JOHN E. DOWDING[1] and ELAINE C. MURPHY[2]

[1] P.O. Box 36-559, Northcote, Auckland, New Zealand.
[2] Department of Conservation, Private Bag 68-908, Newton, Auckland, New Zealand.

ECOLOGY OF SHIP RATS (*RATTUS RATTUS*) IN A KAURI (*AGATHIS AUSTRALIS*) FOREST IN NORTHLAND, NEW ZEALAND

Summary: Home range dimensions and habitat use by ship rats (*Rattus rattus*) at Puketi, a kauri (*Agathis australis*) forest in Northland, were examined by live capture and radio-tracking over five weeks in September and October 1993. Home ranges of six females and five males averaged 0.86 ha in area and 174 m in length, with no significant difference in range area or length between males and females. There was substantial overlap in ranges between and within sexes. One adult male increased the size of his range more than four-fold in seven nights in late October, coinciding with the beginning of the breeding season. Some rats changed daytime den sites frequently and others used the same den for a number of consecutive days; rats were found sharing dens on many occasions. Most rats returned to previously-used dens after denning elsewhere. At night, rats spent most of their time active on or close to the ground.

There are a number of important differences between our findings and those from other studies of ship rats in New Zealand; we suggest that the different times of year at which the studies were carried out are responsible for some of these differences. Our results, with those of others, suggest that in winter rats of both sexes have 0.5-1.0 ha ranges, but that during the breeding season ranges of males increase while those of females stay similar in size. Trapping indices showed that ship rats were not evenly distributed in Puketi Forest.

In December 1993, an aerial poison operation to control brushtail possums (*Trichosurus vulpecula*) was carried out over the study area, at which time five rats (three male, two female) still carried functioning radio-transmitters. The three males died within four hours on the night following the operation but the two females were alive three days later.

Keywords: Ship rat; *Rattus rattus*; home range; radio-tracking; kauri forest; *Agathis australis*; 1080 poison.

Introduction

Ship rats (*Rattus rattus* L.) were introduced to New Zealand accidentally in the second half of the 19th century, becoming widespread in the North Island by about 1860 and in the South Island about 30 years later (Atkinson, 1973). They are now found throughout North, South and Stewart Islands (Innes, 1990) and are known to occur on at least 47 offshore islands (J. Parkes, *pers. comm.*). They are most abundant in mature lowland forests of various types (Innes, 1990).

Ship rats are agile climbers and in New Zealand forests they eat a wide variety of fruits, invertebrates and birds (Innes, 1990). They are generally believed to have had a dramatic impact on the native biota during their initial spread through the North Island, which coincided with the decline of many bird species and the disappearance of others, such as the saddleback (*Philesturnus carunculatus rufusater*)[1], stitchbird (*Notiomystis cincta*) and piopio (*Turnagra capensis tanagra*) from the mainland (Atkinson, 1973). Their impact was emphatically demonstrated more recently when they invaded the Big South Cape Islands in 1962 or 1963. Within five years the greater short-tailed bat (*Mystacina robusta* Dwyer), a flightless weevil and five species of birds endemic to New Zealand had disappeared from the islands and other animal and plant species had declined (Bell, 1978; Ramsay, 1978).

There have been few attempts to study home range size and habitat use by ship rats in New Zealand forests. In mixed podocarp-broadleaf forest in the Orongorongo Valley, Wellington, Daniel (1972) determined average home range sizes of 0.17 ha for 15 adult males and 0.08 ha for 16 adult

[1] Bird nomenclature follows Turbott (1990); plant nomenclature follows Allan (1961), Moore and Edgar (1970) and Connor and Edgar (1987).

females. Each range was based on only 3-7 capture points however, and these values are likely to be substantial under-estimates. In a very small (0.22 ha) forest patch near Palmerston North, four rats had home ranges averaging 0.05 ha in area and 44 m in length (Innes and Skipworth, 1983). In regenerating coastal rimu (*Dacrydium cupressinum*) - rata (*Metrosideros* sp.) - kamahi (*Weinmannia racemosa*) forest on Stewart Island, six rats had home ranges averaging 0.54 ha in area and 142 m in length; ranges of females showed little overlap (Hickson, Moller and Garrick, 1986).

In the only radio-tracking study of ship rats in New Zealand to date, Innes, Hooker and Williams (1992) determined home ranges of four female and five male rats in kohekohe (*Dysoxylum spectabile*) - tawa (*Beilschmiedia tawa*) forest at Rotoehu, Bay of Plenty. Ranges of females were largely exclusive and averaged smaller (0.50 ha) and shorter (103 m) than those of males (1.52 ha and 194 m respectively). Ranges of males overlapped considerably and each male range overlapped the ranges of several females.

