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Seasonal fluctuations of numbers, breeding, and food of kiore (*Rattus exulans*) on Lady Alice Island (Hen and Chickens group), with a consideration of kiore: tuatara (*Sphenodon punctatus*) relationships in New Zealand

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Abstract Kiore were snap-trapped in five forest habitats on Lady Alice Island. Trapping was most successful from late autumn to early spring and in coastal scrub habitat. Breeding extended over at least 6 months (November to April) during which females produced 2–3 litters each averaging five young. Although plant material was most abundant in rat stomachs (averaging 78% volumetrically), a wide range of animal foods was taken. Weevils, scarab beetles, moth larvae of the family Hepialidae, weta (Orthoptera), and down feathers of burrowing seabird chicks were the most frequently recovered. No tuatara remains were found in rat stomachs, but fragments of three skinks (*Cyclodina* and/or *Leiolopisma* spp.) were recorded. We postulate that in the absence of rats, tuatara densities will be highest on islands that have been partly cleared of forest. In the presence of kiore, tuatara are more likely to persist on islands with minimal modification of the original forest.

Keywords Kiore; *Rattus exulans*; population ecology; food; predation; interspecific relationships; tuatara; *Sphenodon punctatus*; Lady Alice Island

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INTRODUCTION

Although widespread throughout New Zealand following their introduction by Maori, kiore are now largely restricted to offshore islands (Moller & Craig 1987; Atkinson & Moller in press). Many of these islands are important fauna and flora reserves where kiore are believed to have an adverse effect on other biota (Atkinson 1972; Crook 1973; Whitaker 1973; Campbell 1978; Ramsay 1978); however, supporting evidence is inadequate to indicate causal relationships (Craig 1986). The rat occurs on seven islands occupied by tuatara, (Newman 1982) and almost all tuatara populations co-existing with kiore have age distributions seemingly biased toward adults, suggesting recruitment failure (Crook 1973). Aspects of rat : tuatara interactions were assessed on Lady Alice Island. In particular, we aimed to determine if, and how frequently, rats took vertebrate prey, especially reptiles (tuatara and lizards). Data on seasonal fluctuations of numbers, breeding, and food of the kiore are presented. These results are discussed with reference to a model proposed to explain variation in rodent demography in New Zealand (Moller & Craig 1987), and consideration is given to how kiore may have affected tuatara populations.

STUDY AREA

Lady Alice Island (138 ha, 35°54′S, 174°44′E) is the largest of the Chickens Island group which lies 10 km south-east of Whangarei Heads off the east coast of North Auckland. Collectively, the islands are a nature reserve. Although highly modified by past burning, Lady Alice Island now supports a diverse forest flora (Percy 1956; Jane & Beever 1965; Cameron 1984). Populations of seabirds (petrels and shearwaters) breed on the island (McCallum et al. 1984) and tuatara occur in numbers near the lower limit of those observed on rat-free islands (Crook 1973).

