCTION

Fossil landsnail and vertebrate faunas, present in many New Zealand Holocene coastal dune sequences dating back to 6500 years BP, are important indicators of paleoenvironments and species turnover in dunefield biotas. A study of the fossil bird faunas of coastal deposits in Northland by Millener (1981) found that some dune areas, which today are unvegetated or have only low sparse vegetation, supported forest earlier in Holocene time. Radiocarbon

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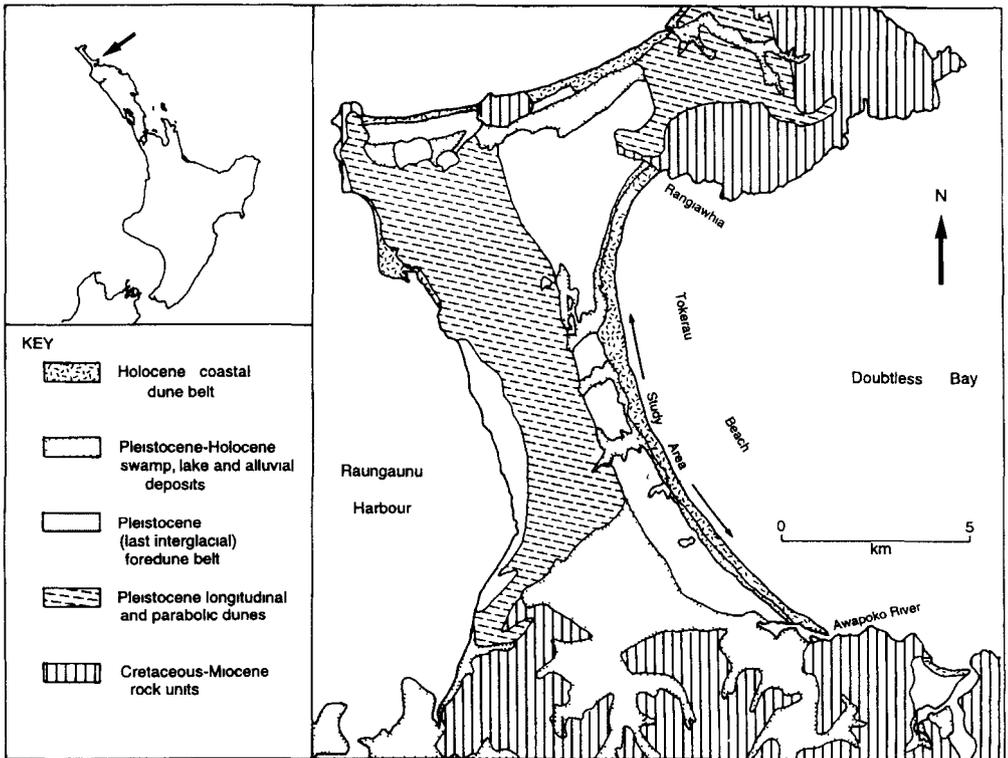


Fig. 1 Location of Tokerau Beach and Holocene dune belt showing study area and geology of Karikari Peninsula tombolo.

dates indicate that the forest was destroyed on those dunefields after about 1000 years BP (Millener 1981). Forest destruction was followed by widespread dune mobilisation.

The present study is concerned with one of the dune areas covered by Millener (1981), Tokerau Beach in northeastern Northland (Fig. 1). It describes the stratigraphy of the Holocene dunefield in the middle part of Tokerau Beach, and interprets the paleoenvironmental history from sedimentology and fossil landsnail faunas.

This study is part of a wider research programme looking at biogeographic relationships and species turnover in landsnail faunas of Holocene coastal dune areas throughout Northland. It follows studies of landsnail faunas of dunefields in eastern Northland between Whananaki and Whangamumu (Brook & Goulstone 1999) and at the Chicken Islands (Brook 1999).

Physical setting

Tokerau Beach extends for 15 km along the eastern margin of a tombolo that joins a series of former islands of Cretaceous volcano-sedimentary rocks and lower Miocene subvolcanic intrusives to mainland Northland (Hay 1975; Brook & Thrasher 1991; Isaac 1996). The core of the tombolo comprises a dunefield of longitudinal and parabolic dunes of mid-late Pleistocene age in the western part, and a coastal foredune belt of last interglacial age in the east (Fig. 1). A Holocene foredune belt behind Tokerau Beach extends along the length of the tombolo. It is mostly about 300 m wide but locally extends up to 700 m inland. It parallels the last interglacial foredune sand ridges, but is separated from that older dune belt along most of its length by a series of narrow (100–300 m wide) hind-dune swamps with interspersed lakes. The southern end of the Holocene foredune belt is bounded by the Awapoko River estuary, and the northern end abuts against the coastal headland at Rangiawhia (Fig. 1).

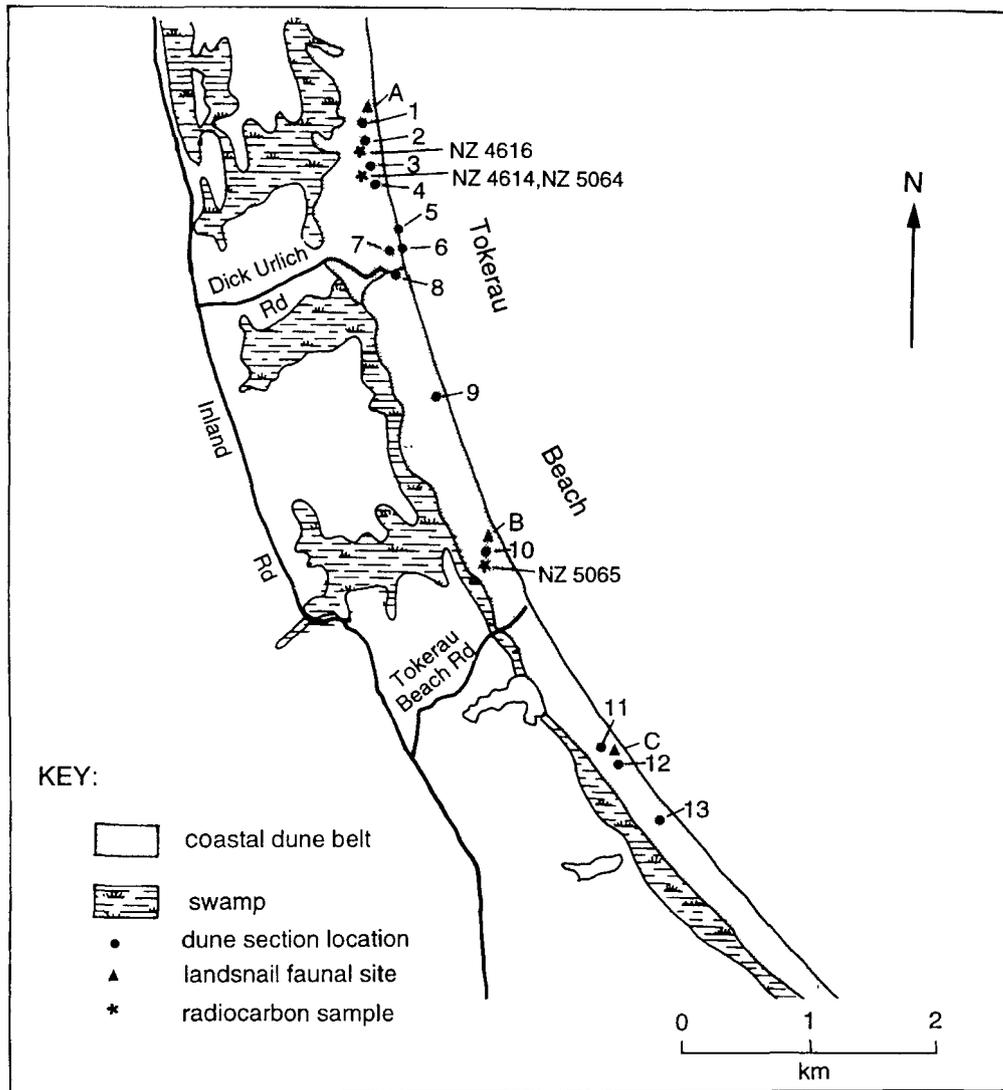


Fig. 2 Location of stratigraphic sections, landsnail faunal sites and radiocarbon sample sites on Tokerau dunebelt.

The study area has been tectonically stable during the late Pleistocene and Holocene. Stability is indicated by intertidal sedimentary deposits of last interglacial age forming constructional terraces up to 2.5 m above present sea level in Rangaunu Harbour on the western side of the tombolo (Brook & Thrasher 1991). These terraces correspond to the maximum sea level height during the last interglacial period (120–125 ka ago), which was up to 3 m higher than at present.

METHODS

Stratigraphy

I examined Holocene dune stratigraphy at 13 sites behind the middle part of Tokerau Beach (Fig. 2, Table 1). Most sites were natural sections exposed in eroded dune faces; two sites (9,

13) were man-made borrow pits. At sites 6, 8 and 13, a theodolite was used to measure horizontal and vertical distances to high water mark (hwm) as determined from the location of strand lines. Field information for each site was obtained over several visits between 1994 and 1998. The degree of section exposure varied over that period as a result of wind and water erosion and the migration of small unvegetated dunes. Stratigraphic and sedimentologic descriptions were recorded for each section, concentrating on the stratigraphic distribution of cultural material, paleosols and sea-rafted pumice. I recognised two distinctive pumice suites in the field. The first is new and is here named Tokerau Pumice. It comprised relatively soft clasts that were typically stained brown by iron oxides but light to medium grey when fresh. The second was Loiseles Pumice (Wellman 1962; McFadgen 1985; Osborne et al. 1991), which contained unweathered, hard, dark grey and colour-banded light and dark grey clasts.

