[1]Ecology Division, Department of Scientific & Industrial Research, Lower Hutt. (Present address: Plant Diseases Division, D.S.I.R. Palmerston North). [2]Ecology Division, Department of Scientific & Industrial Research, Private Bag, Nelson. (To whom reprint requests should be directed). [3]Department of Lands & Survey, Wellington. (Present address: 71 Gordon Road, Rotorua).

POISONING RATS ON STEWART ISLAND

Summary: Poison was used at remote anchorages of southern Stewart Island in spring and summer of 1984/85 to reduce the likelihood of ship rats *(Rattus rattus),* Norway rats *(R. norvegicus)* and kiore *(R. exulans)* boarding fishing boats heading for the Snares Islands. Poison baits were removed at successively slower rates, probably because poisoning had reduced rat numbers.

The effectiveness of poisoning was tested by (i) live-capturing and tracking marked rats at a simulated anchorage near Halfmoon Bay, (ii) poisoning there as in southern Stewart Island, and (Hi) monitoring the survival and responses of the marked population.

Population density approximated 2.0-2.5 ship rats per hectare before poisoning. The minimum monthly home range of ship rats averaged 0.54 ha (mean range length 142 m), which is much larger than previously recorded for ship rats in New Zealand. Neither Norway rats nor ship rats were restricted to the shoreline or along creeks.

Poisoning caused a 93% reduction in an index of rat numbers in a 0.69 ha poisoning zone over 16 days, and a 76% reduction over the larger 10.4 ha effective trapping area including the poison zone.

Poisoning reduces the risk of rats boarding boats, and can protect endangered plants and animals on infested islands.

Keywords: Rats, *Rattus norvegicus*, *Rattus rattus*, *Rattus exulans*, poisoning, islands, conservation, Stewart Island, home range, movements.

Introduction

Rodents have harmed the New Zealand biota (Dingwall, Atkinson and Hay, 1978), so it is important to prevent them reaching hitherto uncolonised islands. Boats working from ports or anchorages with rodents can carry them to offshore islands. Killing rodents living near wharves or moorings is one way to reduce this risk. Poisoning can also clear rats from important sites (e.g. nests, colonies) if endangered species persist on infested islands. Long-term and intensive poisoning on small islands can eradicate *Rattus norvegicus* (Moors, 1985a), but the effectiveness of localised poisoning is not known.

This paper describes the use of rat poison at four places near Port Pegasus in southern Stewart Island. These places are visited by fishing boats *en route* to the Snares Islands, an internationally significant, rodent-free nature reserve in the subantarctic. Controlling rats in remote anchorages is expensive and logistically difficult, so it is important to determine whether or not poisoning significantly reduces the probability of rats boarding boats and how resources should best be deployed.

The isolation of the Port Pegasus area prevented direct monitoring there of the effectiveness of poisoning. Instead, a short-term poisoning campaign was conducted at a simulated anchorage at a more accessible site near Halfmoon Bay. The proportion of a known (tagged) rat population killed by the poison was calculated. Rat movements were studied to improve the efficiency of future poisoning.

Study Areas

Port Pegasus

Poisoning was carried out around boat mooring sites in four places near Port Pegasus (47°13'S, 167°34'E) in southern Stewart Island (Fig. 1).
Vegetation at all sites consists of southern rata *(Metrosideros umbellata)* and kamahi *(Weinmannia racemosa)* forest with rimu *(Dacrydium cupressinum),* some miro *(Prumnopitys jerruginea)* and very occasionally totara *(Podocarpus totara)*. Understorey species principally comprise tree ferns *(Cyathea/Dicksonia squarrosa)* and *(Coprosma* sp. (frequently *C. joetidissima),* and occasionally lancewood *(Pseudopanax crassifolius)* and broadleaf *(Griselinia littoralis)*. Forest extends virtually to high tide mark or to the edge of bluffs overhanging the water. At these 'edges' manuka *(Leptospermum scoparium),* inaka *(Dracophyllum longifolium),* muttonbird scrub *(Senecio reinoldii)* or *Gahnia procera* is often present, and at one site in Burial Cove, flax *(Phormium* sp.). At one other site, a headland in Disappointment Cove, yellow-silver pine *(Lepidothamnus intermedius)* and inaka was present.

Halfmoon Bay

Live trapping was carried out on 5.1 ha of coastal forest (46∞54'S, 168∞06'E) about 2 km SE of the settlement of Halfmoon Bay (Fig. 1). The vegetation has regenerated since the 1930's and the 5-10 m canopy is now dominated by rimu, rata and kamahi. Tree ferns are abundant and there are several dense patches of supplejack *(Ripogonum scandens)*. Sapling canopy species and *Coprosma* spp. make up the generally open understorey. Crown fern *(Blechnum discolor)* and leaf litter provide the main ground cover. The forest extends to the high tide mark, where it gives way to a gradually shelving intertidal zone of sand and smooth stones. Sand containing a cockle bed is exposed at low tide around the mouth of the northernmost of the two small creeks passing through the study area.

