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DISTRIBUTION AND ABUNDANCE OF LIZARDS AT PUKERUA BAY, WELLINGTON: IMPLICATIONS FOR RESERVE MANAGEMENT

by

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ABSTRACT

The distribution and abundance of lizards at Pukerua Bay, Wellington were studied between December 1982 and March 1988, with particular emphasis on habitat use by Whitaker's skink (*Cyclodina whitakeri*), a threatened species with only one known mainland population. Pitfall traps were set for 23 667 trap-days and yielded 2897 lizard captures. Highest capture rate was for common skinks (*Leiolopisma nigriplantare polychroma*) and lowest rate was for Whitaker's skink. Of the five lizard species at Pukerua Bay, Whitaker's skink had the narrowest habitat range, was most sensitive to climatic conditions, and had the slowest growth rate. These features, in combination with predation, and habitat disturbance and degradation, have resulted in critically low numbers of Whitaker's skinks. Because of the proximity of the study site to Pukerua Bay township direct management of predators using poisons will be unsuitable. The area is also a high fire risk. The continuing threats are such that Whitaker's skink at Pukerua Bay should continue to be regarded as highly vulnerable. A series of management possibilities to lessen these threats is provided. It is recommended that threats to the lizard assemblage, and especially to Whitaker's skink, from disturbance, predation and fire could be minimised through a managed revegetation programme.

1. INTRODUCTION

The New Zealand archipelago supports an unusually diverse fauna of lizards when compared with temperate environments elsewhere (Daugherty *et al.* 1990b). Highest local diversities probably occurred in warm lowland forest, especially those near the coast. Over 20 species of geckos and skinks have been recorded from forested areas (Atkinson and Millener 1991). Unfortunately, with the arrival of humans and their commensal predatory mammals, these primeval lizard assemblages have all but disappeared from mainland New Zealand. Estimations of maximum diversity are now obtained from offshore islands (e.g., Towns and Atkinson 1991).

Most lizard species that persist on the mainland are those able to use a wide range of habitats and are therefore resistant to the effects of predation and habitat destruction.

A rare exception to this is a fragment of a coastal forest lizard assemblage that has persisted at Pukerua Bay near Wellington despite extreme habitat modification. The importance of this site is such that a Department of Conservation reserve is proposed for the area.

The following report describes the Pukerua Bay site, and its lizard assemblage, provides estimates of the population densities of each species, investigates the relationship between lizard density and environmental characteristics, and discusses the options for reserve management relative to the habitat needs of key lizard species. Five species of lizard persist at Pukerua Bay. This is probably less than half of the fauna that is likely to have been there before the advent of introduced predators and when forest habitats were more intact (Table 1). The site is likely to have been particularly diverse because of its strategic location at the interface between coastal broadleaf forest, low coastal shrubland, and open beachfront on a warm north-facing slope. Nonetheless, with five species, Pukerua Bay has one of the most diverse lizard assemblages remaining on the mainland. The site has particular conservation value because it includes the only mainland location for Whitaker's skink *(Cyclodina whitakeri),* one of New Zealand's rarest lizards (Towns 1985a).

Table 1 Lizard species presently listed at Pukerua Bay compared with species listed locally and elsewhere in the western Wellington area (data from Pickard and Towns 1988, Towns 1992).

Species	Pukerua Bay	Nearby locations
Skinks		
Cyclodina aenea	*	Widespread
C. alani		Mana Island (now extinct)
C. ornata		Kapiti coast
C. macgregori		Mana Island
C. whitakeri	*	None
Leiolopisma lineoocellatum		Plimmerton
L. nigriplantare polychroma	*	Widespread
L. zelandicum	*	Widespread
Geckos		
Hoplodactylus chrysosireticus		Mana Island
H. duvaucelii		Mana Is?, Marlborough Sounds islands
H. granulatus		Plimmerton
H. maculatus	*	Widespread
Naultinus elegans punctatus		Plimmerton

The following study was based on the assumption that any habitat management would be directed towards benefiting Whitaker's skink, even if it is detrimental to some of the other lizards present. The study therefore sought kinds of information required to measure the effects of management on these lizards at Pukerua Bay. Because lizard assemblages can show relatively slow responses to major environmental change, such as removal of predators and browsers (e.g. Towns 1991), the emphasis in the present study was placed on obtaining an accurate snapshot of habitat availability, habitat use by lizards, and lizard distribution and abundance. Once obtained, the data were used to predict possible changes on the basis of likely management scenarios. Attempts were also made to identify indicator lizard species that could substitute for Whitaker's skinks if their numbers were too low to demonstrate long term trends.

2. STUDY AREA

2.1 Geology and vegetation

The study area is on a northwesterly oriented escarpment that forms a steep coastal hillside from the entrance to Porirua Harbour to Paekakariki (Fig. 1). The main study site was between Pukerua Bay township and Wairaka Point, where the escarpment faces directly north and rises steeply to 160 m asl. In this area greywacke bluffs form outcrops, screes and talus slopes of rocks and boulders. The largest talus slopes extend to about 80m asl. At the foot of some slopes are narrow talus areas (10-20m) and rocks and large boulders are scattered along old beach terraces. The coastline is also rocky forming narrow beaches of rocks, stones and gravel.

By 1982 the study area had been farmed at low intensity for at least 100 years and sheep had access throughout. There was also evidence of repeated fires on the northern cliffs. As a consequence of these kinds of disturbance vegetation on the escarpment and along the shoreline formed a mosaic which in northeast-southwest sequence was:

1. Montpellier broom (*Teline monspessulana*) – Cape ivy (*Senecio anglulatus*) – boneseed (*Chrysanthemoides monilifera*) shrubland and mountain flax (*Phormium cookianum*) on steep faces and burn scars.
2. Small pockets and isolated plants of puka (*Griselinia lucida*) and karaka (*Corynocarpus laevigatus*) at the foot of bluffs (sometimes with *Olearia paniculata*), and scattered along the lower slopes.
3. A remnant stand of karaka trees with the understorey eaten out by stock.
4. A patch of coastal broadleaf forest dominated by kohekohe on a ridge crest with the understorey eaten out by stock.
5. Kanuka shrubland mixed with flax on southwestern bluffs.
6. *Coprosma propinqua* shrubland intermixed with pohuehue (Muehlenbeckia complexa), reverting grassland, scattered tree nettle (*Urtica ferox*), and occasional kawakawa (*Macropiper excelsum*) and kaikomako (*Pennantia corymbosa*) on stable slopes and along the old beach terrace.

2.2 Landuse and ownership

At the beginning of the study period the northeastern portion was a Recreation Reserve administered by Porirua City Council. This area was fenced off from the adjacent

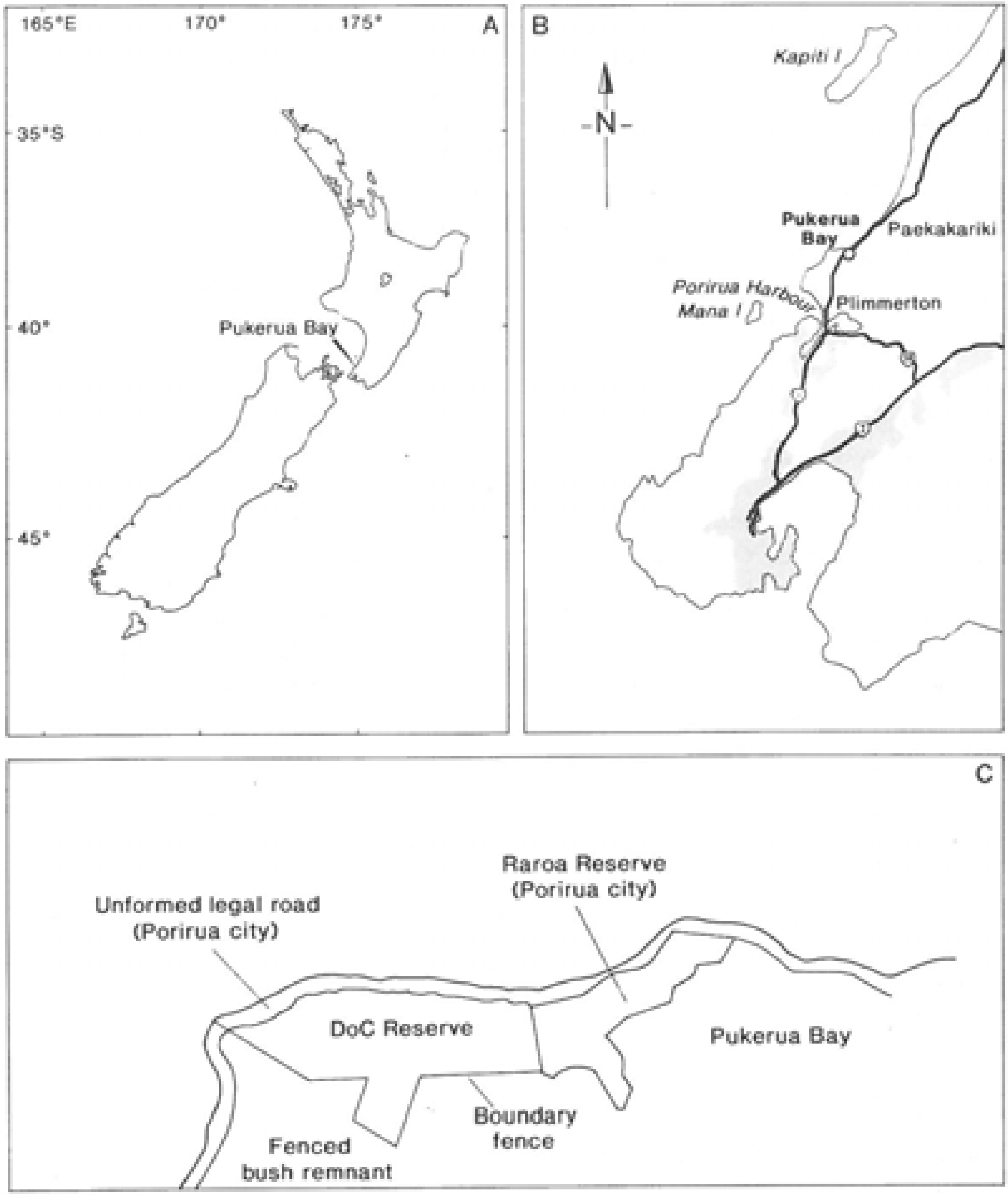

Fig. 1 The Pukerua study site(A) and localities mentioned in the text(B). The two reserves mentioned in the text are shown in (C).

farmland in 1972, but the fence was breached by high seas and stock (sheep) continued to graze the entire area.

