

Diet, population structure and breeding of *Rattus rattus* L. in South Island beech forest

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Abstract: The diet, population structure and breeding of ship rats (*Rattus rattus* L.) from Fiordland National Park were assessed from measurements and gut sample analysis of 248 rats trapped between March 2009 and March 2010, following a mast beech seedfall. They consumed many lepidopteran larvae but fewer weta and more vegetative plant matter than in other habitats, as well as beech seed. Birds and mice made up only a relatively small proportion of the diet. A lizard was also confirmed as a prey item of *R. rattus*, for the first time in New Zealand. The population included a high proportion of young rats and females that were breeding at an early age. A high percentage of females in breeding condition in each season, high uterine scar counts and consistent litter sizes throughout the year indicate high fecundity and year-round breeding. This breeding cycle is consistent with an ample food supply being available for rodents promoting a rat population irruption, which in turn may increase the predation pressure on native biodiversity.

Keywords: age structure, black rat, mammalian pest, mast year, New Zealand, productivity, ship rat, stomach content analysis

Introduction

The ubiquitous rodent pest *Rattus rattus* L. (known variously as black rat, ship rat, house rat, or roof rat) is a predator of native biota in New Zealand and elsewhere (Innes 2005; Pender et al. 2013; Shiels et al. 2014). It can also have indirect effects on this biota through competition, spread of disease and other ecosystem disturbances (Shapiro 2005; Jones et al. 2008; Harris 2009; Banks & Hughes 2012; Shiels & Pitt 2014; Harper & Bunbury 2015). A better understanding of its diet and population dynamics in different habitats can inform management strategies.

Rattus rattus eats a wide range of plant and animal foods (Shiels et al. 2013) but it is also described as a selective feeder (Clark 1981, 1982), with distinct individual diet preferences (Ruffino et al. 2011). It is considered more herbivorous than *R. norvegicus*, *R. exulans* or *Mus musculus* (Grant-Hoffman & Barboza 2010; Bridgman 2012; Shiels et al. 2013). As well as consuming vegetative parts of mature plants, its consumption of fruits, seeds and seedlings can reduce seedling establishment (Wilson et al. 2003; Grant-Hoffman & Barboza 2010). Predation by *R. rattus* also has the potential to reduce populations of large invertebrate species, reptiles, amphibians, forest birds and seabirds (Townes & Daugherty 1994; Innes et al. 1999, 2010; St Clair 2010; Ruscoe et al. 2013; Shiels et al. 2014). While lizards have been confirmed as prey items of *R. rattus* elsewhere (Clark 1981; Caut et al. 2008), they have not been reported in the stomach contents of this species in New Zealand.

Although its diet has been described in various habitats and climatic regions of the world (Copson 1986; Tobin et al. 1994; Cole et al. 2000; Pisanu et al. 2011; Shiels & Pitt 2014; Shiels et al. 2014; Riofrío-Lazo & Páez-Rosas 2015) including New Zealand (studies summarised by Innes 2005 and Bridgman 2012), there have been few studies in *Nothofagus* beech forest. Massive seedfalls in some years (mast years) provide ample plant, invertebrate and vertebrate food sources for rats but there is little information on the dietary responses of rats to beech mast seeding. While *R. rattus* does not normally consume mammalian prey in New Zealand, McQueen and Lawrence (2008) found that mice (*Mus musculus*) contributed a large proportion of the diet of *R. rattus* in beech forest after a mast seeding.

Rattus rattus usually breed in spring/summer in temperate forest habitats, producing on average 5 or 6 pups per litter (Innes 2005), and are able to produce four litters per breeding season (Best 1973). But with adequate food resources, they can breed year-round, leading to higher productivity (Daniel 1972; King & Moller 1997; Harper 2005). Thus they show a numerical response to a beech forest mast seeding (King & Moller 1997; Studholm 2000). These population irruptions are combined with changes in population structure, with an initial influx of young rats (King & Moller 1997). If these young rats eat more invertebrates relative to older rats, as shown for *R. rattus* in podocarp forests (Gales 1982; Sweetapple & Nugent 2007), they could further increase the threat to native fauna of the numerical response. The aim of this study was

to describe the diet, population structure and breeding of *R. rattus* in Fiordland beech forest over a year following mast production of beech seed, to better inform wildlife managers of the potential timing and severity of the impact of this pest species.