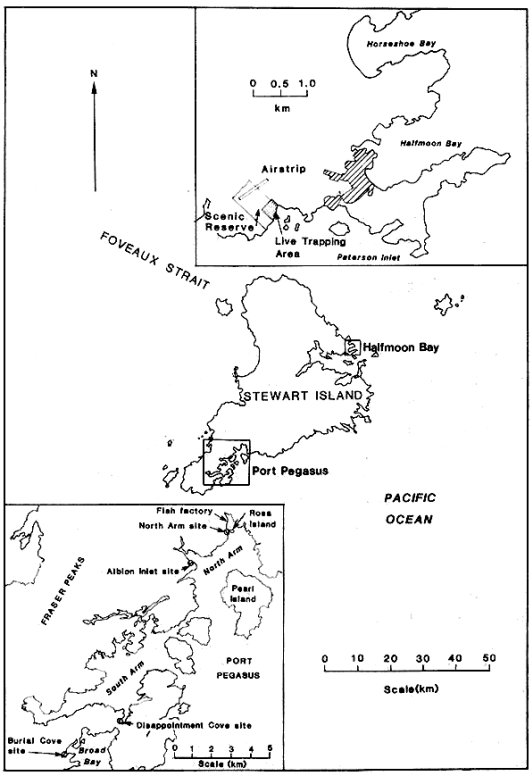

Figure 1: *Location of the Port Pegasus and Halfmoon Bay study areas, the anchorages at Port Pegasus where poison was laid. and the live-trapping area near Halfmoon Bay.*

Methods

Snap-trapping and poisoning at Port Pegasus

Snap-trapping was undertaken between 31 August and 6 September 1984 at three of the four poisoning sites. This trapping was done to provide an index of the rat density at the beginning of poisoning for comparison with earlier studies on Stewart Island, and to assist in the initial reduction of the resident population. Up to 31 wooden Ezeset Supreme rat traps baited with a mixture of peanut butter, rolled oats and grated cheese were used at each site for 2-4 nights. Traps were spaced from less than 1 m to about 25 m apart along a line within 20 m of the shore. In addition, up to 12 traps were set on Rosa Island and eight traps near the derelict fish factory in North Arm. Trap success was calculated as the number of rats caught per 'corrected' trap night (Nelson and Clark, 1973) and binomial 95% confidence intervals were calculated (Mainland, Herrera and Sutcliffe, 1956).

Poison bait stations were laid out between 31 August and 4 September 1984. Stations consisted of 40 cm lengths of 100 mm diameter yellow Novacoil pipe fiXed firmly to the ground with three wire pegs. Six wax-based "Talon WB" poison pellets containing 0.5% brodifacoum were placed on a 10 cm square aluminium foil tray within each pipe. Between 39 and 44 stations were set out at each site at spacings of 2-25m in one or two lines running approximately parallel to the shoreline. The lines extended about 50 m either side of the mooring sites, the first line being laid as close to the shoreline as practicable. Second lines were set 5-10 m further inland at some sites. Except those at Burial Cove, all bait stations were checked and poison was replenished where necessary 1-4 days after installation, and again on 4 and 29 October 1984 and 11 January 1985.

Live-trapping at Halfmoon Bay

Rats were live-trapped in 81 wire mesh cages set out in early December 1984 on a 25 m grid. Fifteen other similar traps were placed at irregular intervals 7-30 m apart between the track and the shore (shown in Fig. 4). Nine traps were moved from the western to the northern margin of the grid at the end of December.

Live-traps were operated continuously for 16 nights in December 1984 and for 13 and 9 nights in January and February 1985, respectively. The timing of live-trapping, and ensuing poisoning and snap-trapping (see later) is shown in Fig. 3.

Initially the traps were baited with about 10 grains of maize, freshly caught fish or a mixture of

peanut butter and rolled oats. The peanut butter and rolled oats mixture was the most successful bait and was used exclusively after the initial seven days of live trapping. Missing or mouldy baits were replaced. When not set, traps were left baited to allow rats free access.

Rats captured for the first time were anaesthetised with chloroform in an anaesthetic box (Moller, 1983) and their species, sex, weight and reproductive condition noted. Numbered stainless steel tags were used for individual recognition and the first joint of at least two toes was clipped (usually one front and one hind toe) in unique combinations. Recaptured rats were released after identification and a brief inspection.

Tracking at Halfmoon Bay

Rat movements were also determined from footprints left in 146 tunnels distributed at 5-25 m intervals along the tracks between live-traps. Tunnels were baited with peanut butter and rolled oats after a 7-day trial also with maize and fish baits.