A further 8 ha of escarpment adjacent to the Recreation Reserve was purchased its owners by the Crown in 1984 and a sheep proof fence was completed by March 1987. Wandering goats appeared for the first time in 1986 and entered the study area. These are now being periodically culled. Few stock have entered the Crown area or the

Recreation Reserve since March 1987. The Crown purchase was intended to protect the area against disturbance by stock and illegal collection of lizards and was to have been administered jointly with Porirua City Council (Towns 1985b). However, the Crown portion remains ungazetted and is currently (1991) Department of Conservation land without a formal reserve designation.

2.3 Lizards present

No community studies of the kind conducted on lizards at Pukerua Bay have been carried out elsewhere in New Zealand. However, all of the species have been the subject of species-based studies; those on common gecko (*Hoplodactylus maculatus*), common skink (*Leiolopisma nigriplantare polychroma*) and brown skink (*L. zelandicum*) have been centred in the southern North Island (Whitaker 1982, Barwick 1959, Gill 1976 respectively). Information on copper skink (*Cyclodina aenea*) and Whitaker's skink were obtained from studies in the Auckland and Coromandel regions (Porter 1987, Southey 1985, Towns 1991).

The common gecko is a nocturnal species that is geographically and ecologically ubiquitous. The species is at present under taxonomic review, but current indications are that the Pukerua Bay taxon is common throughout the North Island and northern South Island (R. Hitchmough pers. comm.).

The common skink is a widespread diurnal species that is part of a complex of closely related species recently revised by Patterson and Daugherty (1990). The complex shows a high degree of morphological, ecological and genetic diversity (Daugherty *et al*. 1990a), but there is no evidence of more than one taxon at Pukerua Bay (C.H. Daugherty pers. comm).

The brown skink is a diurnal species found only in the southern third of the North Island and in the northern South Island (Pickard and Towns 1988). In the Wellington and Manawatu areas brown and common skinks frequently co-occur, but with the brown skinks having a narrower habitat range (Gill 1976).

The copper skink, like all other species of *Cyclodina*, is confined to the North Island where it is the most widespread species in the genus (Pickard and Towns 1988). The species is one of New Zealand's smallest lizards and is regarded as both crepuscular and diurnal (see Porter 1987).

Whitaker's skink is large (up to 20 cm long), nocturnal and highly vulnerable to predation (Towns 1985b; 1991); all locations other than Pukerua Bay are free of introduced mammals (Towns and Robb 1986). The species is also highly prone to evaporative water loss (Cree and Daugherty 1991). To ameliorate water loss these skinks require warm moist environments, such as seabird burrows, as daytime retreats (Cree and Daugherty 1991, Towns 1992).

3. METHODS

3.1 Study sites

Sampling began in December 1982, and continued regularly from March 1983 to March 1988. The main study site was chosen after exploratory surveys using 20 m transect lines every 20 m along 260 m of lower slope and beach platform. A second study area was established between June 1983 and April 1984 at Wairaka Point on a slope with southwestern aspect, but was discontinued because of low trapping success (no Whitaker's skinks in 885 trap-days).

The long term study site was a rectangular quadrat of 768 m^2 through which passed four of the exploratory transects. A total of 114 traps was set on the quadrat and transects with traps in the quadrat on 4m squares (Fig. 2). Precise location of the transects and study site is not given here to protect the Whitaker's skink habitat.

All captures were by pitfall traps. Traps on transects were of 500 ml plastic cups. These were replaced with 4 litre paint tins at the main study site (see Towns 1991).

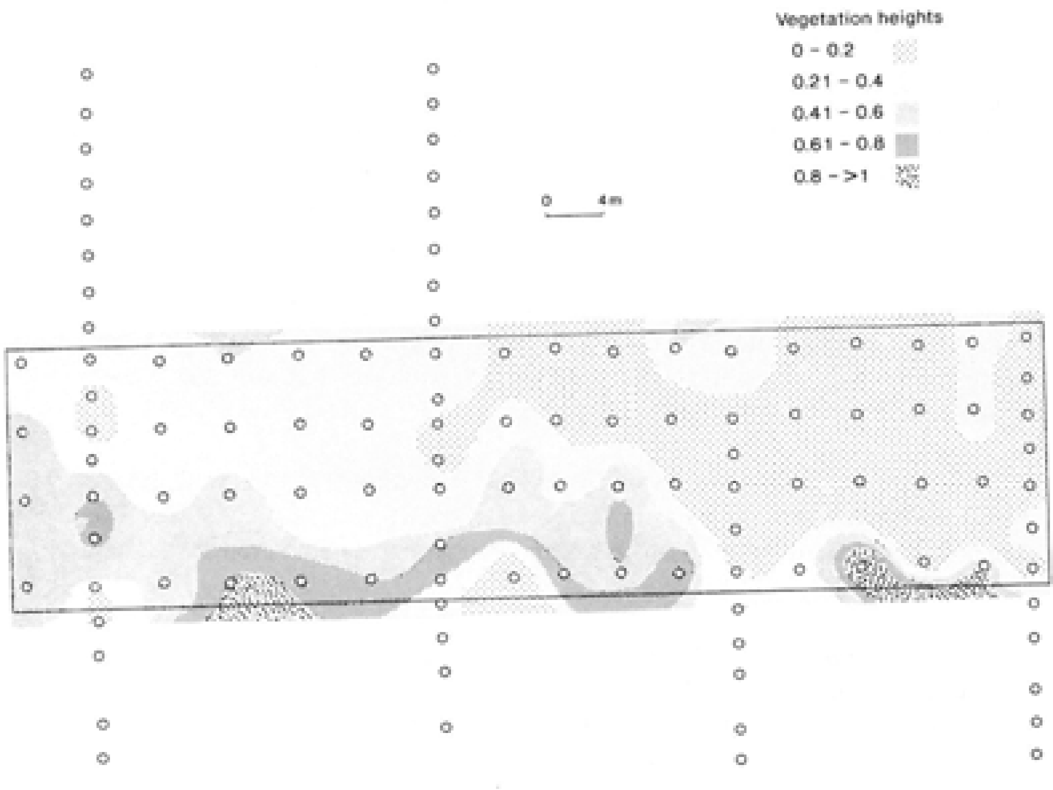

Fig. 2 Vegetation on the study grid Pukerua Bay late 1986. Drawn from mean vegetation heights at 79 sites, pitfall traps shown as circles. Effective trapping area for Whitaker's skink defined by the rectangle.

Traps were set at fortnightly intervals between March 1983 and May 1985, after which the trapping period was reduced to cover the spring-summer-autumn period: August-April 1986, then December-March 1987-1988.

Traps were baited with canned pear and usually set for 48 h. Traps into which sticks or other potential escape routes had fallen were regarded as unset. For comparison between trapping sessions trapping effort was standardised to captures per 100 trap-days (Towns 1991).

Animals captured were permanently marked using a predetermined sequence, measured from snout to vent, weighed to 0.1 gm with Pesola™ balances, and released beside the trap. Capture statistics were stored on an IBM compatible personal computer.

3.2 Population estimates

Population estimates are extremely difficult to obtain for lizards because their cryptic nature, territorial behaviour and trap biases invalidate assumptions in mathematical population models (e.g. Towns 1975). These difficulties can be overcome partly by using very extended study periods (several years) to enable calculations of the minimum number alive (MNA) at the first season. Two assumptions required for MNA are that (a) there is no large scale migration of animals into or out of the study site between years; and (b) that there are few deaths of animals eligible to capture but not caught. The following data were obtained to enable calculation of MNA: 1. Mean distance moved between capture (tests the assumptions on migration). 2. Mean growth rates for each species (enables estimation of potential longevity). 3. Size distribution for each species in each year (enables estimation of number potentially able to be captured at year one).

MNA was then calculated by adding the number of animals potentially able to have been caught after year one to the total caught in year one. Density estimates were obtained by calculating MNA and the effective trapping area (ETA) for each species. ETA was calculated by adding to the trapping grid a boundary strip half as wide as the average distance between captures (e.g. Moller and Craig 1987).

