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Movements, habitat use and response of ricefield rats to removal in an intensive cropping system in Vietnam

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ABSTRACT. Rapid post-control reinvasion typically hampers attempts to manage rodent pests, yet little is known about the demography or behaviours of re-invaders. Here we study the habitat use and movement of *Rattus argentiventer* using radio-telemetry during a non-breeding season (tillering growth stage of rice) and a breeding season (ripening stage of rice) in lowland irrigated rice in Vietnam. On two treatment sites, farmers removed rats by hunting, digging up burrows and by using trap barrier systems (early planted field of rice surrounded by a plastic fence set with multiple capture rat traps), and on two control sites, farmers conducted their normal control practices. The 95% minimum convex polygon home range size of rats during the non-breeding period was 2.4 ha (n = 12) and significantly smaller than during the breeding period (9.8 ha; n = 10). There was no difference in home range size between treatment (removal sites) and control sites. During the non-breeding period, rats preferred to use the bank/channel habitat during the day, and preferred vegetable habitats at night. During the breeding period, rats preferred using rice habitats both during the day and at night. This preference during the breeding period was strongly influenced by the availability of abundant cover and food offered by the mature rice crops. Rats were moving about the rice fields in random directions and were not influenced by the removal of rats at nearby locations. We conclude that even at low population densities, rodent control would need to be conducted over large areas to prevent recolonisation through random dispersal events and that rodent burrows should be destroyed during the non-breeding season when little cover is provided by crops.

KEY WORDS : habitat use, movements, ricefield rat, removal, trap barrier system, bounty system.

INTRODUCTION

Rodents are a significant problem for agriculture in Vietnam. They are considered the number one pre-harvest pests of lowland irrigated rice crops, especially in the Mekong and Red River Deltas (BROWN et al., 1999, 2003b). In particular, the ricefield rat, *Rattus argentiventer* (Robinson & Kloss, 1916), is the most common rodent found in rice crops in Vietnam, and it is an important pest of rice crops in other parts of Southeast Asia including Malaysia and Indonesia. In Indonesia, it causes annual pre-harvest losses of around 17% (GEDDES, 1992; LEUNG et al., 1999). Other rodent species inhabiting rice fields in Vietnam include *R. losea*, *R. rattus* and *Bandicota indica* (BROWN et al., 1999, 2003b). Little is known about how these rodent pest species interact with each other within the rice growing areas or how management should be implemented in a palliative manner to reduce damage to rice crops. Currently, most farmers are reactive in their control actions, only implementing management once the rat problem is moderate to severe.

Methods for controlling damage caused by rodents in rice agro ecosystems include application of rodenticides (BUCKLE, 1999), hunting, fumigation, physical barriers such as the trap barrier system (TBS, SINGLETON et al., 1998, 1999), and cultural practices such as synchronised cropping, sanitation of fields and encouraging predators (such as barn owls) (LEUNG et al., 1999). There are few data on how rat populations respond to such control actions or how quickly reinvasion occurs. Also of interest is how rats respond to control at different stages of crop development when the availability of food and cover changes, and whether there are differences in response in breeding and non-breeding seasons of the rats.

A key strategy for animals successfully reinvading areas is to have high rates of dispersal. One method for measuring rates of dispersal of small mammals into vacant areas is to experimentally remove animals from grids. SCHIECK & MILLAR (1987) studied the response of red-backed voles (*Clethrionomys gapperi*) to removal trapping in a mountain fir forest in Alberta Canada and found that about 80% of the voles caught in the removal area originated from a distance of less than two home ranges away. NAKATA & SATOH (1994) studied the response of individual grey-backed voles (*Clethrionomys rufocanus bedfordiae*) to removal trapping to determine the source of animals moving into the removal grid and the distance that these animals moved from source areas. After 2 weeks, over 90% of the voles initially located within 30 m of the edge of the removal grid were making single-direction movements towards the removal grid. Conversely, BOUTIN et al. (1985) found that only 28% of snowshoe hares (*Lepus americanus*) dispersed into removal areas and that most animals died on their home range rather than dispersing, while SULLIVAN & SULLIVAN

(1986) found that the colonization rate was 25 – 58% per four-week period.