Most of the tracking tunnels used the ink method of King and Edgar (1977). A second method used french chalk powder sprayed onto a black vinyl strip instead of the aluminium ink tray used by King and Edgar (1977). Twenty-four chalk tunnels initially distributed alongside the track (shown in Fig. 4) were replaced by ink tunnels after 10 days because most rat tracks in them were unreadable (rats skidded on the chalk and did not record clear footprints). The chalk system was reintroduced for 24 days toward the end of January 1985 when ink for tunnels temporarily ran out.

Poisoning at Halfmoon Bay

Fifty-one poison stations were set out approximately 10 m apart on 0.69 ha (outlined with a dashed line in Fig. 4) of the live-trapping area adjacent to the shore on 8 February 1985 and were removed 16 days later. The baits, presentation and layout of poison stations were the same as used at Port Pegasus. Missing baits were recorded each day but were not replaced. For the first eight days of poisoning no traps were used; this ensured that visits by rats to the poison stations were not restricted by confinement in traps. Tracking tunnels remained operational throughout the poisoning.

Snap-trapping at Halfmoon Bay

After the final live-trapping session during the poisoning, the area was intensively snap-trapped to detect rats still alive in the last four days of the poisoning. One hundred and fourteen Ezeset Supreme rat snap-traps were placed near the live-traps and tracking tunnels. The snap-traps were prebaited with peanut butter and rolled oats for one night and then set for five successive nights from 21 February.

Results

Trapping and poisoning at Port Pegasus

Snap-trap success varied greatly between sites (Table 1), and the 95% binomial confidence intervals overlap for all sites except Rosa Island. The proportion of successful trap nights was significantly higher on Rosa Island than in all other areas combined ($X^2 = 47$, d.f. = 1, $p < 0.01$).

Some poison was removed from most stations, and only a few remained untouched. Several stations were particularly popular. The daily rates of poison removal in the final period 29 October to 11 January were 80%, 70% and 52% less than in the initial period 31 August to 4 October at Disappointment Cove, Burial Cove and North Arm respectively (Fig. 2).

Between 21 % and 98% (mean = 55%) of stations still contained poison when revisited, so these declines were not due to bait depletion before servicing.

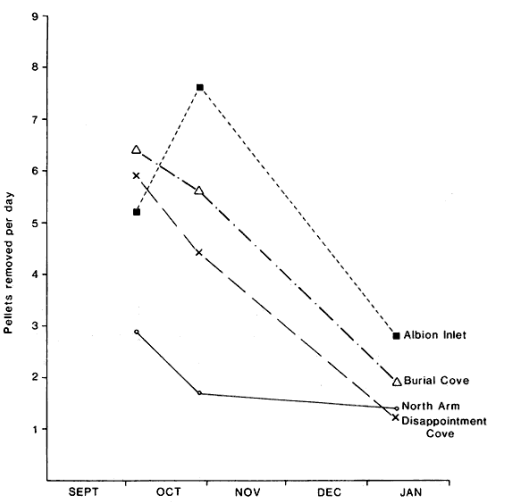

Figure 2: *A verage number of pellets removed from poison stations per day at Port Pegasus.*

Table 1 *Corrected snap-trap success at anchorage sites poisoned at Port Pegasus. Binomial 95 % confidence intervals are shown in brackets.*

Locality	Corrected Trap Nights (ctn)	*Rattus rattus* Number caught	*Rattus rattus* rats/ 100ctn	*Rattus norvegicus* Number caught	*Rattus norvegicus* rats/ 100ctn
North Arm	93	18	19.3 (12-28)	0	0 (0-4)
Albion Inlet	39.5	10	25.3 (13-41)	0	0 (0-9)
Disappointment Cove	78	7	9.0 (4-17)	2	2.6 (0.3-8.7)
Rosa Island	17	14	82.4 (57-96)	7	41.2 (18-67)
Fish Factory	4	2		2	

Table 2: *Number of rats caught and the number dying in traps or during anaesthesis.* + *Includes rats found dead in traps or dying from overdoses before poison was laid.* * *Includes 9 unsexed* R. rattus *caught (4 escaped and 5 had to be released without marking on 12 December).*

Species and sex	Total captures	Number of different individuals caught +	Number found dead in traps	Number dying from chloroform overdose
Male *Rattus rattus*	65	28	10	3
Female *R. rattus*	67	21	3	1
Male *R. norvegicus*	14	3	3	0
Female *R. norvegicus*	14	6	1	1
Total	169*	58	17	5

Table 3: *Number of captures and individual capture rate (based on periods when individuals known to be alive) of ship and Norway rats in live-traps.*

	R. rattus Male	*R. rattus* Female	*R. rattus* Total	*R. norvegicus* Male	*R. norvegicus* Female	*R. norvegicus* Total
No. of different rats	20	20	40	3	5	8
Mean number of times trapped	2.8	3.4	3.1	4.7	2.6	3.4
Range	1-11	1-12	1-12	3-7	1-5	1-7
S.E.	0.6	0.6	0.4	1.2	0.8	0.7
Mean proportion of nights trapped	0.68	0.47	0.57	0.85	0.31	0.51
S.E.	0.07	0.07	0.05	0.15	0.11	0.13

At Albion Inlet possums *(Trichosurus vulpecula)* dislodged many stations and damaged or removed trays containing pellets. Poison removal was reduced over the last period at Albion Inlet (Fig. 2) but we do not know whether this was due to rats or possums.

