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POPULATION DYNAMICS AND DIET OF RODENTS ON RANGITOTO ISLAND, NEW ZEALAND, INCLUDING THE EFFECT OF A 1080 POISON OPERATION

Summary: The objective of this study was to quantify the population dynamics, morphological characteristics, and diet of rodents on Rangitoto Island (Hauraki Gulf, New Zealand) to provide information for the future development of an eradication strategy. An aerial 1080 operation to eradicate possums and wallabies was carried out two months after the study began. The effects of this operation on rodent population dynamics are discussed.

Both ship rats (*Rattus rattus*) and mice (*Mus musculus*) were trapped on Rangitoto Island over a 15 month period. A two month decline in mouse abundance was noticed following poisoning; following this the population recovered rapidly, reaching a peak of 12 captures per hundred trap nights (12 $C100TN^{-1}$) in autumn and then declining over winter. A longer decline in ship rat abundance was observed, although this reached a pre-poisoning level of 1.6 $C100TN^{-1}$ in April. Thereafter the population did not reach pre-poisoning levels again.

Total body length and weight were significantly related to age, and were similar to those of mice and ship rats recorded in other New Zealand studies. The majority of breeding appeared to occur between September and May for both species. There was evidence of delayed reproductive maturity for female mice and rats born at the end of summer. A relatively large number of young mice were caught in autumn, with very few being caught in spring. Invertebrates were the major component of both species' diet, with weta (*Hemideina thoracica*) predominant, while plant matter was a minor constituent. The nematodes *Physoloptera getula* and *Mastophorus muris* were present in the stomachs of 22% of mice and 59% of ship rats.

Keywords: *Mus musculus*; house mouse; *Rattus rattus*; ship rat; population dynamics; diet; 1080 poison; Rangitoto Island.

Introduction

New Zealand has four rodent species, the ship rat (*Rattus rattus* L.), Norway rat (*R. norvegicus* Berkenhout), kiore (or Polynesian rat, *R. exulans* Peale) and the house mouse (*Mus musculus* L.[1]), all of which have been introduced. Their presence has implications for conservation management as they prey on native bird (Bell, 1978; King, 1984), reptile (Whitaker, 1978) and invertebrate (Ramsey, 1978; Bremner, Butcher and Patterson, 1984) species. They may also inhibit regeneration of native vegetation through eating seeds and seedlings and ringbarking saplings and mature trees (Campbell, 1978).

New Zealand's Department of Conservation (DOC) is using offshore islands as a strategy to conserve and protect endangered fauna and flora away from introduced mammals (e.g., Towns, Daugherty and Atkinson, 1990). This has been made possible by some successful eradications of introduced species, including rodents, from a number of these islands (Veitch and Bell, 1990). To ensure such eradications are both effective and efficient it is necessary to identify when the rodent population is most vulnerable. Past rodent eradication operations have been planned to occur during winter, at which time the population has ceased to breed and food is in low supply (e.g., McFadden and Towns, 1991; Taylor and Thomas, 1993).

Rangitoto Island is valued as a botanical reserve because of the unique vegetation colonising the lava flows, and it is also a popular tourist attraction. A management plan to restore a functioning native ecosystem on both Rangitoto and adjoining

[1] Two separate species of house mouse are now recognised: *Mus musculus* and *Mus domesticus*. Mice in New Zealand share morphometric characteristics of both species, but as yet there has been no genetic analysis of New Zealand populations (Murphy and Pickard, 1990).

Motutapu Island was developed (Miller, Craig and Mitchell, 1994) to capitalise on the current eradication campaign for brushtail possums (*Trichosurus vulpecula* Kerr) and brushtailed rock wallabies (*Petrogale penicillata* Griffith). The success of this restoration plan depends on the eradication of rodents and other mammalian predators.

The main objective of this study was to identify the rodent species present on Rangitoto Island and quantify their population dynamics, morphological characteristics, and diet, in anticipation of the development of an eradication strategy. The effects on rodent population dynamics of a 1080 (sodium monofluoroacetate) poisoning operation, to eradicate possums and wallabies, are discussed.