There are few examples where researchers have monitored changes in movements of pest small mammals in natural field conditions using contemporary control methods. EFFORD et al. (2000) looked at home range changes in feral brushtailed possums (*Trichosurus vulpecula*) in New Zealand after applying an 80% control in one half of their experimental plot. They found that possums on the edge of the control area moved their home ranges towards the removal area and that the "vacuum effect" in the possums was largely confined to home range adjustments by individuals that had ranges overlapping the area of reduced density. LEIRS et al. (1997) found that recolonisation of maize fields by the multimammate rat (*Mastomys natalensis*) occurred very rapidly after a rodent control operation.

Despite the economic and social costs caused by *R. argentiventer*, its habitat use and movements in the rice agro-ecosystems of Vietnam is not well understood. In West Java, Indonesia, there are two lowland irrigated rice crops produced each year corresponding with the wet and dry seasons. *Rattus argentiventer* accounted for >95% of rodent species captured (LEUNG et al., 1999) and were found to have home ranges of 1-3 ha, with little differences between males and females, with smaller home range in the breeding season compared to the non-breeding season (BROWN et al., 2001). They mostly utilised banks (burrows) during the tillering stage of the rice crop (non-breeding period), but switch to daytime use of rice paddies throughout the ripening stage of the rice crop (breeding period) (BROWN et al., 2001). Research is therefore required in Vietnam because the cropping system and composition of rodent species are different.

As part of a large project examining the population response to a range of rodent control methods at a village-level (> 100 ha), we examined how individual rats used their environment and how they might respond to removal of other rats through the application of control techniques conducted by farmers. Specifically, we considered whether rats moved in a random pattern (classical diffusion) or directed their movement towards areas of lower population density ("vacuum effect" EFFORD et al., 2000). This was done by radio-tracking individual rats occupying rice fields on sites where farmers conducted a range of recommended rodent management practices (treated sites) and sites where farmers were not influenced in their rodent management techniques (control sites).

MATERIAL AND METHODS

Study site

The study was conducted in Vinh Phuc Province, in northern Vietnam, 40 km north of Hanoi (21°08' N; 105°45' E). Four study sites were selected to comprise part of a main village or sub-villages. Each site was 0.5 to 1 km apart and about 100 - 150 ha in size. The sites were set up in March 1999 to monitor the population dynamics of rats before implementation of ecologically based rodent management (BROWN et al., 2003b). Within each site families manage small plots of land, each 0.04 ha, and each family generally owns a total of 0.5 – 0.7 ha of land. The principal crop grown in the area is rice. There are two main rice-growing seasons each year, the spring rice season (transplanting late February and harvested mid June), and the summer rice season (transplanted mid July and harvested late September). Rice is not grown in winter because it is too cold. Other crops are vegetables (broccoli, cabbage, kohlrabi, onion, pumpkin, tomato) and flowers (chrysanthemum, rose). Summers are hot and wet, and winters are cool and dry. The annual average rainfall is approximately 1600 mm, most falling during May to September. Farmers irrigate their crops from channels using water supplied from large storage dams in nearby hills. The soil type is heavy red clays.

The radio-tracking study was conducted during the spring rice season in 2002. Rice was sown in February 2002 and then harvested in late June and early July 2002. Two sessions of radio-tracking were conducted to coincide with the non-breeding season of rats (during the tillering stage of the rice crop; March) and during the breeding season of rats (during the ripening stage of the rice crop; June).