Most of the sections were of limited lateral extent, and none incorporated the full range of stratigraphic units represented within the dunefield. I interpreted the stratigraphy on the basis of inferred lithostratigraphic correlations among sections, and on chronostratigraphic information provided by the radiocarbon dates reported in Millener (1981) and Osborne et al. (1991). Millener's (1981) dates were recalculated as recommended by Stuiver & Polach (1977). Terrestrial samples were calibrated using the northern hemisphere terrestrial calibration curve of Stuiver and Pearson (1993), with a southern hemisphere offset of -27 years as recommended by McCormac et al. (1998). New Zealand marine calibrations were based on the carbon cycle model calibration curve of Stuiver et al. (1986), with geographic offset Delta-R set to -30 ± -15 as recommended by McFadgen & Manning (1990).

Landsnail faunas

I collected fossil landsnails from 44 sites in the Holocene dunebelt. Species composition of faunas was determined from on-site collection of shells visible in natural exposures and from off-site examination of bulk sediment samples of approximately 2 litres each. Landsnail shells in the bulk samples were separated by sieving, flotation in water and hand-sorting under a microscope. I also sampled the landsnail faunas of present-day prostrate shrubland and sandfield vegetation on the Tokerau dunes at three sites, for comparison with the fossil faunas.

I examined similarities in species composition among the fossil and modern landsnail faunas by Cluster Analysis of a presence/absence data matrix comprising a total of 18 native landsnail species from the 44 fossil and three present-day faunas. Exotic (i.e., non-native) landsnail species in modern faunas were excluded from the analysis. The cluster analysis was computed using the NTSYS statistical package of Rohlf (1989). Similarity of the initial data matrix was calculated using the simple matching coefficient, and clustering by the unweighted pair group method.

I describe patterns of diversity, species distribution and the biogeographic relationships of the fossil and present-day landsnail faunas, and give a paleoenvironmental history for the

Table 1 Location of sections and fossil sites

Section	Grid Reference	Fossil Site Numbers
1	O04/44609915	O04/f135-139
2	O04/44609900	O04/f140-146
3	O04/44659880	O04/f147-150
4	O04/44709865	O04/f151-153
5	O04/44809830	O04/f14, f15
6	O04/44909810	O04/f174-176
7	O04/44809810	O04/f154-156
8	O04/44809790	O04/f157-160, f178
9	O04/45209690	O04/f177
10	O04/45559565	O04/f161, f162
11	O04/46509410	O04/f163-165
12	O04/46659395	O04/f166-171
13	O04/47009340	O04/f172, f173

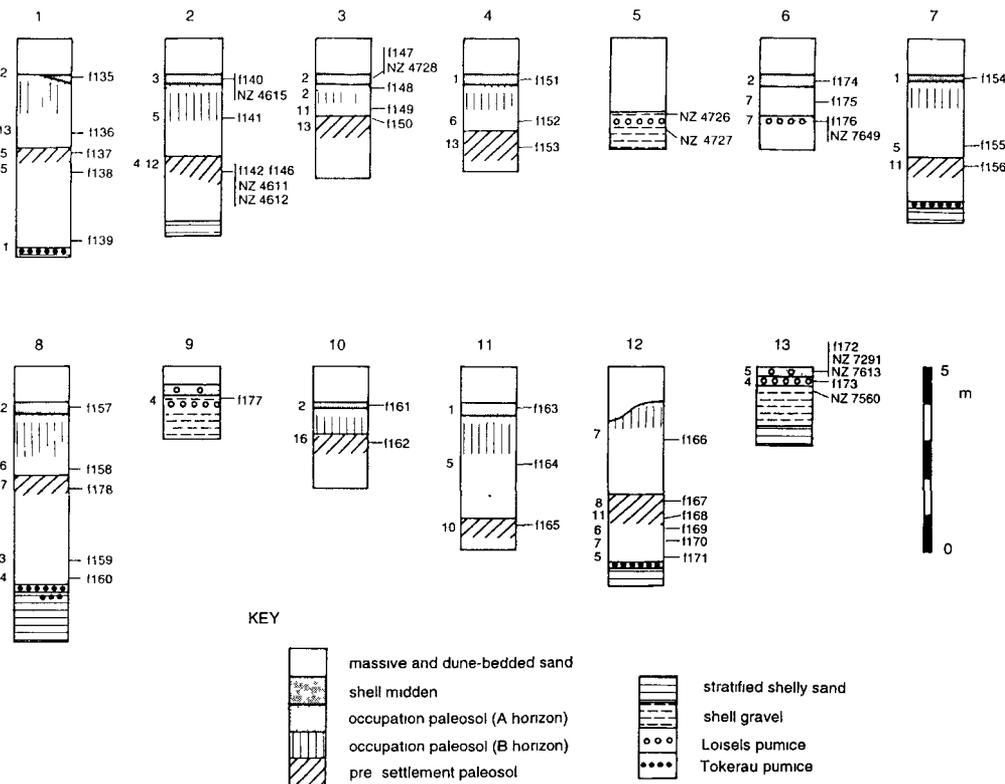


Fig. 3 Stratigraphy of sections 1–13 on Tokerau dunebelt showing location of fossil collections (f prefix, right side of columns), radiocarbon samples (NZ prefix, right side of columns) and number of species in fossil landsnail faunas (left side of columns).

dunefield based on comparison between the Tokerau faunas and landsnail faunas from coastal areas elsewhere in eastern Northland.

Snail taxonomy and collection data

Landsnail identification was based on comparison with reference material in Auckland War Memorial Museum collections. Two of the fossil punctid taxa have not been formally described, but are known from elsewhere in New Zealand and are recognised by New Zealand malacologists as being distinct at the species level. Nomenclature of *Phrixgnathus* sp. “marshalli” follows Brook & Goulstone (1999) and Brook (1999), and that of punctid sp. 24 follows Goulstone et al. (1993) and Brook & Goulstone (1999).

Fossil sites were allocated sheet numbers of the New Zealand Fossil Record File (with prefix O04). Grid references of section locations were based on the national thousand-metre grid of the 1:50 000 topographical map series (NZMS 260 series, sheet O04, 1984 edition). Collections of fossil and modern landsnails made during this study have been deposited in the Auckland War Memorial Museum and the Museum of New Zealand, Wellington. Fossil vertebrate remains collected during fieldwork were sent to Brian Gill at the Auckland War Memorial Museum.

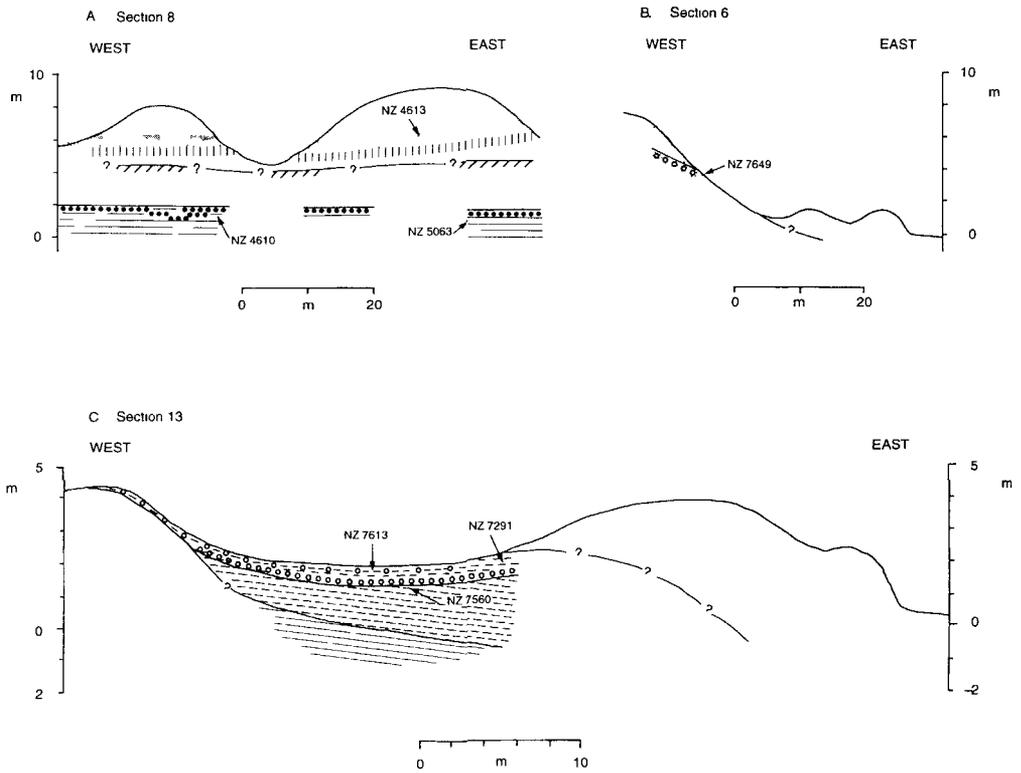


Fig. 4 Drawings of sections 8, 6 and 13 showing location of radiocarbon samples (NZ prefix). ? = inferred correlation; lithologic symbols as for Fig. 3. A. Section 8, based on natural exposure. B. Section 6, based on dug holes and natural exposure. C. Section 13, based on dug holes and exposure in borrow pit.

RESULTS

Stratigraphy

Section stratigraphy is shown in Fig. 3 and 4, and a summary diagram showing stratigraphic relationships in the seaward part of the Tokerau Holocene dune belt is given in Fig. 5. The five stratigraphic units (A-E) and two sea-rafted pumice units depicted in the summary cross-section are described below.

