SHORT COMMUNICATION

# Diet of ship rats following a mast event in beech (*Nothofagus* spp.) forest

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**Abstract:** Diet of 98 ship rats (*Rattus rattus*) was investigated by examination of stomach contents. Rats were trapped (as bycatch in stoat traps) from June to December 2006, in the Dart Valley near Lake Wakatipu, New Zealand, after a *Nothofagus* beech mast. Plant material was found in 43% of all stomachs, invertebrate fragments in 67%, feathers in 8%, hairs in 46% and skin with hairs attached in 12%, and animal (vertebrate and invertebrate) tissue in 76%. Hair samples examined by scanning electron microscopy were from mice, and rat and/or mouse DNA was found in all (10) samples subjected to DNA extraction. Mice may be an important food resource for rats following beech masts, when mouse population densities are high. Presence of feathers indicates predation of roosting or nesting birds, or scavenging. Consumption of beech seed beyond the time of germination may be due to caching of seed.

**Keywords:** Dart Valley, Fenn trapping, mouse, predation

## Introduction

The ship rat, black rat or roof rat (*Rattus rattus* L.) is a widespread pest in New Zealand and can be a serious threat to wildlife. Ship rats are omnivorous (Innes 2005) and in New Zealand have been reported to eat seeds, fruit and other plant parts (Sweetapple & Nugent 2007), invertebrates (Miller & Miller 1995; Rickard 1996; Sweetapple & Nugent 2007), eggs, chicks and incubating adults of forest birds on nests (Clout et al. 1995; Brown 1997; Brown et al. 1998; Innes et al. 1999; Studholme 2000; Dilks et al. 2003), and to scavenge at bird nests that have been preyed on by other predators (Brown 1997; Brown et al. 1998). Ship rats have had severe impacts on seabird and other animal populations on islands following accidental introductions (Towns & Broome 2003).

Ship rat population density typically has an irregular seasonal cycle because of seasonal breeding and recruitment, followed by population decline until the next breeding season, although ship rats can breed in winter if food resources are available (Innes et al. 2001; Sweetapple & Nugent 2007). Ship rat and mouse (*Mus musculus*) populations can dramatically increase in response to favourable environmental conditions (King & Moller 1997; Blackwell et al. 2001, 2003; Dilks et al. 2003; Ruscoe et al. 2004; Harper 2005). Beech (*Nothofagus*) forests in New Zealand have 'mast' years of high seed production (Wardle 1984; Monks 2007) that can provide a massive input of nutrients, allowing rodent populations to increase dramatically (King 1983; Choquenot & Ruscoe 2000; Fitzgerald et al. 2004). Consequent increases in predator populations including stoats can threaten indigenous fauna (King 1983; Murphy & Dowding 1995).

The aim of this study was to determine which food resources were being used by ship rats before and during nesting of birds that are vulnerable to predation by ship rats. Assessment of ship rat diet (by examination of stomach contents) is reported here, using data from rats trapped in the lower Dart Valley at a time when rodent population densities were high following a beech mast.

## Methods and materials

### Beech mast, rodent population response and control

The Dart Valley (at the head of Lake Wakatipu, South Island, New Zealand; 44º39' S 168°30' E; 400 m elevation) has a long narrow catchment area in mountainous country. The valley floor and lower slopes are covered with forest comprised mainly of New Zealand beech (mostly *Nothofagus fusca* and *N. menziesii*). This valley is part of a wider area where long-term monitoring and pest control are carried out by the Department of Conservation to protect threatened indigenous species that are vulnerable to predation by rats and stoats. Monitoring includes indexing rodent populations based on footprint tracks in tunnels. Fenn traps are used to control stoats (*Mustela erminea*) according to the method of Dilks et al. (2003), with hen eggs as bait. Fenn traps also catch ship rats (Innes et al. 2001).

Beech forest in the Dart Valley flowered prolifically (mainly *N. fusca*) in November 2005, followed by a heavy seed crop during autumn and winter 2006. In contrast, seedfall was negligible in autumn of 2007. Beech seed was widely available as a food resource from approximately March until October 2006. While germinating beech seed was available after this, it is not known if this is consumed by ship rats. Rat population density indices reached levels in June 2006 such that control of rats by poisoning was implemented to protect indigenous wildlife. Control was initiated using bait stations, over an area of 27 $km^2$ of mohua (*Mohoua ochrocephala*) breeding territory and increased to 56 $km^2$ in November, when aerial bait distribution was carried out. Rat control was not effective until November (late spring), when density indices within the area of the aerial bait distribution decreased.