Trapping and radio-tracking

At each site, rats were caught using single-capture wire cage traps. Traps were baited with fresh vegetables and set strategically at sites where there was obvious rodent activity to catch as many rats as possible over an area of 250 x 250 m. At each site, fifty traps were set per night for eight consecutive nights in March and six consecutive nights in June. All adult female *R. argentiventer* rats were collared on treatment and control sites and all adult male *R. argentiventer* were collared on control sites only. Resources and labour were limited so we chose not to monitor males on treatment sites. Traps were checked hourly during the first few hours after sunset and early each morning. At capture, each rat was weighed (± 2 g), sexed, and breeding condition determined and to confirm species identification and condition. Females with raised teats and perforated vagina were classified as adults, and males with descended testes were classified as adult. Prior to release, at point of capture, each rat was fitted with a single-stage radio transmitter (Sirtrack, New Zealand) attached to a nylon cable tie which functioned also as a collar around the animal's neck.

A 250 x 250 m grid of bamboo poles set 25 m apart was used to provide reference points for locating radio-collared rats. Radio tracking at all sites was conducted for up to 14 days in both March and June. Four locations or "fixes" were sought each day : one during daylight hours (0800-1400 hrs) for location of rat nests; and three after dusk (1900-2400 hrs) when rats were most active. Night fixes were 1 to 1.5 hours apart. It was not always possible to obtain three fixes for each rat after dusk. Collared rats were tracked with a hand-held 3-element Yagi antenna connected to a radio receiver. More than 80% of location fixes were tracked to within 1 m of their actual location, based on sightings of collared rats. For others, it was not possible to obtain more accurate fixes, because rats were moving around in rice paddies and would swim away before we could obtain an accurate fix. The habitat type (large roadside bank or channel bank, rice paddy, vegetable crop, fallow, flower crop) and activity (e.g. sighted in field or known to be in a burrow) were recorded for each fix.

Home ranges were calculated from 95% and 100% minimum convex polygons (MCP) using RANGES V (KENWARD & HODDER, 1996). We calculated 95% and 100% MCP because the 100% MCP may include forays from their core areas to explore new areas and thus relevant to our hypotheses. Analyses were performed on rats that had >15 fixes, the minimum number of fixes required to estimate 80% of the home range size as found by BROWN et al. (2001) and confirmed with these data. Home ranges were ln-transformed to reduce the skewed distribution for statistical analysis. The range span was also calculated using RANGES V, and is defined as the largest distance across the MCP.

The habitat use for each rat was determined within each individual animal's home range by examining the proportion of fixes within each habitat type (OTIS & WHITE, 1999). Log ratios of usage/availability were calculated for each habitat for each rat as the basis for compositional analysis of proportional habitat use (AEBISCHER et al., 1993). Habitat availability and use was compared between months (March and June) and time of day (Day or Night). During each tracking session, the crop types grown in each field within the 250 x 250 m grid (6.25 ha) area were recorded by walking through each site. The area of channels, banks and paths was estimated by measuring their widths and lengths. The area of each habitat type was then calculated and converted to a proportion of habitat available.

Implementation of treatments

On Treatment sites (T1 and T2), two areas were set up : 1) where rats were captured and collared for radio-tracking (non-removal area, as described above), and 2) where rats were removed. Each area was 6.25 ha in size. The removal areas were 225-250 m from the non-removal areas based on average home range sizes and distances that rats would travel and get caught in a TBS (BROWN et al., 2001, 2003a). Rats were removed by the use of a tactical bounty system (SINGLETON et al., 1999), where farmers were paid 200 dong (USD$0.02 per rat) to hunt and dig rats from the removal area at a stage when rat populations abundance was low. The bounty system operated during both March and June on both Treatment sites. In addition, on T2 in June, two trap-barrier systems (TBS; SINGLETON et al., 1998, 1999) were present with sticky rice as the lure crop (variety Khang Dan, 140-150 days duration, established in late March and harvested after we concluded field work in June). On Control sites (C1 and C2), farmers conducted their normal rodent control practices.