Unit A: The oldest Holocene unit exposed was at the bases of sections 1, 2, 7, 8 and 12. It was best exposed in section 8, where it was at least 1.6 m thick, and had a gently seaward-sloping, subplanar upper surface that ranged from about 1.4 m above hwm 100 m inland of the present coastline to about 1.8 m above hwm a further 70 m inland (Fig. 4A). In other sections only the upper few decimetres of the unit were seen. The base was nowhere exposed. The unit comprised weakly consolidated, subhorizontally stratified fine sand, locally with low angle scour and fill structures. Whole and abraded (transported) marine mollusc shells were scattered throughout the unit and concentrated in thin, discontinuous bands. The shell fauna, with the exception of *Calliostoma selecta*, which is apparently no longer living off eastern Northland (Marshall 1995), consisted of species still washed up on Tokerau Beach (Appendix 1).

In sections 1, 7 and 12, Tokerau pumice formed a single laterally discontinuous horizon 5–

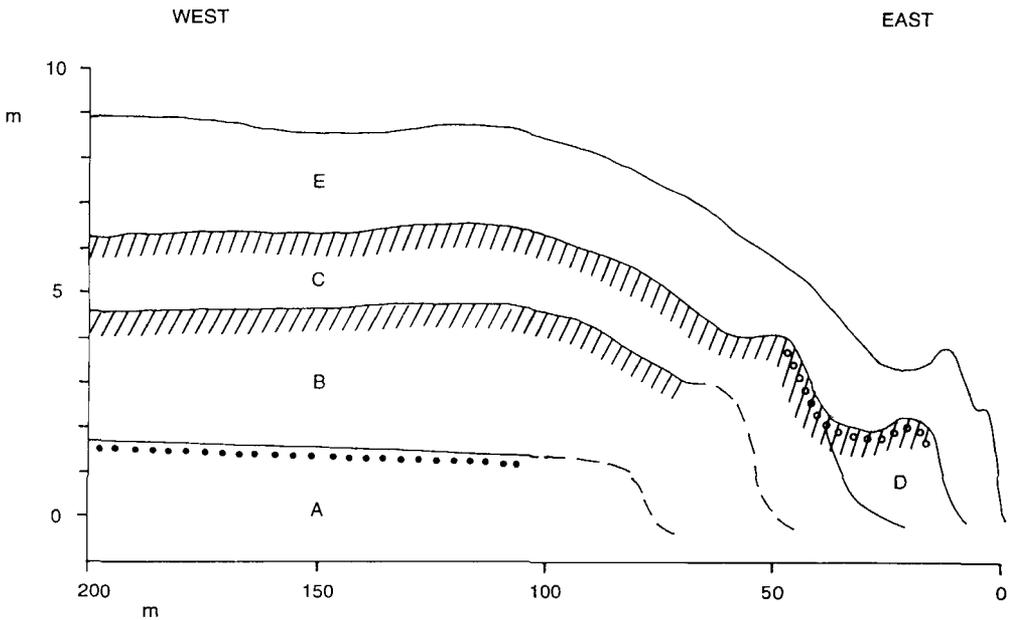


Fig. 5 Diagrammatic cross-section showing stratigraphic relationships in the seaward part of the Tokerau dunebelt. Stratigraphic units A-E as described in text. Dashed line = inferred correlation, cross-hatching denotes paleosols, ● = Tokerau pumice, ○ = Loiseles pumice.

20 cm below the top of Unit A. In section 8, the pumice was present in scour and fill sand extending to 80 cm below the top of the unit. Pumice clasts in these deposits were subangular to rounded and mostly pebble-size, but there were also some larger, cobble-size clasts. Preliminary geochemical analyses indicated that the pumice is compositionally heterogeneous, with low K_2O (0.7–1.6 wt %) and SiO_2 (66.5–77.0 wt %) content (P. Shane unpub. data).

The stratigraphic distribution of Tokerau pumice, restricted to the upper part of Unit A, suggests that the deposit is primary. Section 8 (i.e., at grid reference O04/448979) is here designated as a type locality for Tokerau pumice.

From its sedimentary features and molluscan fauna, Unit A represents intertidal and storm-wave, beach to upper shoreface deposits. Its maximum age is not known, but is probably younger than the end of the post-glacial sea level rise at 6500 years BP (Gibb 1986). Radiocarbon dates on the shell fauna from the upper part of the unit indicate an age range of 5035–2984 years BP (NZ 4610, NZ 4614, NZ 5063, NZ 5064 Table 2). They suggest that the shell fauna is at least in part reworked, and that the upper part of the unit is no older than 3214 years BP. From these radiocarbon dates, a rounded age of c. 3000 years BP is inferred for the emplacement of Tokerau pumice.

Beyond its observed extent 200 m inland from the present coastline, Unit A was buried beneath younger deposits. However, I infer that the Unit A sequence probably passes landward into coeval terrestrial dune deposits along the western margin of the Holocene dunefield. Moa eggshell collected by Millener (1981) from a site near section 10 and dated at 4238–3830 years BP (NZ 5065 Table 2) may have come from such a dune sequence.

Unit B This overlay Unit A in sections 1, 2, 7, 8, 12 and was the lowest exposed unit in sections 3, 4, 10, 11. Thickness ranged from 1.3 m (section 7) to 2.8 m (section 1) and the top of the unit ranged from about 3.7 m above hwm.

Unit B comprised massive and dune-bedded fine sand capped by a moderately consolidated, composite sand paleosol formed on an irregular, hummocked dune surface. The paleosol was 30–80 cm thick, dark brown to orange-brown in colour, with weakly defined lenticular internal layering. It contained locally common mm-diameter rhizomorphs, bird and reptile bones, eggshell, landsnail shells, coprolites and gastroliths. Scattered marine bivalve and gastropod shells and reworked Tokerau pumice clasts were present in some sections. Sand underlying the paleosol was typically weakly consolidated, light-coloured and locally contained mm to cm-diameter rhizomorphs, bird and reptile bones, eggshell and landsnail shells.

Radiocarbon ages of moa eggshell and moa bone collected by Millener (1981) from the paleosol in the vicinity of section 2 indicated that the original soil formed from at least 1991 to 1124 years BP (NZ 4611, NZ 4612 Table 2). Another moa bone sample collected from further inland in the same area, with a radiocarbon age of 3330–2796 years BP (NZ 4616 Table 2), is of unknown provenance. It was presumably either from the lower part of the Unit B sequence or from a terrestrial stratigraphic correlative of Unit A (above).

Unit C This overlay Unit B in sections 1–4, 7, 8, 10–12 and was the lowest unit exposed in section 6. Thickness ranged from about 0.8–2.5 m, and the top was mostly between 5 m and 8 m above hwm. Unit C comprised massive and dune-bedded fine sand capped by strongly humic-stained sand paleosols containing Maori cultural material. Dune sand in the lower part of the unit was closely comparable with that underlying the Unit B paleosol, with locally common mm-diameter rhizomorphs, bird and reptile bones, and landsnail shells.

Two paleosols at the top of the sequence capped a hummocked dune surface. The lower

Table 2 Radiocarbon dates referred to in text. Ranges are expressed as a 95% confidence interval using the New Zealand Delta – R –30 ± 15 years correction for marine shell (Stuiver et al. 1986, McFadgen & Manning 1990), and northern hemisphere terrestrial calibration with a southern hemisphere offset of –27 years (Stuiver & Pearson 1993, McCormac et al. 1998) for bird bone and egg shell.

NZ radiocarbon number	Material dated	Calibrated age		Source	Stratigraphic unit
		Conventional radiocarbon age (BP 1950)	range (BP 1950) at confidence level 95%		
NZ5065	moa egg shell	3720±77	4238–3830	Millener (1981)	?
NZ4610	marine shell	4692±40	5035–4835	Millener (1981)	A
NZ4614	marine shell	3311±37	3300–3071	Millener (1981)	A
NZ5063	marine shell	3510±66	3571–3259	Millener (1981)	A
NZ5064	marine shell	3256±36	3214–2984	Millener (1981)	A
NZ4611	moa egg shell	2184±62	2319–1991	Millener (1981)	B
NZ4612	moa bone	1114±58	1124–918	Millener (1981)	B
NZ4616	moa bone	2934±83	3330–2796	Millener (1981)	?B
NZ4613	marine shell	740±28	464–319	Millener (1981)	C
NZ4615	marine shell	712±33	445–297	Millener (1981)	C
NZ4728	marine shell	623±32	384–237	Millener (1981)	C
NZ7649	marine shell	1449±52	1145–910	Osborne et al. (1991)	C
NZ4726	marine shell	973±40	638–516	Millener (1981)	D
NZ4727	marine shell	1233±28	881–772	Millener (1981)	D
NZ7291	marine shell	1030±60	710–520	Osborne et al. (1991)	D
NZ7560	marine shell	1360±45	1035–805	Osborne et al. (1991)	D
NZ7613	marine shell	1441±34	1100–920	Osborne et al. (1991)	D

paleosol had a 10–20 cm thick, moderately consolidated, black-dark brown, strongly humic-stained and mottled fine sandy A horizon, above a moderately consolidated, orange-brown B horizon extending 40–100 cm down into underlying dune sand. Finely comminuted charcoal was abundant within the A horizon, and in section 3 the paleosol also contained large charcoal fragments, tuatua (*Paphies subtriangulata*) shells and burnt marine shell of cultural origin. In most sections the upper paleosol directly conformably overlay the lower, but it was absent from section 12 and the landward part of section 1. The upper paleosol was 10–30 cm thick and comprised moderately consolidated, black-dark brown, strongly humic-stained fine sand containing scattered Loiseles and abundant cultural material including marine shell, fish bone, charcoal, fire-blackened stones and locally also *in situ* umu. Some of the marine shell component, predominantly tuatua, represented species collected by prehistoric Maori for food. It also typically contained a substantial proportion of abraded, beach-worn shells that were evidently gathered by Maori from coastal shell deposits, burnt and added to the soil, species are listed in Appendix 1.

