15. Population Ecology and Management of Rodent Pests in the Mekong River Delta, Vietnam

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Abstract

Rodent pests are a growing problem in rice agro-ecosystems of Vietnam. However, little is known about which rodent species are responsible for losses to crop production, let alone how best to manage their impact. A survey of rat species in nine provinces in the Mekong River Delta found that the dominant rodent species found in rice ecosystems were the rice-field rat, *Rattus argentiventer* (60%) and the lesser rice field rat, *Rattus losea* (15%). Ten other species accounted for the remaining 25% of the population, and were unlikely to cause significant damage to pre-harvest rice. The breeding patterns of the two main rodent species and the relative population dynamics of rodents in different habitats were obtained from live-trapping studies (capture–mark–release) in a range of representative habitats based in and around the rice growing regions of Long An, Kien Giang and Tra Vinh provinces. Traps were set in rice crops (one and two rice crops per year), channel banks, melaleuca forest, undisturbed grassland, and coconut and banana plantations. Supplementary kill trapping was conducted to determine the breeding status (percentage of adult females breeding, litter size and embryo development) of the rats and to confirm their taxonomy.

Our focus on the ecology of the key rodent pest species has helped to define a range of potential management practices that are considered to be environmentally sustainable, economically feasible and socially acceptable. These practices are divided into routine actions that can be conducted all the time and preventative actions if high rat numbers are forecast.

Keywords

Species composition, habitat use, breeding, rice crops, ecology, *Rattus argentiventer*, *Rattus losea*

Introduction

RATS ARE THE number one pre-harvest pest of rice in many countries in Southeast Asia (Geddes 1992; Singleton and Petch 1994). In Vietnam, rodents are one of the three most important problems faced by the agricultural sector (Huynh 1987) and the level and intensity of damage has increased since about 1992 (Table 1). In the Mekong River Delta, there were 10,125 ha of damaged rice recorded in Long An, Dong Thap and Kien Giang provinces in the 1991/92 winter–spring season. In the winter–spring season of 1992/93, the area damaged increased to 44,000 ha over ten provinces. Crop losses were estimated at 300,000–400,000 tonnes of rough rice. Damage was recorded in Long An Province to over 10,000 ha with 10–30% losses, and 4,000 ha with 50–100% losses; in Ha Tien (Kien Giang Province), 800 ha were damaged with 80% losses. In 1996, the area damaged by rats increased to 130,000 ha over most provinces of the Mekong Delta. Rats also cause damage to other crops such as corn and potato in the suburbs of Ho Chi Minh City, in coastal regions (Binh Thuan Province) and in highland regions (Dong Nai Province). The factors that have lead to increased losses include more intensive farming and a general increase from two to three crops planted per year (Singleton and Petch 1994).

The factors that lead to increases in rat numbers and the importance of various habitats for breeding and shelter have not been addressed in Vietnam. The principal pest species is thought to be *Rattus argentiventer*, however little is known about the taxonomy or the population ecology of the species of rodents which inhabit rice ecosystems in Vietnam. In contrast, rodent species that are hosts for human plague in Vietnam have been studied extensively (Gratz 1988; Suntsov et al. 1997). Population studies of *R. argentiventer* have been conducted in Malaysia (Wood 1971; Lam 1980, 1983; Buckle 1990), Indonesia (Murakami et al. 1990; Leung et al., Chapter 14) and the Philippines (Fall 1977), but these results may not be appropriate for the Mekong River Delta which experiences annual floods. Furthermore, the mosaic pattern of habitats that exist in the Mekong Delta may be favourable or unfavourable for rats.

Table 1.
Area damaged by rats (ha) in the Mekong River Delta and other parts of Vietnam, 1992–1997 (adapted from Hung et al. 1998).

Year	Mekong River Delta	Other areas	Total area damaged in Vietnam
1992	18 640	–	18 640
1993	107 481	–	107 481
1994	134 616	–	134 616
1995	74 408	18 849	93 257
1996	130 777	130 723	261 500
1997	129 512	245 488	375 000

This chapter aims to provide an ecologically-based approach to the management of rodent pests in the Mekong River Delta of Vietnam. With a good understanding of the species composition, biology and behaviour of pest species it should be possible to devise management actions that are sustainable (environmentally and culturally) and could be combined with integrated pest management programs that are in place for insects, weeds and plant diseases (Singleton 1997). To provide some initial insight into the ecology of rodent pests in rice agro-ecosystems in the Mekong River Delta, data were collected from 1994 to 1998 on (i) the composition of rat species and (ii) the population dynamics, habitat use and breeding of the main rodent species, the rice-field rat (*R. argentiventer*) and the lesser rice-field rat (*Rattus losea*). Because none of this work has been published, we will begin by considering the methods adopted. We will then present the results of this study and suggest some preliminary management recommendations. As the data are limited, further studies are necessary to refine these strategies. Also highlighted are areas where critical information is lacking and further research is required.

Methods

Study sites

The provinces of Long An, Kien Giang and Tra Vinh are situated in the Mekong River Delta of Southern Vietnam (Figure 1).