Dart Valley mouse density indices from 1999 to 2007 (from footprint tracking tunnels) fluctuate from zero to near 100%. During the 2006–07 beech mast, the mouse tracking rate increased from less than 10% to over 90%. A rapid decline in mouse density indices followed the successful November rat control, perhaps the result of mice consuming poison baits intended for rats. This effect lasted only 6 weeks. However, by August 2007, mice were undetectable. Mouse populations are expected to decline in years between beech masts (Choquenot & Ruscoe 2000).

### Rat diet assessment

Rats were collected monthly (from June to December 2006) from Fenn traps that were deployed to control stoats. Rats used in this study were from 60 traps placed in lines covering 12 km in the lower Dart Valley, from the Routeburn to Rockburn near Lake Sylvan, and north-west of Chinamans Bluff. Rat bodies that were too decayed to retrieve were discarded on site. The demographic characteristics of the ship rats collected are shown in Table 1. Stomachs were removed from collected rat carcasses (which had been stored frozen) in January 2007 and preserved in 75% ethanol. Tooth wear index (Innes 2005), sex, and reproductive status were recorded. Stomach contents were washed into a glass Petri dish and examined microscopically (×6.4, ×100). Frequency of occurrence of the main food types (plant material, invertebrate fragments and animal tissue (from mammals, birds or invertebrates) was recorded. Plant material (finely ground, brown, starchy material) was assumed (but not confirmed) to be mostly beech seed, after comparison with red beech seed finely ground by hand. Presence of hair, feathers, skin and claws was recorded. Stomach contents that were so decayed that most were unrecognisable (8), or negligible (empty stomach) (14), were not included in data summaries.

Samples of tissue suspected to be from vertebrates were wax embedded and sectioned for light microscopic examination, and the source verified by staining with hematoxylin and eosin (cytoplasm stained pink, nuclei stained blue). Samples of hair were examined using scanning electron microscopy (SEM). Scales on the external surface of individual hairs were compared with photographs of mouse and ship rat hairs (Brunner & Coman 1974). DNA was extracted (by Landcare Research, Auckland) from animal tissue taken from 10 rat stomachs, and polymerase chain reaction (PCR) used to amplify a region of the cytochrome b mitochondrial DNA. Resulting PCR products were sequenced to determine presence of rat and/or mouse tissue.

Small sample sizes in some months combined with the non-representative sampling regime meant it was not possible to conduct statistical analyses of changes in rat diet over time.

**Table 1.** Percentage of total sample of rats collected monthly in the Dart Valley, June–December 2006, by sex, reproductive status, and age. Juveniles are of age class II (based on tooth wear).

| Month | % female | % females reproductively active[1] | % juvenile |
|---|---|---|---|
| June | 57 | 25 | 36 |
| July | 47 | 57 | 13 |
| August | 18 | 0 | 0 |
| September | 23 | 0 | 4 |
| October | 42 | 25 | 14 |
| November | 29 | 33 | 6 |
| December | 15 | 0 | 38 |

[1] Pregnant or lactating.

# Results

Analysis of stomach contents demonstrated that, amongst a variety of food types consumed, animal tissue from vertebrate sources was often present. Microscopic examination confirmed the presence of muscle tissue, and presence of muscle bands strongly suggests this tissue was derived from mammalian or avian sources, rather than invertebrate (M. Downes, University of Otago, pers. comm.). Presence of rodents in the diet was confirmed by both SEM examination of hair and DNA analysis of tissue. Mouse hair scales were identified from 10 samples of hair. Mouse DNA was identified in 6 and ship rat DNA in 8 of the 10 samples of stomach contents. There was no apparent relationship between texture of animal tissue present (coarse or fine) and presence of rat or mouse

DNA. Minute claws found were in a sample containing rat DNA, but not mouse DNA. This sample comprised mostly animal tissue and hair.

Main food types identified were: plant material, invertebrate fragments (mainly exoskeleton), animal tissue, hair in clumps or balls, or attached to skin, and feather fragments (Table 2). Mammalian hair was recorded from at least 10% of the stomachs in every month, and feathers were found in one or two stomachs in every month except November. Soft tissue from vertebrates and invertebrates could not be separated, but was subdivided into finely ground light-coloured material and coarse animal tissue appearing similar to that of ground meat sometimes coloured red. Rats grind their food finely and usually only small pieces of exoskeleton remain recognisable as from an invertebrate source.

