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Land Snails from Norfolk Island Sites

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ABSTRACT. Fourteen sequences of land snails were sampled by corer from the Emily Bay settlement site and four from Cemetery Bay. Thirty-nine samples of modern land snails were collected from six environmental zones on Norfolk Island. The modern fauna is depauperate compared to the prehistoric one, with loss occurring mostly among the larger species. We suggest this is due first to predation by *Rattus exulans* introduced by prehistoric Polynesians and later to habitat loss following European settlement. We consider we cannot use the land snail data to make any interpretation of direct human impact on the Norfolk Island environment. We note however that the density and diversity of snails is high in the prehistoric cultural layer and below it, showing that the settlement area probably provided a more vegetated and wetter environment for the earliest settlers than is now present.

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The aim of this research was to use the land snail fauna to investigate the effects of the Polynesian settlement at Emily Bay on the local environment. We reasoned that a settlement of the extent revealed by the excavations was likely to have caused at least local changes through brush clearance, tree felling, burning, building, gardening, refuse disposal and the like. These changes would, perhaps, have had their greatest effects amongst animals of low mobility, some species of which might also be assumed to be restricted environmentally. Land snails seemed to be appropriate.

Methods

The research was carried out in three stages. Bulk samples of landsnails from Trench EB96:10 were submitted to WP in 1996. At the end of fieldwork in 1997 DN and PW took six grab samples of sand, each of c. 1 kg, from various trenches of the Emily Bay excavations. Three samples came from sands above the cultural layer and three from the fine yellow sand below. The samples were wet sieved through 2 and 1 mm sieves at the Archaeological Materials Laboratory (AML), University of Sydney and dried. The land snails were sorted into apparent species, the results being checked by Stephanie Clark of Invertebrate Identifications Australasia. Final results are in Table 1, which shows that only three of the 12 identified species are common to levels above and below the prehistoric occupation. Seven species are found only below the cultural layer and two only above it. One species (*Omphalotropis albocarinata* Mousson, 1873) dominates, providing more than three-quarters of the total number.

Despite the dramatic nature of these results, we considered that they might be flawed in several ways. First, since they were grab samples, sample sizes were only approximately similar. Next, our initial processing methods were experimental and certainly resulted in the loss or

Table 1. Emily Bay, 1997 samples, counts of each species.

species	upper sand EB97:23 South	EB97:23 West	EB97:25	lower sand EB97:23 Sq. E7	EB97:23 Sq. E13	EB97:24	total
Advena campbellii (Gray, 1834)	—	—	—	—	1	—	1
Allenoconcha basispiralis Preston, 1913	—	2	—	—	—	—	2
Fanulena insculpta (Pfeiffer, 1846)	—	—	—	1	57	7	65
Fanulena perrugosa Iredale, 1945	—	—	—	3	—	—	3
Greenwoodoconcha nux (Sykes, 1900)	—	—	—	—	6	1	7
Mathewsoconcha belli Preston, 1913	—	—	—	3	33	15	51
Mathewsoconcha suteri (Sykes, 1900)	—	—	—	—	4	—	4
new genus, new species	—	—	—	—	1	—	1
Omphalotropis albocarinata Mousson, 1873	58	64	67	29	317	183	718
Palmatina sp. Iredale, 1944	2	—	—	—	—	1	3
Succinea (Succinea) norfolkensis Sykes, 1900	7	11	1	1	19	12	51
Vallonia pulchella (Muller, 1774)	18	5	2	—	—	—	25
total	85	82	70	37	438	219	931

crushing of a few shells. Third, the considerable variation between samples may be real or simply an artefact of their small number. Fourth, no comparative samples were collected from sand bodies away from the site. And finally because little was known of the ecology of many species, environmental interpretation, such as whether the variation was due to the effects of human settlement, could not be made with confidence.

As a result we expanded the research in two directions. This stage of research aimed (a) to sample the current land snail fauna of Norfolk Island in sufficient environmental detail so that we could assess the extent to which prehistoric environments might be determinable by their faunas, and (b) to determine, if possible, the nature of the environment of Emily Bay before, during and after the first human occupation and in particular to test the reality of the radical differences observed a year earlier.