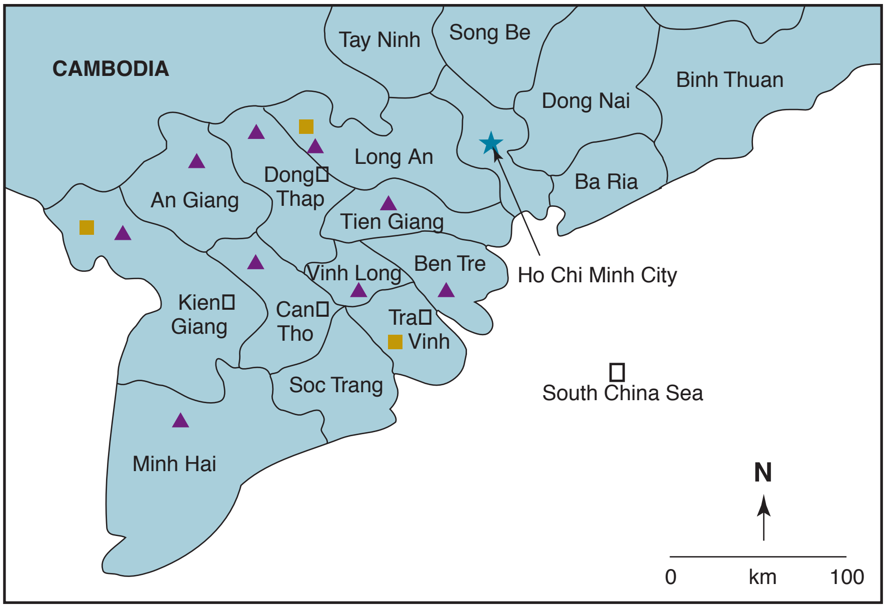

Figure 1.
Provinces of the Mekong River Delta of southern Vietnam. Shown are locations where the composition of rat species was determined (▲) and where the population dynamics of rats were assessed (■).

The annual rainfall in the region is 2,000–2,500 mm, which falls predominantly in the wet season (April to November). The topography is generally flat and some areas are regularly flooded during October and November, when the river systems overflow. The average temperatures range from 22–32°C in the dry season and 25–30°C in the wet season. There is an extensive network of channels and canals running through the delta delivering water for irrigation of rice crops. The width of the channels ranges in size from 1 m (tertiary channel), 2–5 m (secondary channel) and >5 m (primary channel).

The main rice crops grown at each study site were improved variety rice crops (90 day duration such as IR-54404, OM-1490 and OM-1037) and traditional, local variety rice (160–180 days duration). The first crop of improved variety rice was sown when flood waters subsided in December and was harvested in March (dry season crop), then the second improved variety crop was sown soon after, in late March, and was harvested in early July (wet season crop). The second crop was planted in the same paddies as the first. Once the second crop was harvested, the ground was left fallow until December. The traditional, local variety was planted in mid-July and harvested any time from mid-December to February (depending on conditions). The crop stubble of the traditional variety was left until the following season. There can be some overlap of the improved variety rice crops and the traditional variety rice crops.

Rat species composition

The composition of rat species from nine provinces was determined from six sampling occasions from November 1995 to July 1997. Fifty rats were collected at each sampling occasion (except in March 1996 when 100 rats were caught) from rice fields and from a 100 m length of a channel bank. Rats were collected by live-capture wire traps (200 × 100 × 100 mm) and from digging burrows until the required number of rats were obtained. It is not known whether this sampling procedure may cause bias towards some species. There have been no published studies that consider this bias for rodents in Southeast Asia. On subsequent visits to the sites, rats were collected from the same general area or within approximately 100 m of the area used previously. Rats were identified to species following van Peenen et al. (1969), Lekagul and McNeely (1977) and Tien (1985a,b) using external features and skeletal dimensions. Data are presented as percentages.

Population dynamics

Table 2 describes the trapping schedules for capture–mark–release studies and for breeding studies. At Long An, the rats collected were not identified to species, nor were they assessed for breeding condition.

Live-trapping was conducted using hand-made, single-capture traps (100 × 100 × 200 mm) baited with dried fish. The abundance of rats was pooled for each month, and was expressed as the number of rats caught per 100 trap-nights (trap success). On its first capture within a trap session, each rat was identified to species (based on external features, using van Peenen et al. 1969, Lekagul and McNeely 1977, and Tien 1985a,b; it was not possible to identify some animals because of taxonomical problems) and was marked using a numbered brass ear tag (Hauptner, Germany). Each rat was sexed and assessed for breeding condition, weighed (± 1 g), and tail length (if intact), hind foot length, ear length and head-body length were measured (± 1 mm). Each rat was released at the point of capture.

The minimum weight for an adult female classification was based on the lowest weight at which a rat was pregnant (determined by palpation) or lactating. Any rat lighter than this was considered juvenile or sub-adult. Palpation generally detects embryos from the second trimester, and so will underestimate breeding performance.

Breeding

At Kien Giang, kill samples were taken of rats from various habitats from captures in trap–barrier systems (see Singleton et al. 1998 and Chapter 8 for description), from live-capture traps, digging burrows and catching by hand with nets. Females were dissected to determine the condition of the uterus, number of embryos, size of embryos (± 1 mm) and number of uterine scars. Rats were considered pregnant if the uterus contained visible embryos.

Table 2.
Summary of trapping conducted at Long An, Kien Giang and Tra Vinh provinces for capture–mark–release and breeding studies.