3.3 Climate data

Because lizards are ectotherms (obtain body heat from external sources), they are reliant on suitable temperature regimes being provided by the substratum, such as warm rocks (thigmothermic species), or the availability of sites where they can bask (heliothermic species). The large *Cyclodina* skinks and the nocturnal geckos rarely bask, and tend to be thigmothermic, whereas many of the *Leiolopisma* species are heliotherms (Werner and Whitaker 1978, Cree and Daugherty 1991). Mobility of the lizards, and therefore susceptibility to capture, can be strongly influenced by ambient temperature.

Temperature variation during trapping periods was measured from November 1985 to March 1988 using three max-min thermometers in shade at the surface and at 0.20 m and 0.65 m inside PVC pipe buried in the rocky scree in the study site.

3.4 Vegetation and substrate mapping

Information on height of vegetation, its species composition and species diversity, plus composition of the substrate and the layer beneath the surface were obtained at 79 sites in the study quadrat. Substrate was classed as loam, clay, silt, sand, gravel (particle size <5 cm), stones (6-20 cm), boulders (>20 cm) and wood. Vegetation cover was analyzed using a modification of methods for sampling tussock and shrub vegetation (Scott 1965). At each trap site 25 measurements of vegetation height and composition, surface and subsurface substrate were obtained using a graduated length of wire at 25 cm intervals over 1 m^2 and the data stored in an IBM compatible personal computer. Maps were drawn from mean vegetation heights.

3.5 Data processing

Data were processed using SAS, a data management package, and SYSTAT, a statistics package on a personal computer. Details of statistical methods and results are given in Appendix 1.

4. RESULTS

4.1 Relationship between vegetation and substrate

In the course of vegetation and substrate analyses 30 plant species were recorded within the study grid (Appendix 2). The two most widespread species were *Coprosma propinqua* and *Muehlenbeckia complexa*, which together made up 80% of all first encounters. Vegetation in the study grid changed in relation to slope and substrate. At the toe of the slope vegetation on old beach terraces of loam and rounded stones had a high proportion of shrubs, predominantly *C. propinqua*. Amongst these the more open areas contained pasture grasses such as meadow rice grass (4% of encounters) and ratstail (0.3% of encounters). On the slope, vegetation was more dense at the northern end, with extensive areas of *C. propinqua,* much of it intertwined by *Muehlenbeckia*, but also interspersed by some veld grass (1 % of encounters). At the southern end of the grid the substrate had a higher proportion of stones and boulders, vegetation density was lower, and *Muehlenbeckia* formed the predominant cover (Fig. 2).

The distribution of vegetation heights over the grid was related to soil (substrate type). Soils were deeper and with a higher proportion of loam at the seaward side of the grid, and these areas supported the tallest vegetation (mostly *C. propinqua*) (Fig. 2).

4.2 Capture rates of lizards

Traps were set 91 times for a total of 23 667 trap-days during which 2897 lizard captures were made (including recaptures) and 1319 animals were marked prior to release. The highest capture rate was for common skinks (52.6% of total captures) and the lowest was for Whitaker's skink (2.7%) (Table 2).

The proportion of marked animals recaptured varied by species and season. Highest overall recapture rate was for brown skinks (49%) and lowest for common geckos

Table 2 **Mark-recapture data for Lizards Bay March 1983 and March 1988. Total include multiple captures of the same animals.**

Species	No. marked	Total captures	% of total captures
Cyclodina aenea	343	675	23.3
C. whitakeri	56	79	2.7
Leiolopisma n. polychroma	649	1524	52.6
L. zelandicum	138	377	13.0
Hoplodactylus maculatus	133	242	8.4
Total	1319	2897	100.0

(17%). The recapture rate for Whitaker's skink was the lowest for the four skink species (Table 3). The total capture rate for lizards in each season varied little except in 1987-1988 (Appendix 1), when captures and recaptures for all species were particularly low. This low rate coincided with evidence of heavy predation on trapped animals and habitat changes following the removal of stock in early 1987 (see 4.5). This season has therefore been excluded from most calculations involving recapture data.

Table 3 **Between-year variation in percentage of recaptured marked lizards at Pukerua Bay using data obtained between December and March in each season.**

Species	Season					
	1983/84	1984/85	1985/86	1986/87	1987/88	1983–87
C.a.	11	16	24	28	15	37
C.w.	13	14	20	18	0	25
L.n.p.	18	30	19	28	11	44
L.z.	20	31	54	30	0	49
H.m.	17	6	7	0	0	17
N[1]	52	56	61	112	12	

[1] Number of marked animals caught in each season between December and March

Lizard species names are abbreviated as follows: *Cyclodina aenea* (C.a.); *C. whitakeri* (C.w.); *Leiolopisma nigriplantare polychroma* (L.n.p.); *L. zelandicum* (L.z.); *Hoplodactylus maculatus* (H.m.).

Although *total* capture rate varied little, *individual* species (except for Whitaker's skink) showed high levels of year-to-year variation in capture rate (Appendix Table 1.1). In addition to between-year variability in capture frequency, continuous trapping August 1983-May 1985 showed that susceptibility to capture varied by species within years as the seasons changed (Fig. 3). The most strongly seasonal species were the two *Cyclodina*species, with Whitaker's skink being the most seasonal lizard at Pukerua Bay. Most captures of this species (69.7%) were between December and March (inclusive).

4.3 Factors influencing capture rates

4.3.1 Capture rates relative to location

Frequency of captures of lizards at Pukerua Bay was site - as well as time-specific. This can be seen by comparing standardised capture rates at traps along a 40 m transect from the extreme high tide level on the beach through *Coprosma-Muehlenbeckia* shrubland and into rough pasture (Fig. 4). Although all five lizards overlapped in range, there were sites on the transect where each was particulary common. For example, copper skinks were more common above and below the scree slope, than they were on it, whereas the related Whitaker's skink was largely confined to the scree slope. The superficially similar brown and common skinks were widely distributed, but brown skinks did not occur on the open beach, where common skinks were most abundant (along with common geckos). The only species that was rare throughout as well as being constrained to a narrow habitat range was Whitaker's skink.

As with transects, distribution of captures over the study grid varied by species. For example, most captures of brown skinks were at the southern end of the grid, whereas those for other species were more scattered (Fig. 5). The very low capture rate of Whitaker's skink (Fig. 5) was consistent with captures on the transects.

4.3.2 Capture rates relative to temperature

Temperatures measured in the boulder scree showed less seasonal variation as depth increased with up to 10°C difference between temperatures at 0.65 metres and those near the surface (Fig.6). However, the period over which highest temperatures persisted varied between summers, and the effect of these temperatures varied between lizard species.

Analysis of the relationship between 5 capture rate for each species and maximum-minimum temperatures while the traps were set (Appendix 1) showed the following:

1. Minimum temperatures at the surface and at 20 cm were not significantly different, so thoses measured at 20cm have been discarded when making comparisons.

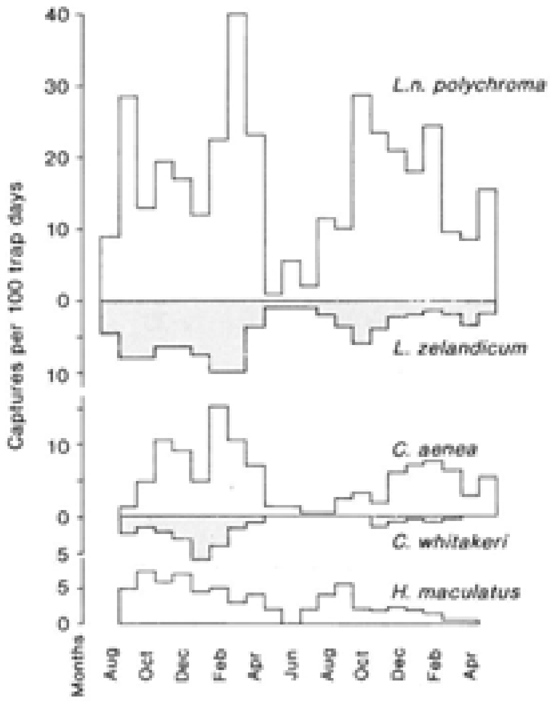

Fig. 3 Seasonality of captures of lizards at Pukerua Bay over 22 months from August 1983 to May 1985 with captures standardised to number per 100 trap-days.

