SYMPOSIUM 5: POPULATION ECOLOGY AND MODELLING

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Outbreaks of rodents in agricultural systems: pest control problems or symptoms of dysfunctional ecosystems?

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Abstract. House mice in Australia and Brandt's voles in China are used to illustrate the factors that lead to episodic rodent management problems in agricultural systems. Outbreaks can develop rapidly in both species, depending on the population density at the onset of breeding, the rate of increase over the breeding season, and the duration of the breeding season. The available data suggest that these demographic parameters are determined by independent processes, which means that knowledge of all three is required to predict outbreaks reliably. As well as dealing with uncertainty in predicting outbreaks, management of both species could be improved by identifying and enhancing natural regulatory processes like predation and minimising agricultural practices that tend to increase the likelihood of outbreaks.

Introduction

Rodents are pests in agricultural systems in many parts of the world. They can have high intrinsic rates of increase so that severe agricultural impacts occur over time scales similar to the production of crops or management of livestock in both temperate and tropical environments. A recent review highlighted the problems with eruptive species on several continents (N.C. Stenseth et al., unpublished). In these cases, the difficulty of managing a pest species is compounded by uncertainty in when to apply controls.

In this paper we explore two questions relating to eruptive rodent species in agricultural systems. Firstly, why do outbreaks occur irregularly? Secondly, to what extent is the likelihood of an outbreak increased by the special characteristics of agricultural systems? House mice (*Mus domesticus*) in Australia and Brandt's vole (*Microtus brandti*) in Inner Mongolia are used as case studies to illustrate some of the features of eruptive pest rodent species. Under favourable conditions, populations of both species can increase from low abundance to exceed damage thresholds within one breeding season. Both species decline rapidly from high population densities, and then persist at relatively low abundance for extended periods. In some areas, the period of low abundance can continue even though environmental conditions appear to be suitable for supporting much larger populations.

House mouse

Outbreaks of house mice occur irregularly throughout the cereal production areas of eastern and southern Australia (Saunders and Giles 1977; Mutze 1989; Singleton and Redhead 1989). For example, there were at least 12 outbreaks in Victoria between 1905 and 1997, with an apparent increase in frequency over the last two decades (Singleton and Brown 1999). Outbreaks cause high economic losses to grain-growers, major social problems, and environmental problems through extensive use of chemicals. They are usually associated with years of above-average crop production, which in turn is linked to winter–spring rainfall (Pech et al. 1999). However, outbreaks do not occur in all years, or in all areas, with apparently suitable climatic conditions.

Brandt's vole

Brandt's vole is endemic to the grasslands of central Inner Mongolia, eastern Mongolia and adjacent parts of Russia. It is considered a pest species because it competes with livestock, contributes to soil disturbance (and hence desertification) through burrowing activities and, particularly during outbreaks, is a reservoir for zoonoses such as bubonic plague. Zhang et al. (2002) compiled a history of outbreaks of Brandt's voles in Inner Mongolia over the last 50 years based on reports in the scientific literature, detailed demographic data from several sites and reports of bubonic plague spilling over into the human population. Approximately 15 outbreaks occurred during this period, though some appeared to be relatively localised. Problems with Brandt's voles and with desertification have become more severe in recent decades, leading to an increased requirement to manage the problem.

Ontogeny of an outbreak

The rapid increase in abundance of rodents from low numbers to an outbreak depends on three factors: (1) the population density at the start of the breeding season, N_B, (2) the rate of increase over the breeding season, and (3) the duration of the breeding season, T_B. For simplicity, it is assumed that the population increase during the breeding season can be characterised by a single exponential rate, r_B.

House mouse

N_B depends on the population density during the previous breeding season and the rate of decline over the non-breeding season. For house mice, there is a significant negative correlation between these two parameters (Davis et al., this volume). Both parameters are unaffected by the winter-to-spring rainfall immediately preceding an outbreak that explains most of the variation in r_B, with the result that there is no significant correlation between r_B and N_B (Davis et al., this volume; N.C. Stenseth et al., unpublished). This is consistent with the more general model for the rate of increase developed by Pech et al. (1999), which included a small, density-dependent component that had an effect only at very high densities (i.e. the density late in the breeding season). Singleton et al. (2001) used data on the breeding status of mice at Walpeup in north-western Victoria to calculate T_B for each year between 1982 and 2000. The relationship between T_B and N_B is weakly negative (R^2 = 0.265, Figure 1a) due mainly to the value for one year (1993–94). Deleting this year, R^2 = 0.042. There is no correlation between r_B and T_B (Figure 1b).