To carry out (*a*) 39 samples of the modern snail fauna were taken from six environmental zones we identified on Norfolk Island. To carry out (*b*) 14 samples were taken by corer from areas of the Emily Bay prehistoric settlement, supplemented by four samples from Cemetery Bay. Since both areas lay within the same environmental zone of beach and dunes, they should display similar patterns of change in land snails over time. While specific methods of analysis are described below, we note here that each species in all samples, both modern and prehistoric, was given an arbitrary alphabetical label pending final species determination. The total range of species identified in this study is given in Table 2; the taxonomy largely follows Iredale's (1945) review of the fauna, with Smith's (1992) modifications.

The modern sample

Despite extensive European use of the island during the last two centuries, a range of environments can be seen on Norfolk Island, especially within different parts of the Norfolk Island National Park, and in a few private properties which have been less subject to cattle grazing. Based on discussions with National Parks officers and Ponder's previous experience of Norfolk Island, our survey divided the island into eight environmental zones: open grassland, flax growth, beach and dunes, pine forest, mixed pines, mixed forest, palm forest and rainforest. The first two of these zones, open grassland and flax growth, proved to be devoid of snails and are thus not included in this analysis. Table 3 lists the stations and the number of samples taken from each environmental zone, while Fig. 1 shows their locations. Samples from stations 12 and 14 were not processed for this analysis.

Table 2. Land snail species recorded in this study.

species	archaeological samples	modern samples
Advena campbellii (Gray, 1834)	✓	✓
Allenoconcha basispiralis Preston, 1913	✓	
Allenoconcha sp. Preston, 1913		✓
Cryptocharopa exagitans (Cox, 1870)		✓
Fanulena insculpta (Pfeiffer, 1846)	✓	✓
Fanulena new species	✓	
Fanulena perrugosa Iredale, 1945	✓	
Greenwoodoconcha nux (Sykes, 1900)	✓	✓
Hawaiia miniscula (Binney, 1840)	✓	
Helix aspersa Muller, 1774		✓
Johannesoconcha multivolva Preston, 1913		✓
Lutilodix imitatrix (Sykes, 1900)	✓	✓
Mathewsoconcha belli Preston, 1913	✓	✓
Mathewsoconcha suteri (Sykes, 1900)	✓	✓
Nancibella quintalae (Cox, 1870)		✓
Neospuparia norfolkensis (Sykes, 1906)	✓	✓
new genus, new species	✓	
Norfolcioconcha norfolkensis (Hedley, 1899)	✓	
Norfolcioconcha sp. Preston, 1913		✓
Omphalotropis albocarinata Mousson, 1873	✓	✓
Pacificella norfolkensis (Preston, 1913)	✓	✓
Palmatina quintali Iredale, 1945	✓	✓
Palmatina sp. Iredale, 1944	✓	✓
Paraloma duncombei Iredale, 1945	✓	✓
Penescosta mathewsi (Preston, 1913)		✓
Pittoconcha concinna Preston, 1913		✓
Pittoconcha sp. Preston, 1913		✓
Quintalia stoddartii (Gray, 1834)		✓
Roybellia depressa Preston, 1913		✓
Succinea (Succinea) norfolkensis Sykes, 1900	✓	✓
Vallonia pulchella (Muller, 1774)	✓	✓
Zonitoides arboreus (Say, 1817)		✓

Our sampling followed methods generally used by malacologists. Within the six selected environmental zones we collected several samples at one to three specific locations, called here stations. Each sample consisted of bags of surface litter collected from haphazardly selected 1×1 m squares. Each bag weighed 1–2 kg. Samples were soaked in methylated spirit before transport to Australia. There, samples were dried and sieved through nested 3, 2, 1 and 0.5 mm sieves in the AML by DN. The sieve residue was also checked for specimens.

Specimens were sorted into species. Most species were represented by less than 20 individuals per sample; where frequency was higher, this was estimated. Twenty-six species were found. These were identified using comparative collections in the Malacology Section, Australian Museum, with the assistance of Stephanie Clark. Table 4 gives the species found in each environment and their approximate numbers in our samples. This table shows that a few species are ubiquitous, being present in all areas; these are also found in most samples.