Live-trapping rates at Halfmoon Bay

At least 58 different rats were live-trapped 169 times during 2884 trap nights (Table 2). The majority (84.5%) of rats caught were *R. rattus,* the remainder being *R. norvegicus.*

Seventeen rats died in live-traps, despite insulation of both the inside and outside of traps with forest litter and a check of all traps by early afternoon.

Thirty-one (64.6%) of the 48 different rats marked and released were recaptured at least once in live-traps. Some were caught up to 12 times (Table 3). There was no significant difference in trappability (proportion of nights on which rats were caught) between Norway and ship rats (both sexes combined) or between males and females of each species ($p > 0.05$).

Tracking rates at Hal/moon Bay

Of 2190 tracking papers or chalk tunnels marked by

rats, positive identifications were possible from 43.2%. Despite baiting of tunnels only 9 (0.4%) papers were 'overtracked' and therefore unreadable. When examining the prints, papers from the same tunnel were considered separately, but if a marked rat left prints on both papers in the tunnel on the same night this was treated as a single record.

Twenty-two (45.8%) of the marked rats entered tracking tunnels, including four which were never live-trapped again after initial capture. Some rats were tracked up to 68 times. Some Norway rats tracked significantly more tunnels per night (mean = 0.63) than ship rats (mean = 0.30 tunnels) (Kolmogorov Smirnov two sample test: $X^2 = 9.60$, d.f = 2, p 0.01).

Population estimates at Halfmoon Bay

Minimum estimates of the population were obtained by adding the number of rats trapped, re-trapped or tracked each day to those known, through subsequent capture or tracking, to have been alive at the time. Marked rats were assumed to be resident in the study area between initial capture and final detection. The minimum number known to be alive (Fig. 3) increased steadily over the first week and a half of the study because of the increasing proportion of the population being marked. Thereafter density varied little until poisoning and snap-trapping at the end of the study.

Between 10 January and 8 February 64% of all the rats trapped had been marked and 50% of all

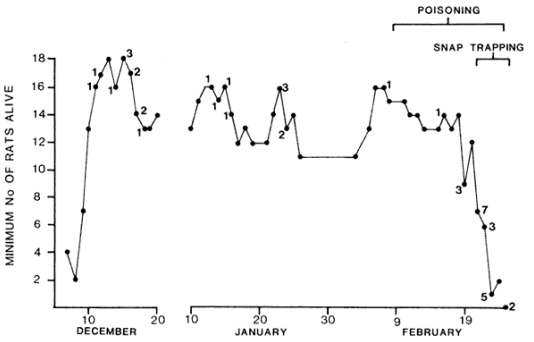

Figure 3: *Minimum number of R. rattus and R. norvegicus alive on the live trapping area between December and February. The number killed in traps or during anaesthesis is given beside the point for that day.*

tracks left in tunnels were from marked rats. Over this period the average minimum number of rats known to be alive was 13 (1 *R. norvegicus* and 12 *R. rattus).* If 50-64% of the population was marked, an average of 21-26 rats resided in the study area at this time. The effective trapping area (Dice, 1938) was calculated to be 10.4 ha after adding a border strip equal to half the calculated mean range length of ship rats (see later) to the three landward sides of the trapping area. (Insufficient range length data were available to allow

Table 4: *Range lengths and minimum home range areas for monthly sample periods, and numbers of fixes for male (M) and female (F) rats with stable range lengths. as revealed by trapping and tracking. .*Home range extended to edge and perhaps beyond study area. + Juvenile.*

Tag Number	Month	Number of fixes	Range length (m)	Home range area (ha)
Rattus rattus				
MI85	January*	19	218	0.37
FI73	December	23	130	0.24
F198	January*	24	140	0.76
	February*	48	115	0.56
F202+	January*	37	159	0.74
	February*	35	222	0.81
F204	January	19	120	0.58
	February	32	90	0.39
F123	February	35	80	0.41
Mean ± S.E.			142± 17	0.54 ± 0.07
R. norvegicus				
M176	December*	24	342	4.0
F206	January	23	128	0.55
Mean ± S.E.			235 ± 107	2.3 ± 1.7

the same calculation for Norway rats). Using this area the average density of rats of both species combined was estimated to be 2.0-2.5 per hectare (1.8-2.3 ship rats; 0.17-0.21 Norway rats per hectare).