Brandt's vole

Fewer data are available to assess all three factors for Brandt's vole. Shi et al. (2002) and Zhang et al. (2002) reported a negative correlation between the rate of increase in the non-breeding season and the population density at the end of the previous breeding season. These two parameters determine N_B, which is highly variable. r_B is not affected by population density but there is a convex upwards relationship between r_B and pasture conditions, reflecting the preference of Brandt's voles for short grass habitat (Zhang et al. 2002). However, populations have low, sometimes negative, values of r_B when grass is very short (< 50 mm) and sparse (< 40% cover), probably due to a shortage of food, and in tall, dense grass (>200 mm, >70% cover), which is thought to interfere with social interactions and with the ability of voles to detect predators (Zhong et al. 1999). Plant biomass during the breeding season is determined by precipitation over the preceding winter (Zhang et al. 2002) and grazing by livestock (Zhong et al. 1999). Hence, there is no significant correlation between N_B and r_B (Zhang et al. 2002). Breeding data from 3 years at a site central to the distribution of Brandt's vole in Inner Mongolia indicate relatively minor variation in T_B (Shi et al. 2002). Early spring rain and flooding of burrows can result in low survival rates of unweaned voles, delaying the effective start to recruitment. However, the frequency of these impacts on vole demography has not been reported so that it is possible that T_B for Brandt's voles may be relatively invariant. In this case, there is unlikely to be any significant correlation between T_B and r_B or between T_B and N_B.

The characteristics of N_B, r_B and T_B for house mice and Brandt's voles are summarised in Table 1.