Study site	Trapping regime schedule (No. traps per trap line)	Duration	Habitats and number of trap lines
Capture–Mark–Release			
Long An	50 traps, 1 night per week	Aug 94–Dec 96	Improved variety rice (1) Grassland (1) Cassava field (1) Melaleuca forest (1)
Kien Giang	35 traps, 2 nights per 2 weeks	Oct 97–May 98	Traditional variety rice (3) Improved variety rice (3) Melaleuca forest (3) Grassland (3) Secondary channel (3)
Tra Vinh	35 traps, 3 nights per 4 weeks	May 97–May 98	Improved variety rice (5) Primary channel bank (1) Banana plantation (1) Coconut plantation (1)
Breeding			
Kien Giang	50 rats each month	Aug 97–May 98	Various

Results and Discussion

Species composition

Twelve species of rodents were recorded from nine provinces (Table 3). Overall, the most common species was *R. argentiventer* (61%) followed by *R. losea* (15%) and *Rattus koratensis* (7.2%). *R. losea* was the most common species in Kien Giang. The *Mus* genus was likely to include *M. caroli* and *M. musculus*.

According to Sung (1998), there are 63 species of rodents belonging to 27 genera and 7 families in Vietnam. The species identified by Sung (1998) are generally similar to those that were found in our samples. In the agricultural fields of the Mekong River Delta, Sung (1998) lists *R. argentiventer* and *M. caroli* as common species with *Rattus flavipectus*, *Rattus exulans*, *Rattus nitidus*, *Mus musculus*, *R. koratensis*, *R. losea* and *Bandicota indica* found primarily around settlements. Other species of rodents identified by Sung from the zoographical zone of the Mekong River Delta were *Bandicota bengalensis*, *Rattus germaini* and *Rattus norvegicus*, but *Rattus rattus* was not listed. We did not capture *Rattus rattus*, *Mus cervicolor* or *M. musculus*, which were species identified by Sung (1998) as being present in the Mekong River Delta. Rodent species can be morphometrically similar but genetically distinct species (e.g. *Mastomys* spp., Granjon et al. 1997). Because of the diversity of species present, it can be easy to misidentify animals, particularly juveniles. Therefore, more work needs to be done to understand the taxonomy of these species in the Mekong River Delta.

Population dynamics at Long An

The highest abundance of rats occurred in September, when the local variety of rice was in the vegetative growth stage (Figure 2). The lowest abundance of rats occurred in June—when the second improved variety crop was at the maximum tillering stage, and in November and December—at the end of the flooding period. The proportion of rats caught in improved variety rice crop habitats compared to other habitats was similar throughout the year. There were no data on breeding from Long An, so we cannot determine whether increases in rat numbers were due to immigration or reproduction.

Population dynamics at Kien Giang

Eight species of rodents were identified from 449 captures. The capture rates of *R. argentiventer* (43.7%) and *R. losea* (45.2%) were similar. The next highest capture rate was *R. flavipectus* (5.1%). Seven captures were not identified to species (1.6%), with the six other species accounting for 4.4% of captures.

Both *R. argentiventer* and *R. losea* were more abundant in the improved rice variety habitat than in other habitats (Figure 3). The relative proportion of each species was similar within these habitats, except *R. losea* was more abundant in improved variety rice in May 1998.

Table 3.
Composition of rat species (%) from nine different provinces in the Mekong Delta (1995–1997). Rats were collected by live-trapping and digging of burrows in rice crops and along channel banks. In each province, fifty rats were collected (except in March 1996 when 100 rats were collected) from six sampling occasions from November 1995 to July 1997).

Species	Ben Tre	Tien Giang	Long An	Can Tho	Dong Thap	Kien Giang	Minh Hai	An Giang	Vinh Long
Rattus argentiventer	50.2	72.0	63.4	67.8	69.7	28.4	57.3	68.6	75.4
Rattus losea	9.8	5.3	8.9	10.5	11.0	45.9	18.7	12.8	8.9
Rattus koratensis	17.3	1.3	8.3	4.3	5.5	6.7	9.0	4.0	8.5
Rattus germaini	8.5	2.0	3.0	1.0	2.7	2.0	2.7	2.4	2.8
Rattus rattus	1.8	4.2	2.1	3.3	1.0	0.2	2.3	2.8	1.2
Rattus flavipectus	1.3	1.3	2.3	2.3	1.8	0.7	0.2	0.4	0.0
Rattus nitidus	2.0	1.7	1.5	2.7	1.3	2.3	3.3	1.6	0.8
Rattus exulans	1.8	3.3	2.5	1.3	0.7	1.8	0.3	2.4	0.8
Rattus norvegicus	2.5	2.7	1.3	1.5	2.3	3.4	3.8	1.2	1.2
Bandicota indica	3.0	4.3	4.5	4.5	4.0	2.6	0.2	0.6	0.4
Bandicota bengalensis	0.0	0.3	2.2	0.7	0.0	0.2	1.2	1.6	0.0
Mus sp.	1.7	1.5	0.0	0.0	0.0	5.9	1.0	1.6	0.0