Rat movements and home ranges at Halfmoon Bay

Minimum home range sizes (Stickel, 1954) were calculated only for those eight rats for which 'stable' ranges had been determined (Table 4). Ranges were considered stable when the observed range length (maximum distance across the home range) did not increase as the number of trap and tracking fixes increased. This stage was usually reached after at least 10 fixes had been recorded. The mean of nine monthly home ranges for six ship rats was 0.54 (S.E. = 0.07) ha, while two Norway rats had monthly home ranges of 0.55 and 4.0 ha. The greatest recorded distance moved in one night was 250 m by male Norway rat 176 (Fig. 4). During three consecutive nights this rat traversed nearly the whole length of the study area. We do not know if he visited the southern end of the study area regularly or irregularly.

Norway rats did not always remain near creeks or the shoreline. Female 206 was consistently located well away from the creek (Fig. 4). Male 176, though spending most of his time along creeks and the shoreline, was occasionally recorded up to 75 m from the nearest water. The distribution of distances from the nearest water to the traps or tracks where ship rats or Norway rats were located was similar to the distribution for all traps and tracking tunnels available in the area (Table 5). The distributions of distance to nearest water were not significantly different for ship rats and Norway rats (X^2 = 3.22, d.f. = 5, p>0.10).

The tracking and trapping data are too few for adequately examining home range overlap between Norway rats (Fig. 4), or between male ship rats. In January and February a mature 141 g adult female

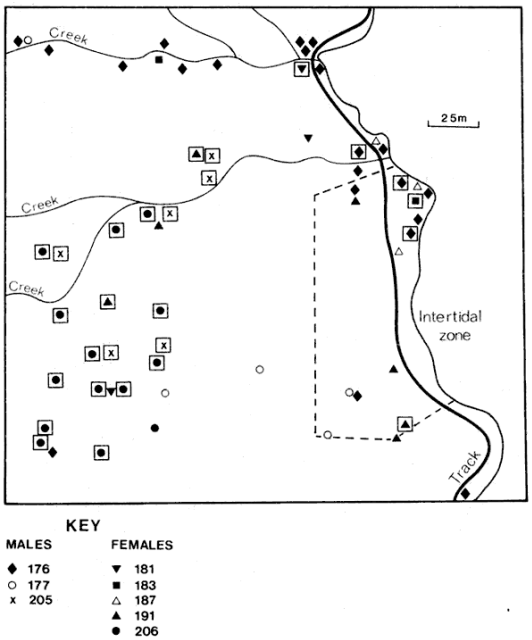

Figure 4: *Fixes of Norway rats in December (unboxed) and January (boxed). The dashed line outlines the area where poison stations were placed.*

Table 5: *Distance to nearest water (creek or shoreline) of aI/locations where ship rats and Norway rats were trapped or tracked. The expected number of rats was determined from the number of all traps and tracking platforms on the study area at progressively longer distances from water (given in the last column). Observed and expected distributions are compared by a goodness-of-fit test.*

Distance to water (m)	*Rattus rattus*		*R. norvegicus*		No. of traps or Tracking tunnels
	Observed	Expected	Observed	Expected	
0- 9	104	94.0	32	24.3	96
10-19	29	38.2	7	9.9	39
20-29	29	28.4	3	7.3	29
30-39	24	18.6	6	4.8	19
40-49	19	15.7	5	4.0	16
>50	31	41.1	8	10.6	42
X^2	8.03		7.01		
d.f.	5		5		
p	>0.05		>0.05		

ship rat (198) and an immature 40 g female (202) repeatedly used the same area (Fig. 5). When snap-trapped at the end of the study, rat 198 did not carry uterine scars, so was not the mother of 202. Once in January, rat 198 was also recorded in the area usually tracked by adult female 204, but at other times in January and throughout February these two appeared to maintain exclusive home ranges (Fig. 5). Otherwise, contiguous boundaries with limited overlap were observed between female ship rats in February (Fig. 5).

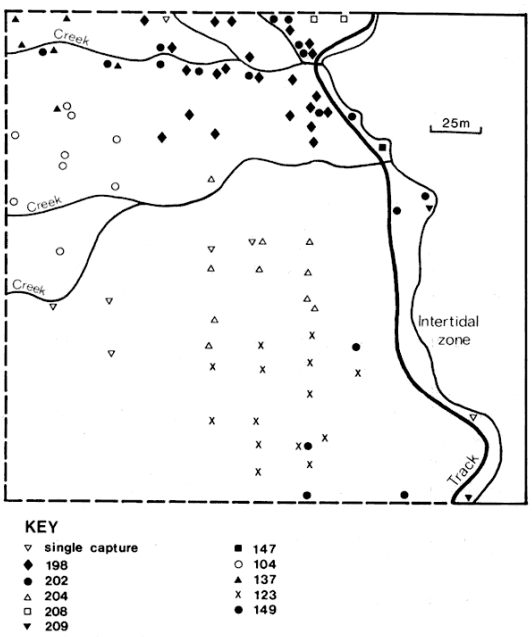

Figure 5: *Fixes of female ship rats in February.*

Snap-trapping at Halfmoon Bay

Snap-trapping killed 7, 3, 5, 0 and 2 ship rats, and no Norway rats, on 5 successive nights after 21 February. Only 8 of the 17 rats snap-trapped were marked, significantly fewer than among those live-trapped or tracked in the last week before snap-trap removal (18/20 rats trapped, $X^2 = 6.1$, d.f. = 2, $p < 0.05$; 50/57 tracks, $X^2 = 12.6$, d.f = 2, $p < 0.01$).