The main aim of our study was to compare the ecology of ship rats in kauri forest with that in other forest types in New Zealand. At Puketi, an area of mature kauri forest in Northland, we determined home range dimensions of 12 rats by radio-tracking and also gathered information on their density, habitat use, and denning behaviour. Large-scale aerial poisoning is now frequently used to control brushtail possums (*Trichosurus vulpecula* Kerr) in New Zealand forests (Cowan, 1990). As part of a wider study of the impact of possum-poisoning operations on other introduced mammals, we also aimed to assess the impact on ship rats of an aerial 1080 poison application.

Methods

Study area

Puketi Forest lies approximately 20 km north of Kaikohe, Northland, between 35°11' and 35°17'S, and 173°42' and 173°48'E. The radio-tracking study site was situated on a small (*c.* 15 ha) raised plateau (390-410 m altitude) on Pukatea Ridge (NZMS260 sheet P05 779632), in a stand of tall, mature kauri known as the Takapau Stand. This is immediately adjacent to the 'Pet' kokako (*Callaeas cinerea wilsoni*) home range described in detail by Best and Bellingham (1991). Kauri form a high, even canopy with a tall, sparse sub-canopy largely of tawari (*Ixerba brexioides*), with scattered rimu, miro (*Prumnopitys ferruginea*) and tawa. Kiekie (*Freycinetia baueriana banksii*) is common and there is a thick ground layer (up to about 2 m) of *Astelia trinervia*, *Gahnia xanthocarpa* and several species of tree ferns. Epiphytes are common, particularly *Astelia* spp. and *Collospermum hastatum.*

Trapping

Between 31 July and 10 August 1993, two live-trapping lines were set up to obtain indices of rat density; one was through the Takapau Stand and the other along Bramley's Ridge, approximately 3 km to the NE. Each line consisted of 20 wire cage traps at 50 m intervals. Traps were baited with a mixture of peanut butter and rolled oats and set for five consecutive nights. Captures per 100 trap-nights (C100TN) were corrected for unavailable traps (Nelson and Clark, 1973).

In late September, kill-trapping lines were set up by Department of Conservation staff at 20 widely-spread sites throughout Puketi Forest. These were primarily to monitor brushtail possum numbers, but they also caught ship rats. Each line consisted of 20 Victor 1.5 traps at 20-30 m intervals, baited with flour containing a synthetic peach-flavoured ester lure. Traps were set for four consecutive nights. The number of rats caught per 100 trap-nights (corrected for sprung traps) was calculated, to give an index of rat density for each line.

Radio-tracking

For radio-tracking in the Takapau Stand, markers (Scotchlite reflecting tape) were placed at 25 m intervals over a 325 x 225 m (7.3 ha) grid; rats were trapped in a central rectangular area of the grid measuring 125 x 75 m (0.94 ha) in Mk 3 Edgar traps (King and Edgar, 1977) baited with a mixture of rolled oats and peanut butter. All rats captured were anaesthetised with Halothane ('Fluothane', I.C.I. New Zealand Ltd., Lower Hutt), weighed, sexed and given a numbered ear-tag. Females with perforate vaginas and males with scrotal testes were classed as adults; males with abdominal testes may have been overwintering adults or juveniles (Twigg, 1975). Single-stage transmitters (Sirtrack Electronics, Landcare Research, Havelock North) were attached to 12 rats by a plastic-coated wire collar, which acted as a loop aerial. Transmitters weighed 4 g and had a battery life of about 6 weeks. At the start of the study transmitters were coated in epoxy resin; some rats chewed through this and destroyed the transmitters. Subsequent transmitters were coated in dental acrylic which rats were unable to damage significantly.

Estimating positions of rats from a distance by triangulation proved inaccurate, because signals bounced from the many large tree trunks in the study area; rats were therefore located on foot using a Telonics TR4 receiver (Telonics, E. Impala Avenue, Mesa, Arizona, U.S.A.) and a 3-element Yagi aerial (Sirtrack Electronics, Havelock North, N.Z.). Moving rats were usually approached to within about 10 m and positions were recorded relative to one or more grid markers; daytime den sites were located exactly. We found no evidence that rats were disturbed by this procedure. At each record, rats were noted as being either on the ground (including the *Astelia-Gahnia* layer up to 2 m) or in trees (above 2 m). Tracking error was tested by one person placing transmitters and a second relocating them; a comparison of actual and estimated locations of transmitters showed that error averaged 1.7 ± 0.3 m (n=20).

Rats were trapped and radio-tracked from 23 September - 3 October and from 15-27 October 1993. Each rat was located once a day during daylight (between 1000 and 1400 hr) and between two and five times at night. Home range sizes were calculated using minimum convex polygons (Harris *et al.*, 1990). Means are quoted ± S.E.