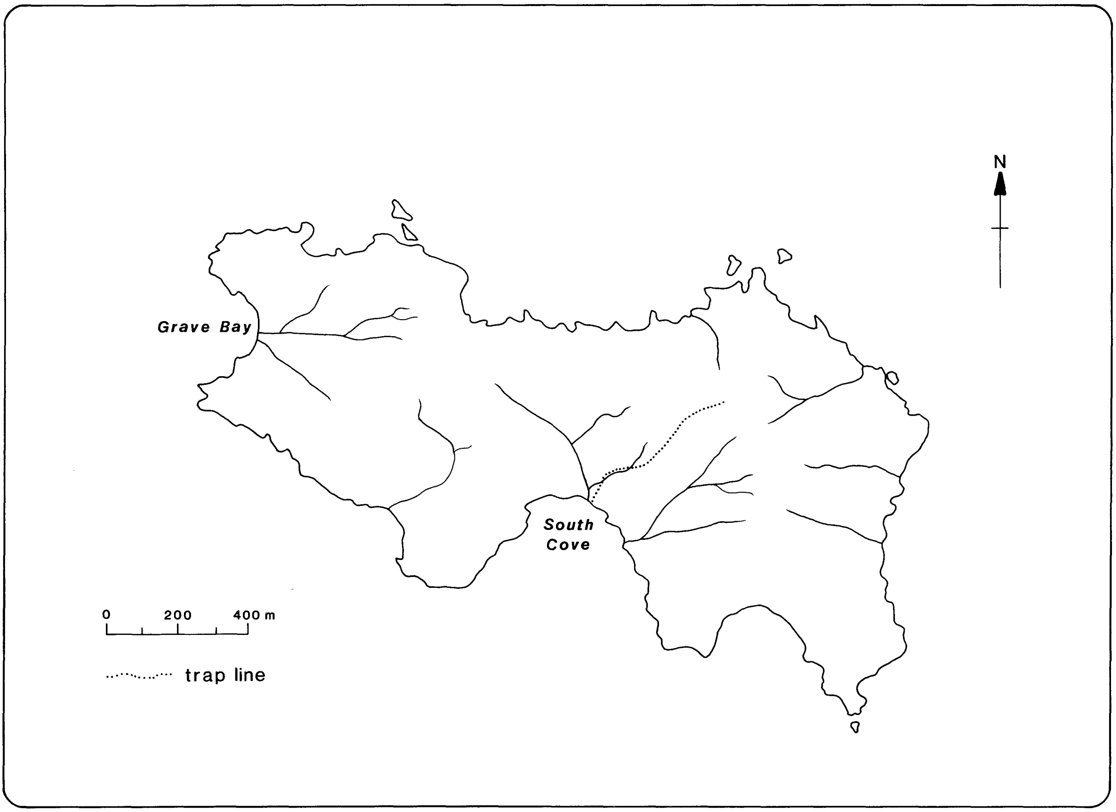

Fig. 1 Lady Alice Island showing position of snap trap line.

MATERIALS AND METHODS

A trapline of 25 stations was established at South Cove and ran from 10 m above high tide mark to the summit (153 m) of the island (Fig. 1). Trapping stations were positioned at about 15 m intervals and at each, two break-back traps ("Ezeset Supreme" brand) were placed under galvanised iron covers. Traps were set for 3 or 4 nights on each of 12 visits to the island between May 1981 and June 1983 (Fig. 2). On the first four visits, traps were baited with peanut butter and rolled oats or "Felix" fish cat food; thereafter traps were baited with petrogel paste lured with either coconut or aniseed essence. Previous tests had shown that petrogel paste, suitably lured, was acceptable kiore bait (McFadden 1984).

The trap-line passed through five different habitat types. Stations 1 and 2 were sited in coastal scrub dominated by taupata (*Coprosma repens*), kawakawa (*Macropiper excelsum*), puka (*Meryta sinclairii*), and mahoe (*Melicytus ramiflorus*). Stations 3 to 6 were in a valley covered by coastal forest with kohekohe (*Dysoxylum spectabile*), puriri (*Vitex lucens*), and parapara (*Pisonia brunoniana*) dominant. The valley passed into a basin (stations 7 to 10) where forest contained pohutukawa (*Metrosideros excelsa*), puriri, kohekohe, and nikau palm (*Rhopalostylis sapida*). Stations 11 to 15 were in hillside forest with an open canopy, where kanuka (*Kunzea ericoides*), houpara (*Pseudopanax lessonii*), rangiora (*Brachyglottis repanda*), *Olearia furfuracea*, and cabbage tree (*Cordyline australis*) were dominant. The trapline terminated in closed canopy hilltop forest (stations 16 to 25) which contained kanuka, pohutukawa, kawakawa, rangiora, and *Olearia furfuracea*.

Rats caught were weighed (± 1.0 g), unless wet or partially eaten, with a 300 g "Pesola" spring balance measured (head length, body length, tail length if complete to ± 1.0mm, and hind foot length to ± 0.5mm), and autopsied on the island. The visibility of tubules in the cauda epididymis of males was

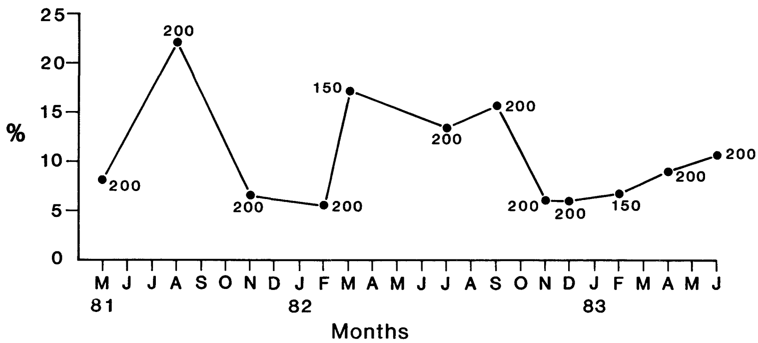

Fig. 2 Corrected percentage snap trap success for each trip, Lady Alice Island. The number of trap nights set is given beside each point.