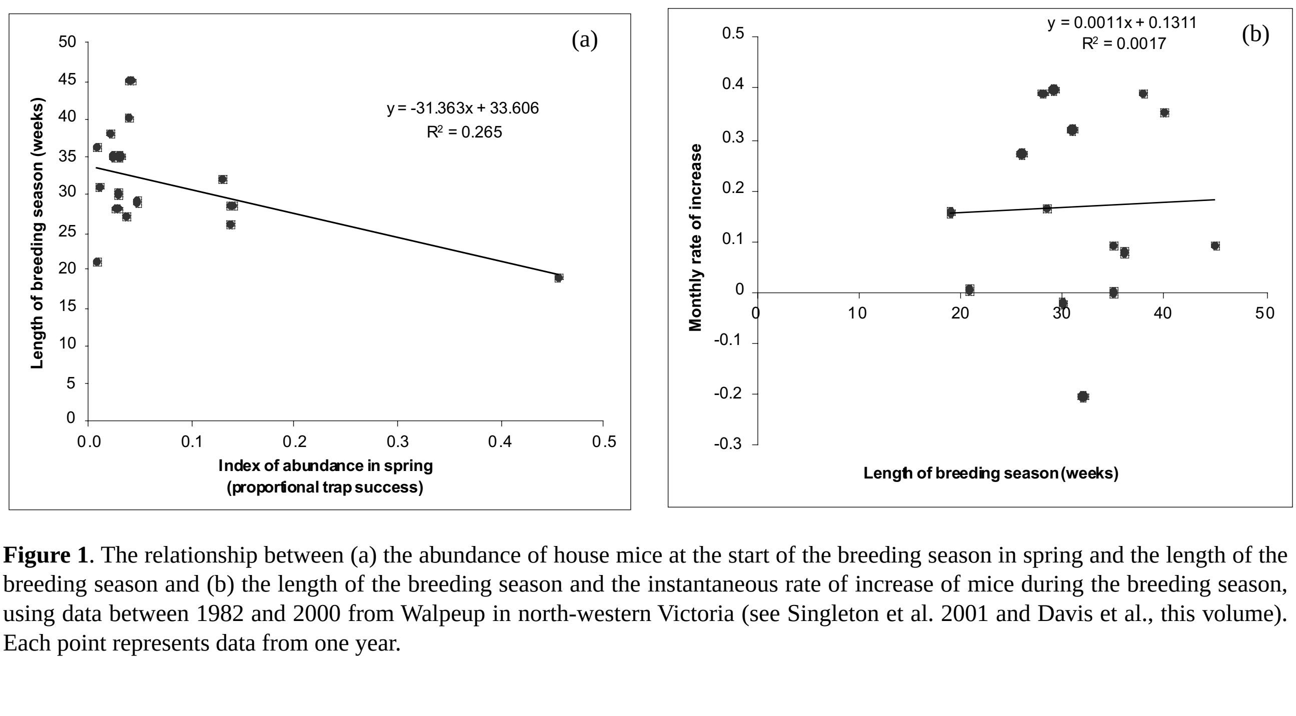

Figure 1. The relationship between (a) the abundance of house mice at the start of the breeding season in spring and the length of the breeding season and (b) the length of the breeding season and the instantaneous rate of increase of mice during the breeding season, using data between 1982 and 2000 from Walpeup in north-western Victoria (see Singleton et al. 2001 and Davis et al., this volume). Each point represents data from one year.

Table 1. Summary of the characteristics of three key demographic parameters that determine the rapid development of outbreaks of house mice and Brandt's voles. N_B is the population density at the start of the breeding season, r_B is the rate of increase over the breeding season, and T_B is the duration of the breeding season (see text for details).

Demographic parameter	House mouse	Brandt's vole
N_B	density-dependent decline from the end of the previous breeding season in both species	
r_B	positive linear relationship with winter-to-spring rainfall	convex upwards relationship with grass height and cover during the breeding season
T_B	highly variable	limited data: probably consistent duration

Discussion

Timing of outbreaks

All three factors, N_B, r_B and T_B, are important in determining the change in population size over the course of the breeding season, as is the subsequent decline in population density to set the initial conditions for the start of the next breeding season. For very low starting densities, there may be insufficient time during the breeding season for the population to reach economically damaging thresholds, even with high rates of increase. Also, high rates of increase may not generate large populations if the breeding season is short. Therefore an outbreak is more likely to occur if a rodent population begins with a relatively high spring density and has a high rate of increase over an extended breeding season. However, outbreaks of house mice occurred in north-western Victoria in two years (1988–89 and 1994–95) with high spring densities but only average rates of increase (Davis et al., this volume), which suggests that an outbreak depends on the joint probability of high values for at least two of the three factors.

For house mice and Brandt's vole, two of the key factors leading to outbreaks, N_B and r_B, are influenced by climatic conditions one year apart, so that between-year variability in the climate will contribute to the erratic occurrence of outbreaks. The third factor, T_B, may be reasonably consistent for Brandt's vole due to the highly seasonal climate in Inner Mongolia, but r_B can be affected by variations in the level of grazing by livestock that are likely to be influenced independently by socioeconomic factors. T_B is the least well understood of the three factors for house mice. The onset of breeding for mice may be determined by access to high-quality food (see, for example, Bomford 1987a,b) which in turn depends on climatic conditions in late winter and early spring. Interspecific competition is unlikely to be important because, over a 20-year period in north-western Victoria, more than 100,000 house mice were caught but only one other small mammal, a carnivorous marsupial mouse, *Sminthopsis murina* (G. Singleton, unpublished data). Ylönen et al. (2002) have demonstrated that the behaviour of mice in areas with different plant cover is consistent with a response to changes in the risk of predation. This risk avoidance behaviour can delay body growth rates and breeding in mice (Arthur and Pech, this volume). However, there is little information about the relative importance of factors, such as disease, predation or lack of food due to intraspecific competition or farm management (e.g. time of harvest or grazing by livestock) or stochastic rainfall events, that could influence when breeding starts and finishes.