Rat density was determined by estimating the area exposed to trapping, as described by Innes *et al*. (1992). Home range 'diameter' was the average of range length and width for each rat, where range length was the longest possible line inside each range and width was the length of a line at right angles to length and measured at its mid-point. To calculate the area exposed to trapping, a border of one-half of the average range 'diameter' was added to the trapping grid, as this estimates the distance from which animals outside the grid will encounter traps (Dice, 1938).

Poison drop

An aerial poison drop, primarily to control brushtail possums, was scheduled for late October over the whole of Puketi Forest. The operation was repeatedly delayed because of unsuitable weather, but a small-scale drop was carried out over our rat study area on 19 December. Cereal pollard baits dyed green, containing 0.08% sodium fluoroacetate (compound 1080) masked with cinnamon, were sown by helicopter at a nominal rate of 5.5-6.0 kg per hectare. At that time, five rats (three males and two females) were still alive, in the study area, and carrying functioning transmitters. These animals were tracked for the three nights following the operation.

Results

Density

In early August, our live-trapping indices showed that rats were more abundant in the Takapau Stand (18.9 C100TN) than on Bramley's Ridge (5.5 C100TN). Kill-trapping indices in September (Table 1) also showed a very wide range of values (0-35.8 C100TN) in different parts of Puketi Forest. Rat numbers in the Takapau Stand appeared to fall between our July - August and September - October trapping sessions; we did not repeat the index line, but of five rats ear-tagged in the central trapping area (Fig. 1) during August, three were not re-trapped in September or October. Between 23 and 30 September, we caught 14 rats (eight females, six males) in the live-trapping area. The average range diameter was 122 ± 7.2 m and the area exposed to trapping was 4.87 ha; overall density was therefore 2.9 rats per ha (1.64 females per ha, 1.23 males per ha). Trapping continued at intervals throughout October; all rats caught in September were recaptured (some up to 11 times), but no new animals were captured, suggesting that we had detected virtually all the rats in the area.

We noted the pelage colour (Caslick, 1956) of 37 rats; 18 (48.6%) were 'alexandrinus', 14 (37.8%) were 'frugivorus' and 5 (13.5%) were 'rattus'.

Table 1: *Ship rat kill-trapping indices from widely-separated sites throughout Puketi Forest, September 1993. Each line consisted of 20 possum traps set for four consecutive nights. C100TN is the number of rats caught per 100 trap nights, corrected for sprung traps.*

Trap line	Number of rats caught	Index (C100TN)
1	9	13.4
2	12	16.6
3	5	7.6
4	18	26.1
5	14	22.4
6	1	1.7
7	14	22.8
8	3	4.4
9	2	3.3
10	7	12.7
11	11	16.1
12	16	26.4
13	13	19.7
14	9	13.1
15	19	35.8
16	1	1.8
17	8	14.5
18	9	13.6
19	0	0.0
20	15	23.3

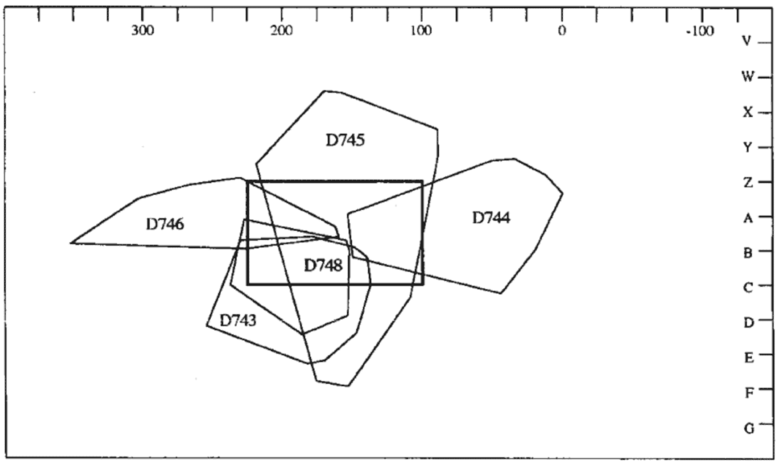

Figure 1: Home ranges of male ship rats at Puketi Forest in September-October 1993. The trapping area is enclosed by a heavy black line. Grid squares are 25 x 25 m.