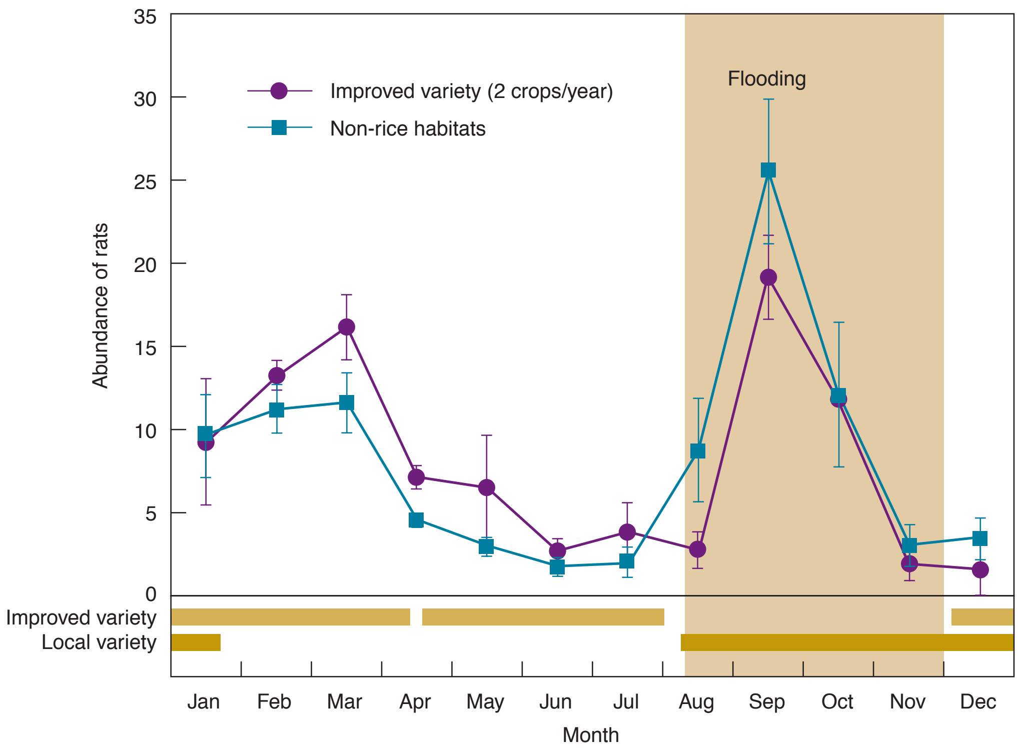

Figure 2.
Mean abundance of rats (per 100 trap nights; ± standard error) per month in improved variety rice (two crops per year) and all other habitats combined, Long An, 1994–1997.

Breeding of adult female *R. argentiventer* and *R. losea* was intermittent, although both species tended to be in breeding condition in similar proportions over time (Figure 3) (November: $\chi^2_1 = 0.11$, $P > 0.05$; February: $\chi^2_1 = 1.03$, $P > 0.05$; March: $\chi^2_1 = 0.16$, $P > 0.05$; May: $\chi^2_1 = 0.14$, $P > 0.05$). No breeding was evident in October 1997, December 1997 (very little trapping occurred because of flooding) or April 1998. The only breeding that occurred in January 1998 was in the melaleuca forest (n = 1). Breeding did not occur in the vegetative growth stage of the improved variety rice crop, but tended to occur in the latter two-thirds of crop growth from late tillering to harvest (a period of two months). Therefore breeding appeared to be linked to the presence of high quality food. The average weight of adult breeding females for *R. argentiventer* was 114.6 g [± 3.2 standard error (SE); range = 62–200 g; n = 63] and for *R. losea* it was 111.0 g (± 3.4 SE; range = 60–200 g; n = 69).

The proportion of adult females in breeding condition was similar in improved variety rice habitat and other habitats [$\chi^2 = 0.69$, degrees of freedom (d.f.) = 1, $P > 0.05$; $\chi^2 = 1.09$, d.f. = 1, $P > 0.05$ for *R. argentiventer* and *R. losea*, respectively). The rate of recapture of tagged rats was very low both within trips (0.7%) and between trips (0.2%).