For both house mice and Brandt's vole, the lack of significant correlations between N_B, r_B and T_B, implies that they are likely to be determined by unrelated processes. The result is that outbreaks are difficult to predict without knowledge of all three factors. Since 1999, the model developed by Pech et al. (1999) has been used to successfully forecast the probability of an outbreak of house mice at one locality in north-eastern Victoria (Pech et al. 2001). The model uses the cumulative winter rainfall from April to October to predict changes in the rate of increase of the next 6 to 9 months but the accuracy of predictions is greatly improved by field estimates of N_B. Also, the model implicitly assumes that T_B is constant, which leads to error in estimating the magnitude of an outbreak (Pech et al. 2001). A logistic model using winter and spring rainfall to predict the occurrence of outbreaks, rather than detailed changes in the abundance of mice, has had limited success for Walpeup in north-western Victoria (N.C. Stenseth et al., unpublished) and for the mallee region of Victoria and South Australia (Kenney et al., this volume), particularly because it predicts more outbreaks than occur. Similar results have been achieved for predicting outbreaks of Brandt's vole (N.C. Stenseth et al., unpublished). The conclusion is that predictions of outbreaks of house mice and Brandt's vole that are based on a single explanatory variable, such as precipitation, will have a high level of error, requiring farmers to take this uncertainty into account when choosing a management strategy (N.C. Stenseth et al., unpublished).

Links between agricultural systems and the causes of outbreaks

For both house mice and Brandt's voles, there are two components that set the initial density, N_B: the density at the end of the previous breeding season and the rate of decline of the population during the non-breeding season. The former component is determined primarily by climatic conditions at least a year before an outbreak occurs. Brandt's voles cache food for winter (Zhong et al. 1999) and competition for this resource may cause the density-dependence in over-winter survival (Zhang et al. 2002). Therefore, grazing by livestock, which can lead to changes in pasture composition and biomass, may modify the strength of the density-dependence. For house mice, Arthur and Pech (this volume) found that the survival rate declined with increasing density when they were exposed to predation by foxes (*Vulpes vulpes*), feral cats (*Felis catus*) and raptors, in short grass habitat. This impact would be enhanced by prophylactic measures such as the control of weeds along fence lines recommended by Singleton and Brown (1999), although conservation farming practices, such as stubble retention, could reduce predation risk and lead to higher survival of mice and higher densities, N_B, at the start of the breeding season. However, the regular monitoring program conducted since 1982 at Walpeup in Victoria has not detected any consistent trend in the size of the over-wintering population that could be attributed to changes in farming practices.

There are several ways that r_B and T_B could be modified by the activities of pastoralists or farmers over the period from spring to autumn. In Inner Mongolia, grazing by livestock has a direct impact on the structure, species composition and biomass of the plant community (Zhong et al. 1999) and hence will affect r_B. Large increases in the number of livestock over the last 50 years appear to have shifted the balance between precipitation-driven grass growth and off-take, so that the conditions preferred by Brandt's vole now tend to occur in years of near-average rainfall (Zhang et al. 2002). Hence, there has been an increase in the frequency of outbreaks compared to earlier periods when short-grass conditions were more likely in exceptionally dry years. In addition, campaigns to control voles may have resulted in secondary poisoning of predators and hence reduced their ability to regulate prey populations (Zhong et al. 1999). In grasslands elsewhere in China, control of small mammals has led to a measurable decline in many species of birds, including raptors such as black-eared kites (*Milvus lineatus*) and upland buzzards (*Buteo hemilasius*) (Lai and Smith 2002). However, little is known about the potential for predators to regulate populations of Brandt's voles in Inner Mongolia.

Recent changes in a range of farming activities may have contributed to increasing problems with outbreaks of mice in south-eastern Australia (Singleton and Brown 1999). These include activities that may directly increase r_B and extend T_B, such as increased diversity and asynchrony in crops, and others such as clearing of remnant native vegetation that might indirectly benefit mice by reducing the abundance of predators. The analysis by Sinclair et al. (1990) suggests that aggregation by raptors could regulate mouse populations at low density in localised irrigation areas. In regions with extensive dryland cropping, a significant impact of predation is more likely during the decline phase of an outbreak when there has been sufficient time for a build-up in raptor populations, particularly Australian kestrels (*Falco cenchroides*) and black-shouldered kites (*Elanus notatus*) (see, for example, Davey and Fullagar 1986).

In contrast to Brandt's vole, the house mouse is an introduced species in Australia, which increases the potential for safe and effective use of biological control agents. The serological prevalence of some mouse-specific viruses, such as mouse cytomegalovirus, minute virus of mice and mouse parvovirus, vary with the density of the host population, but there is no evidence that any of these pathogens could maintain the population at low density (Singleton et al. 2000). In fact, the lack of competition with small native granivorous mammals may be due to the impact on these species of pathogens introduced and spread with the house mouse (Smith et al. 1993).