Materials and methods

The study area was in Fiordland National Park, southwest South Island, New Zealand. It was part of ongoing stoat (*Mustela erminea*) and rodent control programmes carried out by the Department of Conservation and the Kepler Challenge Organising Committee. Rat captures were high from July 2009 to June 2010 (655 captures) compared with July 2008–June 2009 (79) and 2010–2011 (134) (DOC unpubl. data). Captures started to rise sharply from May 2009, peaking in November and December 2009, then declined.

Only a small proportion of the rats caught in Fiordland in 2009–2010 were available for the current study. Most were caught in winter and spring, when rat carcasses stayed fresh enough for autopsy. The majority of the 248 rats used came from trap lines along the Kepler Track, skirting the shorelines of Lake Te Anau, Waiiau River and Lake Manapouri at approximately 200 m a.s.l. ($n = 209$). There were additional samples from the Eglinton Valley ($n = 28$; 300–500 m a.s.l.), Clinton Canyon ($n = 4$; 400–600 m a.s.l.), the mainland north of Pomona Island ($n = 6$; 200 m a.s.l.), and one at sea level just outside Milford township. All the areas were in beech forest habitat (dominant species *Fuscospora fusca*, *Lophozonia menziesii* and *Fuscospora cliffortiodes*), with varying understories both between and within sites. Paired Mk 4 Fenn, DOC 150 or DOC 200 traps were set in wooden boxes and baited with hen eggs and meat. They were checked and rebaited monthly. Rats necropsied in this study were collected from 31 March 2009 to 17 March 2010 and stored in the freezer for later examination.

The rat carcasses were externally sexed, weighed and measured (head + body). Age classes were categorised by tooth wear ratings following Karnoukhova (1971) and Innes (2005). Stomach contents were washed in a 0.5 mm sieve and examined microscopically. Food items were sorted and classified under a stereo microscope by plant type or part. However, the finely chewed plant remains were not identified. Invertebrates were sorted into recognisable taxonomic units using body parts, examined under a dissecting microscope. For hard bodied invertebrates like spiders and beetles, many useful identification features survived mastication by the rats, so in some cases arthropods were able to be keyed out to family, genus or even species. Some bird remains were identified to Order by examination of feathers. Where egg shell remains were clearly not hen egg bait material, they were included in the bird food category for analysis. Results of the diet analysis are presented as a frequency of occurrence: i.e. the percentage of guts with food for each prey category (excluding the guts that were empty or contained only trap bait material).

The breeding condition of the female rats was determined by counting embryos and uterine scars, and examining the nipples for signs of lactation. A female was deemed to be breeding if pregnant or lactating. She was sexually mature if she was either breeding or had previously bred. There was no measure of resorption of embryos so litter sizes may be an overestimation but are comparable with other studies (Daniel 1972; Best 1973; Innes 1979; Sturmer 1988). Ovarian activity was assessed by uterine condition following Innes

et al. (2001). Male breeding status was assessed only by the size and scrotal position of the testes. For statistical analysis, log-likelihood G tests were used to determine significance in differences of categorical data. Separate analyses were run for sex, season and age categories, with all vegetative material classed together and all invertebrate remains classed together. Bird and mammal were the other two food categories used in these analyses. Separate analyses were undertaken to determine significant difference in types of invertebrates eaten by sex, season and age.

Results

Diet

Out of the 248 rats, 227 had vegetative or animal gut contents (summarised in Table 1). The remaining 21 stomachs (8.5%) were empty apart from trap bait remains. These empty gut samples were from rats caught in all seasons, both sexes and both young and older rats; and are not included in the diet analyses.