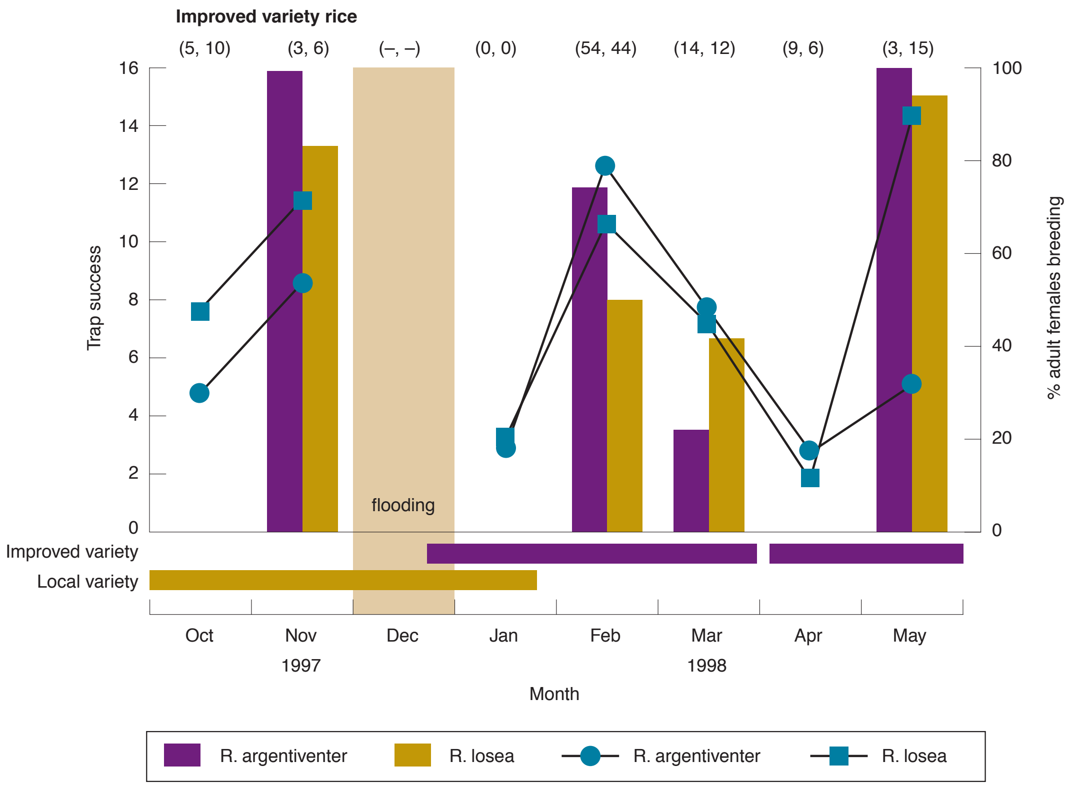

Figure 3.
Abundance of *Rattus argentiventer* and *Rattus losea* (number caught per 100 trap nights) and proportion of adult females breeding (lactating or pregnant) in improved variety rice and other habitats in Ha Tien, Kien Giang, October 1997 to May 1998. Numbers in brackets refer to the number of adult female rats caught for each species *R. argentiventer, R. losea*). No trapping occurred in December 1997 in improved variety rice or in October 1997 in other habitats.

Population dynamics at Tra Vinh

Four species of rodents were identified from 384 captures. The most common species trapped was *R. argentiventer* (61.7%). *R. losea* (20.3%). *R. koratensis* (10.2%) and *R. germaini* (4.2%) made up the other species captured, with 3.6% of captures not identified to species.

Both *R. argentiventer* and *R. losea* were more abundant in the rice habitat than in other habitats (coconut, banana and channel bank combined) (Figure 4). No rats were caught in the rice habitat from November 1997 to May 1998, but some rats were caught in other habitats in February, March and May (≤0.3% trap success).

Only one adult female *R. argentiventer* was found pregnant (by palpation) during May 1998 in the rice habitat (6.7% of adult females) (weight = 174 g). No other adult females were in breeding condition for any other period or habitat. No rats were re-caught within or between trips.

Population ecology of rats in Mekong River Delta

The dynamics of rat populations were different for Long An, Kien Giang and Tra Vinh. In Long An and Tra Vinh, the abundance of rats was highest during flooding, whereas in Kien Giang, the highest abundance was during the early stages of the reproductive phase of the crop. In Kien Giang, the abundance of rats in March 1998 (milky/harvesting stage) was lower than expected considering the breeding that occurred in February (assuming the young were trappable). Unfortunately, no trapping was conducted there during the period of flooding.

Few rats were caught in non-rice habitats in either Tra Vinh or Kien Giang. This suggested that rat populations were building up within the rice fields rather than in adjacent non-crop habitats. Breeding occurred during the reproductive phase of