Conclusion

Irregular outbreaks of house mice in Australia and Brandt's vole in Inner Mongolia appear to be caused primarily by irregular fluctuations in key climatic parameters, and exacerbated by a loss of potential regulatory processes such as predation. For house mice, up to 70% of outbreaks can be predicted from the amount of rain that falls during winter through to early summer (Kenney et al., this volume), a remarkably strong relationship given the independence of N_B, r_B and T_B. Eruptions of Brandt's vole are correlated with positive phases of the southern oscillation index, which is in turn linked to climate, and most outbreaks occur in years with uniform, near-average precipitation (Zhang et al. 2002). However, for both agricultural systems, existing models tend to predict many more outbreaks than actually occur. This suggests that additional factors that have yet to be identified often prevent outbreaks from developing. The challenge is to identify these factors and, if possible, enhance their effectiveness to counter the tendency of current agricultural practices to generate outbreaks of rodents.

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Rodent problems and management in the grasslands of China

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Abstract. In this paper, we review rodent problems and their management in the steppe grassland of Inner Mongolia, alpine meadows in Qinghai–Tibet, and grassland in Xinjiang. The behaviour, ecology and population dynamics of the major rodent species, including functionally similar species such as pikas, and their interactions with grassland ecosystems have been extensively surveyed. Cultivation and overgrazing by livestock are recognised as key factors in accelerating rodent infestation in grasslands. Therefore, improved management of livestock and crop production is an essential component of the solution to the rodent problem. As well as ecologically based management, species-specific control techniques such as immunocontraception are recommended for future rodent management in the grasslands of China.

Introduction

China has huge grasslands covering about 0.28 billion ha, and ranking first in the world. However, the grasslands produce only 8% of the total domestic meat production and 25% of the total domestic requirement for wool. Production input per unit area in grasslands is about 10 or 20 times less than in advanced countries and, in some regions, is becoming worse due to poor management. For example, in 1959, 6–13 Mu (1 ha = 15 Mu) were needed per sheep in Qinghai but this increased to 10–46 Mu per sheep by 1984 because of the degradation of the grassland. Despite this deteriorating trend, there is substantial scope for increased livestock production through better grassland management.

Rodent pests cause serious problems in the grasslands of China. They infest about 10–20% of the total area of grassland every year, and the annual loss of grass biomass has been estimated at 40–50 billion kg. In Qinghai and Tibet, expensive rehabilitation programs are required for 4 million ha of ‘black sandy land’, which have resulted from soil erosion attributed to rodents. Also, rodent populations in the grasslands of Inner Mongolia and Xinjiang are important reservoirs for many serious diseases, including plague. Therefore, better management is urgently needed for pest species of rodents and other small mammals in grasslands.

The major pest species differ from region to region in Qinghai, Tibet, Inner Mongolia and Xinjiang. The following is a brief overview of the environment and rodent problems of these grassland regions.

Grassland in Inner Mongolia

Inner Mongolia is located in the north of China. Western Inner Mongolia is mostly desert, while the east is mostly a huge grassland. The altitude is about 1000 m and the climate is cool and dry: annual average temperature ranges from –1 to 10°C, and annual rainfall varies from 200–400 mm. The dominant plant species are *Caragana microphylla*, *Cleistogenes squarrosa*, *Stipa krylovii*, *Aneurolepidium chinense* and *Artemisia frigida*.

Rodents, and other small mammals such as pikas, cause serious problems in grasslands. They consume about 10–20% of the grass and require constant monitoring by local government to prevent the spillover of epidemics, such as plague, to the human population. Of the 36 ‘rodent’ species in this region, the main pest species are *Rhombomys opimus* in the western part of Inner Mongolia, Brandt’s vole (*Microtus brandti*) and the Daurian pika (*Ochotona daurica*) in central-eastern areas, *Microtus gregalis* and the grassland zokor (*Myospalax aspalax*) in the far east, Mongolian gerbils (*Meriones unguiculatus*) and Mongolian lemmings (*Lagurus prezewaskii*) in the central-north, and the Mongolian gerbil in the central-south. Overall, Brandt’s vole and the Mongolian gerbil are the most serious pests in the grassland of Inner Mongolia, and rodenticides are commonly used whenever outbreaks occur.