Plant material was present in over 84% of gut samples and was the most common food item, followed by invertebrates (81%). Mice or unidentified rodents had been consumed by 7% of the rats, and birds or bird egg by 4% (5 identified as probably passerines). Lizard remains were found in only one (female) gut sample. It was flesh of a skink species. Consumption patterns did not vary significantly between males and females ($G = 2.361$, $\nu = 3$, $P > 0.5$) nor amongst the seasons ($G = 1.76$, $\nu = 9$, $P > 0.99$). Both males and females consumed mice and birds. Although mammals and birds appeared more often in the diet of old rather than young rats, the proportions of the diet consisting of plant material, invertebrates, mice and birds did not vary significantly with age ($G = 5.702$, $\nu = 3$, $P > 0.1$). The plant material was mostly leaves/grass and finely ground, brown, starchy material. The latter was likely (but not confirmed) to be mostly beech seed, which is finely masticated and hard to definitely identify (McQueen & Lawrence 2008; Shiels 2011; FM pers. obs.). The materials included in the plant category were bark, root, fleshy fruit, moss, fungus and lichen (Table 1). It was not possible to determine how much of this vegetation came from the guts of the invertebrates consumed. However, 10% of the samples contained leaves when no invertebrates had been eaten, suggesting that leaves were a dietary component not just an incidental item.

The most frequently consumed identified invertebrates were lepidopteran caterpillars (27%; at least six Geometridae), then spiders (19%; some sheetweb and prowling species) and orthopterans (18%; including ground wētā *Hemiandrus* spp. and cave wētā Rhabdophoridae). Coleopterans (7%) were mainly ground beetles, including two carabids and one Leiodidae. There were 10 harvestmen (including one Palpatores), two flies (Diptera) and one springtail (Collembola).

More wētā and beetles were found in male than female guts but the differences between males and females in types of invertebrates eaten were marginally non-significant ($G = 8.011$, $\nu = 4$, $0.1 > P > 0.05$). Nor were there any seasonal patterns in invertebrate consumption. The young and old rats ate similar proportions of the various invertebrate categories.

Body size and age

The percentage of males in the samples varied by season between 47% in winter and 65% in autumn but there were no

Table 1. Frequency of occurrence (%) of dietary items for *Rattus rattus* caught in Fiordland beech forest, 2009–2010, by sex, age class and season.

Food type	Sex		Age class		Season			
	Male n	Female	1–2	3–6	Autumn	Winter	Spring	Summer
	22	105	62	165	18	83	92	34
Plant material	86.9	80.9	83.9	84.2	94.4	89.9	78.3	79.4
Leaves/grass	45.9	41.9	38.7	46.1	44.4	55.4	35.9	38.2
Moss, lichen, fungus	3.3	8.6	4.8	6.1	5.5	7.2	5.4	2.9
Other ¹	51.6	43.8	48.4	47.9	55.5	49.4	46.7	44.1
Invertebrate	80.3	82.7	85.5	80.0	83.3	81.9	80.4	82.3
Wētā	22.9	11.4	19.3	17.0	11.1	15.7	18.5	23.5
Caterpillar	23.8	30.5	29.0	26.1	33.3	25.3	29.3	20.6
Spider	17.2	20.9	9.7	22.4	22.2	16.9	21.7	14.7
Beetle	9.8	4.8	9.7	6.7	11.1	4.8	9.8	5.9
Other	61.5	66.7	66.1	63.0	55.6	67.5	64.1	58.8
Mammal	6.6	6.7	1.6	8.5	5.6	4.8	7.6	8.8
Bird	5.7	1.9	1.6	4.8	5.6	3.6	4.3	2.9
Lizard	0	0.95	0	0.6	0	1.2	0	0

¹ This category includes the finely chewed plant material likely to be beech seed (based on McQueen & Lawrence 2008), and tentatively identified roots, bark, fruits and buds.