To measure the distance and direction of movements of rats from non-removal areas the average location from the first two days of tracking (calculated by averaging X- and Y- coordinates of the first 5 -8 fixes) and the average location from the last two days of tracking (last 5-8 fixes) were calculated for each rat. Each period of tracking contained at least two daytime locations. The distances (m) and directions (bearings) moved from the first two days to the last two days were then determined. On Control sites, distances and directions towards the principal compass points (± 45° of each of N, E, S, and W) were calculated, and on Treatment sites, distances and directions towards the removal area (± 45° of N for Treatment 1, ± 45° of E for Treatment 2) and away from removal areas, were calculated.

RESULTS

In March, we trapped 51 rats from 2800 trap nights (trap success = 1.8%) in total from all sites, and in June we trapped 21 rats from 2400 trap nights (trap success 0.9%). Twenty-one adult *R. argentiventer* rats were collared for radio-tracking in March, and ten adult *R. argentiventer* rats were collared in June (Table 1). The regional abundance of rats at this time (spring) of year was generally low (mean trap success of 0.5% in March and 1.9% in June from our regular trapping locations as part of the village-level study being conducted, Fig. 1), and we believed we captured the majority of *R. argentiventer* present in the area. In March, 12 and three rats were removed by farmers by hunting and digging burrows from removal areas on Treatment 1 and Treatment 2 respectively, and in June, 63 and 50 rats were removed by farmers from removal areas on Treatment 1 and Treatment 2 respectively, most of which were juvenile animals dug from nests (evidence of active breeding on the sites).

In March, 12 rats had > 15 fixes (57% of rats captured), whereas ten rats in June had > 15 fixes (100%). Nine rats collared and released in March died from suspected poisoning (small movements, lethargic behaviour observed, or were found lying dead on the ground), one died from predation (found radio collar lying with remains of internal organs) and two were thought to be hit by farmers (fatally wounded by blow to body), whereas in June, there was no mortality of radio-collared rats during the tracking period (Table 1). If we combine deaths due to rodenticide and injury, we find that in March, farmers caused a mortality rate in collared rats of 20%, 85%, 67%, and 33% for C1, C2, T1, and T2 respectively (52% overall).

The average home range size of rats (estimated using the 95% minimum convex polygon method) in March was 2.40 ha (± 0.47 SE) and in June was 9.79 ha (± 3.31 SE) (Fig. 2). The ln-transformed home range size for female rats was significantly larger in June than in March, ($F_{1,13}$ = 4.781; P = 0.048), but there was no difference between Treated and Control sites ($F_{1,13}$ = 0.005; P = 0.947;). We could not test for differences between males and females, because no males were captured in June.

TABLE 1

Summary of radio-collared rats in March (non-breeding season) and June (breeding season) at Vinh Phuc, Vietnam. Shown are Control (C1 and C2) and Treatment (T1 and T2) sites, radio-collar frequency, sex, the number of days each animal was tracked, the number of fixes obtained, the fate of the animal, the home range sizes (ha, calculated using 95% and 100% minimum convex polygon, MCP) and home range span (m).