Brandt’s vole is a species with complex social behaviour. Voles that survive over winter usually produce 3–4 litters within a breeding season, whereas the first cohort of a year produces 2–3 litters and the second cohort 1–2 litters.

The third and fourth cohorts do not breed until the next year. Litter size is 8 on average, but can be up to 14, and the breeding season is from March to September. The gestation period is 21 days, and lactation lasts for 15 days. It takes 52–62 days for a male to mature, and 55–65 days for a female. Brandt's voles live in groups, ranging in size from 2–3 in spring, 6–8 in early summer, and up to 22 or even 30 in a nest system in late summer or autumn. Population outbreaks of Brandt's voles occur irregularly, with an interval of 5–7 years (Li and Liu 1999; Z. Zhang et al., unpublished data). The autumn density can range from low values around 2.4 voles/ha to outbreaks at 528.8 voles/ha. Brandt's voles cache plant material, about 11 kg/nest, for over-wintering. Thus, the estimated damage is 0.49 kg/vole during the non-growing season of grass, and 0.36 kg/vole during the growing season. Populations of Brandt's voles are hosts for diseases such as salmonellosis, plague, tularensis, and tick-borne rickettsiosis. The threshold for implementing control in spring is 23 voles/ha, or 385 active holes/ha (Zhong et al. 1991, 1992).

Mongolian gerbils are considered very serious pests in grassland and farmland, and they harbour diseases that are a danger for human health. They prefer drier habitats in grassland and also occur in the transition zone between grassland and farmland. Populations fluctuate greatly every 4 or 5 years: for example, outbreaks occurred in 1964, 1969 (Xia et al. 1982), 1975, 1985 and 1989 (Li and Zhang 1993). The outbreaks coincided with high rainfall, which usually generates good production of grass and abundant food for gerbils.

Overgrazing is a key factor facilitating rodent infestation. Successional transitions in both plant and small mammal communities result from increasing levels of grazing by livestock (Zhong et al. 1985). For example, without overgrazing, *A. chinense and S. krylovii* are the dominant grasses and *O. daurica*, *Citellus dauricus* and *Cricetulus barabensis* are the dominant rodent species at Xilinhot (rainfall 350–400 mm) in central Inner Mongolia. After heavy grazing by livestock, the abundance of *A. frigida*, *Potentilla acaulis* and *C. squarrosa* increases in the plant community, while Brandt's vole, which prefers sparse short grass, becomes the dominant rodent species. Under extreme grazing pressure, *Planta annua* is the dominant plant, and the Mongolian gerbil, which prefers eroded habitats, replaces Brandt's vole. Therefore, control of grazing by livestock is very important for rodent pest management in Inner Mongolian grasslands. For example, from 1987 to 1989, the population density of Brandt's voles decreased by 78% and the biomass of grass increased by 40% in areas where overgrazing was prevented compared to a control area (Zhong et al. 1991).

Alpine meadow in Qinghai–Tibet

Qinghai and Tibet are two important areas for livestock production in China. In Qinghai, grasslands occur at altitudes from 2500 m to 4500 m and the annual average temperature ranges from –5 to 8°C. In Tibet, the altitude of grassland is over 4500 m and the annual average temperature ranges from –3 to 12°C. There are about 0.15 billion ha of grassland, of which millions of hectares are infested by rodents and pikas, with a substantial impact on livestock production. There are estimated to be about 1.5 billion plateau pikas (*Ochotona curzoniae*) and 0.15 billion plateau zokors (*Myospalax baileyi*), which are the two major pest species in the alpine meadow ecosystem. They consume approximately 20–30 billion kg of fresh grass each year, equalling the annual food intake of 20 million Tibetan sheep.