Methods

Study area

Rangitoto Island (174°52'E, 36°47'S) is an extinct volcano in the Hauraki Gulf, 8 km from Auckland, New Zealand's largest city. Four sites on the island were chosen for trapping. These were at the Rangitoto Wharf, an area of coastal vegetation dominated by pohutukawa (*Meterosideros excelsa*[2]) and *Astelia banksii*; a black-backed gull (*Larus dominicanus* Lichenstein) colony on the southern coast, characterised by a large area of broken scoria with occasional islands of pohutukawa dominated vegetation; an inland area on the north-western side of the island, with areas of broken scoria and a large mosaic of vegetation islands dominated by *Griselinia lucida*, Kirk's daisy (*Brachyglottis kirkii*) and *A. banksii*; and the southern side of the main ash cone, which is covered in kanuka (*Kunzea ericoides*) forest (Fig. 1). These were chosen to be broadly representative of habitats on the island; logistical constraints meant that it was not possible to have more study sites.

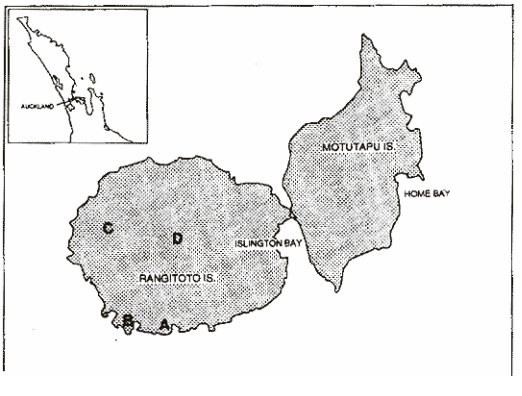

Figure 1: *Rangitoto Island, with trap sites. A=Rangitoto Wharf, B=Gull colony, C=Inland site, D=Ash cone.*

[2] Botanical nomenclature follows Allan (1961), Moore and Edgar (1970), and Connor and Edgar (1987).

Trapping

To provide an index of abundance and to assess population dynamics and diet, rats and mice were snap-trapped at the four sites (after Cunningham and Moors, 1993). Trapping was undertaken at six-weekly intervals between August 1990 and October 1991. From August 1990 to January 1991 15 paired rat and mouse traps (Woodstream Victor, USA, and Ezeset Supreme, Australia) were set at each site. This number was increased to 25 pairs in February 1991 when more traps became available. The traps were baited with cheese, covered with aluminium or wiremesh covers, and set at 15-25 m spacings under vegetation or between rocks. The variability in trap spacings was due to the uneven terrain and patchy vegetation. All traps were set, checked, and reset for three consecutive nights. Ten pairs of Fenn traps were also laid at these sites, and baited initially with fish based catfood and then chicken eggs, to attract stoats (*Mustela erminea* L.).

An index of rodent abundance was calculated and expressed as the number of captures per 100 trap-nights corrected for sprung traps ($C100TN^{-1}$) (Nelson and Clark, 1973). Parts of animals such as tails found in traps were not counted as being a trap success, although cannibalised animals were.

Necropsy

All rats and mice caught were subject to necropsy. Rats caught by possum hunters on the island were also included. Complete necropsies or measurements could not be made on all animals because of missing body parts (e.g., tails) or crushed gut regions.

Total length, head-body length (British Museum new method, Jewell and Fullagar, 1966) and weight were measured. Mean values are shown ± one standard error. Rats and mice were sexed and divided into age classes on the basis of tooth wear. The rate of toothwear was assumed to be similar to that used by Lidicker (1966) and Karnoukhova (1973).

Male rodents were considered fecund if macroscopic tubules were present in the cauda epididymis (Laurie, 1946; Jamieson, 1950). Females were classed as mature if the vagina was perforate, uterine scars were present, or if the animal was pregnant or lactating. Litter size was determined from the number of visible embryos (Pelikan, 1981).

The frequency of occurrence of major food items was visually estimated to the nearest 10% (Daniel, 1973) after washing stomach contents into a glass petri dish. The predominant food types were identified under a dissecting microscope and placed into five categories: invertebrate, seed, endosperm, fruit, and woody vegetation. Some items were able to be identified to species level; however identification was generally to an order or family level. Empty stomachs were included in analyses. Monthly data were pooled to provide a seasonal presentation. The number of nematodes present in the stomachs were counted, and these were identified to species level.

Analysis of data was by ANOVA (random effects model) and chi square (χ^2) test of independence.

Results

A total of 192 house mice and 45 ship rats were caught. The majority of mice were trapped at the Rangitoto Wharf and Gull Colony sites, and none were trapped at the summit. Ship rats were trapped at all sites, and were also caught by possum trappers in all areas of the island. Rats were usually trapped in or near vegetation patches, while mice were often caught out on the open scoria.