The only clear overall trend in these data is that wetter areas contain rather more species than drier ones. More specifically, there are a few species which seem to be environmentally restricted. Four species (*Palmatina quintali* Iredale, 1945, *Lutilodix imitatrix* (Sykes, 1900), *Johannesoconcha multivolva* Preston, 1913 and *Nancibella quintalae* (Cox, 1870)) are found only in the rainforest. Some species such as *Roybellia depressa* Preston, 1913 and "*Norfolcioconcha* sp." (Preston, 1913) seem to be restricted to wetter areas, such as rainforest and palm forest. Four species [*Mathewsoconcha suteri* (Sykes, 1900), *Mathewsoconcha belli* Preston, 1913, *Advena campbellii* (Gray, 1834) and

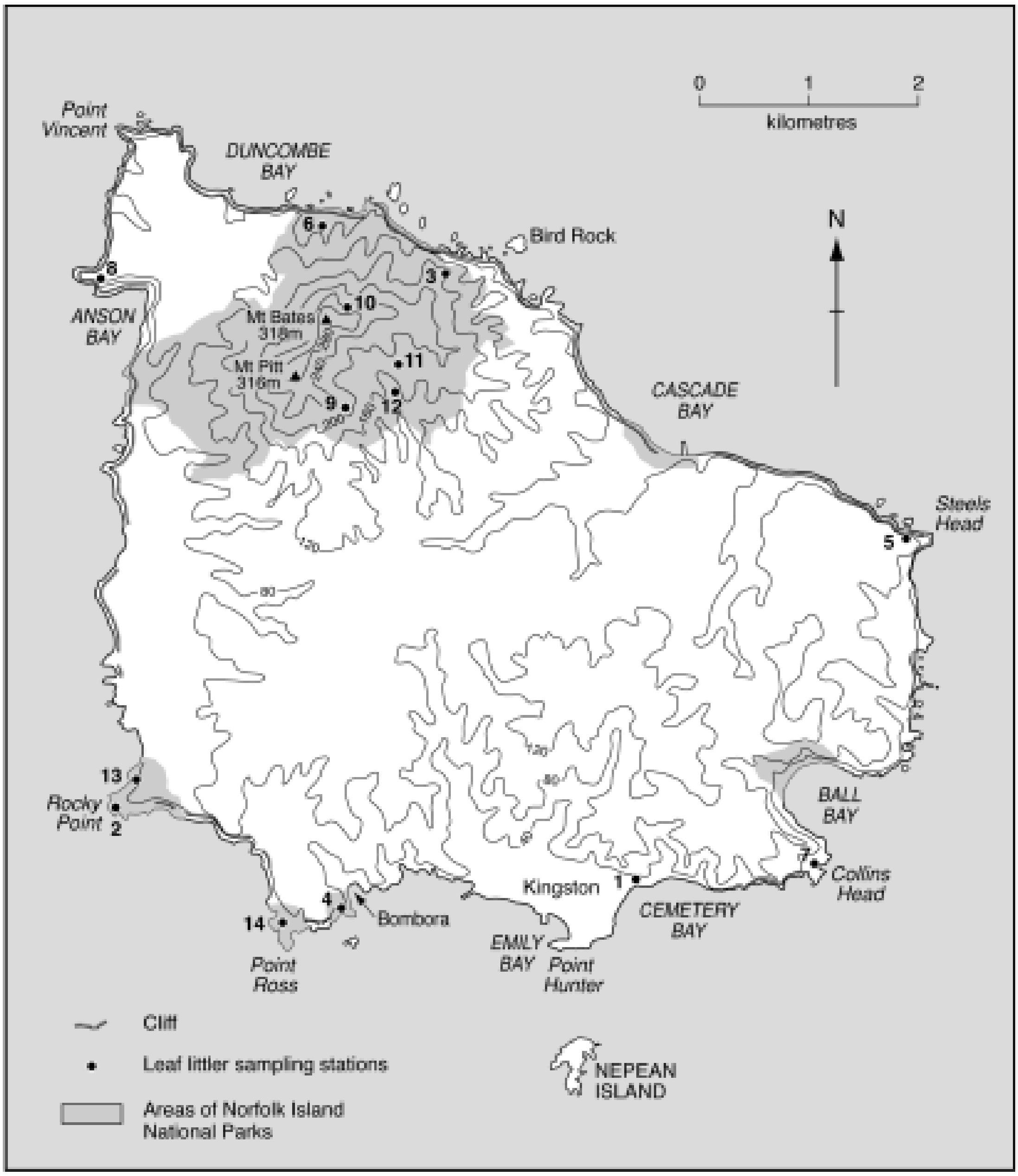

Figure 1. Norfolk Island showing approximate locations of sampling stations for both modern and archaeological samples. For modern sample environments, see Table 3.