Poisoning at Halfmoon Bay

Eighty-three of the 306 poison baits were taken from 16 of the 51 poison stations during the 16-day poisoning period. There was a sharp decline in the take after the first three days, and except for a brief resurgence the rate of bait removal remained low (Fig. 6). In the last three days of poisoning, an average of 0.6 pellets was removed per night compared to an average of 14.0 per night in the first three days: a 96% reduction, and highly significant statistically ($t = 8.00$, d.f = 4, $p < 0.01$).

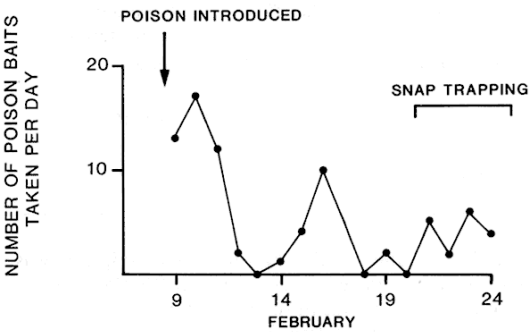

Figure 6: *Rate of removal of poison baits from poison stations in the live-trapping area.*

Two days after removal of bait from two poison stations no tracks were left at nine nearby tunnels, which until then had been visited consistently. Tracking ceased at another nine tunnels within three days of poison being removed from five adjacent stations. Apparently the rats were succumbing within 2-3 nights after eating poisoned baits.

The number of tunnels in the poisoned area which were tracked declined by 93 % from the first three days of poisoning to the last three days before traps were removed. The comparable figure for the entire study area was 76%.

Of 16 marked rats known to be alive in the live-trapping area when poison was first deployed, one was killed in a live-trap, and eight were later snap-trapped. Another rat, caught for the first time after poison was laid, died three days later in a live-trap. The remaining seven (47%) rats probably were poisoned (two were found dead, the rest disappeared). All three of the marked rats whose home ranges overlapped the poison area disappeared during the poisoning.

Discussion

Population density and trappability

Our trap success for all species was similar to that of previous trapping studies on the Stewart Island

Table 6: *Trapping data for Stewart Island.* + 95% *binomial confidence intervals are given within brackets. .*All Pegasus lines except Rosa Island and Fish Factory.*

Source	Date	Habitat	Corrected rat trap nights	Corrected trap success (%) Kiore	Ship	Norway	All rats
Taylor (1975)	Dec 1950	Forest & Scrub	107.5	0.9 (0-5) +	10.2 (5-17)	8.4 (4-15)	20.6 (19-36)
Choate & Gibbs (1964)	May 1964	Virgin & 2nd growth forest	127.5	0 (0-3)	8.6 (4-15)	3.1 (1-8)	11.8 (7-19)
Taylor (1975)	lan 1974	Grassland, scrub, forest	23.5	8.5 (1-28)	34.4 (16-57)	12.8 (3-34)	55.3 (34-77)
Gales (1980)	Mar 1980	Forest	166	0 (0-2)	18.1 (13-25)	1.8 (0.4-6)	19.9 (14-27)
Present Study	Aug/Sep 1984	Forest.	210.5	0 (0-1)	16.6 (5-10)	0.9 (0-1)	17.5 (5-10)
All studies	-	-	635	0.5 (0.1-1. 7)	15.0 (12-18)	3.3 (2-5)	18.7 (16-22)

mainland (Table 6). The capture rate of ship rats was higher than in mixed forest of South Westland and Fiordland, but is within the range for more northerly mixed forests of the New Zealand mainland and large offshore islands (Daniel, 1978). The high trap success on Rosa Island (Table 1) reflects an overall trend for rodents to reach higher densities on small islands (Daniel, 1978; Fitzgerald, 1978; Gliwicz, 1980).

Our estimate of absolute density of ship rats at Halfmoon Bay (2.0-2.5/ha) is close to the average estimated by Daniel (1972) in a North Island mixed forest. Our calculation slightly underestimates rat density because undetected rats probably lived on the trapping area throughout the study and a few marked rats may have survived both poisoning and final snap-trapping. The higher proportion of unmarked rats snap-trapped compared to that live-trapped suggests that some rats were shy of live-traps. The estimate of density may also have been affected by the high death rates in the live-traps. Immigration into the area may have caused the relative stability of the population estimates (Fig. 3), but some reproductive recruitment also occurred at this time since two ship rats gave birth while in live traps and 6 of 14 mature females from the trapping area were pregnant.