Tracking period	Site	Rat No.	Sex	No. days tracked	No. fixes	Fate	95% MCP	100% MCP	Span
March	C1	37	M	8	28	Alive	1.01	1.15	187
		64	M	8	28	Alive	4.99	5.07	496
		47	M	12	45	Alive	3.13	3.96	360
		241	F	7	21	Poisoned	2.32	2.33	329
		15	F	9	30	Alive	1.28	1.85	309
	C2	3	M	2	5	Poisoned	-	-	-
		6	M	2	6	Poisoned	-	-	-
		55	M	11	42	Alive	0.93	0.94	186
		60	M	6	24	Poisoned	2.10	2.27	265
		24	M	1	2	Poisoned	-	-	-
		54	M	1	2	Fatally injured	-	-	-
		41	M	2	5	Poisoned	-	-	-
	T1	75	F	9	28	Poisoned	4.18	4.59	342
		68	F	2	5	Poisoned	-	-	-
		60	F	2	3	Predation	-	-	-
	T2	25	F	12	43	Poisoned	0.14	1.33	199
		39	F	9	39	Alive	3.79	4.43	381
		43	F	2	6	Fatally injured	-	-	-
		44	F	14	52	Alive	4.19	4.83	716
		45	F	13	50	Alive	0.79	0.91	217
		49	F	1	3	Missing	-	-	-
June	C1	66	F	10	34	Alive	16.75	18.28	827
		26	F	9	30	Alive	3.83	3.85	370
		79	F	10	30	Alive	1.04	1.07	193
	C2	53	F	13	46	Alive	4.89	9.90	487
	T1	33	F	14	48	Alive	1.44	1.49	256
		73	F	13	47	Alive	2.56	2.74	287
		20	F	12	43	Alive	15.26	16.03	908
	T2	23	F	14	45	Alive	2.08	4.16	355
		71	F	13	45	Alive	17.07	19.28	755
		57	F	9	32	Alive	32.97	43.91	1433

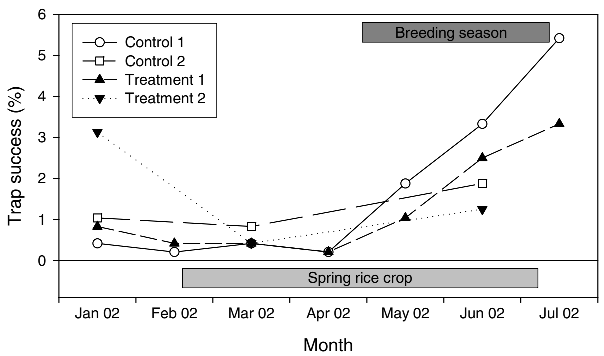

Fig. 1. – Abundance of rats (number of rats captured per 100 trap nights) on four sites used for a separate village-level study, Vinh Phuc, Vietnam from January to July 2002. Shown is approximate timing of the spring rice crop and rat breeding season (based on pregnant and lactating adult females) (P. R. Brown and N. P. Tuan unpublished data).

The home range size of rats calculated using the 100% MCP in March was 2.81 ha (± 0.48 SE) and in June was 12.07 ha (± 4.18 SE). The 100% MCP home range size in March was 0.40 ha larger on average (17.8% increase) and in June was 2.28 ha larger on average (16.3% increase) than 95% MCP. There was no significant difference in size of home ranges between the 95% and 100% MCP (paired t-test; t_{19} = -0.508, P = 0.618), therefore the 100% MCP did not provide additional information for home range analysis.

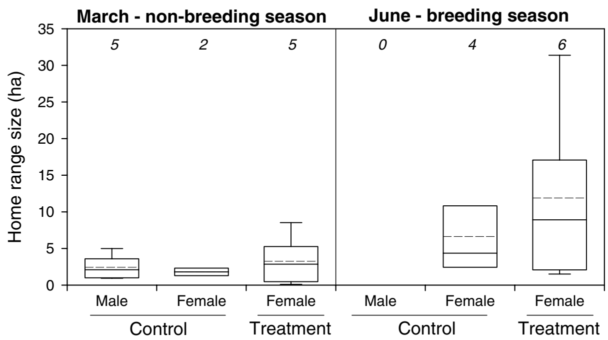

Fig. 2. – Box plot of 95% minimum convex polygon home range sizes (ha) for males and females, in treatment and control sites for March (non-breeding season) and June (breeding season). The box encloses the 25th and 75th percentiles; the solid line shows the median and the dotted line the mean home-range size. Vertical lines span the 10-90th percentiles. Sample sizes are shown at the top.