significant differences in the proportions of males and females caught in every season ($G = 4.286$, $\nu = 3$, $P > 0.1$). Males in age classes 3–6 weighed on average 161.4 g and their mean head-body length was 182.9 mm. Females averaged 139.9 g in weight and 170.9 mm in length. Younger rats (age classes 1 & 2, males and females combined) weighed on average 100.3 g and had a mean head-body length of 157.84 mm. The range of body weights and head-body lengths of the captured rats are given in Table 2, subdivided by sex, age and season. Only two male rats and no females of tooth wear class 1 were caught. There were similar numbers of males and females in classes 2–4, but relatively more males in the older age classes ($G = 8.641$, $\nu = 2$, $P < 0.025$). Male rats were heavier and longer than their female counterparts in every tooth wear class. The heaviest and longest rats were caught in spring and summer. The age distribution of rats by season is plotted in Figure 1. Old individuals (age classes 5 & 6) appeared in the population mostly in winter and spring. Although the proportion of young rats in the population varied from 45% in autumn and 32% in winter down to 25% in spring and 16% in summer, the seasonal effect was marginally non-significant ($G = 6.356$, $\nu = 3$, $0.1 > P > 0.05$).

Breeding

The breeding parameters for females and males are presented in Table 3. While pregnant females were caught year-round, lactation was observed only in spring and summer (Fig. 2). The percentage of the population breeding exceeded 40% in every season except winter and there was no significant difference amongst the seasons in the percentage of breeders. The majority of the females were sexually mature, even in autumn. The three individuals that were pregnant in autumn were in age classes 2 or 3, and the other four autumn-caught females all had previously bred and were in age classes 2–4. Breeding percentage was 20% in the females in tooth wear class 2 and increased with age, as did the percentage sexually mature. Non-breeders that showed signs of ovarian activity (uterine classes ‘cord’ or ‘string’) approached 50% in summer.

Table 2. Morphometrics for *Rattus rattus* caught in Fiordland beech forest, 2009–2010, by sex, age class and season.

		n	Body weight (g)		Head & body length (mm)	
Season	% Male					
Autumn	65.0	20	109.7	55–185	160.5	138–173
Winter	47.2	91	127.6	45–195	169.9	124–202
Spring	60.4	101	150.8	80–240	175.5	148–205
Summer	52.8	36	139.2	60–210	173.5	144–205
Age class	Sex					
1	M	2	50.0	45–55	131.0	124–138
	F	—	—	—	—	—
2	M	37	107.2	60–145	163.0	144–184
	F	30	95.0	60–150	153.3	142–174
3	M	58	145.9	105–205	177.9	165–192
	F	51	131.0	85–175	167.0	149–185
4	M	23	175.7	155–205	186.4	170–196
	F	28	153.7	120–215	176.9	160–190
5	M	13	195.9	170–240	195.8	186–205
	F	3	163.3	155–175	181.7	178–185
6	M	3	201.7	195–205	195.7	192–198
	F	—	—	—	—	—