Table 3. Modern sample: environment, location, station number and number of samples taken. Stations 2, 3, 4, 6, 9, 10, 11 and 13 are within the Norfolk Island National Park. Stations 12 and 14 were not used in this analysis.

environmental zone	location	station number	total number of samples
beach and dunes	Cemetery Bay	1	6
flax growth	Anson Bay	8	0
pine forest	Rocky Point	2	2
pine forest	Rocky Point	13	2
mixed forest	Anson Bay	6	5
mixed pines	Mt Pitt	3	5
mixed pines	Bumbora	4	3
mixed pines	Collins Head	7	4
palm forest	Mt Bates	10	2
palm forest	Mt Bates	11	3
rain forest	Mt Pitt	9	4
rain forest	Steeles Point	5	3

Vallonia pulchella (Muller, 1774)] are found only in the beach and dunes.

We conclude that the presence or absence of some species may be used to indicate the relative wetness of the local environment of the Emily Bay settlement site, which is in the beach and dune zone. However, even if clearly indicative numbers of these species are not present the diversity of the fauna may be helpful as an environmental indicator.

It should be noted here that, as Brook and Goulstone (1999, see also Brook, 1999a,b) found in similar environments in New Zealand, present diversity is likely to be less than in the pre-human past. This is due to the activities of the predators *Rattus exulans* and, more recently, *R. rattus*, introduced by Polynesians and Europeans respectively, as well as to anthropogenically induced environmental change. We note that three introduced specimens occur in these samples, namely *Helix aspersa* Muller, 1774, *Vallonia pulchella* (Muller, 1774) and *Zonitoides arboreus* (Say, 1817).

The archaeological sample

Fourteen cores were taken from the Emily Bay site area in 1999. Our initial plan was to take cores in two transects across the site, but the layout of the archaeological excavations and previous disturbances made this impossible, so sets of four cores were taken from three areas. Two sets (2, 3) were taken near the southeast and northeast ends of Trench EB97:23. Set 4 was taken 75 m east of this, near Trench EB96:10 (Anderson, Smith and White, this vol., fig. 29). Sets 1 and 5 each consisted of one core which showed disturbance and were therefore abandoned. They are not included in our analysis.

Four cores were taken from Cemetery Bay in two sets each of two cores. Set 6 was taken from within a small sand quarry, which had removed sand from above a clay layer, while Set 7, 16 m away, started at the current sandy ground surface, about 1 m higher.

Table 4. Modern sample: approximate number of individuals of each species per environmental zone and number of species per zone.

species	rain forest	mixed forest	palm forest	beach and dunes	mixed pines	pine forest
Advena campbellii (Gray, 1834)	—	—	—	1	—	—
Allenoconcha sp. Preston, 1913	63	26	19	10	4	2
Cryptocharopa exagitans (Cox, 1870)	16	110	16	—	10	—
Fanulena insculpta (Pfeiffer, 1846)	18	0.2	6	15	9	4
Greenwoodoconcha nux (Sykes, 1900)	75	34	74	—	107	—
Helix aspersa Muller, 1774	1	—	1	3	—	—
Johannesoconcha multivolva Preston, 1913	1	—	—	—	—	—
Lutilodix imitatrix (Sykes, 1900)	1	—	—	—	—	—
Mathewsoconcha belli Preston, 1913	—	—	—	10	—	—
Mathewsoconcha suteri (Sykes, 1900)	—	—	—	80	—	—
Nancibella quintalae (Cox, 1870)	21	—	—	—	—	—
Neospuparia norfolkensis (Sykes, 1906)	1	5	5	—	—	1
Norfolcioconcha sp. Preston, 1913	1	—	1	—	—	—
Omphalotropis albocarinata Mousson, 1873	133	105	160	381	205	280
Pacificella norfolkensis (Preston, 1913)	38	29	15	445	69	190
Palmatina quintali Iredale, 1945	10	—	—	—	—	—
Palmatina sp. Iredale, 1944	150	10	55	1	—	—
Paralaoma duncombei Iredale, 1945	—	—	1	—	—	1
Penescosta mathewsi (Preston, 1913)	2	5	—	—	—	—
Pittoconcha concinna Preston, 1913	—	—	6	—	—	—
Pittoconcha sp. Preston, 1913	—	—	1	—	—	—
Quintalia stoddartii (Gray, 1834)	15	—	—	—	8	4
Roybellia depressa Preston, 1913	61	90	1	—	10	—
Succinea (Succinea) norfolkensis Sykes, 1900	12	20	15	12	40	30
Vallonia pulchella (Muller, 1774)	—	—	—	235	—	—
Zonitoides arboreus (Say, 1817)	73	—	1	15	1	1
number of species per environmental zone	19	10	16	12	10	9

Cores were taken with a 10 cm diameter sand corer which extracted samples 10 cm in depth, thus providing samples of equal volume (785 cm^3). Cores were not of equal depth in either area, since the depth of each stratigraphic layer varied, while some cores were halted by obstructive stones. In general, the advent of a new layer could be detected by feel or could be predicted within each set once the first core was taken. In order to keep the core samples from each layer as separate as possible, not every sample was exactly 10 cm in depth. This variation has been taken into account in the averaging of data. Table 5 shows the number of core samples taken from each stratigraphic layer by each analysed core.