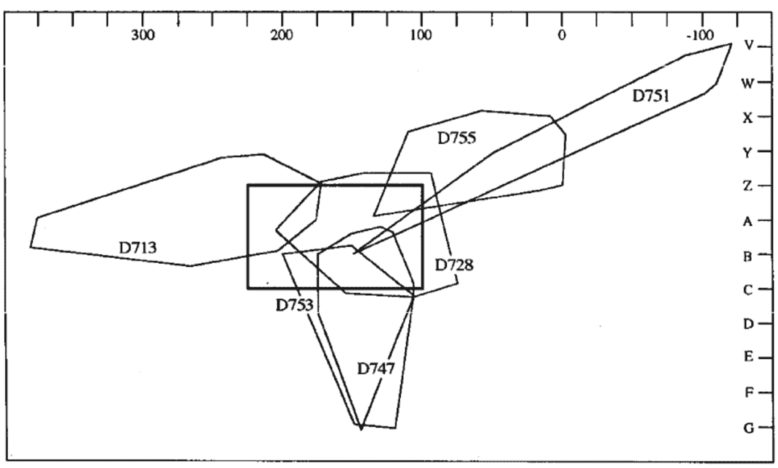

Figure 2: Home ranges of female ship rats at Puketi Forest in September-October 1993. The range of female D750, based on only 13 records and lying entirely within the range of D728, is omitted for the sake of clarity. The trapping area is enclosed by a heavy black line. Grid squares are 25 x 25 m.

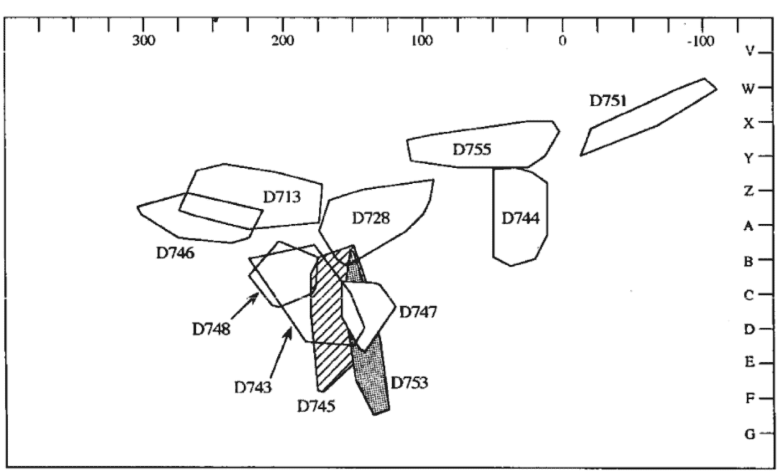

Figure 3: 70% core ranges of ship rats at Puketi Forest in September-October 1993. In the area of greatest overlap, ranges of two rats are highlighted to improve clarity. Grid squares are 25 x 25 m.

Table 2: *Home range dimensions of ship rats radio-tracked at Puketi Forest during September and October 1993.*

Rat	Sex	Weight (g) at first capture September	Weight (g) at first capture October	Number of records	Number of records to range asymptote	Range length (m)	Range area (ha)	70% core area (ha)
D713	F	136	143	62	39	214	1.09	0.35
D728	F	130	148	75	44	136	0.85	0.30
D747	F	120	113	63	38	149	0.71	0.13
D750	F	91	105	13		86	0.31	
D751	F	124	131	51	36	311	0.62	0.15
D753	F	125	135	47	27	152	0.75	0.19
D755	F	113	114	57	33	151	0.71	0.27
D743	M	102	116	45	34	126	0.79	0.34
D744	M	105	120	60	32	157	0.95	0.25
D745	M	161	144	75		215	1.83	0.31
D746	M	109	108	60	30	193	0.61	0.21
D748	M	110	112	63	45	104	0.52	0.15

Home range dimensions and overlap

Home range areas of seven female and five male rats we radio-tracked were not significantly different, averaging 0.79 ± 0.07 ha for females and 0.94 ± 0.23 ha for males (t=0.69, d.f.=9, P=0.51) (Table 2). The range of D750, a female which was found dead after only 13 locations had been recorded, was excluded. Range lengths of females averaged 185.5 ± 27.5 m and those of males 159.0 ± 20.5 m (difference not significant, t=0.75, d.f.=9, P=0.48). For combined sexes, range area averaged 0.86 ± 0.11 ha and length averaged 173.5 ± 17.3 m. Excluding male D745 (whose range may still have been increasing at the end of radio-tracking - see below), home range sizes reached asymptotes (Harris *et al*., 1990) at an average of 35.8 ± 1.8 records.

We found substantial overlap in ranges both between and within sexes. Fig. 1 shows the ranges of the five males. There is almost complete overlap between the ranges of D743 and D748, with 90% of D748's records within D743's range and 76% of D743's records within D748's range; both are overlapped by D745.