The trap successes for kiore and Norway rats on Stewart Island (Table 6) are low compared to other islands around New Zealand, but are typical of mainland areas (Moller, 1977; Moors, 1985b). The conclusions of this study are therefore more likely to be applicable to large islands and the mainland, than to smaller islands. Our finding that Norway rats were at least as trappable as ship rats (Table 3) is surprising, since Norway rats are reputed to be particularly hard to catch. Similar trappability of the two species suggests that the overall lower catch rates of Norway rats on Stewart Island (Table 6) reflect a lower absolute density than ship rats in the forests there.

Occurrence of kiore and Norway rats on Stewart Island is more patchy than that of *R. rattus,* which was trapped in good numbers by us and by previous workers (Tables 1 and 6). Preference of *R. exulans* for grassland (Taylor, 1975) or low scrub (P.J. Moors, pers. comm.) on Stewart Island may explain the absence of this species from the catch from forests. Competitive interactions between the rat species may also restrict habitat use, particularly by kiore (Taylor, 1975, 1978; Moller, 1977).

Rat movements

Ship rats at Halfmoon Bay moved greater distances than has previously been reported in New Zealand (Daniel, 1972; Innes and Skipworth, 1983; Moors, 1985b). Furthermore, the actual average home range size in our study would have been higher than our estimates suggest, because four of the eight rats tracked had home ranges which appeared to extend beyond the edge of the trapping area.

Previous studies have indicated that home ranges of female ship rats are predominantly non-overlapping (Innes and Skipworth, 1983; Daniel, 1972). While some data in our study support that conclusion, a juvenile and adult female frequently used the same area (Fig. 5). Some of the contiguous boundaries between adult females may have occurred by chance

rather than resulting from territorial exclusion. Daniel (1972) reported that male ship rats had overlapping home ranges, but he combined data collected over long periods. More intensive studies are still needed, particularly of male ship rat movements.

Information on Norway rats was too sparse and the trapping area too small for an adequate description of home ranges. Live-trapping on Motuhoropapa Island in the Hauraki Gulf suggested male Norway rats had overlapping home ranges, but the spatial arrangement of females was not known (Moors, 1985b). Our results showed that Norway rats were often found well away from the shoreline and from creeks. This supports Taylor's (1978) suggestion that Norway rats become closely associated with water only when stoats are present. However, our observations differ markedly from those of P.J. Moors (pers. comm.) in the Scollay's Flat region of southern Stewart Island, where most Norway rats were trapped within 5 m of running water. Clearly, Norway rat movements vary considerably even on the same island without stoats.

Poisoning campaign

The large size of home ranges revealed in our study indicates that an 8-10 m spacing of poison bait stations was much closer than was necessary to put several bait stations inside the range of each resident rat. Assuming that home ranges are approximately circular, rats visiting the shoreline (and any boats moored there) may have range centres 40-110 m inland (Le. half the range length measured; Table 4). Poison stations could in future be placed up to 100 m back from the shoreline to maintain a wide buffer zone around the anchorage. There was no evidence for linear home ranges of rats along the shoreline to support a concentration of poison stations here, but use of one or two lines of poison stations near the shoreline is logical and simple to service.

The 93% decrease in tracking rate and the 96% decrease in poison removal from the initial to final three days of poisoning suggests that the majority of rats living in the poison zone were poisoned. None of the rats with home ranges known to include the poisoned area appeared to survive the 16-day poisoning campaign. The 76% decline in tunnel visiting on the entire trapping area from the initial to final three days of poisoning exceeds the 47% of tagged individuals known to be present which died or disappeared over that time.

There were undoubtedly other marked rats alive but undetected in the area just before poison was used and which died during the 16-day campaign. In contrast, probably all the marked rats which survived poisoning were detected in the intensive snap-trap removal experiment. The proportion of known residents killed must therefore underestimate the actual effectiveness of poisoning. The modest decline in the minimum number alive over the poisoning period (Fig. 3) results from this same bias due to detection only of survivors and also from the capture of new (untagged) rats in the live-traps set in the last 6 days of poisoning before removal snap-trapping. The declines in tracking rates and poison pellet removal rates are therefore our best unbiased and instantaneously responsive indices of the proportion of rats poisoned.

An initial drop in poison removal after the first three days was followed by a 3-4 day pause and then a minor resurgence (Fig. 6). This resurgence may have resulted from expansion of home ranges of neighbouring rats into areas that became vacant after poisoning of their original residents. Barbehenn (1974) showed swift re-invasion of vacated areas by *R. rattus* in Guam, and Innes and Skipworth (1983) demonstrated that female ship rats started to expand their home range 2-3 nights after the removal of a neighbour. The rate of immigration is likely to be affected by density and reproductive rates in surrounding areas, both of which will vary seasonally. John Innes (pers. comm.) found ship rat numbers recovered within three months after poisoning in Pureora Forest was stopped.