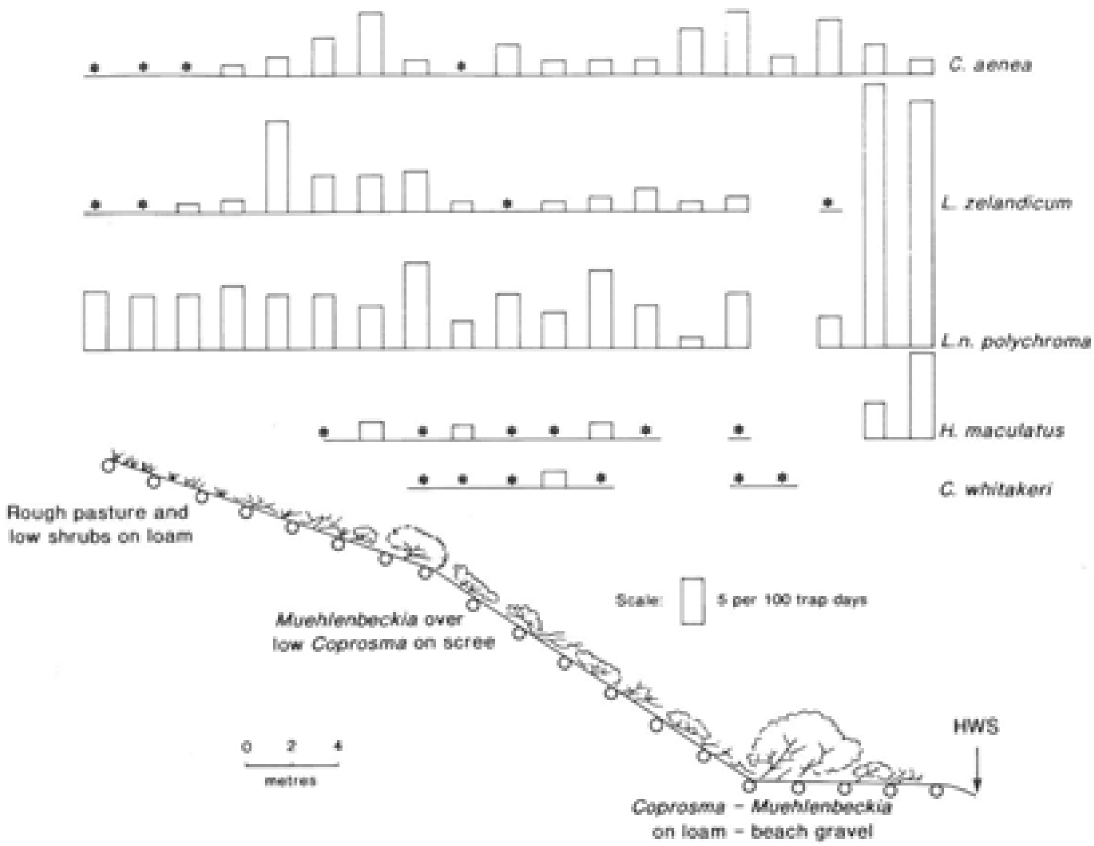

Fig. 4 Capture frequencies of lizards (per 100 trap days) along two transects at Pukerua Bay. Comprised of 201 *C. aenea*, 20 *C. whitakeri*, 591 *L. N. polychroma*, 167 *L. zelandicum* and 82 *H. maculatus* (total 1066 captures) caught over 8101 trap days; * marked sites where captures were <0.5 per 100 trap days.

2. There was no clear relationship between capture rate and temperatures measured for common skinks, brown skinks and common geckos.
3. There were strong relationships between capture rate and both maximum and minimum temperatures for copper skinks and between capture rate and minimum temperature for Whitaker's skink. Both species were more likely to be caught on warmer nights (Appendix Table 1.3).

4.3.3 Capture rates relative to behaviour

Capture rates of lizards can also be influenced by territorial behaviour or the frequency with which they use a specific home range. Indications of site specificity of lizards at Pukerua Bay were obtained by comparing capture frequencies (Table 4) with information on distance between captures (Table 5).

Most lizards (77.4%) were captured only once, with the highest proportion of single captures obtained for common geckos (91.9%) and the lowest for brown skinks (69.7%). Although relatively few individual brown skinks were captured, many were subsequently recaptured, thereby leading to their high overall capture rate (Table 4).

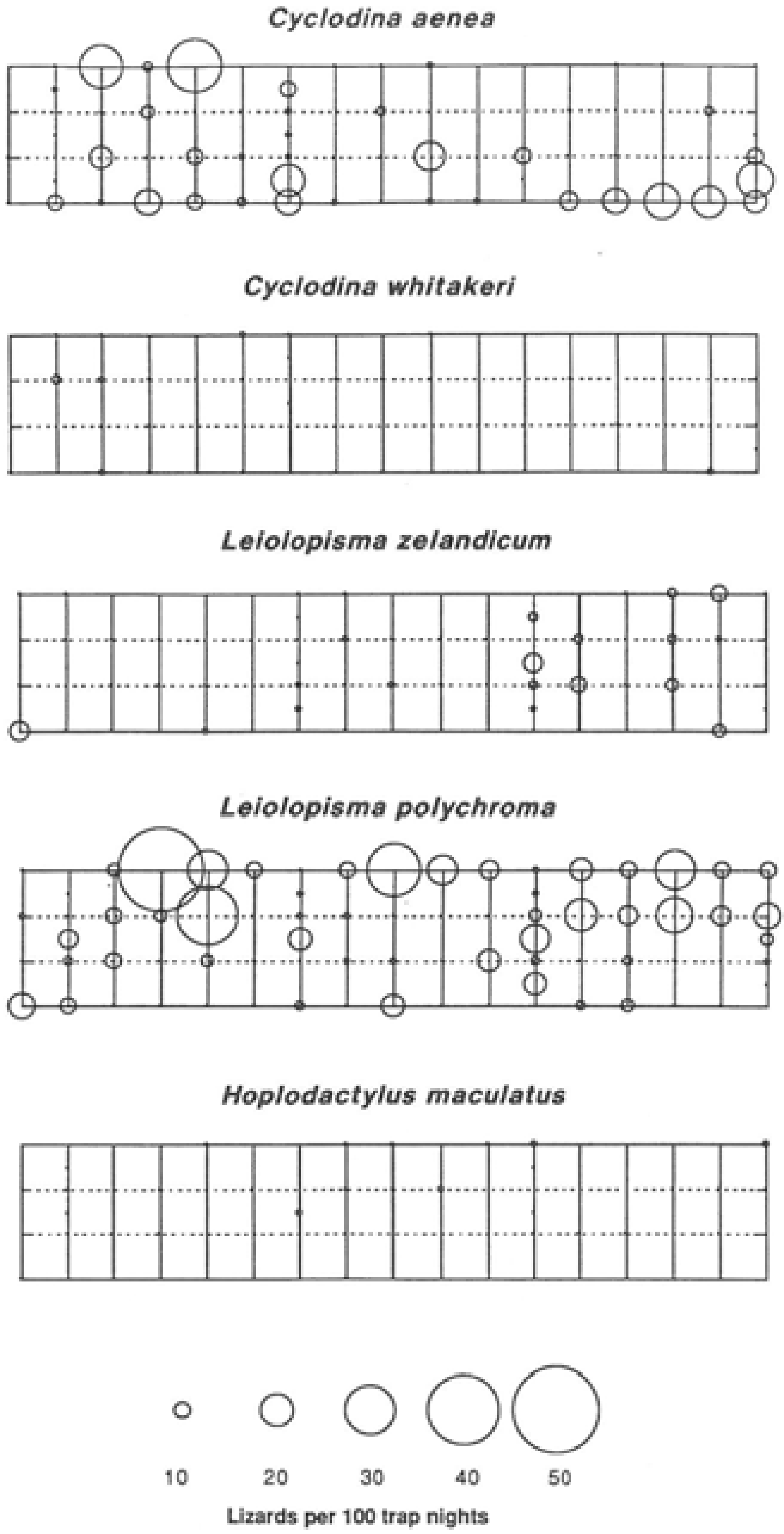

Fig. 5 Proportional bubble plots showing frequency of captures by trap site on the study grid with captures standardised to numbers per 100 trap-days.

Table 4 Summary of capture frequencies for each species over four seasons (December–March, 1983–1987), with percentages in parentheses.

Captures	Species					
	C.a.	C.w.	L.n.p.	L.z.	H.m.	Total
1×	296 (78.7)	45 (84.9)	433 (75.7)	108 (69.7)	79 (91.9)	961
2×	53 (14.1)	6 (11.3)	81 (14.2)	30 (19.4)	5 (5.8)	175
3×	15 (4.0)	2 (3.8)	20 (3.5)	12 (7.7)	2 (2.3)	51
4×	9 (2.4)	0	13 (2.3)	3 (1.9)	0	25
5×	2 (0.5)	0	12 (2.1)	1 (0.6)	0	15
6×	0	0	7 (1.2)	1 (0.6)	0	8
7×	0	0	3 (0.5)	0	0	3
8×	1 (0.3)	0	2 (0.3)	0	0	3
9×	0	0	1 (0.2)	0	0	1
Total	376	53	572	155	86	1242

Lizard species names are abbreviated as follows: *Cyclodina aenea* (C.a.); *C. whitakeri* (C.w.); *Leiolopisma nigriplantare polychroma* (L.n.p.); *L. zelandicum* (L.z.); *Hoplodactylus maculatus* (H.m.).

Table 5 Proportion (%) of lizards captured two or more times between August 1983 and March 1988 relative to distance from the first point of capture.

Species	Cumulative % at capture distances (m)			Mean distance moved (m)	Maximum distance moved (m)	Number recaptured
	0	0–2	0–4			
C.a.	71	74	75	6.3	64	276
C.w.	75	80	85	2.4	29	20
L.n.p.	67	77	87	3.4	60	716
L.z.	56	81	93	2.0	56	204
H.m.	82	87	89	2.0	29	82
Total captures						1298

Lizard species names are abbreviated as follows: *Cyclodina aenea* (C.a.); *C. whitakeri* (C.w.); *Leiolopisma nigriplantare polychroma* (L.n.p.); *L. zelandicum* (L.z.); *Hoplodactylus maculatus* (H.m.).

The proportion of recaptures at the site (trap) of first capture was also highest for common geckos (82%) and lowest for brown skinks (56%). However, when all captures up to 4 m from first capture are included 93% of brown skink movements are accounted for, probably because of a high degree of site attachment in this species. A very small proportion (7%) of brown skinks undertook long distance movements of up to 56 m (Table 5). This contrasts with the small copper skinks, for which 75% of captures were within 4 m of the original trap. The remaining 25% of recaptures resulted from movements of up to 64 m (the longest distance recorded for all species), suggesting that copper skinks were the least site-attached species.