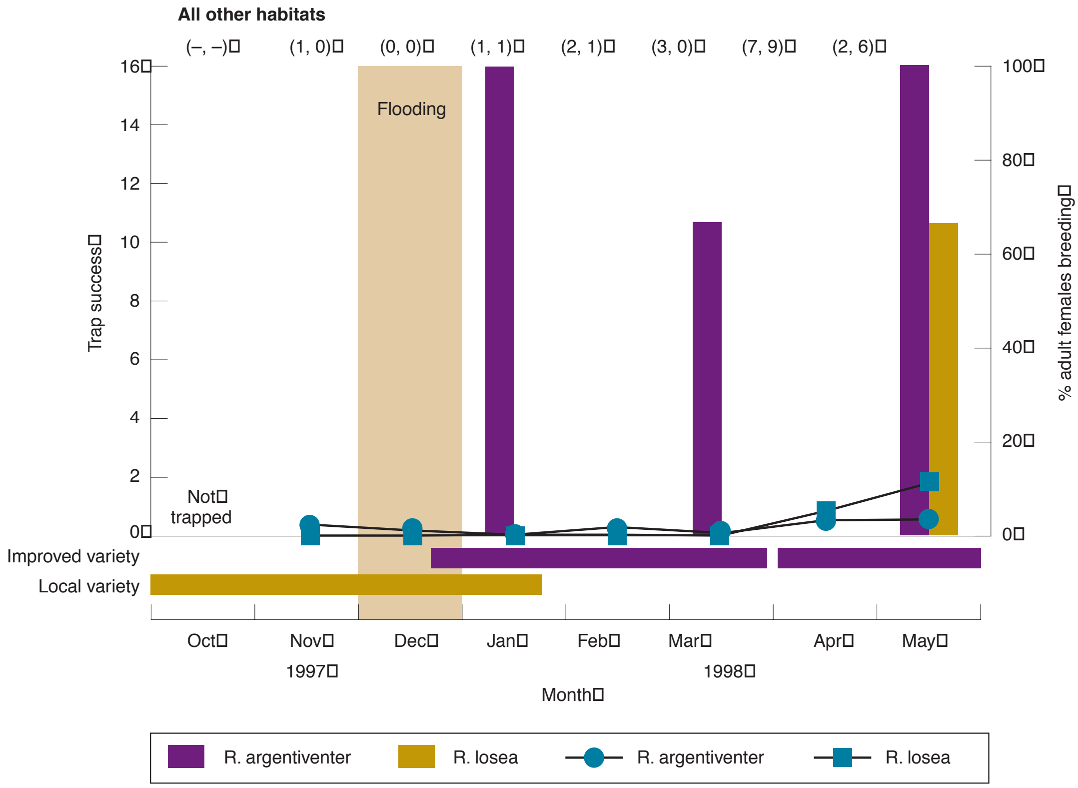

Figure 4.
Abundance of *Rattus argentiventer*, *Rattus losea* and other species (number caught per 100 trap nights) and proportion of adult females breeding (lactating or pregnant) in rice habitats and other habitats in Tra Vinh, May 1997 to May 1998. Numbers in brackets refer to the number of adult *R. argentiventer* and *R. losea* females caught, respectively. No trapping occurred in June or July 1997.

the crop in Kien Giang, but a comparison cannot be made with Tra Vinh where only one rat in breeding condition was caught.

In Tra Vinh, the population abundance of rats remained very low after flooding. These low numbers could be attributed directly to the floodwaters (a) drowning rats, (b) making food scarce, and/or (c) making it difficult for rats to find shelter. Furthermore, low numbers could be indirectly attributed to the waters driving rats to patches of high ground where farmers focused their control campaigns. When floodwaters subsided and new crops were planted, rat populations were at such low densities that they could not recover. For three months after the floodwaters had subsided, the only rats present in Tra Vinh were found in a banana plantation. How long does it take for rats to recolonise the rice habitats after such a flooding event? From our data, it seems that the effect of flooding on rat populations in Long An or Kien Giang are not as severe as found in Tra Vinh. Tra Vinh is situated toward the edge of the delta, and the area is more prone to flooding events than the other provinces that have a higher elevation and where floodwaters can subside more rapidly. We would not expect the effect of flooding on rat populations to be the same each year because the severity and duration of flooding differs between years.

A radio-telemetry study is required to gain an understanding of the habitat use of rats during flooding, and to determine if rats breed when the local traditional variety rice is in the reproductive phase of growth. Furthermore, when flooding occurs it is important that farmers know where they can concentrate their rat control activities.

In Kien Giang, there were few rats caught in April (from transplanting to maximum tillering). We would expect that populations would increase during April as new rats enter the trappable population from births in February and March. Are the low numbers attributable to low survival rates and poor recruitment of young in March and April 1998, or had these rats emigrated to other areas? Another factor that complicates our interpretation is that the catchability of rats is low, or the animals are very trap shy.

The population dynamics of rats in Indonesia follows a general pattern of increasing abundance during the fallow period after harvesting as young enter the trappable population (Murakami et al. 1990; Leung et al., Chapter 14). The difference in Vietnam is that there is no fallow period between crops. Subsequent crops are sown within a few days of harvest. Leung et al. (Chapter 14) found that the factors limiting rat populations in Indonesia were food quality, availability of nesting sites and human activities such as land preparation and rodent control activities. If rice is planted soon after harvest, then high quality food is available to the rats sooner. We therefore expect that rat populations in Vietnam would have a higher survival rate in the period between breeding seasons.

The low recapture rates of rats found in the Mekong River Delta are a problem for live-trapping studies. Wood (1971) obtained recapture rates in Indonesia of 14% within a trapping period and 6% between trapping periods for *R. argentiventer*. Our estimates were both <1%. Population parameters are more difficult to estimate when recapture rates are low (Krebs et al. 1994). It is not known whether *R. argentiventer* or *R. losea* in

Vietnam are trap-shy or are transient animals moving through a trapping area. To improve population parameters, the recapture rate of rats needs to be enhanced. Research is required to examine better methods for trapping rats and to compare results with other areas such as Indonesia (L.K.-P. Leung and Sudarmaji, unpublished data).

One critical population parameter that we have not been able to gain sufficient information on is the survival rates of rats (we have been restricted by low recapture rates). How is survival influenced by crop stage and flooding? Survival rates of rats could be estimated using static life tables rather than by following individuals over time. This approach requires a comprehensive set of data to follow cohorts through time and an accurate method for ageing rats using eye lens weight (Murakami et al. 1992).

Breeding at Kien Giang

The only breeding (embryos in the uterus) evident from kill trapping was in February and March 1998, where 100% of adult female *R. argentiventer* were pregnant. The mean number of embryos was 11.4 (± 0.4 SE, range = 6–18, n = 65). The mean weight of pregnant females was 91.1 g (± 5.1 SE, range = 29–183, n = 65). These rats were significantly smaller than live-captured pregnant or lactating *R. argentiventer* (t = 3.87, d.f. = 126, P < 0.001). The minimum weight of pregnant females by kill-trapping was half that from live-trapping. This difference is interesting, because it suggests there could be a bias in the collection methods (rats caught in burrows versus rats caught in live-capture traps). Therefore, more work is required to understand this bias and to look at improvements to trap design and trapping procedures.

At harvest in October 1997, many adult females had uterine scars. The mean number of scars for *R. argentiventer* was 10.8 (± 0.5 SE, range = 6–17, n = 39), which was not significantly different to the mean number of embryos (t = 0.93, d.f. = 102, P > 0.05). The litter size was significantly higher for rats with more sets of uterine scars (one-way analysis of variance—ANOVA; F = 28.4, d.f. = 2,36, P < 0.001). The mean number of scars for rats with one set was 8.0 (± 0.4 SE, n = 16), two sets was 12.1 (± 0.7 SE, n = 15) and for three sets was 14.0 (± 0.6 SE, n = 8). This is evidence to show that *R. argentiventer* can have up to three litters during a single breeding season and that the size of the litter increases with each litter.