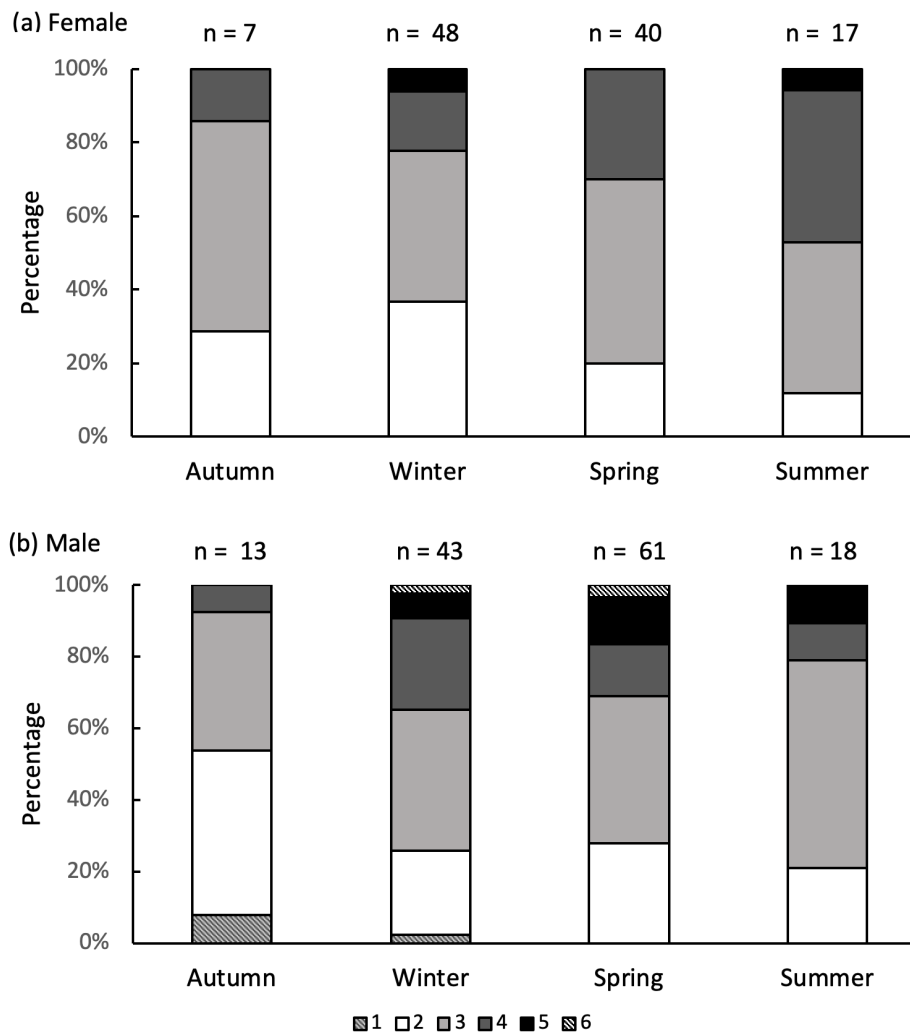


Figure 1. The percentage of (a) female and (b) male *Rattus rattus* captured in each season plotted by age class (defined by tooth wear).

The litter size averaged 5.5 embryos (Table 3). Numbers of uterine scars averaged over 11 in each season, and increased with age class.

Neither testis size nor position varied significantly through the year (Table 3) but sample sizes were small in autumn. There was a clear increase in breeding status of the male rats with teeth wear category, with the oldest rats having the largest testes that were most often descended.

Discussion

Diet

The foods consumed by *Rattus rattus* in this study include the range of plant types, invertebrate and vertebrate prey described in other studies of this species in New Zealand using similar techniques (early studies summarised by Innes 2005; McQueen & Lawrence 2008; Russell et al. 2009). We did not find any age- or sex-related dietary differences as described by Gales (1982) and Sweetapple and Nugent (2007), but this may have been because of differences in methodology.

The high frequency of occurrence of plant material described here is similar to the findings of Best (1969) for

South Island podocarp forests. It is greater than in some other New Zealand studies that have shown greater reliance on invertebrate food sources (Daniel 1973; Innes 1979; Gales 1982; Miller & Miller 1995; Rickard 1996).

There were high consumption rates of leaves. Some other studies have assumed green vegetation has been from the gut of wētā (Daniel 1973; Rickard 1996) but our records indicate that leaves are eaten directly. Sturmer (1988) also found that leaf material was not just a by-product of invertebrate consumption and made up a high proportion of *R. rattus* diet on Stewart Island. Sweetapple and Nugent (2007) reported that some of the herbaceous foliage consumed by ship rats in podocarp-hardwood forest must have been eaten directly.

We did not find any marked seasonal change from plant to animal food as reported for podocarp/hardwood forests (Best 1969; Daniel 1973; Innes 1979; Sweetapple & Nugent 2007). This finding is in line with the year-round availability of invertebrates in beech forest (Clout & Gaze 1984; Murphy & Kelly 2003) and the reliance on herbaceous plant material.

Unlike in some other studies (Daniel 1973; Innes 1979; Smith 1986; Sturmer 1988; Miller & Miller 1995), wētā were not the most common invertebrate prey item. Species of ground and cave wētā were more abundant than tree wētā in the rat