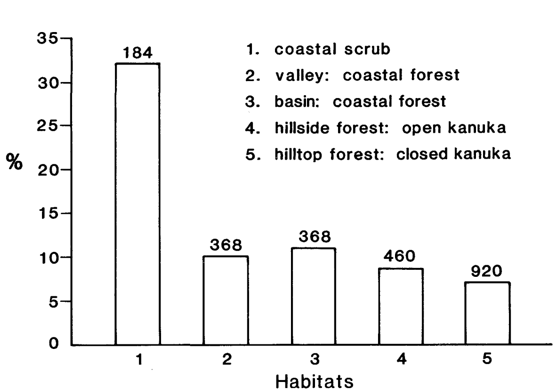

Fig. 3 Corrected percentage snap trap success for each habitat sampled on Lady Alice Island. The number of trap nights set is given above each bar.

noted and the length of one testis measured (±0.5 mm). The uterine condition of females (undeveloped, enlarged, or pregnant) was recorded and the number of uterine scars and/or embryos, counted. Rats were deemed to be immature if evidence of reproductive activity was lacking, i.e., females with an undeveloped uterus (irrespective of whether the vagina was open or closed) and males with faint epididymal tubules (irrespective of whether the testes were abdominal or scrotal) were considered immature.

The lower jaw was removed from the skulls and each individual was assigned to an age class from tooth-wear indices on the upper molars (Karnoukhova 1972).

Stomach contents were washed with a weak detergent solution to remove petrogel paste and all material recovered was preserved in 70% ethanol, following preliminary sorting. Generally, qualitative analysis only was applied. Most stomachs (n = 134) were checked for vertebrate remains, and the proportion by volume of plant and animal material recorded for some others (n=35). Identification of the principal invertebrate constituents was attempted for 98 stomachs.

Trapping success figures were corrected for interference using the method proposed by Nelson & Clark (1973), i.e., effective trap nights were determined by subtracting half a trap night for each trap found sprung by any cause. Where appropriate, statistical analyses were carried out using either Student's t, or χ^2 tests. The alpha level of significance was set at 0.05.

RESULTS

Trapping success

Two hundred and forty rats were caught over 2300 trap-nights giving a corrected trapping success of 10.2%. The number of kiore caught each trip varied significantly (χ^2 = 56.8, d.f.= 11, P < 0.001). Low numbers were trapped in late spring (November) and summer (December–February), and high numbers in late autumn (May), through winter (June–August), to early spring (September) (Fig. 2). Trapping success also varied significantly among habitats (χ^2 = 89.2, d.f.= 4, P < 0.001), with particularly high numbers of rats being caught in coastal scrub (Fig. 3); the numbers of rats trapped in the other habitats were not significantly different from each other (χ^2 = 5.8, d.f.= 3, P > 0.10).

Age and breeding data

Autopsy data from trips 1–3 were incomplete and were excluded from most further analyses. Only four pregnant females were trapped, three in February (6,5,5 embryos) and one in April (two very small embryos probably being resorbed, plus four recent uterine scars) (Fig. 4). However, the recovery of a