Table 5. Emily Bay and Cemetery Bay: number of core samples in each layer for each core.

core and set number	upper sand layer	clay layer	cultural layer	lower sand layer
EB2, Set 3	4	1	6	8
EB3, Set 3	3	2	4	6
EB4, Set 2	3	—	5	12
EB5, Set 2	2	2	4	—
EB6, Set 2	3	—	5	10
EB7, Set 4	9	2	5	15
EB8, Set 3	4	2	3	3
EB9, Set 4	9	1	5	15
EB10, Set 4	9	1	5	15
EB12, Set 2	4	—	5	8
EB13, Set 3	3	2	3	2
EB14, Set 4	8	2	5	15
total, Emily Bay	61	15	55	109
CB1, Set 7	8	1	—	5
CB2, Set 6	—	1	—	7
CB3, Set 6	—	1	—	7
CB4, Set 7	7	1	—	7
total, Cemetery Bay	15	4	—	26
total, both areas	76	19	55	135

As discussed elsewhere (Anderson, Smith and White, this vol.), the stratigraphy of the site area at Emily Bay is divisible into four main layers. These form the analytical framework of our analysis.

1 Wind-blown dunes of yellow-brown sand with considerable surface configuration on which grow a plantation of Norfolk pines. It is called here the Upper Sand layer.
2 A stiff, chocolate brown Clay layer, which slopes lightly from northeast to southwest and varies in thickness from 3 to 20 cm. The contents of this include European period material suggesting it derives from the historic period. This layer is sometimes underlain by a very thin layer of yellow sand: our analyses include this with the Clay layer.
3 Grey-brown sand, containing a considerable component of cultural material including bird and fish bone, basalt flakes and the remains of structures. This Cultural layer also slopes slightly northeast to southwest. It is sometimes up to 60 cm thick, though generally rather less. Our analyses attributed material to the Cultural layer only when clearly within a grey-brown sandy matrix. We note that very small amounts of cultural and midden material were pushed down into the fine yellow sand below, but decided that the possible contamination of our snail samples was likely to be insignificant.
4 Clean yellow sand, which continues down to the water table in all cases. Called here the Lower Sand layer, it is of variable thickness.

The stratigraphy of the Cemetery Bay cores was similar to Emily Bay, but layer 3, the Cultural layer, was absent. Following Anderson, Smith and White (this vol.), we have divided our core samples into Upper Sand (cf. Trench CB95:01, Layers 1–5), Clay (Layers 6–7) and Lower Sand (all layers below 7).

We believe that the stratigraphic integrity of the cores was fairly high but not total, based on the evidence of two introduced species. *Hawaiia miniscula* is found in many parts of the world (Cowie, 1997). In the Emily Bay cores, it is found in the Clay and Cultural layers, with one specimen in the Lower Sand layer. Six specimens occur in the Lower Sand layer of the Cemetery Bay cores. *Vallonia pulchella* is a small (2 mm diameter) snail of European origin. Sixty six specimens (18%) occur in the Cultural layer and ten (3%) in the Lower Sand layer from a total of 359 at Emily Bay, clearly indicating some movement of material. Similar movement is found in the Cemetery Bay cores. There are two possible reasons for this movement. First, both areas are long-term nesting sites for burrowing mutton birds (*Puffinus pacificus*) whose bones are found throughout the layers, and second, dune movement will have inevitably re-sorted some of the snail shells. These examples show that it would be unwise to rely on single species or small numbers in any interpretation.

Sample processing. Processing procedures were similar to those used elsewhere in Pacific archaeology (refs in Neuweger, 1999). In the field each core sample was bagged and labelled with its core number and depth. Each was then wet sieved through 2 and 1 mm geological sieves, oven-dried, and stone and other large objects such as roots discarded before return to Sydney. Samples were sorted with the aid of a magnifying lens and shells extracted were allocated arbitrary alphabetical labels pending final species identification. Species were identified using comparative collections in the Malacology Section, Australian Museum and with the assistance of Stephanie Clark.