Population fluctuations

Following the 1080 poison drop in November 1990, a small decline in mouse abundance was observed. This decline was followed by a marked increase in abundance two months after the operation. The population reached a peak of 12 $C100TN^{-1}$ in April. Mouse abundance returned to pre-poisoning levels in October 1991 (Fig. 2). Rat abundance in October, prior to the poisoning, appeared lower than it had been the month previously. Abundance continued to decline until February. The population recovered to pre-poisoning levels with a peak of 1.6 $C100TN^{-1}$ in April, but then declined to very low numbers for the rest of the study (Fig. 2).

Sex ratio

There were no significant differences in the numbers of male and female mice (101:91, P=0.173), or male and female rats caught (32:13, P=0.137) when analysed by age class using χ^2 test of independence (see Table 1). These results should be interpreted with care due to sample sizes of less than five in some months.

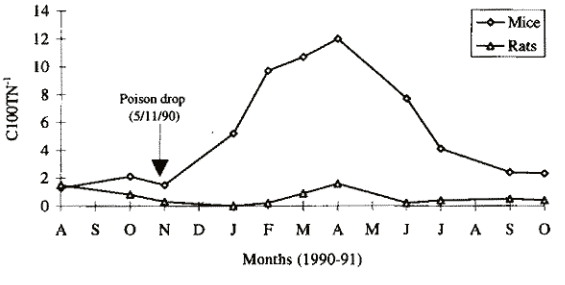

Figure 2: *Number of rats and mice caught per 100 trap nights, corrected for sprung traps, over a 15 month study period on Rangitoto Island.*

Table 1: *Body measurements (mean ± S.E.) from snap trapped mice and rats from Rangitoto Island (n=sample size).* *from Lidicker (1966) and Karnoukhova (1973).* **n=15. ***one rat was not able to be aged.*

Age Class* (n)	Age	Weight (g)	Head-body length (cm)	Total length (cm)
Mice				
1 (0)	0-1 month	-	-	-
2 (27)	1-2 month	10.2 ± 2.0	6.6 ± 0.6	13.9 ± 1.2
3 (97)	2-4 months	16.5 ± 2.6	7.8 ± 0.5	17.0 ± 0.8
4 (31)	4-6 months	18.4 ± 2.8	8.2 ± 0.4	16.5 ± 0.8
5 (21)	6-8 months	19.5 ± 2.5	8.3 ± 0.4	16.8 ± 0.8
6 (12)	8-10 months	21.2 ± 2.7	8.4 ± 0.6	16.9 ± 0.9
7 (4)	10-14 months	21.8 ± 2.1	8.7 ± 0.9	17.1 ± 0.8
Ship rats***				
1 (0)	0-1 month	-	-	-
2 (5)	1-4 months	41.2 ± 4.2	10.7 ± 0.4	22.1 ± 0.9
3 (18)	5-7 months	81.8 ± 7.2	14.0 ± 0.4	31.3 ± 1.0
4 (16)	6-12 months	129.6 ± 7.4	16.1 ± 0.4	37.9 ± 0.6**
5 (2)	1-2 years	161.7 ± 0.9	17.9 ± 0.5	39.9 ± 0.5
6 (3)	2-3.5 years	147.0 ± 17.2	16.9 ± 0.5	39.3 ± 0.4

Body size

There were no significant sex-related size differences in either mice or rats (P>0.05). The mean body weight, total length and head-body length were therefore pooled by age class for both sexes of mice and of rats. Body weight, head-body length and total length were significantly related to age for mice (weight, F=55.045, d.f.=5, P<0.01; head-body length, F=36.303, d.f.=5, P<0.01; total length, F=38.422, d.f.=5, P<0.01), and rats (weight, F=14.679, d.f.=4, P<0.01; head-body length, F=18.317, d.f.=4, P<0.01; total length, F=25.588, d.f.=4, P<0.01) (Table 1).

Fecundity and reproduction

Of the 91 female mice caught, 20 (22%) were pregnant, and a further 15 (17%) were lactating. Pregnant mice were caught between November 1990 and June 1991, and then again between September and October 1991 (Fig. 3). No trapping was carried out in August.