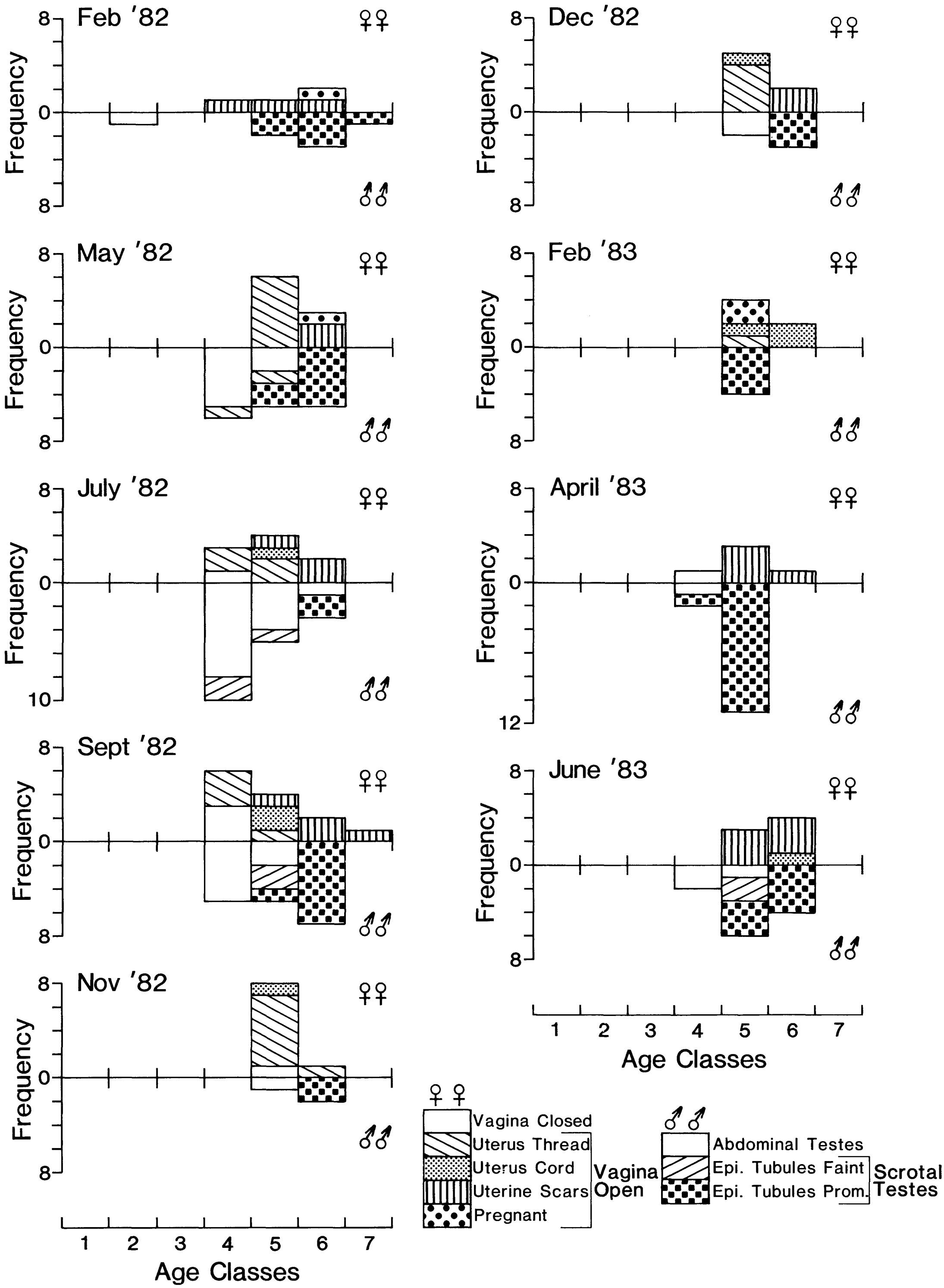

Fig. 4 Age (tooth-wear class) and breeding condition of kiore caught each trip, Lady Alice Island.

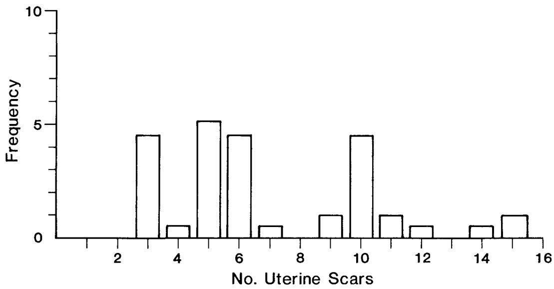

Fig. 5 Number of uterine scars per parous female kiore (n = 28), Lady Alice Island.