Poisoning at anchorage sites

Possum interference was severe at one site and is likely to be a problem in most areas of New Zealand where similar operations are tried. Possums are not always poisoned by Talon, and their interference increased during a 2-month poisoning trial at Pureora Forest (J. Innes, pers. comm.). Removing possums by cyanide, or pinning the tunnels down, may reduce the problem.

The 52-80% reduction in rate of removal of poison at three of the southern Stewart Island anchorages after 19 weeks of poisoning is unlikely to have been due to decreased attractiveness of bait, since pellets remained dry and intact (R. Thomas, pers. comm.). Poison may have been ignored later in the summer when preferred foods became available. The decline in the rate of poison removal might have reflected a natural decline in rat numbers over this period, although there was no dramatic or pedictable spring or mid summer change in the numbers of ship rats studied by Daniel (1972) in a mainland forest. There was no suggestion of declining rat numbers in

December and January at Halfmoon Bay (Fig. 3), so natural decline at Pegasus is an unlikely explanation of the decreased removal of poison there (Fig. 2). Instead, it probably reflects a sustained fall of rodent numbers by poisoning, as demonstrated in the short term near Halfmoon Bay.

Further research on the ability of rat species to board boats would allow better targeting of poisoning efforts. Also boat-boarding may be an individually learned habit shared by a few "rogue" rats in the population. The reduction of rats along the shoreline will presumably reduce the number of rats swimming to anchored boats. Similar poisoning could reduce the risk of rats reaching other island refuges. The effectiveness of poisoning suggests that nests, roosts or colonies of endangered animals (e.g. snails), or clumps of endangered plants, could be protected from rats.

Acknowledgements

Funding for this study was provided by the Department of Lands and Survey under the Special Employment Scheme. Robin Thomas and staff of the Department of Lands and Survey on Stewart Island provided assistance and hospitality, and helped greatly in field work at southern Stewart Island anchorages. Phil Moors suggested the chalk powder system of tracking rats and, with John Innes, Tony Pritchard, John Flux and John Gibb commented on the manuscript, which was typed by Jocelyn Berney. Jo Garrick and Jocelyn Tilley prepared the figures.

References

Barbehenn, K.R. 1974. Estimating density and home range size with removal grids: the rodents and shrews of Guam. *Acta Theriologica 19*: 191-234.

Choate, T.S.; Gibbs, W.A. 1964. Small mammal investigations on Stewart Island. *Science Record 14*: 84-85.

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.

Daniel, M.J. 1978. Population ecology of ship and Norway rats in New Zealand. *In:* Dingwall, P.R.; Atkinson, LA.E.; Hay, C. (Editors) *The ecology and control of rodents in New Zealand nature reserves*. Department of Lands and Survey Information Series No.4, pp.145-152.

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

Dingwall, P.R.; Atkinson, LA.E.; Hay, C. (Editors) 1978. *The ecology and control of rodents in New Zealand nature reserves*. Department of Lands and Survey Information series No.4.

Fitzgerald, B.M. 1978. Population ecology of mice in New Zealand. *In:* Dingwall, P.R.; Atkinson, LA.E.; Hay, C. (Editors) *The ecology and control of rodents in New Zealand nature reserves*. Department of Lands and Survey Information series No.4, pp.163-171.

Gales, R.P. 1980 (unpublished). Ecology of introduced rats on Stewart Island. Diploma of Wildlife Management thesis, University of Otago.

Gliwicz, J. 1980. Island populations of rodents: their organization and functioning. *Biological Review 55:* 109-138.

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.

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.

Mainland, D.; Herrera, L; Sutcliffe, M.L 1956. *Statistical tables for use with binomial samples -contingency tests, confidence limits, and sample size estimates*. Department of Medical Statistics, New York University College of Medicine.

Moller, H. 1977. (unpublished). Ecology of *Rattus exulans* on Tiritiri Matangi Island. M.Sc. thesis, University of Auckland, New Zealand.

Moller, H. 1983. An apparatus for anaesthetizing small mammals. *Journal of Zoology 201:* 579-581.

Moors, P.J. 1985a. Eradication campaigns against *Rattus norvegicus* on the Noises Islands, New Zealand, using Brodifacoum and 1080. *International Council for Bird Preservation. Technical Publication 3*: 143-155.

Moors, P.J. 1985b. Norway rats *(Rattus norvegicus)* on the Noises and Motukawao Islands, Hauraki Gulf, New Zealand. *New Zealand Journal of Ecology 8*: 37-54.

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

Stickel, LF. 1954. A comparison of certain methods of measuring ranges of small mammals. *Journal of Mammalogy 35:* 1-15.

Taylor, R.H. 1975. What limits kiore *(Rattus exulans)* distribution in New Zealand? *New Zealand Journal of Zoology 2*: 473-477.

Taylor, R.H. 1978. Distribution and interactions of rodent species in New Zealand. *In:* Dingwall, P.R.; Atkinson, LA.E.; Hay, C. (Editors) *The*

ecology and control of rodents in New Zealand nature reserves. Department of Lands and Survey Information series No.4, pp. 135-141.