In calculating minimum number of individuals (MNI), broken shells were also allocated to species as follows. Any shell which was only slightly damaged (e.g., apex removed) could be identified by features such as edge angle or spire size and counted along with whole shells. With more heavily broken shells numbers of individuals were calculated either from the number of particular elements present (e.g., apertures) or from assessment of broken pieces within a specific depth unit. Broken shell numbers form 12% of the total. However, breakage was not the same for all shells but varied directly with size as Table 6 shows.

A total of 9376 individual land snails were identified from the studied cores, 4601 from Emily Bay and 4775 from Cemetery Bay.

Results

Emily Bay. Table 7 gives the species count by stratigraphic layer for the Emily Bay cores and Table 8 presents the

Table 6. Emily Bay, archaeological sample. Left side: percent of broken shell numbers, by species. Right side: mean size of the adult of each species. Abbreviations: L = long, W = wide.

species	broken (%)	species	mean size of adult (mm)
Advena campbellii (Gray, 1834)	45.5	*Advena campbellii* (Gray, 1834)	22 diameter
Greenwoodoconcha nux (Sykes, 1900)	39.1	*Succinea (Succinea) norfolkensis* (Sykes, 1900)	L 12, W 6
Fanulena insculpta (Pfeiffer, 1846)	28.2	*Mathewsoconcha suteri* (Sykes, 1900)	10 diameter
Mathewsoconcha suteri (Sykes, 1900)	23.1	*Mathewsoconcha belli* Preston, 1913	10 diameter
Succinea (Succinea) norfolkensis (Sykes, 1900)	19.6	*Fanulena insculpta* (Pfeiffer, 1846)	7 diameter
Omphalotropis albocarinata Mousson, 1873	15.6	*Greenwoodoconcha nux* (Sykes, 1900)	4 diameter
Fanulena new species	11.6	*Omphalotropis albocarinata* Mousson, 1873	L 4, W 3
Hawaiia miniscula (Binney, 1840)	9.5	*Fanulena perrugosa* Iredale, 1945	L 4, W 3
Mathewsoconcha belli Preston, 1913	9.0	*Fanulena* new species	L 4, W 3
Pacificella norfolkensis (Preston, 1913)	3.1	*Neospuparia norfolkensis* (Sykes, 1906)	L 4, W 3
Norfolcioconcha norfolkensis (Hedley, 1899)	3.1	*Gastrocopta insignifica*	L 4, W 2
Palmatina sp. Iredale, 1944	2.8	*Allenoconcha basispiralis* Preston, 1913	4 diameter
Vallonia pulchella (Muller, 1774)	1.7	*Palmatina* sp. Iredale, 1944	L 3, W 1.5
Paralaoma duncombei Iredale, 1945	0.6	*Pacificella norfolkensis* (Preston, 1913)	L 2, W 1
Neospuparia norfolkensis (Sykes, 1906)	0.0	*Vallonia pulchella* (Muller, 1774)	2 diameter
Gastrocopta insignifica	0.0	*Paraloma duncombei* Iredale, 1945	2 diameter
Fanulena perrugosa Iredale, 1945	0.0	*Norfolcioconcha norfolkensis* Hedley, 1899	2 diameter
Allenoconcha basispiralis Preston, 1913	0.0	*Palmatina quintali* Iredale, 1945	2 diameter
new genus, new species	0.0	*Hawaiia miniscula* (Binney, 1840)	2 diameter
Palmatina quintali Iredale, 1945	0.0	new genus, new species	1 diameter
total	12.7		

percentage distribution of each species within each layer. Four points are immediately apparent. First, almost two-thirds of the total number of specimens comes from the Cultural layer even though this is volumetrically much smaller than Upper Sand or the Lower Sand layers. Second, there are notable changes in the proportional representations of four species. *Omphalotropis albocarinata* Mousson, 1873 and *Succinea (Succinea) norfolkensis* Sykes, 1900 both show marked declines in the Upper Sand and Clay layers, while *Pacificella norfolkensis* (Preston, 1913) and *Vallonia pulchella* (Muller, 1774) show considerable rises. The two latter species are particularly common in the modern samples drawn from the beach and dune zone. Third, *Mathewsoconcha suteri* (Sykes, 1900), *Mathewsoconcha belli* Preston, 1913, *Greenwoodoconcha nux* (Sykes, 1900) and *Advena campbellii* (Gray, 1834) are missing from the Upper Sand and Clay layers as they were in the 1997 results (the two specimens of *M. belli* Preston, 1913 in the Clay come from the interface with the Cultural layer). However, in contrast to our second point, above, three of these species,