A slightly different Unit C sequence was exposed at the coast in section 6 (Fig 4B), where the upper and lower paleosols dipped seaward at 20° and were separated by about 80 cm of weakly consolidated dune sand (i.e., section 4 of Osborne et al 1991). The lower paleosol in that section lacked a B horizon, and had a 20 cm thick A horizon of weakly consolidated, dark brown moderately humic-stained fine sand with scattered marine shell, charcoal fragments and common pebble-size Loiseles pumice clasts.

Radiocarbon dates on tuatua midden shells indicated that the upper paleosol in Unit C had an overall age range of 464–237 years BP and was at least in part younger than 384 years BP (NZ 4613, NZ 4615, NZ 4728 Table 2). The age of the lower paleosol horizon is not known directly but the presence of cultural material in section 3 indicates that it post-dated the Polynesian settlement of New Zealand considered to have been at about 800–700 years BP (Anderson 1991, McFadgen et al 1994). The presence of Loiseles pumice in the lower paleosol in section 6 indicates a maximum possible age of approximately 660 years BP for formation of that soil (see below). A radiocarbon age of 1145 ± 910 years BP obtained by Osborne et al (1991) on marine shell within the pumice pod in the lower paleosol in section 6 (NZ 7649 Table 2) was substantially older than the pumice, and strongly suggests reworking of pre-existing coastal shell deposits.

Unit D This lies to seaward of Units A–C, immediately inland of the present-day coastline, and is a lateral correlative of Unit C. It was well exposed in borrow pits on the landward margin of the present coastal foredune (sections 9, 13) and was also formerly well exposed in a wave-eroded seaward foredune face north of Dick Ulrich Road (section 5, Millener 1981, fig 103–104). Unit D represents a progradational sequence of stratified, seaward-dipping (5°–6°), shelly sand and overlying slightly sandy shell gravel. The basal shelly sand lithofacies was at least 50 cm thick, weakly consolidated, and contained broken and abraded *Dosinia anus* and tuatua shells. In section 13 the top of the sand was at about the elevation of present high water mark and dipped seaward paralleling internal stratification. The overlying shell gravel lithofacies comprised tightly packed whole, broken and abraded shells of predominantly *Dosinia anus*, *Tawera spissa*, tuatua and *Zethalia zelandica* with a number of other species in lesser abundance (Appendix 1). Sand was mostly confined to interstices between shells, but locally formed mm to cm-thick lenticular pods parallel to overall stratification within the shell gravel.

The shell fauna of Unit D comprised marine species still commonly washed up on Tokerau Beach. The basal shelly sand and bulk of the overlying shell gravel lag lithofacies are inferred to have accumulated as prograding intertidal beach deposits on an upper shoreface. However, the upper seaward part of the shell gravel formed a beach-parallel backshore ridge

of probable storm wave origin that extended up to 2.5 m above hwm. The ridge was backed by a corresponding 12 m wide paleohollow at c. 2 m elevation, which was underlain by a shell gravel sequence. The latter was locally capped by a dark brown-black, strongly humic-stained sandy paleosol, a lateral correlative of the lower paleosol in Unit C. The paleosol and upper few decimetres of the underlying shell gravel lithofacies contained charcoal fragments and landsnails.

Sea-rafted Loiseles pumice was present in the upper part of Unit D in sections 5, 9 and 13. The pumice clasts were subangular to rounded, predominantly pebble size, some up to cobble size. In section 5 the pumice occurred in a 5–10 cm thick band enclosed within tightly packed shell gravel, about 70 cm above hwm and 30 cm below the top of the shell gravel unit (Fig. 3, Millener 1981, fig. 103, 104). In section 9, on the landward side of the paleohollow behind the backshore shell gravel ridge, Loiseles pumice formed a discontinuous, cm-thick horizon 15–20 cm below the top of the shell gravel, and scattered clasts of pumice were also present in the overlying shell gravel and paleosol (Fig. 3). In section 13 the pumice formed a tightly packed lensing layer up to 30 cm thick within the upper part of the shell gravel lithofacies at about 1.5 m above hwm and, as in section 9, scattered pumice clasts were also present in the overlying shell gravel and paleosol horizons (Fig. 3, 4C, Osborne et al. 1991, fig. 6).

The basal pumice horizons in the three sections are considered here to be synchronous primary deposits, whereas pumice clasts in overlying shell gravel and paleosol horizons were clearly reworked. The pumice layer in section 5 apparently accumulated on the seaward face of the backshore shell gravel ridge, whereas the basal pumice layers in sections 9 and 13 accumulated at slightly higher elevations within the hollow inland from the ridge.

Radiocarbon ages are available for shell gravel lithofacies immediately above and below the primary Loiseles pumice layer in sections 5 and 13 (Millener 1981, Osborne et al. 1991). The dates for section 5 indicate that the pumice layer was deposited between 881 and 516 years BP, assuming no reworking of enclosing shell deposits (NZ 4762, NZ 4727, Table 2). That age range is consistent with the range of 660–510 years BP determined for the arrival of Loiseles pumice elsewhere in northern New Zealand by McFadgen (1982, 1994).

Shell samples dated by Osborne et al. (1991) from above and below the basal Loiseles pumice layer in section 13 (i.e., their section 6) gave ages of 1035–805 years BP and 1100–920 years BP respectively (NZ 7560, NZ 7613, Table 2). Osborne et al. (1991) argued that the pumice was first stranded in northern New Zealand between 1035 and 920 years BP. Their conclusion hinged on assumptions that (a) the section represented a continuous primary depositional sequence, and (b) that the dated shells were the same age as their enclosing facies. However, stratigraphic relationships indicate that the Loiseles pumice layer at section 13 was deposited on the floor of a hollow inland from the backshore shell ridge, upon a disconformable erosion surface truncating primary, seaward-dipping stratification in the shell gravel lag deposits beneath the disconformity (Fig. 4C). Whereas the last-named lithofacies was deposited on a shoreface before the backshore ridge to seaward had formed, the overlying pumice was deposited after the formation of the backshore ridge. Shell from below the pumice does indicate a maximum possible age for arrival of the pumice (1100 years BP), but it cannot be used to determine a minimum age, as argued by Osborne et al. (1991). The pumice layer evidently formed as a storm overwash deposit ponded behind the backshore ridge. The shell gravel above the pumice, which contains reworked pumice clasts, probably had a similar origin. However, the presence of charcoal fragments, humic-staining and landsnails within the pumice layer and overlying shell gravel layer (see below) indicates that both accumulated in a primarily terrestrial setting. The upper shell gravel layer then clearly does not represent continuous primary deposition from the marine environment, as was suggested by Osborne et al. (1991), but rather the intermittent deposition of material

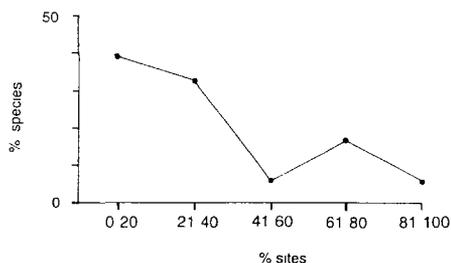


Fig 6 Frequency distribution curve of sites per species for fossil landsnail faunas at Tokerau

eroded (reworked) from pre-existing coastal deposits by overwash storm waves I conclude that radiocarbon dates on shells from the upper shell gravel layer are inappropriate for determining a minimum age for the underlying Loiseles pumice layer at this site

Unit E This incorporated a sandy foredune up to 4 m high backing the coastline, and dune sand stratigraphically above Unit C that formed the present-day land surface inland from the coast The coastal foredune disconformably overlay the Unit D sequence, whereas inland dune sand was mostly conformable on Unit C paleosols, but was locally strongly disconformable on those and underlying stratigraphic units where wind erosion

had formed deep deflation hollows The inland dune sequence was highly variable in thickness, and extended to a maximum elevation of 10–13 m The coastal foredune and inland dunes were mostly capped by vegetation (see below), locally with a weakly developed A soil horizon, but they were largely unvegetated in deflation hollows and an area of mobile transverse dunes north of Dick Ulrich Road

Unit E represents the most recent and continuing phase of dunefield development at Tokerau, incorporating both erosional and depositional elements The maximum age of the unit is not known directly, but dates obtained from the upper midden paleosol in the underlying Unit C indicate that it is younger than 384 years BP (above, Table 2)

Landsnail faunas

I found a total of 18 species of fossil native landsnail at Tokerau Three of those species, along with five introduced landsnail species of European origin, were still living on the dunefield (Appendix 2)

Fossil faunas Species diversities at the 44 fossil sites sampled are shown on the left-hand side of stratigraphic columns in Fig 3, and a frequency distribution curve for sites per species is shown in Fig 6 Landsnail species diversity per site ranged from 1–16, with a mean of 6.2 ± 3.9 SD The mean was much lower than the total species number, but the maximum site diversity (f162) came close to the total diversity The number of sites per species ranged from 2–44 and the mean of 15.1 ± 12.4 SD was low with high variance *Paralaoma caputspinulae* was the only species present at all sites The next most widespread species were *Tornatellinops novoseelandica* (35 sites), *Phrixgnathus* sp “marshalli” (29 sites), *Succinea archeyi* (27 sites) and *Paracharopa chrvsaugeia* (26 sites) The remaining 13 species (72% of fauna) were present at fewer than half of the sites sampled, and four species (*Suterilla neozelanica*, *Phenacohelix giveni*, *Serpho kivi*, *Delos coresta*), comprising 22% of the total species number, were present at less than 10% of sites