The mean number of mouse embryos per female was 6.7±0.4 (range 5-10, n=19). Several female mice showed signs of having bred more than once, having both embryos and fresh scars, or a large number of uterine scars per female (7.9±1.0, range 4-21, n=23) (Fig.4). The number of scars increased significantly with age (F=11.4, d.f.=5, P<0.01). Of females caught during the winter months, only two had uterine scars. Two pregnant rats (15%) were caught in March, and six lactating rats (46%) were caught, four in February and two in April. The mean number of rat embryos was seven, and the mean number of uterine scars was 7.4±1.2 (range 5-12, n=6) per female.

The youngest fecund female mice were in age class 2 and were caught between January and March 1991. The oldest non-fecund females were in age class 4. These were caught in March and October 1991. The youngest fecund male mouse was in age class 2 and was caught in January 1991. The youngest fecund female rats were in age class 3 and were caught between February and September 1991, while the oldest that was not fecund was in age class 4 and was caught in June. The youngest fecund male rat was age class 2 and was caught in November 1990, while the oldest that were not fecund were in age class 3 and were caught between February and April.

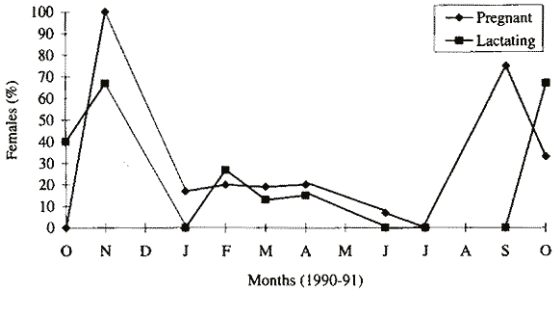

Figure 3: *Proportion of female mice that were pregnant or lactating.*

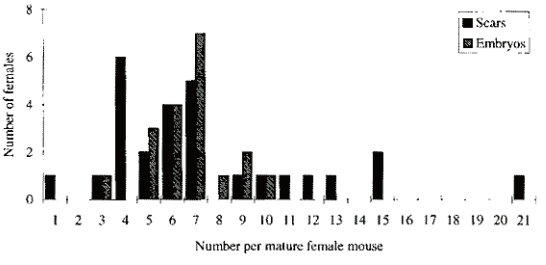

Figure 4: *Number of embryos and uterine scars per mature female mouse.*

Age distribution

Mice and rats from two different cohorts were caught. Most of the mice trapped were young - 81% were in age classes 2, 3 and 4 (i.e., 1-6 months old). 52% of rats caught were in age classes 2 and 3 (i.e., 1-7 months).

Seasonal differences in the age distribution of mice were observed (F=14.2, d.f.=4, P<0.01). The trend in mice was for few young to be present in spring, with the majority in age class 4. By autumn the majority of animals were in age classes 2 and 3. Some mice in age class 2 were caught in September, which suggests that there may be some winter breeding. A seasonal trend was also observed for rats, but this was not significant (P=0.23).

Analysis of stomach contents

Analysis of stomach contents of 179 house mice and 26 ship rats revealed invertebrates were the major component of both species' diets on Rangitoto Island (Figs. 5 and 6). For both species the most common invertebrate group overall was the tree weta (*Hemideina thoracica* White), although these were least frequent in autumn and winter. Spiders, cockroaches, centipedes, earwigs and amphipods were also found in the mouse stomachs, with slugs and cockroaches also found in rats.

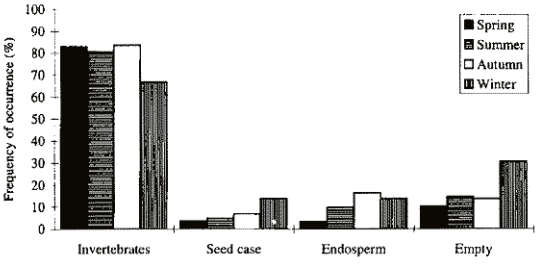

Figure 5: *Seasonal variations in the frequency of occurrence of food types in the diet of mice trapped on Rangitoto Island.*

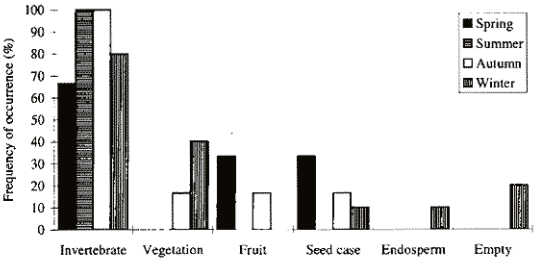

Figure 6: *Seasonal variations in the frequency of occurrence of food types in the diet of rats trapped on Rangitoto Island.*

Seeds found in mouse stomachs were *Collospermum hastatum*, and those in rats were karo (*Pittosporum crassifolium*). Endosperm was found at similar frequencies during summer, autumn and winter. The plant material found in rats was largely unidentifiable woody vegetation, with unidentified fruit in spring and autumn. The greatest number of empty stomachs were observed in winter.