With 87% of captures within 4 m of original trap, common skinks also were highly site specific. The remaining 13% of captures indicated high mobility and consisted of two identifiable groups. One group of common skinks was centred along the beach front below the study grid and was distinctively melanic, with the dark coloration obscuring almost all markings. The second group was centred above the grid in reverting grassland. These were distinctively pale brown, with very well defined yellowish lateral

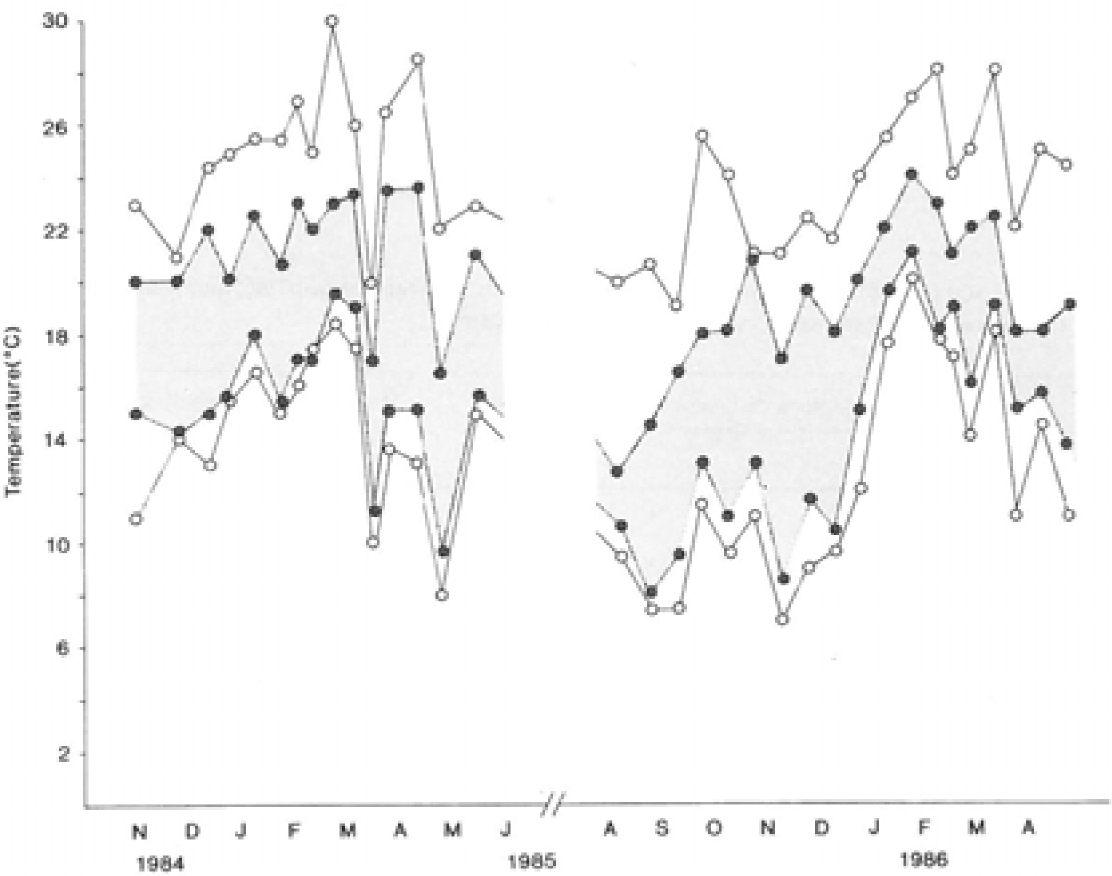

Fig. 6 Temperature variation (max-min) from samples obtained on the surface (open circles) and at 65 cm within the boulder bank (closed circles, shaded) at Pukerua Bay between November 1984 and April 1986.

markings. Skinks from both colour groups occasionally moved into the grid, and one individual from grassland remained there, eventually losing its pale coloration. There was no identifiable size, sexual or genetic difference between these two forms (C.H. Daugherty pers comm., Patterson and Daugherty 1990).

Whitaker's skinks had the highest proportion (84.9%) captured once of all skinks, but the proportion of second and third captures was similar to that of other skinks (Table 4). Despite their large size Whitaker's skinks did not move widely and had the shortest recorded maximum movement (29 m) for any skink species at Bay (Table 5).

4.4 Population estimates

4.4.1 Influence of longevity on capture rates

Important components of population size estimates are growth rate and longevity (susceptibility to capture over time). Mark-recapture data of measured and weighed animals provided this information.

Multiple captures comprised 30.3% of all captures of brown skinks but were as low as 8.1% for common geckos (Table 4). There was little difference in the mean time between recaptures, which for all species was about 11 mo. The maximum time between captures ranged from 4 y 5 mo for common skinks and 4 y 1 mo for copper skinks to 2 y 11 mo for brown skinks. The relatively short period for recaptures of brown skinks contrasts with the high proportion of recaptures obtained for the same species (Table 6).

Data from multiple captures used to estimate growth rates and potential longevity are summarised in Appendix 3. Estimated maximum ages for individuals in each species range from 6-8 y. The maximum known age recorded was for a Whitaker's skink (at least 7 years). Because of merging of growth cohorts as growth rates lowered with age (Appendix 3), size classes could he identified for up to five years for Whitaker's skink and only for four years for other species (Table 7). Identification of the size classes enabled calculation of the number of animals potentially able to have been caught in year one hut not caught until up to year four (or five). (Appendix 3, Table 7).

4.4.2 Population estimates by minimum number alive (MNA)

For most, but not all species the number of unmarked lizards diminished over time. An exception was copper skinks where the number captured in year 4 was much higher than in years 1-3 and 5 (Table 3). The MNA estimate is based on the assumption that departures from the study areas were offset by arrivals, in which case diminishing eligible size classes for the estimate would be expected. This assumption may have been violated for copper skinks, for which gains appear to have exceeded losses.

The MNA estimate was calculated from an ETA that varied between species depending on the mean distance between captures (Table 5). For Whitaker's skink the ETA was lower than all other species (945 m^2) because none were caught outside the central grid. The density estimate for Whitaker's skink was calculated from the ETA extrapolated to 656/ha, but this assumes equivalent densities for Whitaker's skinks throughout the inhabited area. Total area occupied by Whitaker's skink at year one was 0.4-0.5 ha, so the total population was probably between 260-330 animals.

Table 6 Time (days) between recaptures of lizards at Pukerua Bay between August 1983 and March 1988. There was no significant difference between species (ANOVA: df=4; F=0.09; p>F, 0.99)

Species	N	Minimum (days)	Maximum (days)	Mean	Standard deviation
C.a.	96	6	1510	352.7	398.3
C.w.	13	13	1125	335.7	315.5
L.n.p.	165	5	1596	337.2	439.4
L.z.	53	13	1076	357.5	387.3
H.m.	36	14	1316	355.8	327.3
Total	363				

4.5 The effects of predation on lizards in traps

In each season a small number of lizards was found dead in traps. In most years this amounted to less than 5% of the total number captured (Table 8). Some of this mortality could be attributed to predation by mice, which characteristically peeled the skin and flesh off the rear third of the lizard (Newman 1988). Larger predators (such as rats and mustelids) left chewed fragments in the traps. Lizards that died from unknown causes may in fact have succumbed to stress from being chased by predators in the trap (although a few might have been affected by heat stress). The level of interference identifiable by mice was very low in most years, except in 1987-1988, when predation from attacks by mice was almost seven times higher than previously (Table 8). This

Table 7 Estimates of lizard numbers in year one calculated by minimum number alive over four (all species other than Whitaker's skink) or five years (Whitaker's skink). Data used were from December to March each year and effective trapping area (ETA) was estimated separately for each species.

Species	Season						Density/ha
	1983/84	1984/85	1985/86	1986/87	1987/88	Total	
C.a.	77	76	139	118		410	2494
C.w.	27	8	13	13	1	62	656
L.n.p.	186	207	102	52		547	4919
L.z.	62	21	40	21		144	1477
H.m.	33	15	8	16		72	738

Abbreviated lizard names and ETA for each species are as follows:
Cyclodina aenea (C.a.: 1644m^2); *C. whitakeri* (C.w.: 945m^2); *Leiolopisma nigriplantare polychroma* (L.n.p.: 1112m^2); *L. zelandicum* (L.z.: 975m^2); *Hoplodactylus maculatus* (H.m.: 975m^2).

high level of predation of lizards was also found in 1987-1988 following an irruption of mice on nearby Mana Island (D. G. Newman pers comm.). Only one Whitaker's skink was found killed by mice in traps (1.8% of total captures).

5. DISCUSSION

5.1 Lizard-habitat profiles

Relationships between vegetation, substrate and lizard distribution can be established, but they must be treated with caution. Lizard distribution is a complex interplay between territoriality within species, competitive encounters between species, availability of specific food resources (such as some berry producing plants for geckos), basking sites for heliothermic species, refuges from predators and shaded areas for species that avoid temperature extremes.

The following relationships were established by comparing lizard capture frequencies and distribution with mean vegetation height and composition of the substrate at each trap site (see Appendix Table 1.4).

1. Common skinks were most abundant where there was minimal vegetation cover.
2. Copper skinks were most common under vegetation where there was loam but not gravel in and below the ground surface.
3. Brown skinks were least common at sites with a high proportion of loam below the surface.
4. Whitaker's skinks had a distribution that could not be linked clearly to physical characteristics of the habitat.
5. Common geckos were most common at sites that lacked loam.