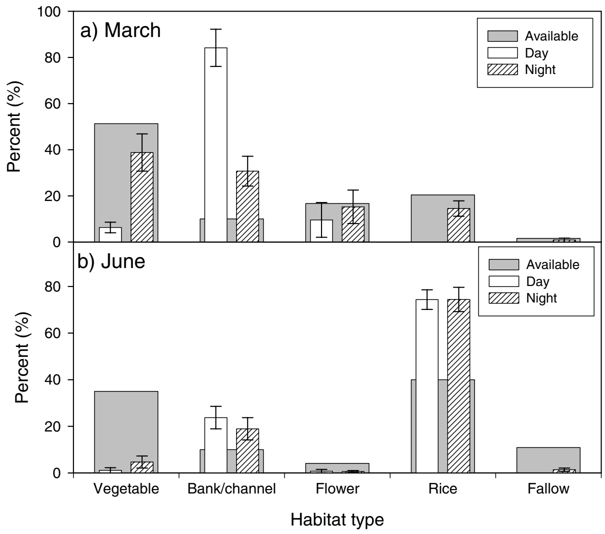

Fig. 3. – Habitat use of ricefield rats (sexes and sites combined) showing the percentage of habitats available to rats and the percentage of radio-telemetry location fixes within each habitat type for day and night fixes, Vinh Phuc Province, Vietnam 2002. (a) March, the non-breeding period for rats during the tillering stage of rice, and (b) June, the breeding period for rats during the ripening stage of rice. Error bars represent standard error of means from habitat use of individual rats.

The home range span of rats was used as an estimate of possible linear movements (Table 1). There was no significant difference between home range span between months ($F_{1,13}$ = 1.409; P = 0.256) or treatment ($F_{1,13}$ = 0.253; P = 0.624). The average home range span in March was 332.3 m (± 44.0 SE, n = 12) and in June was 587.1 m (± 123.4 SE, n = 10). This confirms that the distance between non-removal and the removal areas was set at the right distance (225-250 m).

In March, rats spent most time during the day in the bank/channel habitat (82.8% compared to 10% available) and at night most fixes occurred in the vegetable habitat (37.7% compared to 51.3% available) (Fig. 3a). Rats were not located in rice fields during the day at any stage during March. Rats used the flower habitat roughly in proportion with availability (day fixes = 10.3%; night fixes = 15.91; available 16.7%). Some rats consistently had day and night fixes in flower fields suggesting they had constructed a burrow there and were feeding within the field.

In June rats were spending more time in rice habitats with 73.2% of day fixes and 73.9% of night fixes in rice paddies compared to the 40.0% available (Fig. 3b). Rats had reduced their use of bank/channel habitats to 25.0% and 18.8% for day and night fixes respectively (compared to 10% available). Very few fixes occurred in vegetable, flower or fallow fields. The availability of crops changed between March and June because of changes in the types of crop grown.

The ratios of usage/availability confirm that in March, rats preferred to use bank habitats, and in June, rats preferred to use rice habitats and banks to a lesser extent (Table 2).

The distances moved by rats from the average of the first 2 days to the last 2 days were generally twice as large on treated sites as they were on control sites (Control March = 88.0 m ± 30.6 SE, n = 7; Treatment March = 190.9 m ± 94.0 SE, n = 5; Control June = 184.9 m ± 65.8 SE, n = 4; Treatment June = 411.8 m ± 166.1 SE, n = 6) (Fig. 4), but the distances moved were not significant (Time $F_{1,18}$ = 2.86; P = 0.108; Treatment $F_{1,18}$ = 0.278; P = 0.604; interaction $F_{1,18}$ = 0.06; P = 0.811).

The directions moved by rats on control and treatment sites were proportional with the directions available. On control sites, there were three rats that moved towards North, three to East, five to South and zero to West, with no preference for direction moved (the association between the observed directions used and directions expected was not significant : χ^2_3 = 4.636; P = 0.2004). On treatment sites, there was one rat that moved towards the removal area and 10 rats that did not move towards the removal area (1/5 rats in March and 0/6 rats in June), with no preference for direction moved (χ^2_1 = 1.778; P = 0.1824). Therefore, the direction of movements were essentially random on both control and treatment sites.