Of rats classified as being immature, 6 females (18%) had a closed vagina and 35 males (80%) had abdominal testes (Fig. 4). For males with scrotal testes, the mean testis length of immatures (17.1 mm, n = 15, range = 14–20 mm) was significantly shorter than that of matures (20.6 mm, n = 55, range = 18–24mm; t = 7.88, d.f.= 68, P < 0.01). Immature rats predominated in May, July, and November 1982 samples. More mature than immature rats were trapped in February of both years, and in April and June 1983 (Fig. 4). Whereas one rat of each sex was reproductively active at age class 4, most mature young male (the only age class 2 individual caught during this study) in February indicated that breeding had commenced before this month. Sexually active males were caught on each trapping trip (Fig. 4). Uterine scars were visible in 28 females and the frequency distribution of scar counts suggested that 12 of these females had carried 2 or 3 litters (Fig. 5).

Fig. 6 Percentage of mature kiore (male = hatched bars, female = open bars) in each tooth-wear age class, Lady Alice Island. Sample sizes are given at the top of each bar.

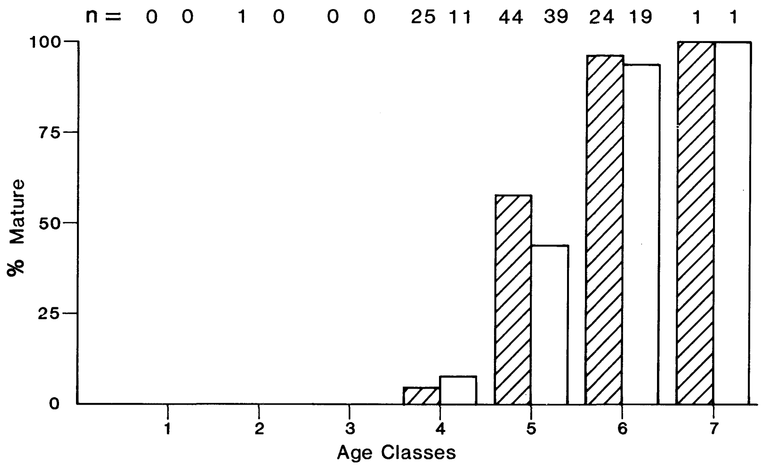

Table 1 Mean body length and weight of immature and mature kiore caught on Lady Alice Island between November 1981 and June 1983. Ranges are given in parentheses.

Sex	Mean body length (mm) Immature	Mean body length (mm) Mature	Mean weight (g) Immature	Mean weight (g) Mature
Males	142.2 n=51 (99–170)	160.7 n=55 (146–175)	103.8 n=47 (32–187)	140.0 n=41 (111–175)
Females	137.4 n=35 (110–155)	152.3 n=36 (138–165)	88.7 n=32 (48–120)	117.1 n=29 (95–150)

individuals were > age class 5 (Fig. 6). For both sexes, the largest immature specimens exceeded in body length and weight the smallest mature animals (Table 1). Neither the sex ratios of immatures (33 females : 44 males, χ^2 = 1.3, P > 0.10), nor matures (37 females : 51 males, χ^2 = 1.9, P > 0.10) deviated significantly from parity.

Food

Of 134 kiore stomachs checked for the presence of vertebrate material, only three contained fragments of lizard skin, apparently from the tails of skinks (*Cyclodina* and/or *Leiolopisma* spp.), and 21 held varying quantities of down feathers from petrel and shearwater chicks. During this study a kiore was observed at night feeding on a freshly dead allied shearwater chick, *Puffinus assimilis*, just inside the entrance of a burrow. The rat may well have killed the chick which had appeared to be in good condition when checked earlier that day.

Plant material was present in greater volume (78%, range = 40–99%) than animal material in the 35 stomachs analysed.

The most frequently occurring invertebrates in 98 stomachs were insects, particularly Coleoptera, Lepidoptera, and Orthoptera (Table 2). Weevils (Curculionidae) and scarab (Scarabaeidae) beetles predominated amongst the Coleoptera, and moths of the family Hepialidae (*Wiseana* sp.) were the most plentiful lepidopterans. Most orthopterans recovered were weta (Stenopelmatidae). Other beetle families represented were: Carabidae, Chrysomelidae, Dermestidae, Elateridae, and Staphylinidae; lepidopteran families included: Noctuoidea, Oecophoridae, Psychidae, and Tineidae; and dipteran families: Calliphoridae, Ephydridae, Psychodidae, Sciaridae, Stratiomyidae, Syrphidae, and Tipulidae.