Of six females tracked, there was a high degree of overlap between the ranges of D747 and D753 (87% and 94% overlap respectively) and the ranges of both were overlapped by that of D728 (Fig. 2). The range of D750 (13 records only and almost certainly under-estimated) lay entirely within that of D728 and overlapped those of D747 and D753. These four females were all of the 'rattus' colour morph. Comparison of Figs. 1 and 2 shows the extensive overlap of ranges between sexes.

We found evidence that rats meet and sometimes forage together. On three occasions in August we caught two rats in a trap simultaneously (two males, two females, a male and a female) and on six occasions while radio-tracking we found rats within 2 m of each other.

The distribution of records in plotted home ranges showed that rats had favoured foraging areas. Each range was therefore reduced to a peeled polygon (Kenward, 1992) containing 70% of records, excluding den sites. These 70% cores averaged 0.24 ± 0.02 ha (range 0.13-0.35 ha), with no significant difference in area between males and females (female mean 0.23 ± 0.04; male mean 0.25 ± 0.03; t=0.43, d.f.=9, P=0.68). Cores contained 70% of non-den records in an average of 27.6% of home range areas, but still showed some overlap between and within sexes (Fig. 3).

Denning

The number of daytime dens used by each rat during the study varied from two to nine, but most animals (8 of 11) used either three or four. Some rats changed den sites frequently and others used the same den for a number of consecutive days. Female D713 was an example of the former; she used nine different dens in 17 days and changed den sites daily in one period of seven consecutive days. By contrast, female D728 used one den for eight consecutive days, then moved to a second for six consecutive days. Nine of the 11 rats returned to one or more of their previously-used dens after denning elsewhere.

There was no obvious overall pattern to the location of daytime den sites within home ranges, although four rats (two female, two male) had most or all of their dens on the edges or in corners of their ranges, often away from their core areas. The most pronounced case was female D728, whose four den sites were all in a small area in one corner

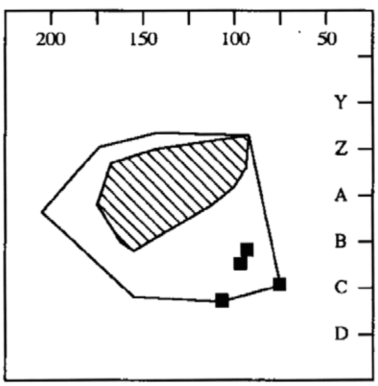

Figure 4: Home range (solid line), 70% core area (cross-hatched) and den sites (solid squares) of female ship rat D728 at Puketi Forest in September and October 1993. Grid squares are 25 x 25 m.

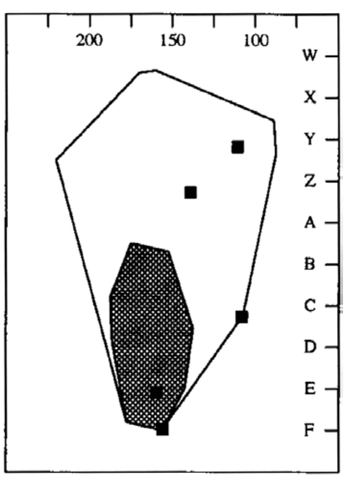

Figure 5: Home range of male ship rat D745 up to 20 October (shaded area) and up to 27 October (solid line), showing den sites (solid squares) used between 20 and 27 October. Grid squares are 25 x 25 m.

of her range, an average of 45 m from her 70% core area (Fig. 4). Female D713 used nine dens during our study. Although these were scattered around her range, she appeared to favour those in one corner. Twelve (67%) of 18 daytime locations were spread between four dens at the extreme western end of her range, about 100 m from her core area.

We found that rats sometimes denned together during the day. Two males whose ranges overlapped to a large extent were found sharing dens on four occasions at three different sites. Three females denned together in various combinations at different sites; D728 and D747 twice, D747 and D753 twice, and all three animals on four occasions. Two cases of a male denning with one or more females in late October may have been associated with sexual activity.

Rats sometimes returned to dens at night for an unknown length of time, then resumed foraging. Eight of the 11 rats were detected in dens at night at least once and on average 3.1% of night-time records were of rats in dens. Night-time den records were all between 2250 hr and 0120 hr, at a time of year when rats were becoming active in the evening at about 1900 hr. This suggests that some animals were moving around their range for 4-5 hr before returning to dens.

Habitat use

Two females (D751 and D755) were recorded (once each) moving on the ground in the daytime. All other daytime records (n=149) were of rats stationary in dens up trees. At night, rats spent an average of 91% of the time moving on the ground, including among the ground layer of *Astelia* and *Gahnia* (Table 3). When night-time den records are excluded, active rats were moving on the ground for an average of 93.5% of records and in trees (above 2 m) for an average of 6.5% of records.