The plateau pika is distributed over about 32% of the grassland in Qinghai. Population densities oscillate greatly, ranging from less than 1 pika/ha to 150 pikas/ha (Fan et al. 1999). Pikas live in social groups and have a breeding season from March to September. They reproduce two or three times a year, average litter size is 4.7 ± 1.3, and the male:female sex ratio is 87:100, resulting in high rates of population increase. The maximum life span of a pika is 957 days (average is 120 days). For the first cohort of a year, the male's life span is 108 days, and the female's life span is 106 days. For the second cohort, the life span is reduced to 58 days for males and 66 days for female. Survival rates for the third cohort are even lower, with life spans of 25 days for males and 15 days for females (Wang and Dai 1990). Pikas prefer habitats with low sparse grass, and benefit from heavy grazing by livestock. The daily food intake per pika is 60 ± 8 g fresh grass. About 6.2 million KJ/ha.yr of the primary grass production is consumed by pikas, about 1.3 times that for all sheep. Pikas also spread diseases like salmonellosis, plague, tularensis, tick-borne rickettsiosis and pseudotuberculosis.

The plateau zokor lives underground and occurs in nearly 12% of grassland. Population densities are usually stable and can reach over 70 zokors/ha in seriously infested areas. Plateau zokors are mostly solitary and have a breeding season from March to July. They reproduce only once a year, with an average litter size of 2.7 ± 0.1. Each year, one zokor produces 242 mounds, or about 1024 kg of soil, which cover approximately 23 m^2 of grassland. In areas with very high population densities, zokor mounds can cover the whole surface (up to 2683 mounds/ha). The population density of zokors is significantly correlated with the loss of grass (Fan et al. 1988): mounds cover grass and zokors' feeding activity destroys the roots of grass.

The management of livestock is very important for rodent control because overgrazing is the major factor causing serious rodent infestations. In Qinghai, plateau pikas and zokors can be controlled effectively by rodenticides, followed by the use of herbicides to control weeds and exclosures to reduce grazing by livestock, and then re-planting of grass. The threshold for initiating control is 4 zokors/ha, and 30 pikas/ha (or 150 mounds/ha). However, traditional bait delivery techniques do not work well for zokors because of their fossorial behaviour. A baiting machine has been invented that places baits in artificial tunnels, which connect with the active tunnels of zokors. This technique increases the efficiency of control from 60% to about 80%, and the work efficiency is more than 20 times greater than traditional manual baiting (Jing et al. 1991). Recently, a bacterial toxin called botulin toxin-C was invented for killing pikas and zokors. Population reductions of over 90% can be achieved using this toxin (Wang and Shen 1988).

Grassland in Xinjiang

Xinjiang is a fourth province with grasslands that are important for livestock production in China. Rodents cause major problems in the grasslands of northern Xinjiang. The Xinjiang lemming (*Lagurus luteus*) is the most serious pest species in this region. The abundance of this rodent oscillates greatly every 4 or 5 years. Population densities can reach 2080 active holes per ha and grasslands are severely damaged during outbreaks. Large die-offs can occur after outbreaks but the cause is unknown. For example, in the early summers of 1959, 1982, 1989 and 1993, massive die-offs of lemmings were observed in rivers and lakes (Yu X., Zhao F. and Ye Y., unpublished data).

Recommendations for management

Long-term studies in the grasslands of Inner Mongolia and alpine meadows of Qinghai–Tibet have demonstrated that overgrazing and cultivation facilitate rodent infestations. Conversely, outbreaks of rodents lead to degradation of the grasslands and reduce agricultural production by decreasing the carrying capacity of livestock. Also, the damage to the grasslands can cause other serious environmental problems. The recent frequent sand storms sweeping across Beijing from Inner Mongolia were attributed to the deterioration of grasslands, partly accelerated by rodent activity. In the headwaters of the Yellow River and the Yangtze River, two of the most important rivers in China, serious problems with soil erosion have been exacerbated by rodent damage to vegetation. In response, the Chinese central government has launched a large program for managing rodent problems in grasslands. As usual, poisons, including botulin toxin-C, are the common tools for rodent management. These methods can only solve the rodent problem in the short term. Integrated management emphasising an ecological approach, combined with fertility control, is required for a sustainable solution.

For heavily degraded grassland, chemical control of rodents should be considered first, followed by weed control and re-sowing of grasses. Grazing by livestock should not be permitted in the first year of rehabilitation, and limited grazing is acceptable only after the grassland has fully recovered. For lightly degraded grassland, rodent control may not be necessary but the other rehabilitation techniques are required. Grazing can be resumed when the grassland has recovered. Poisoning of rodents, chemical control of weeds, and re-sowing of grass are all essential for the restoration of abandoned, formerly-cultivated grassland (Fan et al. 1999).