Present-day habitats and faunas Sandfield and prostrate shrubland native plant associations were widespread on the Tokerau dunefield The seaward dune face had open sandfield vegetation dominated by *Spinifex sericeus* with common *Calystegia soldanella*, scattered pingao (*Desmochaeonius spiralis*), *Isolepis nodosa* and shrubs of *Cassinia leptophylla*, *Coprosma acerosa* and *Pimelia arenaria* Stabilised dune areas behind the foredune crest had a mosaic cover of spinifex sandfield dominated by *S sericeus*, *C soldanella* and *I nodosa* with scattered *C leptophylla*, *C acerosa*, flax (*Phormium tenax*) and *P arenaria*, and

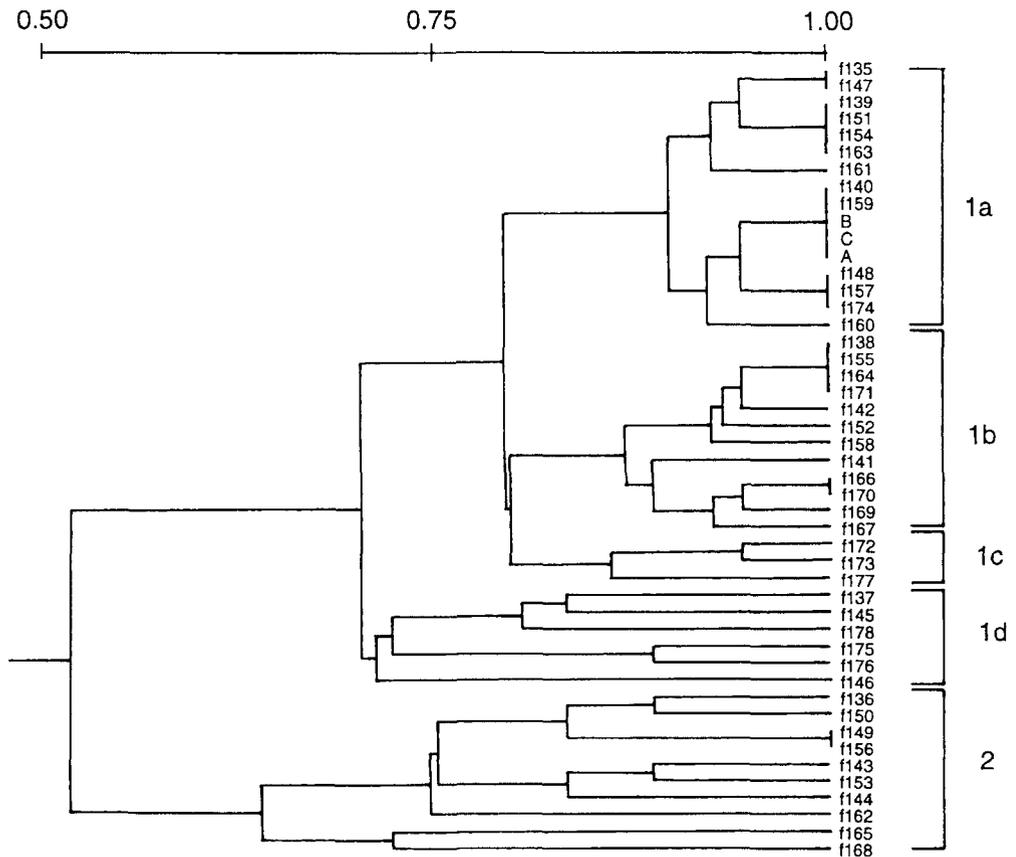


Fig. 7 Dendrogram classification of fossil and present-day landsnail faunas by cluster analysis of species presence – absence data.

prostrate shrubland dominated by *C. acerosa*, *I. nodosa* and *Muehlenbeckia complexa* with less common bracken (*Pteridium esculentum*), *C. soldanella*, *C. leptophylla*, flax, *P. arenaria* and spinifex. Areas of mobile sand in deflation hollows supported sparse spinifex and locally also pingao, with scattered *C. leptophylla*, *C. acerosa*, *I. nodosa*, *P. arenaria* and toetoe (*Cortaderia splendens*). A number of exotic plant species were also common on the Tokerau dunefield including some which were locally displacing the native vegetation cover (e.g., *Ammophila arenaria*, *Caprobotus* sp., *Cortaderia selloana*, *Melianthus major*, *Pennisetum clandestinum*, *Solanum linneanum*, *Ulex europaeus*).

Three areas of spinifex sandfield and prostrate shrubland vegetation at 2–5 m elevation and 20–50 m inland from the coast were sampled for landsnails (A-C, Fig. 2). All three sites had a native snail fauna of *Tornatellinops novoseelandica*, *Succinea archeyi* and *Paralaoma caputspinulae*, and the introduced species *Cantareus aspersus*, *Oxychilus alliarius* and *Prietocella barbara* were also ubiquitous. Two other introduced species (*Cochlicopa lubrica*, *Vallonia excentrica*) were represented by rare empty shells at a single site each.

Classification and distribution of faunas: A classification of native snail faunas from the 44 fossil and three present-day sites produced by cluster analysis of species presence/absence

data is illustrated as a dendrogram in Fig 7. The analysis identified two broad groupings, one incorporating ten relatively high diversity sites with 10–16 species each (Group 2, Fig 7) and the other including the remaining 37 sites which all had between one and eight species each. Within the latter group there were four main subclusters of sites, labelled 1a–d on Fig 7.

Subcluster 1a incorporated 16 sites with between one and four species each, and had a combined total of five species. *Paralaoma caputspinulae* was ubiquitous, and *Tornatellinops novoseelandica* and *Succinea archevi* occurred at about half of the sites (9 and 8 respectively).

Subcluster 1b incorporated 12 sites with between four and eight species each and a combined total of 12 species. Four species (*Tornatellinops novoseelandica*, *Succinea archevi*, *Paralaoma caputspinulae*, *Phrixgnathus* sp. “marshalli”) were ubiquitous, and *Paracharopa chrysauga* was present at all but one site.

Subcluster 1c incorporated three sites with four to five species each and a combined total of six species. *Suterilla neozelanica*, *Paralaoma caputspinulae* and *Phrixgnathus* sp. “marshalli” were ubiquitous, and *Paracharopa chrysauga* was present at two sites.

Subcluster 1d incorporated six sites with between five and eight species each and 12 species in total. Three species (*Tornatellinops novoseelandica*, *Kokikora angulata*, *Paralaoma caputspinulae*) were ubiquitous, and punctid sp. 24 and *Phrixgnathus* sp. “marshalli” were present at five and four sites respectively.

The Group 2 cluster of sites (Fig 7) had a combined total of 17 species. Six of those species were present at all ten sites (*Tornatellinops novoseelandica*, *Charopa coma*, *Paracharopa chrysauga*, *Kokikora angulata*, *Paralaoma caputspinulae*, *Phrixgnathus* sp. “marshalli”). The next most widespread species were *Cavella buccinella*, *Phenacharopa novoseelandica*, punctid sp. 24 (8 sites each), and *Succinea archevi*, *Phenacohelix tholoides* and *Amborhytida dunniae* (7 sites each). The other five species were all present at fewer than half of the sites. Five species were restricted to Group 2 sites (*Phenacohelix giveni*, *P. tholoides*, *Amborhytida dunniae*, *Delos coelesia*, *Seipho kivi*).

In summary, there was a trend of increasing faunal diversity from subclusters 1a to 1b/1d to cluster 2, primarily involving the addition (i.e., rather than replacement) of species. The presence of *Suterilla neozelanica* distinguished subcluster 1c faunas from all the others, although species composition was otherwise closely comparable with subcluster 1b faunas.

The stratigraphic distribution of the various faunal types is listed in Table 3. The most notable features were an overall upwards increase in diversity from dune to paleosol faunas in Unit B and a converse overall upwards decrease in Unit C. Low diversity 1a faunas were represented in the Unit B dune lithofacies, the upper and lower paleosols in Unit C and in present-day dune habitats. The slightly more diverse 1b faunas were present throughout the Unit B sequence and in the dune lithofacies in the lower part of Unit C, whereas 1d faunas were present in the Unit B paleosol, and the Unit C lower paleosol and overlying dune lithofacies in section 6 (f175, f176). High diversity Group 2 faunas were restricted to the Unit B paleosol and lower part of the overlying Unit C dune lithofacies, and 1c faunas, characterised by the presence of *Suterilla neozelanica*, were restricted to the upper part of the Unit D sequence to landward of the backshore shell ridge. Thus some of the stratigraphic units, including the dune lithofacies in Unit B, upper paleosol in Unit C, upper landward part of the Unit D sequence and also the present day dune habitats, had low diversity landsnail faunas of fairly uniform composition, whereas the Unit B paleosol, and dune and lower paleosol lithofacies in Unit C contained a mix of lower and higher diversity faunas.

The overall 112% increase in total landsnail species diversity from the dune lithofacies to overlying paleosol within Unit B (Table 3) involved the simple addition of species. Similarly, the 76% decrease in overall species diversity between that paleosol and the upper paleosol in Unit C resulted from the progressive disappearance of a total of 13 species through the upper

part of the dune sequence. The greatest diversity reduction (i.e., from 15 to 8 species) was between the dune lithofacies and overlying lower paleosol in Unit C, and another four species present in the latter unit were absent from the upper paleosol in Unit C. The upper midden paleosol had a total of four species of which all except *Paracharopa chrysaugia* still live on the Tokerau dunefield.

DISCUSSION

Pumice stratigraphy and age

The Holocene coastal dune sequence at Tokerau is notable in containing two stratigraphically discrete, primary deposits of sea-rafted pumice: Tokerau pumice and Loiseles pumice. I infer that the Tokerau pumice was initially emplaced at Tokerau c. 3000 years BP. Its geochemistry indicates an oceanic arc origin outside the Taupo Volcanic Zone, probably on the Tonga-Kermadec ridge (P. Shane pers. comm. 1998). Tokerau pumice represents the presently oldest known foreign, sea-rafted pumice found in New Zealand Holocene coastal deposits.