Stomachs with negligible contents ($n$ = 14) contained invertebrate fragments ($n$ = 3), hair ($n$ = 2), and plant material ($n$ = 3). Four of the decayed stomachs were dyed green, indicating that poison bait had been consumed before these rats were trapped.

# Discussion

This study provides evidence that mice and rats are preyed on and/or scavenged by ship rats in beech forest following a mast event. Mouse hair in a considerable number of samples suggests that not all mice eaten were neonates. Rat DNA in stomach samples may have been that of the individual captured rat, or from scavenging of dead rat bodies from traps, or from predation on live rats. Evidence of scavenging was observed on trap lines in the Dart and Caples area. Presence of minute claws in one sample with rat but no mouse DNA suggests an embryonic or newborn rat had been eaten.

Rodents have not been reported before as part of the diet of ship rats in New Zealand, to the authors' knowledge. Predation on mice by ship rats has been suggested to explain increase in mouse tracking rate following widescale poisoning of rats (Innes et al. 1995), differences in spatial distribution (Miller & Miller 1995), and differences in age distribution of mice between habitats with different levels of protective cover (Tompkins & Veltman 2006), although competitive pressure from ship rats was also considered as an alternative explanation in the latter case.

Feathers, sometimes in relatively large amounts, in rat stomachs could have been from birds that were roosting or nesting (incubating parent or chicks), or from scavenging of dead birds. Declines in mohua populations during winter coincident with high rat densities have been reported in New Zealand from Eglinton Valley, Fiordland (Dilks et al. 2003); Mt Stokes, Marlborough; Catlins State Forest Park, Otago; and the current study area. Mohua start nesting in spring (October) (Elliott 1996) and are unlikely to be nesting from June to September. However, mohua, and other birds taking refuge at night in confined spaces such as holes in tree trunks, may be vulnerable to predation by rats, especially during rat plagues. This could be confirmed by following radio-tagged birds over winter during a rat plague. The focus of pest control to protect mohua has been nests and incubating adult females. If major population declines in winter are due to rat predation then additional measures may need to be taken to prevent local extinction events.

Yellow-crowned parakeets (*Cyanoramphus auriceps*) can nest throughout the year during heavy beech masts (Elliot et al. 1996) and were nesting in the Dart Valley from July 2006. Eggs, chicks and the incubating (female) parent are particularly vulnerable to predation because this species is a hole-nester. Robins (*Petroica australis*) and grey warblers (*Gerygone igata*) nest from early spring (August), and several other birds species that are commonly found in beech forests can start nesting in September (Heather & Robertson 1996). Rat predation on nests can therefore occur throughout the year, and is

**Table 2.** Occurrence of plant and animal (vertebrate and invertebrate) remains in the stomachs of rats trapped in the Dart Valley, June–November 2007.

| Month | n | Plant | Animal tissue | | Invertebrate | Mammalian | Bird |
|---|---|---|---|---|---|---|---|
| | | | Fine | Coarse | exoskeleton | hair | feather |
| June | 10 | 9 | 7 | 3 | 9 | 6 | 2 |
| July | 14 | 13 | 10 | 3 | 8 | 8 | 1 |
| August | 9 | 9 | 5 | 2 | 4 | 2 | 2 |
| September | 19 | 16 | 8 | 5 | 12 | 4 | 1 |
| October | 36 | 32 | 13 | 15 | 26 | 15 | 2 |
| November | 8 | 4 | 1 | 6 | 5 | 10 | 0 |
| TOTAL[1] | 98 | 85 | 45 | 34 | 66 | 47 | 8 |

[1] Includes data from two rat stomachs collected in December; they included material from all five food categories.

more likely to occur following a beech mast, if there is a plague of rats.

Plant material (assumed to be mostly beech seed) was found in most rat stomachs over the study period. However, it is important to note that the plant material present was not identified beyond doubt to be beech seed. Rats may have been consuming some other source of plant material such as beech seedlings (Wilson et al. 2003) after beech seed germinated in October. No evidence of fruit or other identifiable plant parts was seen in the samples. Rats are known to cache foods (Innes 2005), and it is possible that beech seed was stored by rats and eaten later.

The rats used in this study were not a systematically collected sample and therefore are not representative of the rat population of the lower Dart Valley at the time of the study. However, the consumption of mice by ship rats during a beech mast has apparently not been previously reported. This may be a significant factor in maintaining ship rat populations at high density throughout the winter and spring following a mast seeding event. Further investigation should be carried out to quantitatively determine the importance of mice as a food resource in driving eruptions of rat populations in this situation.

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