For most species these relationships were not strongly expressed. One exception was copper skink, which showed relationships with substrate and vegetation cover. Copper skinks may therefore act as the best predictor of the effects of habitat change on lizards at Pukerua Bay.

Table 8 **Mortality of lizards in traps for each season (December–March; 1983–1988) as a percentage of total captures separated into predation due to mice and to other causes.**

Season	Total captures	Dead in traps	Dead from unknown causes	Killed by unknown predators	Killed by mice
1983/84	322	0.93	0.62	0	0.31
1984/85	234	4.70	3.42	0.43	0.86
1985/86	258	3.88	2.32	0.78	0.78
1986/87	428	3.74	1.40	1.17	1.17
1987/88	130	10.78	2.31	0.77	7.69

Vegetation height and composition will be directly affected by management of the Pukerua Bay Reserve, so the likely response by resident lizards is derived from two models.

The first model is based on the likely relative distribution and abundance of lizards prior to habitat destruction for farming and the arrival of predatory mammals. Combined with this is an extrapolation of probable prehistoric vegetation cover (Fig. 7). The forest merging into coastal broadleaf forest in Fig. 7 is at present represented by isolated fragments. A key missing (and irreplaceable) element in the model is burrowing seabirds, which once must have been extensive, and elsewhere provide important Whitaker's skink habitat (e.g. Macredie 1984, Southey 1985).

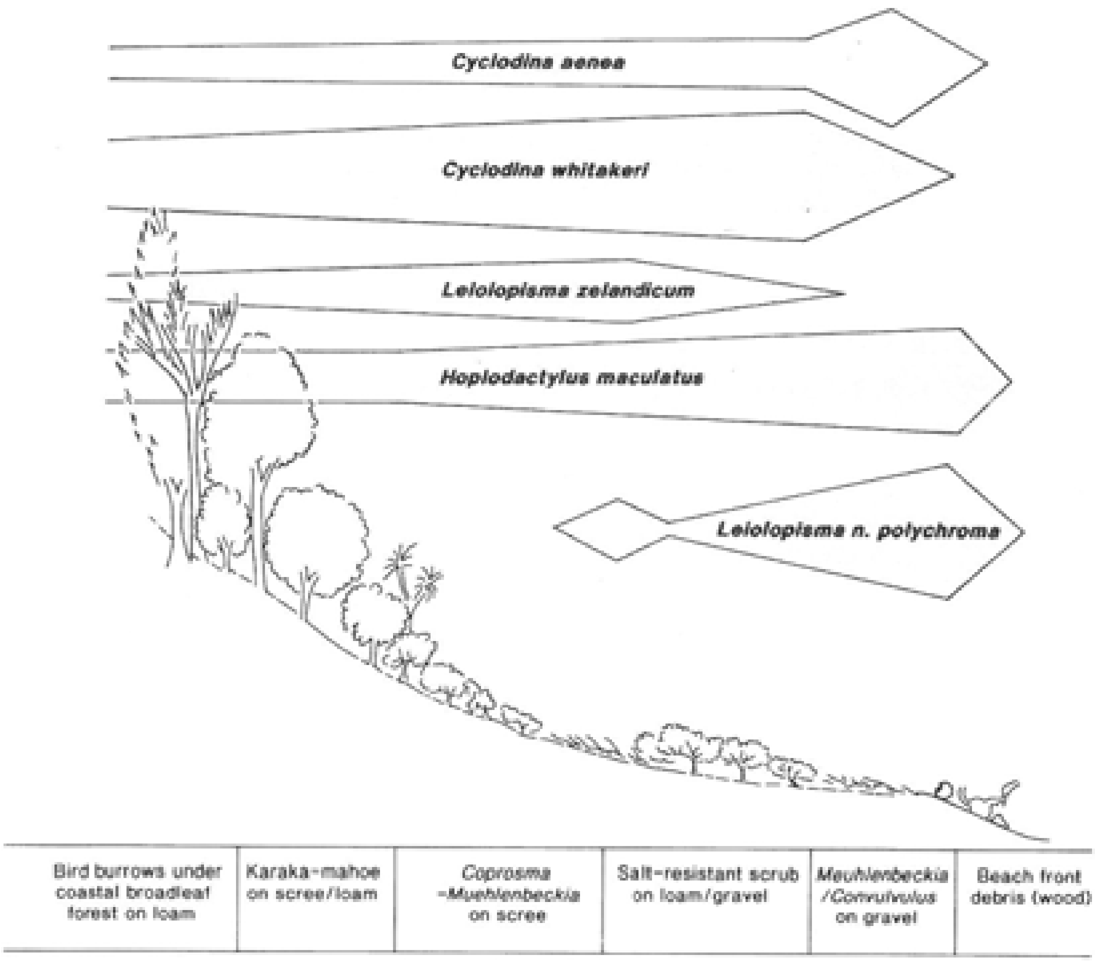

Fig. 7 Model of prehistoric vegetation at Pukerua Bay and the distribution of resident lizards, with relative abundance shown by width of kites. Note that additional species may have been present (Table 1).

The second model is derived from present distributions of the species at Pukerua Bay, the relationship between activity and temperature, and information on their habitat use elsewhere (Barwick 1959, Cree and Daugherty 1991, Gill 1976, Porter 1987, Southey 1985, Towns 1991, Whitaker 1982) and is summarised as:

Copper skink: forest-shrub-ecotone; moist sites; high loam; seasonal, sensitive to night-time temperature Whitaker's Copper
Whitaker’s skink: forest-shrub; moist sites; burrows/rocks/stones; highly seasonal, sensitive to night-time temperature
Common skink: low vegetation cover; dry sites; stones; weakly seasonal, not sensitive to temperature
Brown skink: forest-shrub-ecotone; moist sites; wood; weakly seasonal, not sensitive to temperature
Common gecko: forest-shrub-low vegetation cover; dry sites; stones; weakly seasonal, not sensitive to temperature

The species with habitat use most similar to Whitaker's skink is the copper skink, although the two differ in their moisture requirements (Cree and Daugherty 1991).

In combination the two models suggest that Whitaker's skinks may once have dominated the lizard assemblage (at least by biomass), and species such as copper skinks and common skinks are probably more widespread and common now than they might have been in the past. Both latter species do well in modified habitats. Copper skinks may be preyed on by Whitaker's skinks where the latter species is abundant. Copper skinks are rare where the two species co-occur on predator-free Middle Island. At Pukerua Bay copper skinks are likely to have been confined to areas where they were inaccessible to other reptilian predators such as tuatara.

The advent of predatory mammals, disappearance of burrowing seabirds and lack of alternative habitats has greatly reduced the range of Whitaker's skinks. The extent to which their range can be expanded in the future will depend on patterns of vegetation development and management options that are followed.

5.2 Patterns of vegetation development

Changes to vegetation at Pukerua Bay in the Crown reserve and Porirua City reserve began as soon as stock were excluded from the reserve area in 1987. The most visible changes include expansion of *Muehlenbeckia* over previously bare areas, extensive areas of rank grass, coppicing of karaka trees and the appearance of new karaka seedlings. Individual *Coprosma propinqua* shrubs that were browsed back by stock began expanding. Browsing has not ceased in the reserve because possums and rabbits will continue to have some effects on vegetation. However, despite the effects of wild browsing animals, a gradual process of change is already underway.

Vegetation around the study grid is likely to change without further intervention over the next 10 years as follows:

1. A gradual increase of young karaka trees and the development of a shrubby understorey around the existing karaka grove. The understorey is likely to include *Coprosma* species, kawakawa and possibly an outer fringe of *Urtica ferox.*
2. Increased cover of *Coprosma propinqua* on loam, but with scattered plants of puka, kaikomako, akiraho, mahoe and kawakawa overtopping in places.
3. Increasing density of the *Muehlenbeckia* on scree and loam with much of it scrambling over shrub species.
4. Expansion of salt-resistant species such as taupata and ngaio along the beach front.
5. Expansion of weed species such as boneseed into open areas, especially sites along the beach.

Changes in the longer term are more difficult to predict. Eventually the hillside should tend towards a coastal mosaic with pockets of emergent coastal broadleaf forest on deeper soils and dominated on the lower rocky slopes by karaka.

5.3 Long term prospects for Whitaker's skink

The main study site was chosen because the capture rates for Whitaker's skinks were higher there than elsewhere, so the overall density throughout the known inhabited area may be over-estimated. In the event that 260-330 individuals is an over-estimation of the number at Pukerua Bay, the population may be marginally viable.

None of the density estimates recorded here for lizards in the study area are unrealistic. The estimate for Whitaker's skinks at Pukerua Bay is in the middle of the range estimated by Southey (1985) for the species in the Mercury Islands. Lowering the vulnerability of the Pukerua Bay population will only be possible through management that aims towards an order of magnitude increase in numbers. Without such an increase the species is unlikely to overcome the threats from disturbance, fire and predation that it faces on this mainland site. Such an increase may be very difficult to achieve and will need to rely on:

1. Improvements of the quality of existing habitats to raise the carrying capacity for Whitaker' skinks.
2. Substantial increase of suitable habitat into which the population can expand.

With appropriate revegetation of the more extensive screes, the area available to Whitaker's skinks could be more than doubled. Any expansion beyond this may not be possible because of the ecological and physiological constraints that tie the species to areas of deep boulders. However, appropriate habitats around the boulder areas could provide suitable refuges that would be used periodically while rocky areas remain the winter retreats. This would have the effect of increasing the density of Whitaker's skinks in existing habitats.