Loiseles pumice, like Tokerau pumice, is also exotic to New Zealand and has geochemical characteristics indicating close affinities with oceanic arc tholeiite volcanics along the Tonga-Kermadec ridge (Shane et al. 1998). In New Zealand, sea-rafted Loiseles pumice is present in coastal deposits in the east of the North Island, in the extreme northwest of the western North Island, and on Chatham Island (Wellman 1962; McFadgen 1985, 1994). Stratigraphic studies by these authors indicated that the first appearance of Loiseles pumice in many New Zealand coastal sections is close above that of Polynesian cultural material; primary pumice deposits were dated at 660–510 years BP by McFadgen (1982, 1994). However, the usefulness of the first appearance datum of Loiseles pumice as a chronostratigraphic marker has been questioned, including in particular by Osborne et al. (1991) and Shane et al. (1998).

The criticisms by Osborne et al. (1991) were in part concerned with the sedimentologic characteristics of sea-rafted pumice deposits and the difficulties of differentiating between primary and reworked deposits, but were mainly centred on their claim that radiocarbon dates from the Tokerau dune sequence indicate an earlier age of 1035–920 years BP for the first stranding of the pumice in northern New Zealand.

Shane et al. (1998) argued against the use of Loiseles pumice as a stratigraphic marker, because the pumice unit as currently recognised comprises a compositionally heterogeneous suite, with interclast diversity within and between sites indicating original derivation from

Table 3 Stratigraphic distribution of native landsnail species associations determined by cluster analysis

		Faunal classification (no. of sites)	No. of species	
			Total	Site range
Present-day		1a(3)	3	3
Unit D	above pumice	1c(3)	6	4–5
Unit C	upper paleosol	1a(9)	4	1–3
Unit C	lower paleosol	1a(1), 1d(2)	8	2–7
Unit C	dune lithofacies	1b(6), 2(2)	15	5–13
Unit B	paleosol	1b(2), 1d(4), 2(8)	17	4–16
Unit B	dune lithofacies	1a(3), 1b(4)	8	1–7

two or more volcanoes and/or eruptive episodes. They suggested that discrepancies in radiocarbon ages for the first appearance datum of the pumice reported by McFadgen (1982, 1994) and Osborne et al (1991, see also Froggatt & Lowe 1990) could reflect the separate and sequential emplacement of two different pumice units. Shane et al (1998) did not describe the stratigraphic and depositional setting of the sequences from which their samples were obtained and, in particular, they did not provide any information on the stratigraphic distribution of the samples and their relationship to other stratigraphic markers, or whether the samples were from primary or reworked deposits.

The present study has shown that the emplacement date of 1035 ± 920 years BP determined by Osborne et al (1991) for primary Loiseles pumice in section 13 at Tokerau is unreliable, being based on a sequence in which the pumice disconformably overlies shell lag gravel and is overlain by reworked shell gravel. Further, the dated first appearance of Loiseles pumice in Section 5 at Tokerau (881–516 years BP) is consistent with the age range of 660–510 years BP for the first appearance datum at other North Island sites as determined by McFadgen (1982, 1994). At present there is no reliable chronological evidence that coastal deposits of Loiseles pumice *sensu lato* in New Zealand are anywhere older than 660 years BP. Accordingly, I conclude that the first appearance of Loiseles pumice (i.e., characterised by the presence of dark grey and colour-banded light and dark grey clasts) within a stratigraphic sequence, remains a useful indicator of the maximum age for overlying deposits.

However, Shane et al (1998) demonstrate a clear need for further work to document the stratigraphic and geographic distribution of the various lithologic types represented within Loiseles pumice deposits around the North Island coast, in order to identify any patterns of regional and/or temporal variation in clast assemblages. Until such work is undertaken it will not be possible to determine whether the presently recognised compositional heterogeneity within and among sites resulted from (a) reworking of older exotic pumice clasts (e.g., of Tokerau pumice) into Loiseles pumice assemblages, (b) primary emplacement of a compositionally diverse Loiseles pumice suite, or (c) sequential stranding of more than one exotic pumice assemblage after c. 660 years BP.

Snail biogeography and habitat

The Tokerau native landsnail fauna is dominated by widely distributed species, 16 of the 18 species recorded during this study (89%) have a geographic distribution extending from Northland to south of the Auckland region. Of the remaining two species, one (*Amborhytida dunni*) is restricted to the Northland and Auckland regions, and the other (*Phenacohelix tholoides*) is a northern Northland endemic.

I did not find one landsnail species that had previously been recorded from the Tokerau dunefield. Powell (1951) recorded fossil *Placostylus ambagiosus* Suter from dunes at Aurere at the southern end of Tokerau Beach, based on a collection of six worn shells made in 1934 (Auckland War Memorial Museum colln. AK 25000, AK 92789). The fact that the fossil and modern distributions of that species are otherwise restricted to northern Aupouri Peninsula, led Powell (1951) to conclude that the Tokerau record resulted from human transportation. The absence of the species from Holocene dune sequences in the present study area supports that view.

The total number of native landsnail species recorded in the study area, and the maximum number of species per site, are both lower than in fossil faunas from some coastal dunefields between Whangamumu and Whananaki in eastern Northland (Brook & Goulstone 1999) but similar to fossil and present-day dunefield faunas from Lady Alice Island in the Hen and Chickens Group (Brook 1999). However, whereas only six of the Tokerau landsnail species were represented in the Lady Alice Island fauna (*Torinatellinops novoseelandica*, *Cavellia*

buccinella, *Charopa parva*, *Paralaoma caputspinulae*, *Phrixgnathus* sp “marshalli”, *Delos coresia*), all except *Amboihytida dunni* were present in dunefield faunas between Whangamumu and Whananaki

Four of the Tokerau native landsnail species have present-day geographic distributions that are entirely or predominantly restricted to coastal areas. *Suterilla neozelanica* typically lives beneath stones and stranded flotsam in the supralittoral zone, but on exposed rocky headlands it can also live in shrubland and forest litter well above the shoreface (pers obs). *Succinea archevi* is now entirely restricted to spinifex and shrub sandfield habitats on coastal dunefields (Powell 1979, unpub data), although fossil records indicate that it once also lived further inland (Climo 1980). *Phrixgnathus* sp “marshalli” lives in coastal shrubland and forest, whereas punctid sp 24 has a wider ecological tolerance, living in coastal forest, shrubland and shrub-sandfield habitats (pers obs).

The other native species represented in the Tokerau fauna have a coastal and inland distribution. Most are restricted to shrubland and forest, but *Tornatellinops novoseelandica* and *Phenacohelix tholoides* also live in shrub-sandfield vegetation on coastal dunes, and *Paralaoma caputspinulae* predominantly lives in open, sparsely vegetated habitats (pers obs).

As described above, the only native vegetation types now present on the Tokerau dunes are spinifex-shrubby sandfield and flax-prostrate shrubland, which support a low-diversity native snail fauna comprising *Tornatellinops novoseelandica*, *Succinea archevi* and *Paralaoma caputspinulae*. By analogy, the compositionally identical and closely comparable fossil snail faunas in subcluster 1a of Fig 7 presumably occupied similar low, open vegetation.

The species composition and predominantly higher diversity of fossil snail faunas within subclusters 1b and 1d are characteristic of taller, more floristically-diverse shrubland vegetation, whereas the co-occurrence of *Suterilla neozelanica* and *Phrixgnathus* sp “marshalli” in the low diversity subcluster 1c faunas indicates low shrubland vegetation on the dunefield coastal margin. The high diversity faunas in the Group 2 cluster (Fig 7) have species compositions broadly characteristic of floristically diverse shrubland, broadleaf forest and broadleaf-podocarp forest (e.g., Brook 1999, Brook & Goulstone 1999). Although those landsnail faunas do not provide unequivocal evidence of the former existence of forest on the Tokerau dunefield, it is reasonable to assume that forest did establish during the long period of dune stability from c. 2000–900 years BP, and that the Group 2 landsnail faunas from the Unit B paleosol and lower part of the overlying Unit C sequence represent forest assemblages.

Putting the cluster analysis faunal groupings into a stratigraphic context leads to the following conclusions. The low to moderate diversity 1a and 1b fossil snail faunas in dune lithofacies in the lower part of Unit B indicate a former patchy mixed sandfield and shrubland vegetation cover, the low to high diversity 1b, 1d and Group 2 faunas in the Unit B paleosol and overlying Unit C dune lithofacies indicate a mosaic shrubland and forest vegetation cover, the low to moderate diversity, 1a and 1d faunas present locally in the lower paleosol of Unit C, and correlative low diversity 1d faunas in Unit D, indicate a mixed sandfield and shrubland vegetation cover, and the low diversity 1a faunas in the upper paleosol of Unit C indicate an open, patchy sandfield and low shrubland vegetation cover.