To confirm that rats were indeed breeding in June, the animals that could be retrieved were assessed for breeding condition (presence of embryos or litter of pups in the burrow). Of the three female rats recaptured, one was pregnant and two had young pups in their burrow, confirming that they were indeed breeding (100%). The breeding condition of the other females could not be ascertained because it was not possible to recapture the animals.

TABLE 2

Habitat selectivity of ricefield rats during March (tillering stage of rice crop; non-breeding season) and June (ripening stage of rice crop; breeding season) for day and night fixes for each habitat, Vinh Phuc province, Vietnam. The selectivity index is calculated by dividing the proportion of observations of rats in each habitat type by the proportion of habitat available. A selectivity value of > 1 implies preference while a value of < 1 implies avoidance.

Month	Time	Vegetable	Bank	Flower	Rice	Fallow
March	Day	0.12 ± 0.04	8.42 ± 0.81	0.57 ± 0.45	0.00 ± 0.00	0.01 ± 0.00
	Night	0.76 ± 0.16	3.07 ± 0.65	0.91 ± 0.43	0.71 ± 0.16	0.53 ± 0.52
June	Day	0.02 ± 0.02	2.37 ± 0.48	0.05 ± 0.05	3.65 ± 0.21	0.01 ± 0.00
	Night	0.09 ± 0.05	1.89 ± 0.48	0.04 ± 0.02	3.65 ± 0.26	0.86 ± 0.45

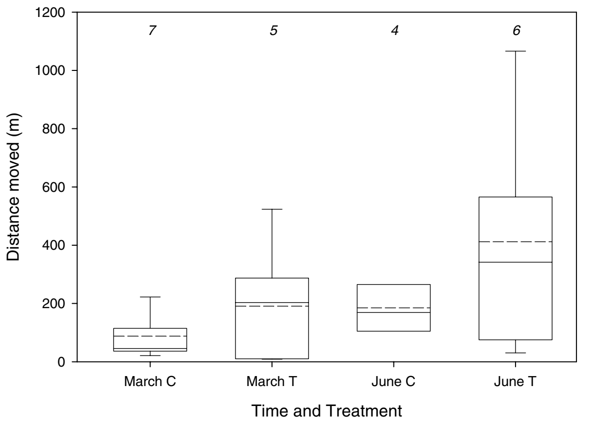

Fig. 4. – Box plot of distances (m) moved by rats from first 2 days to last 2 days of tracking on Treatment (T) and Control (C) sites in March and June 2002. The box encloses the 25th and 75th percentiles, the solid line shows the median and the dotted line the mean distance travelled, and the vertical lines span the 10-90th percentiles. Sample sizes are shown at the top.

DISCUSSION

The removal of ricefield rats during a low-density phase in an intensive cropping system in Vietnam did not induce movements of neighbouring rats towards the removal area. Rats on non-removal areas were moving randomly with regard to directions, and we believe that for *R. argentiventer*, recolonisation events during low-density phases occur through random dispersal events (classical diffusion). We could not support the "vacuum effect" proposed by EFFORD et al. (2000) for brushtail possums in New Zealand, however the density of rats in this study was low. KREBS et al. (1976) found that recolonisation rates were higher when densities of *Microtus townsendii* were higher because of competition for space, so this study should be repeated at higher densities (>10% trap success) to test this hypothesis.

It is likely that populations of ricefield rats are made up of predominantly transient animals with high rates of dispersal, as found for multimammate rats (*Mastomys natalensis*) in Tanzania (LEIRS et al., 1996). We found rats moved around a great deal, and in some cases rats had very large home ranges (> 5 ha) and did not consistently use a particular burrow or nest site. In studies conducted in both Vietnam and Indonesia, ricefield rats have recapture rates of less than 1% (BROWN et al., 1999, 2003b; LEUNG et al., 1999; JACOB et al., 2003b), and part of this reason may be because of the high proportion of transient animals. We therefore predict that rats inhabiting these highly modified and intensive rice production systems would have higher rates of dispersal than rats living in stable environments.