5.4 Management possibilities

Three key elements require consideration when managing the reserve at Pukerua Bay: habitat quality for target species; risks from increased predator pressure; and the risk of fire. The most successful regime will be one that increases habitat quality for target lizard species but not for their predators. Models of the likely changes in these elements of the community are therefore useful (see Table 9). The potential for fire and predation have been maintained at relatively low levels at Pukerua Bay until 1987 by grazing (Table 9, scenario A). However, this has had detrimental effects on lizard habitat and has reduced Whitaker's skink numbers to critical levels.

Removal of grazing has the long term potential to improve the habitat for several lizard species including Whitaker's skink (Table 9, scenario B). However, the proximity of the site to Pukerua Bay township, and the large numbers of visitors, raise both the fire risk within the reserve and its potential effects on nearby dwellings. With the likely long term increase in rank grasses, periodic irruptions of mice such as that reported in 1988 are likely, and will lead to associated increases in predator pressure from cats and
On the other hand, with an urban area in the near vicinity predator control becomes hazardous and might therefore be an unacceptable operation.

Management of the revegetation process has potential to lower both the effects of predators and potential fire hazards by passive means, but will need to be directed with some care. In this model (Table 9, scenario C) the aim should be to build on the benefits of natural revegetation (Table 9, scenario B) but direct management activities towards areas that contribute to mouse population changes (such as rank grass) and high fire risk (rank grass and dry twiggy vegetation). If mouse numbers can be depressed by manipulation of the revegetation process, other predators are less likely to be attracted to the area. Lizards should not then represent an accessible food source because of the high quality cover for them that is provided by dense vegetation.

5.5 Future management pathways

Future management hinges on administrative as well as biological considerations. The Crown reserve at Pukerua Bay is bounded on two sides by land administered by Porirua City Council: the adjoining Raroa Recreation Reserve, and the paper road along the existing coastal walkway. Appropriate management of both of these areas of City Council land are vital to meeting targets proposed here. Other habitats will also require a partnership approach. The driftwood environments along shorelines are important for common skinks and common geckos, and if left undisturbed, could be used at times by Whitaker's skinks. Successful management of the Crown reserve will therefore rely on development of complimentary agreements between the Crown and the City Council, possibly with these agreements fixed in local bylaws. The following suggestions are made on the assumption that these agreements, already made in principle (Towns 1985b), will operate successfully.

5.5.1 Low intensity management and natural revegetation

Under this regime *Coprosma propinqua* would expand further, the more open mobile screes would gradually become bound by *Muehlenbeckia,* and scatterd karaka and species such as puka, kaikomako, mahoe, taupata and kawakawa would probably spread amonst the *C. propinqua.* This is a low cost option but has relatively high risks that could become expensive. The dry twiggy litter that forms under *C. propinqua* makes it prone to burning. It is not a favourable habitat for some lizards. Rank grass also poses a fire risk, as well as a source of seed responsible for periodic irruptions of mice. The spread of weeds such as could inhibit regeneration of native species and require

Table 9 **Likely interaction between habitats, lizards and predators at Pukerua Bay under three management scenarios.**

Scenario A: Continued grazing
Effect on substrate: Mobilization of scree slopes

Vegetation	Lizards	Mice	Other predators
Further spread of low pasture	Expansion of common skinks where cover available	Maintained at moderate levels by loss of cover and high predation	Increasing impact on lizards through loss of alternative foods
Reduction of binding vegetation on scree	Reduction of brown and common skinks		
Eventual loss of forest remnants through wind/ salt damage	Eventual loss of Whitaker's skinks through predation/ loss of cover		

Scenario B: No grazing, natural revegetation
Effect on substrate: Gradual stabilization of scree slopes

Vegetation	Lizards	Mice	Other predators
Extensive rank grass for some years	Reduction in numbers of common skinks	Periodic irruptions in response to seeding grasses	Low impact on lizards because of increased cover in most years
Increased binding vegetation on scree	Increase in copper and brown skinks		Periodic high impacts following mouse irruptions
Gradual improvement of forest remnants	Maintenance of Whitaker's skinks, but little spread due to predation during and following mouse irruptions		
Rapid spread of weeds and fire-prone species			

Scenario C: No grazing, managed revegetation
Effect on substrate: Stabilization of scree slopes

Vegetation	Lizards	Mice	Other predators
Reduced areas of rank grass	Reduction of common skinks	Maintained at moderate numbers	Reduced impact on lizards due to increased cover and reduced numbers of mice
Rapid improvement of forest remnants from protection against wind	Expansion of copper, brown and Whitaker's skinks due to increased cover and shelter		
Minimised spread of fire prone species and weeds			

expensive remedial action. Nonetheless, as long as fire bans can be enforced successfully (they haven't so far), the habitat will improve for Whitaker's skink as open bouldery slopes become covered and bound by vegetation. Extensive potential scree habitat exists in Raroa Reserve.

5.5.2 Moderate intensity management with selected planting

With this regime the processes mentioned in 1 would be allowed to continue naturally, but weed species would be controlled, and areas of *C. propinqua* on the lower slopes would be gradually underplanted with coastal species such as mahoe and karaka. Mahoe is a species that supports particularly dense litter invertebrates (Hicks *et al*. 1975), and the cavities formed by roots of older plants are often used as retreats for large *Cyclodina* skinks (Southey 1985). This option would extend habitats suitable for Whitaker's skinks beyond the bouldery areas, although the screes would likely form the main winter retreats. Fire risks and the frequency of mouse irruptions should diminish as dry shrubby vegetation and rank grasses are shaded out.

5.5.3 Intense management with widespread planting

The target for intensive management would be Whitaker's skink and the habitat manipulated to meet their needs. There could be three components to management:
(a) Expansion of rocky habitats on the old beach terraces using rocks either imported or obtained from the foreshore.
(b) Linkage between Whitaker's skink populations using rock groynes (stable artificial screes).
(c) Extensive plantings on reverting pasture using coastal species from the area. This is the most expensive option that in the short term could also result in intrusive habitat changes that might not be aesthetically pleasing until covered by vegetation such as *Muehlenbeckia.*

5.6 Measuring the effects of management

Because it is secretive, seasonal, strongly influenced by climate, slow to mature and long-lived, Whitaker's skink is an extraordinarily difficult subject for management. However, it should be possible to measure the effects of change, in some cases indirectly, as long as monitoring programmes are carefully designed. There are two ways this can he done, and both should be used.

1. A grid of up to 20 traps within the original study site can be used to measure relative numbers of lizards for comparison against the data provided in this report. A second grid of the same number of traps should be established outside the reserve. A suitable location is west of the reserve boundary near Wairaka Rock in an area still grazed by stock. Comparison of lizard numbers (from traps set concurrently) and vegetation within these grids will indicate the effectiveness of actions within the reserve.

2. Trapping for McGregor's skink on Mana Island and lizards at Pukerua Bay should if possible be conducted concurrently. By standardising the trap effort and comparison of the two locations influences other than climate should become apparent. For example the effects of mouse irruptions on lizards at Pukerua Bay should be indicated by differences in trap success when compared with mouse-free Mana Island.

6. RECOMMENDATIONS

1. That the reserve be gazetted under a category that allows experimental management.
2. That a permanent fire ban be maintained in the Crown and adjacent Porirua City reserve.
3. That removal of driftwood from the beach fronting the reserves should be discouraged.
4. That threats to the lizard assemblage, and especially to Whitaker's skinks, disturbance, predation and fire be minimised through a managed revegetation programme.
5. That the effects of management in the reserve be assessed through a monitoring programme using a small number of pitfall traps inside and outside the reserve area.
6. That the conservation values of the area be promoted through an advocacy and education programme aimed especially at local schools.

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APPENDIX 1

Statistical methods used to test levels of significance when comparing samples

Programming and analyses were conducted by Graeme Elliott and Ross Pickard.

Methods and results listed below are provided for each kind of analysis separately. Tests were conducted using SAS, and SYSTAT, a statistics package, on a personal computer.

1.1 Comparisons of capture frequencies

1.1.1 Method

Capture frequencies of lizards were compared with ANOVA in the months December-March over the five study seasons. Comparisons between individual seasons of the same species in different years were either with ANOVA (multiple comparisons) or Student's T Test (paired comparisons). All data for these tests were normalised using the arcsin √p transformations of capture rate per 100 trap-days (Rohlf and Sokal 1969).

Appendix Table 1.1. Comparison of lizard capture rates in different years by ANOVA.

Species	F value	Degrees of freedom	P>F	Significance
Cyclodina aenea	22.19	3,33	0.0001	***
Cyclodina whitakeri	1.47	3,23	0.2496	NS
Leiolopisma n. polychroma	6.41	3,33	0.0015	**
Leiolopisma zelandicum	8.55	3,31	0.0003	***
Hoplodactylus maculatus	4.69	3,25	0.0098	**

Levels of significance are denoted as <0.05 (*), <0.01(**), <0.001 (***).

1.1.2 Results

Total lizard captures were not significantly different between seasons 1-4 (p (F 1.28, df 4,21) > 0.01), but were significantly different between seasons 4 and 5 (T = 3.8, p<0.01). When species were treated individually, capture rates between seasons were significantly different for all species except for Whitaker's skink (Table 1.1). Therefore, whereas the total caught did not vary significantly, the contribution made to that total varied by season and by species.