Onset of breeding in late October

All female rats radio-tracked in both September and October were perforate, and were therefore considered to be adults. In September, none of the males we tracked had descended testes. However, during the last week of our study (21-27 October), three of them had descended testes (the other two were not captured). The first was D745 who, up to 20 October, had a home range 0.42 ha in area and 114 m in length. This range overlapped to a large extent with those of two females and to a much lesser extent with that of a third. On the night of 21 October he was found well outside his previous range and on 22 October was found sharing a den with three females, also outside his previous range. On 23 October he was trapped and found to have descended testes, which he had not had when examined six days earlier. Between 21 and 27 October, he increased the size of his range more than four-fold to 1.83 ha in area and 215 m in length (Fig. 5), overlapping the ranges of five females. During this period he sometimes returned to a daytime den in his previous range and sometimes denned in the new part of his range. On 26 October, males D743 and D748 were captured and both had descended testes, which neither had at their previous capture on 23 October. Radio-tracking ended on 27 October and we were unable to study these two males further.

Table 3: *Habitat use by ship rats at night in the Takapau Stand, Puketi Forest, during September and October 1993. All records were radio-tracking fixes. Percents are for habitat use by each rat.*

Rat	Number of night-time records					
	Stationary in dens		Moving on the ground		Moving up trees	
	No.	%	No.	%	No.	%
D713	1	2.6	36	92.3	2	5.1
D728	4	8.5	40	85.1	3	6.4
D747	2	5.4	34	91.9	1	2.7
D751	2	5.7	31	88.6	2	5.7
D753	1	2.9	33	97.1	0	0.0
D755	0	0.0	36	94.7	2	5.3
D743	0	0.0	19	86.4	3	13.6
D744	1	2.5	35	87.5	4	10.0
D745	2	4.1	45	91.8	2	4.1
D746	1	2.6	33	86.8	4	10.5
D748	0	0.0	35	94.6	2	5.4
Mean		3.1		90.6		6.3
S.E.		0.8		1.2		1.1

Effect of the poison operation

Checks of bait coverage showed that baits were evenly distributed throughout the study area (J.E. Dowding and E.C. Murphy, *unpubl. data*). On the evening immediately following the poison drop, all five rats with transmitters were active by 2115 hr. One was found dying at 2245 hr and by 0115 hr (i.e., within four hours of becoming active), the three males were dead. Autopsy revealed green dye in the stomachs of all three, confirming that they had eaten baits. The two females were still alive and moving on the third night after the drop. On the third night, heavy rain fell over the study area; the next day all baits were wet and many had begun to disintegrate.

Discussion

Density

Rats appeared to be patchily distributed in Puketi Forest. The density index in July-August was more than three times higher in the Takapau Stand (where traps were adjacent to a walking track) than on Bramley's Ridge (where they were adjacent to a forest road). Rats may have been avoiding the road because there was little cover, but vegetation was very different in the two areas. Logging and salvage were carried out on Bramley's Ridge until 1973 (Best and Bellingham, 1991) and the area is now regenerating, with few large trees and much manuka (*Leptospermum scoparium*) present. The live-trapping and kill-trapping indices cannot be compared (timing, trap type, spacing and bait were all different), but the latter also showed clearly that rats were at very different densities in different parts of the forest. The fall in rat numbers seen in the Takapau Stand between trapping sessions agrees with findings in another Northland kauri forest (Smith, 1986), where the density index fell from 15 C100TN in July to 6 C100TN in October. Our density estimate in the Takapau Stand (2.9 ship rats per ha) lies between the values calculated by Hickson *et al.* (1986) on Stewart Island (1.8-2.3 per ha in January - February) and by Innes *et al.* (1992) at Rotoehu (6.2 per ha in December - January). However, rat density in New Zealand forests varies during the year, being lowest in spring and highest in autumn (e.g., Daniel, 1972; Smith, 1986). Our study was undertaken in September - October, and estimates from the three studies are therefore not strictly comparable.

We found the brown-backed, grey-bellied 'alexandrinus' morph to be common at Puketi, as it is in nearby Waipoua Forest (Smith, 1986); this colour morph does not appear to occur in other parts of the North Island (Innes, 1990).

Range sizes and overlap

Innes *et al.* (1992) found home ranges of male ship rats at Rotoehu Forest to be larger (mean 1.52 ha) than those of females (mean 0.50 ha) and to overlap more. We found no significant difference in range size between males and females and our range sizes (average 0.86 ha) were closer to those of females in their study. We also found considerable overlap in ranges of females, particularly near the centre of our grid; the three females that apparently had largely exclusive ranges were also those furthest from our trapping area and probably overlapped the ranges of females that we did not radio-track. In one case we know this occurred - during attempts to re-trap D755 outside the usual trapping area (to replace a transmitter), we caught another female (D752) at three different sites all within D755's range. 70% cores defined areas of more intensive use, but they also showed some overlap. In one area (between grid positions C150 and D150 - see Fig. 3), the 70% cores of four rats (two males, two females) overlapped, suggesting that this may have been an important foraging area at the time.