DISCUSSION

Demography

Seasonal breeding appears to be a general pattern for kiore in New Zealand and results in marked fluctuations in density. Densities usually reach lowest levels in spring and early summer, and peak in autumn (Atkinson & Moller in press). On Lady Alice Island, peak numbers were caught in late autumn and numbers caught remained high throughout winter to early spring. Low numbers were captured in late spring and summer.

Study of the kiore on Tiritiri Matangi Island led Moller & Craig (1987) to propose a demographic model for kiore in New Zealand. The model is based on the seasonal availability of food modified by the influences of predation and dispersal. On predator-free Tiritiri Island, where the vegetation is highly modified and dominated by grassland, the breeding season of kiore is particularly concentrated and short (Moller & Craig 1987). Seed forms the main food for kiore in grassland when it is available, and dietary studies, together with measurements of grass seed abundance, suggests that the seasonal availability of grass seed causes the strong pattern in breeding and resulting population fluctuations. The model predicts that kiore on Lady Alice Island, relative to Tiritiri, should occur at lower density for much of the year, have a longer breeding season, and that females should have a smaller mean litter size. With the more diverse forest habitat on Lady Alice Island and in the presence of a predator, the morepork owl, *Ninox novaeseelandia*, (Atkinson & Campbell 1966; Saint Girons et al. 1986) kiore densities should be lower than on Tiritiri, more food should be available per rat, and food suitable to sustain breeding may be available over a longer period. Thus, breeding effort could be spread in time and reproduction be by several small litters.

Mean snap trap success on Tiritiri was 20.8% in grassland (range = 1–91%) and 21.5% (range = 2–38%) in forest remnants (Moller & Craig 1987); on Lady Alice Island it was 10.2% (range = 5.6–22.1%). Births were restricted to a 3 month period on Tiritiri, from late November to early February (Moller & Craig 1987). We trapped pregnant females in only February and April, but Craig (1980) caught a pregnant female (five embryos plus one resorbing) on Lady Alice Island in late November 1979 along with two females with large uterine scars suggestive of recent births. These findings indicate that breeding on Lady Alice may extend over at least 6 months. Average litter size (live embryos per pregnant female) on Tiritiri was 6.7 (n = 15, range = 4–9; Moller & Craig 1987); on Lady Alice, incorporating Craig's (1980) sample, it was 4.8 (n = 5, range = 2–6). Predictably these results are markedly lower than on Tiritiri.

Table 2 Occurrence of invertebrate food items in 98 kiore stomachs, Lady Alice Island.

Food	No. of stomachs	Food	No. of stomachs
Annelida		Coleoptera	
Oligochaeta	5	larvae	29
Arthropoda		adult	79
Arachnida		Diptera	
Araneae	29	larvae	16
Chilopoda	28	adult	21
Insecta		Lepidoptera	
Orthoptera	49	larvae	26
Phasmida	1	adult	59
Mallophaga	2	Hymenoptera	1
Hemiptera	3	**Mollusca**	
		Gastropoda	3

Size and predation

As noted by Atkinson & Moller (in press), kiore from Lady Alice Island are heavier than any recorded elsewhere in New Zealand or overseas. These authors speculate that a founder effect, selection since establishment, or a local environmental effect related perhaps to food supply may be involved. Contributing to a local effect, it is possible that predation by moreporks may keep kiore density low, resulting in more food per rat and thus promoting their heavier weight. Large rats may be taken less frequently as prey by moreporks than small individuals. The abundance of moreporks on Lady Alice Island has, in fact, been attributed to the presence of kiore (Chambers et al. 1955; Skegg 1964; Whitaker 1978; McCallum et al. 1984), which make up the bulk of the diet of morepork chicks (Chambers et al. 1955.)

Influence on the tuatara

Our results support the findings of other workers that although plant material predominates in the diet of kiore, a wide range of animal foods is taken (e.g., Bettesworth 1972; Hicks et al. 1975; Campbell et al. 1984; Meads et al. 1984). Invertebrates made up the bulk of the animal food, but the down feathers of seabirds and the fragments of three lizards (skinks) were recovered. Our results suggest, therefore, that on Lady Alice Island reptiles are a comparatively minor constituent of the diet of kiore. Even so, kiore may have had a considerable impact on the island's herpetofauna, especially on vulnerable species such as the nocturnal skinks, *Cyclodina* sp. (Towns & Robb 1986). The marbled skink, *C. oliveri*, is not known from Lady Alice Island, but occurs on three other islands in the Chickens group—all three being rat-free (Whitaker 1978).