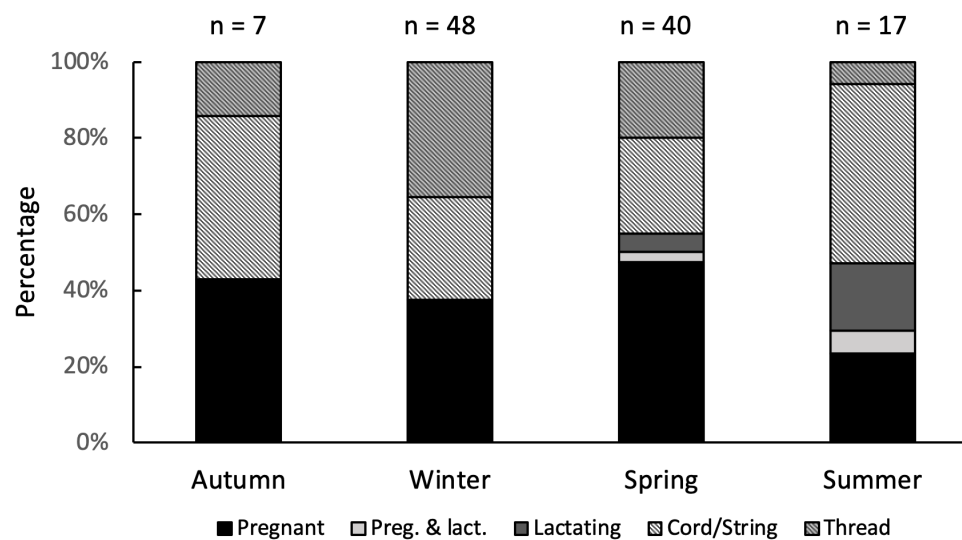


Figure 2. The percentage of female *Rattus rattus* (age classes 2–5) captured in Fiordland National Park in 2009–2010 that were breeding (pregnant and/or lactating), non-breeding but showing ovarian activity (cord/string) or sexually inactive (thread) in each season.

Table 3. Breeding statistics for (a) female and (b) male ship rats in Fiordland beech forest, 2009–2010, by season and age class.

(a) Females		Breeding	Sexually mature	Uterus classes 'cord'/'string' not pregnant	No. embryos where present		No. uterine scars where present	
Season	n	%	%	%	n	Mean (\pm SE)	n	Mean (\pm SE)
Autumn	7	42.9	100.0	42.9	3	5.00 (1.00)	4	11.25 (2.75)
Winter	48	37.5	62.5	27.1	19	5.58 (0.25)	14	12.36 (2.67)
Spring	40	55.0	82.5	25.0	20	5.65 (0.22)	15	11.20 (1.64)
Summer	17	47.1	94.1	47.1	4	4.75 (0.75)	14	11.07 (1.90)
Age class								
2	30	20.0	26.7	10.0	5	5.20 (0.66)	3	4.00 (1.53)
3	51	52.9	92.2	39.2	26	5.35 (0.23)	24	8.67 (1.02)
4	28	57.1	100.0	42.6	14	5.93 (0.22)	18	15.11 (1.22)
5	3	66.7	100.0	33.3	1	5.00 (–)	2	24.50 (1.50)
Total	12	47.32	76.8		46	5.50 (0.16)	47	11.51 (0.96)

(b) Males		Testis size (%)			Testis scrotal position (%)		
Season	n	Small	Med	Large	High	Med	Low
Autumn	13	7.7	84.6	7.7	38.5	53.8	7.7
Winter	43	11.6	51.2	37.2	32.6	46.5	20.9
Spring	61	16.4	45.9	37.7	23.0	49.2	27.9
Summer	19	15.8	63.2	21.1	26.3	57.9	15.8
Age class							
1	2	100.0	0.0	0.0	100.0	0.0	0.0
2	37	45.9	54.1	0.0	83.8	16.2	0.0
3	58	0.0	84.5	15.5	8.6	87.9	3.4
4	23	0.0	17.4	82.6	0.0	47.8	52.2
5	13	0.0	0.0	100.0	0.0	0.0	100.0
6	3	0.0	0.0	100.0	0.0	0.0	100.0
Total	136	14.0	53.7	32.4	27.9	50.0	22.1

stomachs in the current study. This diet is consistent with few tree wētā occurring at low altitude in southern South Island (Gibbs 2001; Morgan-Richards et al. 2001). A preference for Lepidoptera was suggested by Sturmer (1988) and this theory is supported by the high occurrence rates of caterpillars in the diet of rats in this study, as well as those of Best (1969), Clout (1980) and Craddock (1997). There was likely a wealth of lepidopteran larvae living in the forest litter, especially as it was a beech mast year (Dugdale 1996; Fitzgerald et al. 1996). We did not record any cockroaches, cicadas, stick insects or snails, which have been recorded as common prey items in other studies (Daniel 1973; Meads et al. 1984; Smith 1986; Sturmer 1988; Rickard 1996; Blackwell 2000).