The home range size of rats during the non-breeding season (tillering stage, March; 2.7 ha) was of the same order as that found for ricefield rats in Indonesia (2-3 ha, BROWN et al., 2001). However, the home range size was much larger during the breeding season (ripening stage, June; 10 ha) than in Indonesia. We were surprised to find that home range sizes were larger during the breeding season. In house mice in Australia, for example, home ranges were significantly smaller during the breeding season (CHAMBERS et al., 2000). The home range size of *Rattus rattus* in macadamia nut orchards in Hawaii did not vary between males and females and did not vary through different stages of nut development (TOBIN et al., 1996). CHRISTENSEN (1996) found no seasonal variation in home range sizes of *Mastomys natalensis* in Tanzania as determined by capture-mark-release data. However, both male and female *Calomys venustus* in Argentine agroecosystems had larger home ranges during the breeding season compared to the non-breeding season (PRIOTTO et al., 2002). It is not clear why *R. argentiventer* might have a larger home range during the breeding season (June), but it could be related to the farming activities or farmers preparing for harvest. We expected that adult female rats, if they are actively breeding, would have stable, small home ranges particularly if they are caring for young in the nest. The recaptures of rats in June confirmed that the rats were indeed breeding (pregnant or suckling new born pups).

We could not prevent farmers from undertaking extraneous rodent control on our study sites. On our control sites in March, farmers poisoned nine radio-collared rats with rodenticide and two other rats died through farmers causing fatal injury. This reflects the rat control efforts employed by farmers during the tillering stage of the rice crop. Farmers are generally busy with preparations for harvest in June, so they have little time for undertaking rodent control. No deaths of radio-collared rats occurred on any site in June. The impact of these activities on this study is difficult to determine. Rats in this intensive rice growing agroecosystem are subject to a wide array of disturbances including ploughing of fields, harvesting of crops, irrigation of crops, and application of chemicals for weed or insect control. Rat populations have developed strategies for survival under these conditions through high reproductive output (LAM, 1983; TRISTIANI et al., 1998) and through their ability to recolonise areas.

Rats were using a range of habitats that were available to them, and their choice of habitat was related to cover and availability of food. When cover from tillering rice was low (March), rats were spending time in burrows in the bank/channel habitat, and when rice was ripening (June), rats were spending their time in the rice fields. We could not measure availability of food for rats, but observations made at the time showed that abundant food was always available through ripening vegetable crops such as kohlrabi, tomatoes, cabbage and broccoli, and particularly in June, abundance of maturing rice. Food was therefore probably not a limiting resource. In March, rats preferred to use the bank/channel habitat during the day, but preferred vegetable habitats at night. In June, rats preferred using rice habitats during the day and at night. This preference in June was strongly influenced by the availability of abundance cover and food offered by the maturing rice crops. These findings are similar to that found for *R. argentiventer* in Indonesia (BROWN et al., 2001).

These results suggest that there would be little point in destroying rat burrows along channels and bank habitats during the later stages of crop growth (after maximum tillering stage of rice) because rats were predominantly utilising rice crops (BROWN et al., 2001). It would be interesting to monitor the changes in habitat use and movements of rats after harvest of the rice crop to see whether they revert back to using the channel/bank habitat or disperse to other habitats offering sufficient food and cover. JACOB et al. (2003a) found that the home range size of *R. argentiventer* in Indonesia decreased by 67% after harvest. The findings from the current research will help in refining appropriate management practices that farmers can use on a large scale (e.g. village level) (SINGLETON, 1997; BROWN et al., 2003b; LEIRS, 2003; JACOB et al., 2003b).

Further research is required to examine recolonisation when population densities are higher and to look at other compensatory mechanisms such as breeding performance and recruitment.

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