At the onset of the breeding season, the testes of overwintering male rodents descend into the scrotal sac (Twigg, 1975). Testes became scrotal in the last week of October in at least three of the males we radio-tracked, indicating that our study was undertaken immediately prior to, and at the beginning of the breeding season. Our results, coupled with those of Innes *et al*. (1992), suggest that males and females have similar-sized ranges during winter but that in spring, male ranges become larger while female ranges remain similar in size. This change in male range size coincides with the onset of the breeding season and presumably reflects the attempts of males to find and mate with as many females as possible. Our observations of male D745 are consistent with this; his home range increased rapidly after 21 October from 0.42 to 1.83 ha, a value similar to the average of 1.52 ha reported by Innes *et al*. (1992) for males in December and early January.

In contrast to the findings of Hickson *et al*. (1986) and Innes *et al*. (1992), we found that ranges of females overlapped, in some cases to a large extent. In one case, the 70% cores of two females overlapped considerably. Again, this may have been a result of the time of year; when females are breeding, their ranges may become more exclusive. However, we also found that four of the females we tracked had overlapping ranges, denned together in different combinations and were all of the 'rattus' morph. This suggests that they may have been related, which could provide another possible explanation for some of our observations - related animals may tolerate more range overlap and/or sharing of dens than unrelated animals.

Denning

We found many examples of rats denning together, both between and within sexes, a finding that does not appear to have been reported in non-commensal situations. Some rats appeared to den alone, but could have been denning with animals not carrying transmitters, especially near the edges of the grid. The fact that some rats appeared to have separate denning and foraging areas in their ranges may have been because den sites were fixed but core areas changed, depending on the food resources being exploited.

Habitat use

Innes *et al*. (1992) found rats mostly up trees; 72% of records were of rats 2 m or more above ground. We found active rats on the ground much more often; this may have been simply because of the physical structure of the forest in our study area (the sub-canopy layer was relatively open and sparse), or because the main food sources being exploited by rats at the time were on the ground.

Poison drop

Our observation that in December three male rats ate poison baits but two females did not is interesting. The sample is clearly too small to allow definite conclusions and the experiment needs to be repeated, preferably in late winter or early spring when most possum-eradication operations are undertaken. Apart from chance, possible explanations for our finding include: (a) female ship rats may be more neophobic than males; (b) there may be a sexual difference in bait palatability (e.g., one sex may be more able to detect 1080, or one sex may dislike cinnamon); (c) there may be a seasonal effect, with females more wary during the breeding season.

Conclusions

There are a number of substantial differences between our findings and those of Innes *et al*. (1992). Although vegetation types were very different in the two study areas, we believe that the different time of year was largely responsible for these differences. Little is known of the social life of ship rats (in New Zealand or elsewhere) but they are not colonial and are generally assumed to be rather evenly spread in suitable habitat (Innes, 1990). In late winter and early spring at Puketi, ship rats appeared to be social animals, often denning together, foraging in close proximity and with considerable overlap in ranges within and between sexes. Evidence from our study and others in New Zealand (Hickson *et al*., 1986; Innes *et al*., 1992) suggests that this situation may change to some extent during the breeding season.

Our results suggest that caution may be needed in interpretation of data from some of the methods commonly used to estimate rat density, such as snap-trapping lines and tracking tunnels. If male home range areas and lengths change during the year, indices from different seasons will not be comparable. Similarly, our finding that females at Puketi had an average range length 80% greater than that of females at Rotoehu (Innes *et al*., 1992) suggests that density indices from different areas may not be strictly comparable either. In addition, it cannot be assumed that ship rats are evenly distributed in large tracts of forest in New Zealand.

Acknowledgements

This study was funded by Science and Research Division of the Department of Conservation. Particular thanks to Adrian Walker, Karen Riddell and Steve McManus (Department of Conservation, Kaikohe) for logistic support and advice, help with field-work, and for providing the data summarised in Table 1. We are grateful to Ian Bunckenburg and pupils of Mt. Cook School, Wellington, for pre-fabricating Edgar traps, and to Bridget Farrell (DoC, Christchurch) and Amanda Campbell (DoC, Auckland) for library assistance. We thank Ralph Powlesland, Dave Towns, John Parkes and Dave Morgan for comments on the draft manuscript.