Landsnail shells are absent from the Unit C lower paleosol in most of the sections examined, and in particular from those sections where the paleosol has a black A horizon and well-developed B horizon. The presence of abundant comminuted charcoal throughout the A horizon in those sections is evidence of repeated firing of the vegetation cover, and suggests the possibility that the soil formed mainly under seral manuka (*Leptospermum scoparium*)-kanuka (*Kunzea ericoides*) shrubland – a habitat type that is generally inimical to native landsnail species (pers obs). However, the alternative possibility, that landsnail shells were

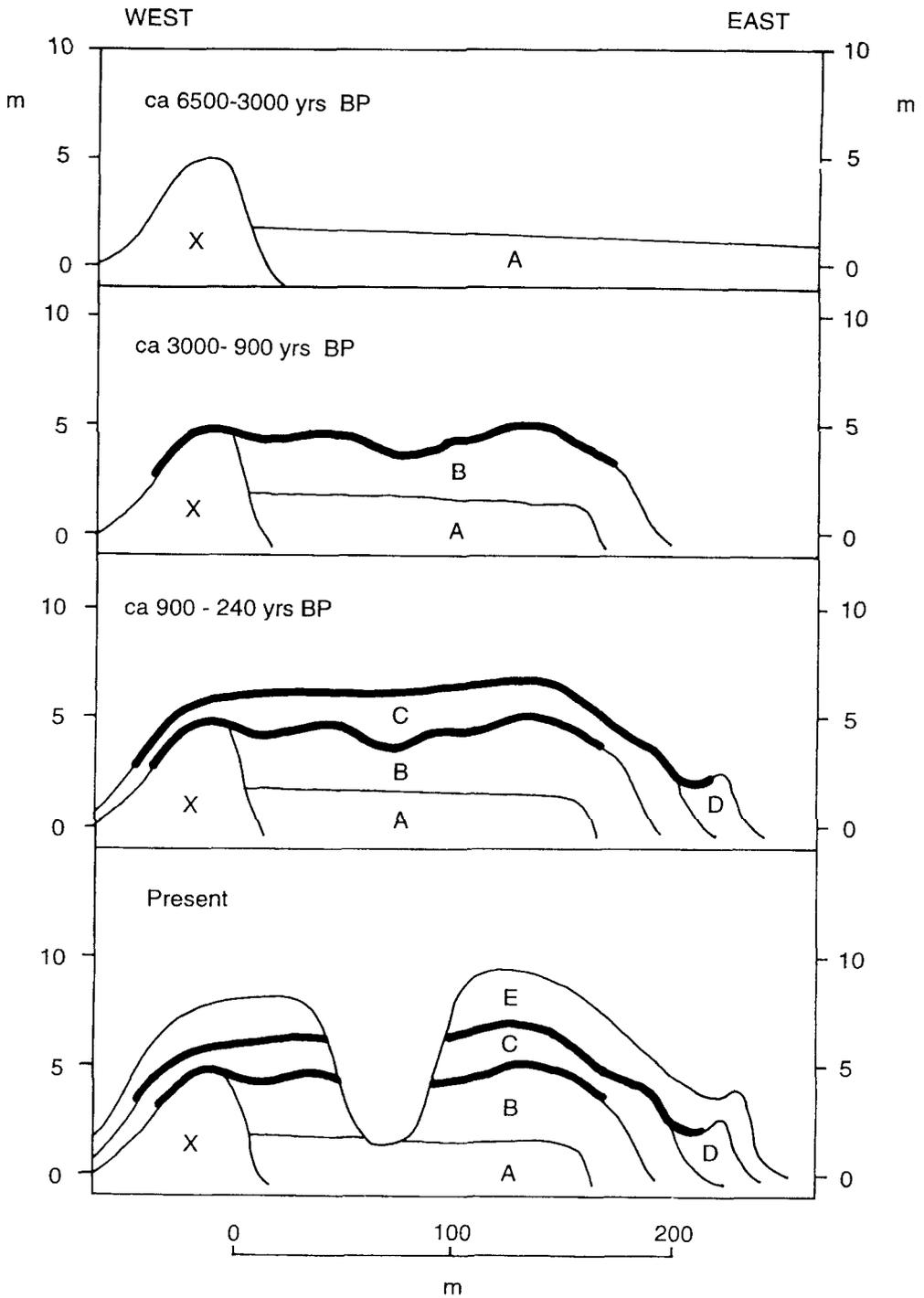


Fig. 8 Suggested model of dunefield development at Tokerau since c 6500 yrs BP. Stratigraphic units A-E as described in text, paleosols capping units B and C indicated by thick lines. The existence of a mid-Holocene foredune ridge (x) on the landward margin of the dunefield is conjectural.

originally present in the soil and have been secondarily dissolved by acidic groundwaters, cannot be discounted

Paleoenvironmental history

The inferred history of dunefield formation at Tokerau since about 6500 years BP, as determined from stratigraphy, sedimentology and landsnail faunas, is shown in Fig 8 and can be summarised as follows

c. 6500–3000 years BP Holocene coastal sedimentation at Tokerau presumably began following the maximum post-glacial sea level rise at 6500 years BP. A belt of sandy foredunes is inferred to have formed along the landward margin of the present-day dune belt, separated from the last interglacial-glacial dune and swamp deposits further inland by a narrow belt of swamps and lakes, and with a wide, gently sloping, prograding shelly sand beach to seaward (forming the Unit A sequence). At the time of deposition of sea-rafted Tokerau pumice, about 3000 years BP, the upper shoreface extended at least 200 m inland from the present day coastline

c. 3000–900 years BP In the early part of this period the coastal dune belt prograded seaward to near the present-day coastline, and the newly formed, low coastal dunes had a patchy sandfield and shrubland vegetation cover with intervening areas of moving sand (forming the dune lithofacies in the lower part of Unit B sequence). Subsequently, from at least 2000 to about 900 years BP, the dunes were stabilised beneath a shrubland-forest vegetation cover, and a sandy soil (capping the Unit B sequence) formed on the dunefield surface

c. 900–240 years BP This period marks another cycle of dune build-up followed by stabilisation and soil formation (Unit C sequence). The initial accretionary phase involved burial of the pre-existing Unit B groundsoil by landwards-migrating dunes with sand apparently derived from erosion of a coastal foredune. Landsnail faunas indicate that the mobile dunes supported mostly patchy shrubland vegetation, but the presence of high diversity faunas in the lower part of Unit C at some sites (i.e., sections 1, 3) suggests that pre-existing forest-shrubland vegetation locally persisted for some time after the start of the dune build-up

At the same time as the dune was building up, shell gravel accumulated on the upper shoreface on the seaward margin of the dunefield, forming a beach-parallel backshore ridge (Unit D sequence). This change from sand-dominated to shell gravel-dominated sedimentation in the littoral zone marked an increase in wave exposure on Tokerau Beach. Sea-rafted Loiseles pumice, which probably washed ashore between 660 and 516 years BP, was incorporated into the upper seaward part of the shell ridge, and accumulated, along with reworked shell gravel, as storm overwash deposits in a hollow inland from the shell ridge

The dunefield and landward margin of the shell gravel deposits were subsequently capped by two successive soil horizons. The lower soil, which probably formed after 600 years BP, typically has a weathered subsoil B horizon that is characteristic of development beneath shrubland or forest vegetation. At sites where the B horizon is only weakly developed or absent (i.e., sections 3, 6), snail faunas indicate a sandfield and shrubland vegetation cover. This soil post-dates the arrival of Loiseles pumice at Tokerau and provides the earliest record of Maori occupation in the area, containing abundant charcoal that is evidence of widespread firing of dunefield vegetation, and rare marine shell midden

An overlying sandy soil horizon, generally conformable on the lower soil and with a radiocarbon age range of 464–237 years BP, is of anthropic origin, comprising predominantly midden shell, fish bone, charcoal, cooking stones, and shell gravel mined from coastal

deposits This soil, which was presumably used by prehistoric Maori for agricultural purposes, contains a landsnail fauna characteristic of sparse, low vegetation

c. 240 years BP-present At some time after approximately 240 years BP there was a period of renewed dune build-up, which buried existing groundsoils and formed a sandy foredune to seaward and on top of the shell gravel ridge Parts of the dunefield subsequently became stabilised by a vegetation cover of native sandfield and prostrate shrubland species, and later also by exotic grasses, herbs and shrubs, but extensive local erosion also formed deep deflation hollows and areas of sparsely and non-vegetated, mobile dunes Over the last 100 years or so the Tokerau dunefield has been repeatedly fired, and the vegetation cover has also been damaged by rabbits, stock and, more recently, off-road vehicles

Causes of depositional episodes at Tokerau

The Tokerau area has been tectonically stable since at least late Pleistocene time (Brook & Thrasher 1991), so none of the depositional episodes represented in the coastal dune sequence are attributable to tectonic changes in land elevation Similarly, the depositional episodes cannot be attributed to cyclical changes in external sand supply, given that the Holocene littoral-subtidal sand body in Doubtless Bay is essentially a closed system with negligible external input from longshore drift and fluvial erosion

I infer that the initial formation of the Holocene coastal dunefield at Tokerau followed and resulted from the maximum post-glacial sea level rise at 6500 years BP A later phase of beach progradation and accretion preceding the arrival of Tokerau pumice at c 3000 years BP correlates with, and may have been caused by, a sea level transgression of the order of 0.6–0.9 m between 4500 and 3500 years BP identified by Gibb (1986) Similarly, the main phase of dune progradation at Tokerau dating to c 3000–2000 years BP correlates with, and may have resulted from, a subsequent regression of sea level to more-or-less the present level at that time (Gibb 1986) It is not possible from present information to correlate either of the two later depositional episodes at Tokerau with sea level changes which, according to Gibb (1986), have varied only by a few decimetres since 2000 years BP

The dune-building phases of the two latest depositional episodes were not progradational as in the earlier episode, but instead involved the inland transport and accumulation of sand eroded from a seaward foredune Further, the dune-building phase from c 900–600 years BP was coeval with a shift from sand-dominated to shell gravel lag deposition on Tokerau Beach, which indicates a change in the prevailing wave environment within Doubtless Bay The implication is that the depositional episodes since approximately 900 years BP have been in part owing to the influence of long term cyclical climatic changes on prevailing local wind and wave regimes The dune-building phases possibly represent periods of stronger and/or more frequent onshore winds, greater wave exposure and increased coastal erosion, while the preceding and intervening phases of dune stabilisation and soil formation represent periods of lesser wind and wave exposure