We have confirmed the consumption of mice following beech mast seedfall described by McQueen and Lawrence (2008). However, the rats in our study consumed mice less frequently than those in the Dart Valley, which does not appear to be the result of differences in sampling periods but may be because mouse abundance was exceptionally high in the Dart Valley in the 2006–07 season (McQueen & Lawrence 2008). Mice are seldom caught in DOC150/200 or Fenn traps (DOC unpubl. data), so the rats are more likely to have preyed upon rather than scavenged the mice.

Bird (and bird egg) remains made up only a low proportion of the rat diet and the only identified order was Passeriformes as in other studies (Rickard 1996; Harper 2007). However, this finding may underestimate the impact of rats on bird populations. Rats are known to be egg and chick predators (Norman 1975; Clout et al. 1995; Brown 1997; Brown et al. 1998; Caut et al. 2008; Jones et al. 2008; Banks & Hughes 2012) and Sugihara (1997) suggested that rats are ‘fastidious feeders that may consume egg contents without actually ingesting eggshells’.

The single skink identified in the gut samples in this study is significant as lizard consumption by *R. rattus* in New Zealand has not been reported before even though lizard skin is tough and elastic and likely to remain in large fragments. *Rattus rattus* has been implicated in lizard population declines both in New Zealand and elsewhere (Townsend et al. 2006; Banks & Hughes 2012; Smith et al. 2012; Harper & Bunbury 2015) so lizards are likely to be common components of rat diet. Stable isotope analysis might provide a better insight into some of the food types eaten by rats (Major et al. 2007; Meckstrooth et al. 2007).

Size and age structure

Rat weights and lengths recorded in this study fall within the range of those published for *R. rattus* in New Zealand, with females typically smaller than males (Innes 2005).

There were higher proportions of young rats in our samples than those reported by Efford et al. (2006). Innes et al. (2001) included age class 3 as young rats but we have similar proportions of young rats per season using just classes 1 & 2. The presence of high numbers of young rats year-round suggests that there was winter breeding. The lack of rats in age class 1 in spring and summer might indicate more recruitment from summer and autumn, as found by Innes et al. (2001), but very young rats are seldom trapped unless the trap is near a rat den.

Breeding

The high percentage of female rats in breeding condition at age classes 2 & 3 were not reported by Innes et al. (2001) or

Efford et al. (2006) for *R. rattus* in North Island forests. These early breeders combined with high uterine scar counts and consistent litter sizes through the year indicate high fecundity in this population.

There was a high percentage of females in breeding condition in each season, indicating year-round breeding. This finding is confirmed by the presence of young rats in the population year round. The lack of lactating females in autumn and winter is probably an artefact of small sample sizes and assessment technique – in total only seven females were confirmed as lactating. The percentage pregnant in summer was low compared with other New Zealand studies (summarised by Efford et al. 2006) but higher for autumn and winter. This pattern may have been because of the availability of highly nutritious beech seed (Murphy 1992; Beggs 1999) and/or invertebrates (Fitzgerald et al. 1996) following the mast seeding. The high number of females with uterine scars in summer is another indication of winter breeding (King & Moller 1997). Mature males were present in autumn and winter, but this is not necessarily an indication of winter breeding (Daniel 1972; Sturmer 1988).

Conclusions

The combined findings of high numbers of young rats and indicators of year-round breeding tallies with the rat population irruptions seen after seedfall in New Zealand beech forests. Our findings suggest that any increased predation pressure on the native biota comes directly from this numerical response, not from any changes in diet. However, the increased numerical response of rats is enough on its own to lead to significant declines in threatened bird species and rat control is necessary to protect some populations (Innes 2005; Elliott & Kemp 2016).

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