Nematodes were found in the stomachs of 22% of mice, with an average of 0.7±0.1 nematodes per stomach, and in 59% of rat stomachs, with an average per stomach of 11.7±2.6. The number of nematodes present in mouse stomachs increased significantly with age ($F=6.49$, d.f.=5, $P<0.01$), with few being found in mice under age class 4. The age-nematode relationship was not significant in rats ($F=3.28$, d.f.=4, $P<0.1$). The helminth species found were *Mastophorus muris* and *Physoloptera getula.* In several cases these occupied the whole stomach.

Discussion

Ship rats and house mice appear to be the only rodent species present on Rangitoto Island, despite Norway rats being present on adjoining Motutapu Island (Atkinson, 1986; Taylor, 1989; *pers. obs.*). Although only four sites were trapped in this study; possum traps, from which rats were recovered, were laid all over the island, effectively giving a large number of trap nights with a variety of baits and lures. While Norway rats tend to be more difficult to trap than ship rats, this is unlikely to be the reason for their absence in this study. In New Zealand, Norway rats are mostly associated with wetland habitats (Moors, 1990), which are lacking on Rangitoto Island. Taylor (1984) also records that islands with ship rats and mice are less likely to have Norway rats on them.

The 1080 poisoning operation had an impact on both the mouse and rat populations, with the index of abundance declining following poisoning. Murphy and Bradfield (1992) report a dramatic decline in ship rat numbers following a 1080 poison drop; from 1.98 $C100TN^{-1}$ pre-poisoning to 0.09 $C100TN^{-1}$ after the poisoning. This decline was particularly obvious for at least 3-4 months following the poison operation. Innes *et al.* (1994) also record declines in mouse and ship rat numbers (over 90% ship rats killed) following four 1080 operations.

The mouse population recovered faster than the rats, markedly increasing two months after poisoning. Several studies (e.g., Innes *et al.*, 1994; M.N. Clout, Auckland University, Auckland, N.Z. *pers. comm.*) have indicated that in forests where ship rats and mice co-exist, mouse abundance is significantly lower than that of the rats; however following the poisoning of a significant number of ship rats, mouse abundance increases dramatically. Innes *et al.* (1994) suggested that this could be due to an improved food supply for mice, or a release from predation pressure.

While it is impossible to determine, we suspect that mouse abundance relative to ship rat abundance prior to poisoning may have been higher than that found in the studies mentioned above. Although the sites where mice and rats were caught tended to overlap, there was a trend for mice to be caught out on the broken lava, while ship rats were caught in the vegetation islands. No mice at all were caught in the kanuka forest on the ash cone where forest floor cover was minimal. We speculate that the lava may offer the mice a release from predation or competitive pressure of ship rats.

Dowding and Murphy (1994) found that of five ship rats tracked during a 1080 operation at Puketi forest, the three males died through being poisoned. The two females survived at least until the third night after poisoning. After this time the baits had been rained upon and had begun to disintegrate. Dowding and Murphy suggested that ship rats may exhibit a sex-related difference in relation to

accepting green-dyed, cinnamon lured, 1080 baits, although cautioned that their sample size was to small to determine this. We did not find any evidence to suggest that more males than females had been killed on Rangitoto, with the sex ratio of trapped animals remaining relatively constant throughout. Like Dowding and Murphy (1994) though, our sample size was too small in some months to allow definite conclusions. We concur with Dowding and Murphy (1994) that more experimentation on potential sex-related differences in bait take is needed, especially if 1080 baits are to be used in multi-species targetting (Morgan, 1993).

Despite the dynamics induced by the poisoning, the population fluctuations shown by both species on Rangitoto Island are largely typical of feral rodent populations in New Zealand, with a peak in abundance (especially of young animals) in autumn and increased mortality through winter (Bronson, 1979; Innes, 1990; Murphy and Pickard, 1990).