The proportion of rats in breeding condition collected by kill-trapping in March 1998 was higher than that found by live-capture trapping (χ^2_1 = 4.42, P < 0.05), whereas there was no difference in February (χ^2_1 = 0.64, P > 0.05).

Breeding was evident only during the reproductive stage of the rice crop. The relative percentages of *R. argentiventer* adult females in breeding condition during the different crop stages were: the vegetative growth stage, 0% (0/22 rats); tillering stage, 9% (1/11 rats); flowering stage, 100% (5/5 rats); and at harvest, 76% (57/76 rats).

Breeding of rats in Kien Giang was linked to the development of the improved variety rice crop. No breeding occurred in the vegetative stage of growth, but breeding was initiated at some point prior to maximum tillering stage to take advantage of high quality food during the reproductive and ripening stages of rice development. This is generally the case with *R. argentiventer* in other regions such as Indonesia (Murakami et al. 1990; L.K.-P. Leung and Sudarmaji, unpublished data) and Malaysia (Wood 1971; Lam 1980, 1983; Buckle 1990). The discovery that breeding by rats commenced prior to maximum tillering of rice crops led to an important re-evaluation of what triggers breeding by rats (Leung and Sudarmaji, unpublished data). Although we have limited data, we hypothesise that breeding is linked with the rice crop stage, and that if there are three rice crops grown per year (2 × improved variety and 1 × local traditional variety), then there will be three distinct breeding seasons per year. Furthermore, if the crops are not grown in synchrony (planting over a period of >2 weeks in an area), then the duration of time in which high quality food is available is prolonged. Therefore, we would expect that the breeding season would be prolonged, resulting in a higher numbers of rats.

Ecologically-based population management practices for rats in the Mekong River Delta

Rats have always been part of the rice-cropping ecosystem in Southeast Asia; *R. argentiventer* in particular is believed to have evolved from a grassland existence (Lekagul and McNeely 1977). The reason why rats have become a major pest of rice crops in the Mekong River Delta is thought to be due to the increased amount of cropping occurring (three crops per year instead of one or two; Singleton and Petch 1994). Other factors may include the increased awareness of the problem of rats and the mosaic of favourable habitats for rats.

We have applied our knowledge of the ecology of rodents in the Mekong River Delta reviewed in this chapter, to develop an ecologically-based appraisal of the appropriateness of different management actions (Table 4). These actions were developed by the Institute of Agricultural Sciences in Ho Chi Minh City, and were discussed by rodent scientists at an annual meeting of the Australian Centre for International Agricultural Research (ACIAR) funded project on the management of rodent pests in Southeast Asia in April 1998 at the International Rice Research Institute (IRRI, Los Baños, the Philippines).

There are two types of actions; routine actions that can be conducted all the time and actions that can be conducted if high rat numbers are forecast. For each action, eight parameters were considered: the timing of implementation, the feasibility, whether it is economical, socially acceptable, environmentally friendly, ecologically sustainable, the scale of adoption and whether it has an ecosystem focus. We also considered priority for implementation of each practice.

Ecologically-based pest management is a new paradigm for pest management (National Research Council 1996). It promotes the use of information on the biology and ecology of the pest species to formulate management actions. This approach has been used for house mice in Australia (Singleton 1997; Singleton and Brown 1999) and for *R. argentiventer* in Indonesia (Leung et al., Chapter 14). Our current knowledge of the biology and ecology of rats in southern Vietnam has allowed Table 4 to be formulated. Manipulative field experiments are now

Table 4.
Decision analysis of recommended best practices for managing Rattus argentiventer and Rattus losea in rice agro-ecosystems of the Mekong River Delta, Vietnam. (Timing: lp = land preparation; sb = seed bed; tp = transplanting; b = booting; Suitability of actions: ✓ = yes; X = no; ? = unknown).

Management actions	Parameters for ecologically-based pest management								
	Timing	Feasible	Economic	Socially acceptable	Environ friendly	Sustainable	Scale of adoption	Ecosystem focus	Priority
Routine actions									
Field sanitation and dyke management	lp›b	✓	✓	✓	✓	✓	village	?	high
Synchronous seeding and planting	sb, tp	?	? labour	✓?	✓	?	village	✓	medium
Reduce bund size within rice fields	lp	✓	✓	?	✓	✓	village	✓	high
Keep water level high in the field	Dry crop	?	✓	✓	✓	✓	village	n/a	high
Encourage natural enemies of rats in rice ecosystems	all	?	?	✓	✓	?	district	✓	high
Linear TBS[a] to halt movement into paddies	< sb, tp	?	?	✓	? ✓	✓	?	✓	
Management of rats on high ground	Flood	✓	✓	✓	✓	✓	village	✓	
Locate and destroy rat burrows by fumigating and digging	< sb, tp	✓	✓	✓	✓	✓	village	?	
Establish TBS[a] with trap crops	Each crop	?	✓	✓	? ✓	✓	?	✓	
Actions if high numbers forecast									
Rat drive using nylon nets	Flood	✓	✓	✓	✓	✓	village	✓	
Apply chemical bait in fields and villages	< sb, tp	✓	?	✓	X	X	village	X	
Burn rice straw after harvest	Dry crop	✓	✓	✓	X	X	village	X	
Drive tractor through fallow fields (high terrain)[b]	Flood	?	?	✓	?	X	village	X	

[a]TBS = trap plus barrier system
[b]Plant Protection Departments perform this activity.

required to examine the effectiveness of these actions. Until these actions have been critically tested, they remain a 'best guess' of what limits rodent populations in the rice agro-ecosystem of southern Vietnam.