Table 7. Emily Bay core samples: minimum number of individuals by species for each analytical unit.

species	upper sand	clay	cultural	lower sand	total
Advena campbellii (Gray, 1834)	—	—	8	4	12
Allenoconcha basispiralis Preston, 1913	1	—	—	1	2
Fanulena insculpta (Pfeiffer, 1846)	11	1	108	51	171
Fanulena perrugosa Iredale, 1945	—	1	4	—	5
Greenwoodoconcha nux (Sykes, 1900)	—	—	36	9	45
Hawaiia miniscula (Binney, 1840)	—	2	3	1	6
Mathewsoconcha belli Preston, 1913	—	2	149	28	179
Mathewsoconcha suteri (Sykes, 1900)	—	—	10	2	12
Neospuparia norfolkensis (Sykes, 1906)	—	—	2	2	4
new genus, new species	—	2	4	2	8
Norfolcioconcha norfolkensis (Hedley, 1899)	3	—	5	5	13
Omphalotropis albocarinata Mousson, 1873	162	52	2114	620	2948
Pacificella norfolkensis (Preston, 1913)	170	3	35	20	228
Palmatina quintali Iredale, 1945	1	—	1	—	2
Palmatina sp. Iredale, 1944	27	8	157	32	224
Paralaoma duncombei Iredale, 1945	59	—	120	98	277
Succinea (Succinea) norfolkensis Sykes, 1900	2	2	81	21	106
Vallonia pulchella (Muller, 1774)	157	126	66	10	359
total	593	199	2903	906	4601

Table 8. Emily Bay: percentage of each species per core sample in each analytical unit, using the minimum number of individuals as the counting basis.

species	upper sand	clay	cultural	lower sand	total
Advena campbellii (Gray, 1834)	—	—	0.3	0.4	0.3
Allenoconcha basispiralis Preston, 1913	0.2	—	—	0.1	0.04
Fanulena insculpta (Pfeiffer, 1846)	1.9	0.5	3.7	5.6	3.7
Fanulena perrugosa Iredale, 1945	—	0.5	0.1	—	0.1
Greenwoodoconcha nux (Sykes, 1900)	—	—	1.2	1.0	1.0
Hawaiia miniscula (Binney, 1840)	—	0.5	0.1	0.1	0.1
Mathewsoconcha belli Preston, 1913	—	0.5	5.1	3.1	3.9
Mathewsoconcha suteri (Sykes, 1900)	—	—	0.3	0.2	0.3
Neospuparia norfolkensis (Sykes, 1906)	0.5	—	0.2	0.6	0.3
new genus, new species	—	0.5	0.1	0.2	0.2
Norfolcioconcha norfolkensis (Hedley, 1899)	—	—	0.1	0.6	0.2
Omphalotropis albocarinata Mousson, 1873	27.3	26.1	72.8	68.4	64.0
Pacificella norfolkensis (Preston, 1913)	28.7	1.5	1.2	2.2	5.0
Palmatina quintali Iredale, 1945	0.2	—	0.03	—	0.04
Palmatina sp. Iredale, 1944	4.6	4.0	5.4	3.5	4.9
Paralaoma duncombei Iredale, 1945	9.9	—	4.1	10.8	6.0
Succinea (Succinea) norfolkensis Sykes, 1900	0.3	0.5	3.7	2.3	2.3
Vallonia pulchella (Muller, 1774)	26.5	63.3	2.3	1.1	7.8
mean number per core sample	9.7	13.2	52.8	8.4	19.2

namely *A. campbellii*, *M. belli* and *M. suteri* are only found in the beach and dune zone in the modern sample. Fourth, there are no species that appear only in the European period Clay and Upper Sand layers, unlike the 1997 results.

Cemetery Bay. Analysis of the Cemetery Bay material is set out in Table 9. This shows that there is a high degree of overlap with the Emily Bay data in the species represented and that there are similar numbers of species in the pre-human Lower Sand layer and the Clay layer. There are many fewer species in the Upper Sand layer, but the three represented are those most common at Emily Bay. The similarity in overall pattern to the Emily Bay data supports its reality.