Human activities have clearly affected the Tokerau dunefield but there is no evidence that they have caused any major changes in depositional regime There is no stratigraphic record of human occupation before the arrival of Loiseles pumice at Tokerau, indicating that anthropic influence there probably does not extend beyond approximately 660 years BP The main aspects of human disturbance include the firing of dunefield vegetation and modification of soils by prehistoric Maori (both during a phase of dune stability), and the subsequent modification of dune vegetation by firing, invasion of exotic plant species, and browsing by introduced rabbits and ungulates during the historic dune-building phase The locally extensive erosion of the inland part of the dunefield during historic time has no parallel in earlier dune-

building episodes, suggesting that it could be related to the influence of browsing mammals on dune erosion, as suggested by McFadgen (1994) for Chatham Island dune sequences

CONCLUSIONS

The Holocene coastal dune belt at Tokerau Beach has had an episodic depositional history that included a progradational phase from approximately 3000–2000 years BP, a period of dune stabilisation and soil formation from approximately 2000–900 years BP, renewed dune mobilisation and accretion from approximately 900–600 years BP with subsequent stabilisation and soil formation, and another mobile phase beginning after approximately 240 years BP which has continued to the present day

Two stratigraphically distinct, exotic, sea-rafted pumice units are represented in the Tokerau dune sequence Tokerau pumice (new), which has a primary depositional age of c 3000 years BP, and Loiseles pumice, which has a primary depositional age between 881 and 516 years BP I have shown that an older age of 1035–920 years BP determined for Loiseles pumice at Tokerau by Osborne et al (1991), and quoted in Froggatt & Lowe (1990) and Shane et al (1998), is unreliable

Fossil landsnail faunas and sedimentary features indicate that the Tokerau dune belt had a patchy cover of sandfield and shrubland vegetation during the progradational phase from c 3000–2000 years BP and that an extensive shrubland-forest mosaic developed on the dunes during the subsequent stable phase from c 2000–900 years BP With renewed dune build-up after c 900 years BP there was a progressive reversion to patchy shrubland vegetation on the dunefield, but an extensive shrubland cover re-established during the next stable phase after c 600 years BP That vegetation cover was probably largely destroyed after c 450 years BP as a result of firing by prehistoric Maori, and was replaced by patchy, open shrub and sandfield vegetation and Maori gardens In spite of vegetation clearance the dunes remained stable until after c 240 years BP, when there was renewed sand build-up and erosion During the historic period surviving native sandfield-shrubland on the Tokerau dunes has been modified by repeated firing, invasion of exotic plant species, and browsing by introduced rabbits and ungulates

The landsnail fauna of the Tokerau dunefield increased from a total of eight species during the dune progradation phase at 3000–2000 years BP, to a maximum diversity of 17 species during the following period of dune stability from c 2000–900 years BP Since 900 years BP there has been a progressive reduction in total native snail diversity to 15 species during the period of dune accretion at c 900–600 years BP, dropping markedly to eight species and then four species during the earlier and later parts respectively of the following period of dune stability from c 600–240 years BP, to three species at present The landsnail extinctions after c 900 years BP parallel extinctions of forest and shrubland bird species at Tokerau described by Millener (1981) and are evidence of pervasive habitat destruction and degradation on the dunefield over that time period and in particular after about 600 years BP The history of landsnail extinctions contrasts with the situation on dunes behind pocket beaches on the eastern Northland mainland coast and at the Chicken Islands where landsnail faunal diversity increased or remained more-or-less the same during the early prehistoric occupation period, before declining in later prehistoric-historic time (Brook 1999, Brook & Goulstone 1999) That contrast presumably in part reflects different human land use histories in the respective areas during prehistoric time but is probably also related to generic differences in volumes and extent of dune migration and build-up consequent upon dunefield size and setting as well as differences in the proximity and composition of peripheral forest and shrubland communities and the ability of the various taxa within them to disperse onto dunefields

In spite of the fact that the present day native dune biota is considerably less diverse than

in pre-human time, and has also been modified by the introduction of a large number of exotic plant and animal species (including at least five European landsnail species), the Tokerau dunefield still has very high conservation value for least two reasons. Firstly, extensive areas of sandfield-prostrate shrubland remain that are dominated by, and have a relatively high diversity of, native plant species characteristic of that habitat type (e.g., Partridge 1992). Secondly, the Tokerau dunes support one of the largest of the few remaining populations of the endemic dune snail *Succinea archeyi* (Powell 1979, unpubl. data). Conservation management and, in particular, control of invasive exotic plant species will be necessary if these relict values are to be preserved.

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APPENDIX 1: LIST OF MARINE MOLLUSCS PRESENT IN STRATIGRAPHIC UNITS A, D AND MIDDEN PALEOSOL OF UNIT C

Estuarine and rocky shore species are denoted by # and * respectively. Food items and reworked broken, abraded shell in midden paleosol are denoted by (i) and (ii) respectively.

BIVALVIA

# <i>Austrovenus stutchburyi</i> (Gray)	C(i)
<i>Bassina yatei</i> (Gray)	A, C(ii), D
<i>Divaricella huttoniana</i> (Vanatta)	A
<i>Dosinia anus</i> (Philippi)	A, C(i, ii), D
<i>Maetra discors</i> Gray	A, C(i, ii), D
<i>Oxyperas elongata</i> (Quoy & Gaimard)	A, C(ii), D
<i>Panopea zelandica</i> (Quoy & Gaimard)	A, D
<i>Paphies subtriangulata</i> (Gray)	A, C(i, ii), D
<i>Paphies ventricosa</i> (Gray)	A, C(i)
<i>Pecten novaezelandiae</i> Reeve	A, C(i), D
<i>Resania lanceolata</i> Gray	A, D
<i>Spisula aequilatera</i> (Deshayes)	A, C(i, ii), D
<i>Tawera spissa</i> (Deshayes)	C(ii), D
<i>Tucetona laticostata</i> (Quoy & Gaimard)	A, C(ii), D

GASTROPODA

<i>Alcithoe arabica</i> (Gmelin)	A, C(i), D
<i>Calliostoma selectum</i> (Dillwyn)	A
<i>Cominella adspersa</i> (Bruguère)	A, C(i, ii), D
* <i>Dicathais orbita</i> (Gmelin)	C(i)
<i>Maoricolpus roseus</i> (Quoy & Gaimard)	A, D
* <i>Nerita atramentosa</i> Reeve	C(i)
<i>Penion sulcatus</i> (Lamarck)	A, C(i)
<i>Sturthiolaria papulosa</i> (Martyn)	A, C(i, ii), D
* <i>Turbo smaragdus</i> Gmelin	C(i)
<i>Zethalia zelandica</i> (Hombron & Jacquinot)	C(ii), D

APPENDIX 2: DISTRIBUTION OF LANDSNAIL SPECIES AMONG SITES ON THE TOKERAU BEACH DUNEFIELD

Letters A-C are sites at which modern faunas were collected, and numbers with an f prefix denote fossil sites. Introduced European species are denoted by an asterisk.

TUTUILANIDAE	
<i>Suterilla neozelanica</i> (Murdoch)	f 172, f173, f177
ACHATINELLIDAE	
<i>Tornatellinops novoseelandica</i> (Pfeiffer)	A-C; f136–138, f140–146, f148–150, f152, f153, f155–160, f162, f164–171, f173–176, f178
SUCCINEIDAE	
<i>Succinea archeyi</i> Powell	A-C; f135, f136, f138, f140–142, f146, f147, f149, f150, f152, f155, f156, f158–160, f162, f164–171, f175, f177
CHAROPIDAE	
<i>Cavellia buccinella</i> (Reeve)	f136, f144, f146, f149, f150, f153, f156, f162, f165
<i>Charopa coma</i> (Gray)	f136, f141, f143, f144, f149, f150, f153, f156, f162, f165–170, f175, f176, f178
<i>Charopa parva</i> Suter	f136, f145, f146, f150, f162
<i>Huonodon hectori</i> (Suter)	f144, f162, f165–168, f170, f175, f176
<i>Paracharopa chrysaugaia</i> (Webster)	f136–138, f143–145, f149, f150, f152, f153, f155, f156, f158, f161, f162, f164–173, f178
<i>Phenacharopa novoseelandica</i> (Pfeiffer)	f136, f143–145, f149, f150, f153, f156, f162, f178
<i>Phenacohelix giveni</i> Cumber	f143, f144, f153, f162
<i>Phenacohelix tholoides</i> (Suter)	f136, f143, f144, f150, f153, f162, f168
<i>Serpho kivi</i> (Gray)	f162, f168
PUNCTIDAE	
<i>Kokikora angulata</i> Climo & Goulstone	f136, f137, f143–146, f149, f150, f153, f156, f158, f162, f165, f167, f168, f175, f176, f178
<i>Paralaoma caputspinulae</i> (Reeve)	A-C; f135–178
<i>Phrixognathus</i> sp. “marshalli”	f136, f138, f141–146, f149, f150, f152, f153, f155, f156, f158, f162, f164–173, f176–178
punctid sp. 24	f136, f137, f143–146, f149, f150, f152, f153, f156, f160, f162, f175, f176
RHYTIDIDAE	
<i>Amborhytida dunnae</i> (Gray)	f143, f149, f150, f153, f156, f162, f168
<i>Delos coresia</i> (Gray)	f136, f153, f165
COCHLICOPIDAE	
* <i>Cochlicopa lubrica</i> (Müller)	B
HELICIDAE	
* <i>Cantareus aspersus</i> (Müller)	A-C
HYGROMIIDAE	
* <i>Prietocella barbara</i> (Linnaeus)	A-C
VALLONIDAE	
* <i>Vallonia excentrica</i> Sterki	C
ZONITIDAE	
* <i>Oxychilus alliarus</i> (Miller)	A-C