These actions were designed for the rice-growing areas of southern Vietnam. Some of the actions could be appropriate for other areas of Southeast Asia, particularly northern Vietnam, where many of the farming practices are similar, although major flooding events are rare.

A major hurdle to the success of these actions is being able to forecast when rat numbers are likely to cause damage. These monitoring systems could be operated by farmers themselves or by government officers. The amount of time farmers require to implement these actions also needs to be investigated.

Where to from here?

The challenge ahead is whether these actions will be readily adopted at the village and/or district level. This is an essential requirement for mobile animals such as rodents, which can readily reinvade small areas following a reduction in rodent densities. In Vietnam, the level of interaction

Table 5.
Strength of ecologically-based knowledge for the management of rats in the Mekong River Delta. If we have sufficient data on the ecology and population biology of rats, then 'Yes' appears in the table, if we lack sufficient data, then 'No' appears in the table. The likely level of success in reducing rat populations using each recommended action is based on our current knowledge (low, medium or high).

Recommended action	Sufficient data	Likelihood of sucess
Routine actions		
Field sanitation and dyke management	No	High
Synchronous seeding and planting	No	High
Reduce bund size within rice fields	Yes	High
Keep water level high in paddies	No	High
Encourage natural enemies of rats in rice ecosystems	No	Low
Linear TBS[a] to halt movement into paddies	No	Low
Management of rats on high ground during flooding	No	Medium
Locate and destroy rat burrows by fumigating and digging	No	Medium
Establish TBS[a] with trap crops	Yes	High
Actions if high numbers are forecast		
Rat drive using nylon nets	No	Low/Medium
Apply chemical bait in fields and villages	No	Medium
Burn rice straw after harvest	No	Medium
Drive tractor through fallow fields (high terrain)	No	Low

[a]TBS = trap–barrier system

between researchers (Institute for Agricultural Sciences) and provincial extension staff (Plant Protection Departments) is very good, which bodes well for the success of implementation of actions by farmers.

Given our current understanding of the ecology of rodent species in the Mekong River Delta, we are able to determine the likelihood of success of a range of management practices on rodent populations even though we do not currently have sufficient scientific evidence (Table 5). We identify where we have sufficient data and which actions have a low, medium or high chance of success in reducing rat populations. We lack experimental data for many recommended actions, however, we can draw upon knowledge gained from studies conducted in Indonesia (Leung et al., Chapter 14). As our understanding improves, the likelihood for success will also change. This is an area for further research.

An important output from a decision analysis process is clearer identification of the key gaps in our scientific knowledge for developing effective management of a particular rodent pest. To further our understanding of the ecology of the major rodent species, we have listed a series of ecological parameters and indicated the amount of information that is known about each in Table 6 (following Singleton and

Table 6.
Summary of the extent of information available on various ecological parameters of the major rodent pest species in southern Vietnam (– = no information; * = anecdotal reports; ** = restricted to a single sample or survey; * = restricted to one or two growing seasons or a long-term data set not calibrated against other measures).**

Parameter	*Rattus argentiventer*	*Rattus losea*	Other species
Abundance	***	***	*
Habitat use	***	***	*
Dispersal	–	–	–
Breeding	**	**	–
Survival	–	–	–
Age structure	–	–	–
Diet	–	–	–
Predator/prey	–	–	–
Disease	–	–	–
Taxonomic status	**	**	**
Species interaction	*	*	–
Crop damage	*	–	–
Post-harvest damage	–	–	–

Petch 1994). We have a good understanding of the abundance, habitat use and breeding characteristics of *R. argentiventer* and *R. losea*, but we lack specific information for a range of other ecological parameters.

The ecological approach used here to critically examine management practices has allowed us to develop an integrated management strategy. Developing field projects to evaluate these recommendations in close association with farmers at the village or district level (as pointed out by Leung et al., Chapter 14) will provide the necessary feedback for developing an effective management strategy.

Conclusions

Although we have collected data for a limited period of time, we have been able to formulate proposals for the management of rodent pests in southern Vietnam. Current evidence suggests that *R. argentiventer* in Vietnam behaves in a similar fashion to *R. argentiventer* in other Southeast Asian countries. However, the interaction with *R. losea* requires further study. We suggest specific hypotheses about the likely population ecology of *R. argentiventer* and *R. losea* in the Mekong River Delta. These hypotheses need to be tested when at least two years data, but preferably three or more years of data, have been collected.

Suggested areas for further research include:

- Conduct a radio-telemetry study to examine the habitat use of rats during flooding periods.
- Conduct a trap catchability study to examine the best trapping method available and to test it over different crop stages and breeding and non-breeding stages.
- Estimate survival rates of rats over different crop stages and during flooding.
- Conduct manipulative field experiments to examine the effectiveness of actions to limit rat damage.
- Develop a monitoring system to enable forecasting of high rat numbers.

The information gained from this research will help establish a better understanding of the population ecology and habitat use of rodent pests.

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