In terms of absolute numbers there are considerable differences between the two areas, with many more shells per unit volume in the pre-human layer at Cemetery Bay compared to Emily Bay, while the reverse is true of the Upper Sand layer. We presume that the differences relate both to minor environmental differences resulting in different snail population densities at the times of accumulation and to local taphonomic processes.

Table 9. Cemetery Bay core samples: minimum numbers of individuals of each species.

species	upper sand	clay	lower sand	total
Advena campbellii (Gray, 1834)	—	1	8	9
Allenoconcha basispiralis Preston, 1913	—	—	1	1
Fanulena insculpta (Pfeiffer, 1846)	—	4	96	100
Fanulena new species	—	—	1	1
Greenwoodoconcha nux (Sykes, 1900)	—	2	11	13
Hawaiia miniscula (Binney, 1840)	—	—	6	6
Lutilodix imitatrix (Sykes, 1900)	—	—	1	1
Mathewsoconcha belli Preston, 1913	—	4	263	267
Mathewsoconcha suteri (Sykes, 1900)	—	3	53	56
new genus, new species	—	—	1	1
Norfolcioconcha norfolkensis (Hedley, 1899)	—	—	10	10
Omphalotropis albocarinata Mousson, 1873	8	81	3683	3772
Pacificella norfolkensis (Preston, 1913)	1	—	6	7
Palmatina sp. Iredale, 1944	—	3	218	221
Paraloma duncombei Iredale, 1945	—	1	7	8
Succinea (Succinea) norfolkensis Sykes, 1900	—	—	57	57
Vallonia pulchella (Muller, 1774)	28	169	48	245
total	37	268	4470	4775
mean number per core sample	2.5	67.0	171.9	106.1

Discussion and implications

We start by noting that our modern samples suggest that land snails may be indicative of environments in two ways. First, some species appear to be restricted to certain environments and second, wetter environments, that is those with more permanent moisture, host a greater diversity of species.

Snail diversity is high in both the Lower Sand and Cultural layers. The number of species in both layers is comparable to that of wet environments such as rainforest and palm forest in our modern sample. This may suggest a damper environment with more vegetation in the Emily Bay area in the past. However, these layers do not contain those species which are found only in wetter forest areas today, so we do not think that the difference was particularly great.

Diversity in the fauna is lower in layers attributable to the European period, both in the Clay layer which dates to an early European time and the dunes of the Upper Sand layer. The dominant species are those found in the beach and dune zone today, confirming that the environment has remained much the same throughout this period.

There are, however, three other variables to be taken into account.

First, high density and diversity of the snail fauna in the Cultural layer may be directly attributable to human activity. Humans generally increase the floral diversity of a site by transporting a variety of plants to it: snails may come accidentally with these plants. Food refuse also attracts snails and an increase in this is the common result of human occupation. Our results are clearly similar to those of Brook and Goulstone (1999: 125) who have demonstrated that diversity in the land snail fauna in sand dune areas on several islands in New Zealand increases within the Maori occupation period.

Second, human settlers almost certainly increased the level of fire in the landscape and this would have affected the snail population. To what extent the vegetation of Norfolk Island was modified in pre-European times is not clear from the limited palaeoenvironmental studies so far carried out (see Macphail, Hope and Anderson, this vol.).

Third, the decline in diversity in both the Clay and Upper Sand layers may be the consequence of predation on snails by *Rattus exulans*. We note that it is the larger among the common beach and dune zone species that have declined or disappeared (Table 6). *Rattus exulans* had arrived on the island before the Europeans—probably introduced by the Polynesian settlers—and had reached pest proportions when the Europeans arrived. It is an eclectic omnivore, and we presume that the larger snails would be a more attractive prey and therefore under greater threat of extinction. By the time the Clay layer was deposited, early in the European period, our data suggest that many species were already in decline (Table 7). The large scale loss of vegetation cover and diversity through cattle grazing and other land use in the European period may have played some part in the final extinction, as demonstrated by our data for the Upper Sand layer.

The pattern of faunal change we present here is highly comparable with that demonstrated in greater detail by Brook and Goulstone (1999, see also Brook, 1999a,b) for similar environments dating to a similar time period in New Zealand. But, as Brook (1999b: 136) says, the relative contributions of rat predation and habitat modification "will probably never be disentangled".

Conclusion

We conclude that the environmental impact of the Polynesian settlement of Norfolk Island can be seen in changes in the land snail fauna. This was probably not a direct impact but likely through the introduction of *Rattus exulans*. The decline in species in the Emily Bay area in the European period is probably attributable to local clearance and rodent predation.

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