The range and mean litter size of mice on Rangitoto Island was similar to that found by Pickard (1984; 5-9, 6.4±1.2) and Efford, Karl and Moller (1988, reported in Murphy and Pickard, 1990; 2-12, 6.9±2.1) on Mana Island, and on Allports Island (Murphy, 1989; 4-8, 5.9±1.1). The range and mean number of scars, and the fact that only two mice caught outside the breeding season had scars, indicates that the mice may be breeding more than once in a breeding season. Whether this is a consequence of the reduction in rat numbers (see above) could not be determined in this study. Mice can produce a litter every 20-30 days if conditions are suitable (Murphy and Pickard, 1990) which can account for a rapid increase in numbers.

It would appear that the majority of mice on Rangitoto Island cease breeding in autumn. This is supported by the delayed reproductive maturity observed in several female mice. Studies at Woodhill and Hunua forests, and on Mana Island, also found that mice born during spring or summer matured at about 8 weeks old, while those born at the end of summer did not mature until the next spring (Badan, 1979; Pickard, 1984). Mice have been known to breed all year round in New Zealand (e.g., Fitzgerald, 1978; King, 1982; Efford, Karl and Moller, 1988; Murphy, 1992) and this is thought to be related to the quality of available food (Bomford and Redhead, 1987; Murphy, 1992).

The litter size of the two pregnant ship rats caught was higher than that recorded by Innes (1979) in the Tararua Ranges (4.95±1.3), although it was similar to those recorded in the Orongorongo Valley (6.1±1.8) by Daniel (1972). However the low sample size does not allow meaningful comparisons. Very few pregnant ship rats have been caught in other studies (e.g., Daniel, 1972; Best, 1973; Innes, 1979; Sturmer, 1988). Given the limited number of rats trapped in this study, it is difficult to determine their breeding season with any certainty. However, it is unlikely to be different from other studies, where the majority of pregnant or lactating females that have been trapped, were caught between mid September and mid April (Innes, 1990).

Invertebrates were by far the greatest component of the mouse and rat diet on Rangitoto Island, with tree weta being the most common invertebrate. Plant matter, including endosperm, appears to play a less significant part in the diet of rats on Rangitoto Island when compared with several other studies (e.g., Best, 1969; Daniel, 1973; Sturmer, 1988), but similar results have been reported by Innes (1977, 1979), Clout (1980) and Gales (1982). New Zealand studies of wild mice have reported them eating both invertebrate and plant material (Murphy and Pickard, 1990), with seasonal differences being apparent in some (Badan, 1979, 1986; Pickard, 1984). The higher numbers of rats and mice with empty stomachs over winter suggests that food may be limited at this time. During winter there was also a reduction in the frequency of invertebrates in both rat and mouse diet, but they remained the dominant component.

The gut nematodes *Physoloptera getula* and *Mastophorus muris* are frequently found in ship rats (Daniel, 1973; Charleston and Innes, 1980) and mice (Badan, 1979; Pickard, 1984); both of these nematodes have obligatory indirect life cycles with arthropods as intermediate hosts (Charleston and Innes, 1980). Therefore it is likely that mice and ship rats are infected directly from their invertebrate food. While the sheer volume of nematodes inside the stomach may physically hinder the intake of food (Crompton, 1984; Munger and Karasov, 1989), there does not appear to be any evidence to date to suggest that stomach nematodes affect host survival or reproduction (Spratt, 1990).

Mice had similar body lengths and weights to those on Mana and Allports Islands (Pickard, 1984; Murphy, 1989; Murphy and Pickard, 1990). The rats were of similar body size to those caught in North Island forests, and slightly larger than those from the South Island or Stewart Island (Sturmer, 1988; Innes, 1990). We suggest that the rats and mice are obtaining sufficient protein from their diet on Rangitoto for growth and reproduction (Lloyd, McDonald and Crampton, 1978).

Implications for an eradication strategy

Successful island rodent eradications (e.g., McFadden and Towns, 1991; Taylor and Thomas,

1993) have been timed to coincide with low population numbers and the cessation of breeding, and a limited food supply. All indications from this study are that the rodents on Rangitoto Island are very similar in terms of their population dynamics and diet to other New Zealand island and mainland rodent populations. Any rodent eradication operation on Rangitoto Island should therefore be timed to occur during the winter months. Eradication of rodents has not yet been attempted on the scale required for Rangitoto Island (and adjoining Motutapu Island) (Miller, Craig and Mitchell, 1994); however the successful eradications that have been achieved in New Zealand (e.g., McFadden and Towns, 1991; Taylor and Thomas, 1993; Veitch and Bell, 1990) suggest that this can be done.

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