1.2 Relationships between capture rates and temperature

1.2.1 Method

Temperatures measured by maximum-minimum thermometers while traps were set were obtained at three levels (see 3.3). The resulting six temperature variables were tested for significant differences by Student's T Test.

Capture statistics for lizards obtained while temperatures were measured were normalized using log of captures per 100 trap days. Relationships between temperature and capture rate were tested by regression.

1.2.2 Result

All measures of temperature differed significantly except for minimum temperatures measured at the surface and at 20 cm depth (Table 1.2).

Regressions produced no significant relationships between temperature variables and capture rate for common skink, brown skink and common gecko. The nearest to significant relationship was for common skinks and maximum surface temperature (Table 1.3). Both copper skinks and Whitaker's skinks showed strong positive relationships between capture rate and temperature. The best predictor for Whitaker's skink was minimum temperature at the surface. There was also a weak negative link between maximum temperature at 65 cm and capture rate of Whitaker's skink (Table 1.3), suggesting that activity was suppressed during highest temperatures. Because of the many 0 capture points for Whitaker's skink a more robust estimate might he obtained for that species using maximum likelihood estimates based on a Poisson distribution model as for habitat characteristics (below).

Appendix Table 1.2. T-Test comparison of temperatures at Pukerua Bay between November 1984 and April 1987 from max, min 1 (maximum, minimum) on surface, max, min 2 at 20 cm and max, min 3 at 65 cm.

	T value	Degrees of freedom	P	Significance
Max 1 vs 2	–8.462	42	0.000	***
Max 2 vs 3	–19.448	42	0.000	***
Max 1 vs 3	–13.949	42	0.00	***
Min 1 vs 2	0.943	42	0.351	NS
Min 2 vs 3	11.109	42	0.000	***
Min 1 vs 3	9.783	42	0.000	***

1.3 Relationships between capture rates and habitat characteristics

1.3.1 Method

Data obtained from the study grid were analyzed as follows:

1. Average vegetation height was calculated for each trap site.
2. Average proportion of the different surface and subsurface types were calculated from the following substrate classes: moss, loam, clay, silt, sand, gravel (<5cm dia), stones (>5cm dia, <20 cm), boulders (>20cm), wood, and creeping vegetation.
3. Vegetation heights were normalised using the arcsin $\sqrt{p}$ transformation.
4. Capture data for lizards were used from the months December-March inclusive, and no data were used from the final trapping season, when livestock were excluded.
5. Lizard capture rates standardised to numbers per trap-day were normalised by log transformation.

Appendix Table 1.3 Regressions of log-transformed captures of lizards against maximum-minimum temperatures at Pukerua Bay (conventions as in Table 1.2)

Taxon	Temperature measure	Regression coefficient	R^2	Probability	Significance
All species	Max 1	0.079	0.101	0.038	*
	Max 2	0.004	0.000	0.925	NS
	Max 3	0.056	0.048	0.160	NS
	Min 1	0.058	0.082	0.063	NS
	Min 3	0.073	0.112	0.028	*
L. n. polychroma	Max 1	0.067	0.065	0.099	NS
	Max 2	0.021	0.006	0.628	NS
	Max 3	0.036	0.017	0.401	NS
	Min 1	0.023	0.012	0.491	NS
	Min 3	0.025	0.012	0.491	NS
L. zelandicum	Max 1	0.067	0.001	0.846	NS
	Max 2	–0.430	0.035	0.230	NS
	Max 3	–0.160	0.005	0.656	NS
	Min 1	–0.042	0.001	0.881	NS
	Min 3	–0.028	0.000	0.927	NS
C. aenea	Max 1	0.431	0.110	0.029	*
	Max 2	0.126	0.009	0.553	NS
	Max 3	0.611	0.206	0.002	**
	Min 1	0.494	0.217	0.002	**
	Min 3	0.608	0.289	0.000	***
C. whitakeri	Max 1	0.430	0.026	0.305	NS
	Max 2	–0.172	0.004	0.696	NS
	Max 3	0.780	0.078	0.069	NS
	Min 1	0.945	0.185	0.004	**
	Min 3	0.853	0.133	0.016	*
H. maculatus	Max 1	–0.528	0.037	0.215	NS
	Max 2	–0.371	0.017	0.406	NS
	Max 3	–0.520	0.033	0.240	NS
	Min 1	–0.318	0.020	0.360	NS
	Min 3	–0.338	0.020	0.365	NS

Regression was initially used to seek variables that might affect the numbers of lizards caught. However, the distribution of the residuals showed that the data were not consistent with the assumptions of regression models and were therefore reanalysed using a maximum likelihood model. This model assumed a Poisson distribution for residuals. Two species, Whitaker's skink and common gecko, produced results which did not conform to the maximum likelihood model and for these a logistic regression was used to investigate the relationship between trap success and environmental variables.

1.3.2 Results

F values (maximum likelihood model) with significance levels have been rejected in this analysis. The resulting associations (Table 1.4) appear biologically meaningful for all species other the Whitaker's skink. The negative relationships between Whitaker's skinks, common geckos, and the presence of wood are probably trivial because wood was rarely encountered.

Appendix Table 1.4. Relationship between lizard distribution and environmental features.

Species	Variable	Parameter estimate	F value	DF	Probab-ility
		Maximum likelihood model			
L. n. polychroma	Vegetation height	−1.211	7.172	1,77	0.009
L. zelandicum	Subsurface loam	−0.714	5.406	1,77	0.023
C. aenea	Loam	0.993	9.029	1,77	0.004
	Gravel	−1.251	7.735	1,77	0.007
	Vegetation height	1.005	5.941	1,77	0.017
	Subsurface gravel	−0.966	8.041	1,77	0.006
	Subsurface loam	0.742	7.194	1,77	0.009
		Logistic regression			
C. whitakeri	Wood	−147.256	7.775	1,77	0.007
H. maculatus	Wood	−146.705	7.211	1,77	0.009
	Subsurface loam	−2.531	8.342	1,77	0.005

The maximum likelihood model and logistic regression explained a relatively low proportion of variation in capture rate (Table 1.5), with the highest proportion (21%) explained for the copper skink. Of all species, therefore, copper skinks may be the best predictors of the effects of changes in the habitat as a result of revegetation of the reserve.

Appendix Table 1.5. Proportion of variation in capture rate explained by maximum likelihood and logistic regression.

Species	Proportion of variation explained	F value	Degrees of freedom	Probability
L. n. polychroma	0.085	7.172	1,77	0.009
L. zelandicum	0.066	5.406	1,77	0.023
C.aenea	0.205	3.764	5,73	0.004
C. whitakeri	0.092	7.775	1,77	0.007
H. maculatus	0.187	8.754	2,76	0.000

APPENDIX 2
Plants recorded in the study grid at Pukerua Bay September–November 1986

Species are listed with percentage occurrence (first encounters only). Species marked * are adventives and those marked + were recorded but not as a first encounter. Identifications verified by C. Ogle (pers comm.).

Name	Common name	Percentage of encounters
*Bromus diandrus**	ripgut brome	0.46
*Cerastium glomeratum**	annual mouse-ear chickweed	0.15
Coprosma propinqua		16.23
Cordamine sp*	bitter cress	0.05
Dichondra repens	Mercury Bay weed	+
*Ehrharta erecta**	veld grass	1.22
*Fumaria muralis**	scrambling fumitory	+
*Galium aparine**	cleavers	0.86
*Geranium molle**	dove's foot cranesbill	0.15
*Geranium robertianum**	herb Robert	0.05
*Holcus lanatus**	Yorkshire fog	0.05
*Hypochoeris radicata**	catsear	+
*Lolium perenne**	perennial ryegrass	0.91
Microlaena stipoides	meadow ricegrass	4.06
Muehlenbeckia complexa	small-leaved pohuehue	63.79
Oxalis rubens		+
Pellaea rotundifolia	button fern	0.05
Poa cita	silver tussock	0.15
*Poa pratensis**	Kentucky bluegrass	1.88
*Polycarpon tetraphyllum**	allseed	+
*Rumex brownii**	hooked dock	0.05
*Sporobolus africanus**	ratstail	0.25
*Stellaria media**	chickweed	0.15
*Trifolium repens**	white clover	0.20
*Trifolium dubium**	suckling clover	+
Urtica ferox	tree nettle	0.91
*Verbascum thapsus**	woolly mullein	0.15
*Vicia disperma**	small French tare	0.05
*Vicia sativa**	vetch	0.05
Dead wood		0.10
No vegetation		7.40
Total percentage		100.00
Total encounters		1972

APPENDIX 3

Data used for determining growth patterns

The snout-vent length (SVL, mm) is given for the midpoint of each size range and the size range of the data used in calculations of minimum number alive (year one) is given for each season. Cut-off points for data excluded (i.e., lizards born after year 1) were determined from growth rates of known-age animals.

Range	Season				
	1983/84	1984/85	1985/86	1986/87	1987/88
		Cyclodina aenea			
SVL midpoint range	42–57	39–57	42–57	48–57	
Number	77	76	139	118	
		Cyclodina whitakeri			
SVL midpoint range	50–95	60–100	65–90	75–95	80
Number	27	8	13	13	1
		Leiolopisma n. polychroma			
SVL midpoint range	39–63	42–60	51–63	57–60	
Number	186	207	102	52	
		Leiolopisma zelandicum			
SVL midpoint range	36–66	39–60	48–60	57–60	
Number	62	21	40	21	
		Hoplodactylus maculatus			
SVL midpoint range	50–65	55–65	60–65	55–65	
Number	33	15	8	16	