References

Allan, H.H. 1961. *Flora of New Zealand, Vol. I.* Government Printer, Wellington, New Zealand. 1085 pp.

Atkinson, I.A.E. 1973. Spread of the ship rat (*Rattus r. rattus* L.) in New Zealand. *Journal of the Royal Society of New Zealand 3:* 457-472.

Bell, B.D. 1978. The Big South Cape Islands rat irruption. *In:* Dingwall, P.R.; Atkinson, I.A.E.; Hay, C. (Editors), *The ecology and control of rodents in New Zealand nature reserves*, pp. 33-40. Information Series No. 4, Department of Lands and Survey, Wellington, New Zealand. 237 pp.

Best, H.A.; Bellingham, P.J. 1991. *A detailed habitat study of North Island kokako in Puketi Forest, Northland.* Science and Research Internal Report No. 103. Department of Conservation, Wellington, New Zealand. 371 pp.

Caslick, J.W. 1956. Colour phases in the roof rat, *Rattus rattus. Journal of Mammalogy 37:* 255-257.

Connor, H.E.; Edgar, E. 1987. Name changes in the indigenous New Zealand flora, 1960-1986 and *nomina nova* IV, 1983-1986. *New Zealand Journal of Botany 25:* 115-170.

Cowan, P.E. 1990. Brushtail possum. *In:* C.M. King (Editor), *The handbook of New Zealand mammals,* pp. 68-98. Oxford University Press, Auckland, N.Z. 600 pp.

Daniel, M.J. 1972. Bionomics of the ship rat (*Rattus r. rattus*) in a New Zealand indigenous forest. *New Zealand Journal of Science 15:* 313-341.

Dice, L.R. 1938. Some census methods for mammals. *Journal of Wildlife Management 2:* 119-130.

Harris, S.; Cresswell, W.J.; Forde, P.G.; Trewhella, W.J.; Woollard, T.; Wray, S. 1990. Home-range analysis using radio-tracking data - a review of problems and techniques particularly as applied to the study of mammals. *Mammal Review 20:* 97-123.

Hickson, R.E.; Moller, H.; Garrick, A.S. 1986. Poisoning rats on Stewart Island. *New Zealand Journal of Ecology 9:* 111-121.

Innes, J.G. 1990. Ship rat. *In:* King, C.M. (Editor), *The handbook of New Zealand mammals*, pp. 206-225. Oxford University Press, Auckland, New Zealand. 600 pp.

Innes, J.G.; Hooker, S.; Williams, D. 1992 (unpublished). *Radio-tracking ship rats at Rotoehu Forest, Bay of Plenty.* Forest Research Institute Contract Report FWE 92/17. Forest Research Institute, Rotorua, New Zealand. 10 pp.

Innes, J.G.; Skipworth, J.P. 1983. Home ranges of ship rats in a small New Zealand forest as revealed by trapping and tracking. *New Zealand Journal of Zoology 10:* 99-110.

Kenward, R.E. 1992. Quantity versus quality: programmed collection and analysis of radio-tracking data. *In:* Priede, I.G.; Swift, S.M. (Editors), *Wildlife telemetry: remote monitoring and tracking of animals,* pp. 231-246. Ellis Horwood Ltd., Chichester, England. 701 pp.

King, C.M.; Edgar, R.L. 1977. Techniques for trapping and tracking stoats (*Mustela erminea*): a review, and a new system. *New Zealand Journal of Zoology 4:* 193-212.

Moore, L.B.; Edgar, E. 1970. *Flora of New Zealand, Vol. II.* Government Printer, Wellington, New Zealand. 354 pp.

Nelson, L., Jr.; Clark, F.W. 1973. Correction for sprung traps in catch/effort calculations of trapping results. *Journal of Mammalogy 54:* 295-298.

Ramsay, G.W. 1978. A review of the effect of rodents on the New Zealand invertebrate fauna. *In:* Dingwall, P.R.; Atkinson, I.A.E.; Hay, C. (Editors), *The ecology and control of rodents in New Zealand nature reserves*, pp. 89-95. Information Series No. 4, Department of Lands and Survey, Wellington, New Zealand. 237 pp.

Smith, K.M. 1986 (unpublished). *The diet of the ship rat,* Rattus rattus rattus *L. in a kauri forest in Northland, New Zealand.* M.Sc. Thesis, University of Canterbury, Christchurch, New Zealand. 152 pp.

Turbott, E.G. (Convener) 1990. *Checklist of the birds of New Zealand, 3rd edition.* Ornithological Society of New Zealand, Wellington, New Zealand. 247 pp.

Twigg, G.I. 1975. Techniques in mammalogy: catching mammals. *Mammal Review 5:* 83-100.