Also, it could be that in the area we trapped, few reptiles were present. Our rat trap line ran exclusively through forest, whereas on islands where kiore are present many lizard species are confined to refuge areas such as boulder beaches and cliffs (Towns et al. 1985). Further, on Stephens Island, small juvenile tuatara generally occupy forest edge habitat (M. E. McIntyre, pers. comm.).

Kiore are known to take the eggs of birds (Atkinson 1985) and may take those of tuatara. Female tuatara spend several nights excavating and filling their nests (Cree & Thompson 1988). The newly-laid eggs may remain exposed or incompletely covered for several days, so are likely to be vulnerable to predation by rats. However, work on the nesting ecology of tuatara at Stephens Island indicates that female tuatara aggregate in specific areas (rookeries) of open habitat (often sheep pasture) to nest (Daugherty et al. in press). Investigation of the ecophysiology of tuatara eggs indicates that soil temperatures in forest on Stephens Island are too cool for successful incubation (M. B. Thompson, G. C. Packard, M. J. Packard, pers. comm.). Before conversion of forest to sheep pasture on that island, Thilenius (1899) reported that female tuatara moved out of the forest to nest on cliff faces and other open areas. Daugherty et al. (in press) suggest that the present population of tuatara on Stephens Island may be artificially high as a result of the provision of new nesting areas (clearing of forest).

No nesting activity of tuatara was observed in the vicinity of our rat trap line on Lady Alice Island, but partly exposed nests were found in open sand dunes behind Grave Bay on the north-western side of the island (Fig. 1). Naturally open areas occur between beach and forest edge, and may provide ideal nesting sites for tuatara. It should be noted, however, that rat density in coastal scrub was particularly high, and that a young tuatara (< 1 year old) found dead behind Grave Bay, carried wounds consistent with attack by kiore (Newman 1988). Intensive monitoring of tuatara rookeries and surrounding forest edge on kiore-occupied islands should provide valuable insight as to how recruitment of tuatara may be affected by kiore. More important than obtaining evidence that kiore eat young tuatara and/or their eggs is the need to know if they eat enough of them to affect the population dynamics of the tuatara.

Wide variations in density occur among tuatara populations (e.g., Newman 1987), even amongst those on kiore-occupied islands (Crook 1973). On Red Mercury and Stanley Island of the Mercury group, and on Cuvier Island, all of which have kiore, just a few large tuatara (mostly males, possibly no longer sexually active) remain (Crook 1973; T. Lovegrove & I. McFadden pers. comm.). On the three main islands of the Chickens group tuatara are more abundant, with breeding still occurring on Lady Alice Island at least (Newman & Watson 1985). Comparison of the extent of habitat modification between Cuvier, Red Mercury, and Stanley Islands on the one hand, and the three main Chickens Islands on the other, suggests that the latter, which support fire-modified but diverse forest floras (see McCallum 1983), are less modified than the former. Feral cats and goats, as well as domestic sheep and cattle, were present on Cuvier Island up to the early 1960's (McCallum 1983), rabbits occur on Stanley Island (D.R. Towns pers. comm.), and Red

Mercury Island has been extensively burnt, most recently in 1934 (McCallum 1983). As suggested by Craig (1986), the influence of kiore on tuatara may be confounded by a number of variables, but particularly by the extent of habitat modification. The very high densities of kiore recorded in grassland on Tiritiri Island by Moller & Craig (1987) suggest that even a comparatively minor constituent in their diet could suffer severe depredation. All tuatara islands where kiore occur have been cleared to varying extent by both Maori and Europeans (McCallum 1983; Bell et al. 1985; Newman 1987). The status of tuatara populations existing with kiore may well reflect the extent of island clearance and subsequent, if any, reforestation (c.f. Craig 1986).

We suggest, therefore:

1 That in the absence of kiore, tuatara densities will be higher on islands that have been partly cleared of forest (provision of new nesting sites—Daugherty et al. in press).

2 That in the presence of kiore, tuatara are more likely to persist on islands where modification of the original forest has been kept to a minimum (forested islands support lower densities of kiore than those cleared for grazing—Atkinson & Moller in press).

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