Traditional chemical control causes environmental pollution and risks to humans, livestock and wildlife. Therefore, it is necessary to develop non-toxic, non-polluting and sustainable control techniques for managing grassland rodents. The development of agents for fertility control, especially immunocontraceptive vaccines, is a recent area of research that may result in new tools for managing rodents. An immunocontraceptive vaccine that stimulates an animal’s immune system to block fertilisation, implantation or embryo development could be delivered in a non-toxic bait using traditional techniques. Immunocontraception has the advantage of being species-specific, non-polluting and humane, with little or no undesirable consequences for agricultural production or the environment. In Australia, major advances have been achieved in the development of immunocontraceptive vaccines for the management of house mice (*Mus domesticus*) (Chambers et al. 1999). In addition, population models have shown that this control technique is potentially very effective for rodent management (Zhang 2000; Shi et al. 2002; Davis et al., this volume).

Acknowledgments

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Simulation of fertility control in an eruptive house mouse (*Mus domesticus*) population in south-eastern Australia

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Abstract. We simulated fertility control of house mice during and following years that populations erupt by combining time-series abundance data with estimates of survival based on capture–mark–recapture data. Analysis of seasonal rates of increase suggest that compensation to any method of control that reduces the density of mice is not expected until the winter decline—rates of increase over the annual decrease phase are density-dependent while rates of increase over the increase phase are not. Fertility control that sterilises one third of the female mice is predicted to have a large impact on the dynamics of mice such that plague densities are avoided. These results assume that the control agent operates over the whole breeding season and the presence of sterile females does not affect the reproductive output of the remaining fertile females. Nevertheless, we conclude from our simulation that achieving high sterility rates is not necessary for effective management of house mice outbreaks in Australia.

Introduction

House mouse populations occasionally erupt in the grain-growing regions of southern and eastern Australia, causing substantial losses to crops, high social stress through mice invading houses, shops, businesses and hospitals, and environmental and animal welfare concerns because of the high use of poisons (Caughley et al. 1994). Recently, the focus has been on developing species-specific fertility control through the use of immunocontraceptive vaccines (Chambers et al. 1999a; Singleton et al. 2001a). Immunocontraception involves dosing or infecting an animal with a reproductive protein that generates an immune response which blocks fertilisation.

Populations of wild house mice typically have an annual breeding season that begins in early spring and ends in autumn, though there is considerable inter-annual variability in both the commencement of breeding and the length of the breeding season (Singleton et al. 2001b). Seasonality in breeding produces an annual cycle in the abundance of mice. The annual cycle can be clearly seen in periods of high numbers of mice but can be difficult to detect during periods of low abundance. Management of mice using fertility control agents aims to eliminate the rapid seasonal increases in numbers of mice that are associated with eruptions. This concept has been tested in enclosure studies, which indicated that sterilising approximately two-thirds of the population would be sufficient to prevent eruptions (Chambers et al. 1999b).

This paper brings together analyses of time-series data and capture–mark–recapture data from a 19-year study of field populations to predict the short-term effects of fertility control on the population dynamics of house mice.

Materials and methods

Study site

Mice were live-trapped using Longworth traps at regular intervals of approximately 6 weeks near Walpeup in north-western Victoria (35.08°S, 142.02°E) from 1983 to 2001. Between 1990 and 1992, trapping was opportunistic and there was no trapping during the summer of 1999. Details of the trapping protocol are given in Singleton (1989). Between October 1983 and July 1984, there was a more intensive capture–mark–recapture study during a period when the population density of house mice increased from low levels to the extremely high levels that are characteristic of a plague.

Concurrent to the capture–mark–recapture study, traps were set in nearby farmland to collect data on the breeding ecology of wild house mice. Necropsies of female mice provided information on the commencement and end of the breeding season (Singleton et al. 2001b). Finally, daily rainfall is recorded at the Mallee Research Station and these data were used to calculate cumulative rainfall between April and October each year, which is positively correlated with crop yield and has been used to model the rate of increase of mouse populations (Pech et al. 1999).

Statistical analyses

To obtain an index of abundance of mice at the farm scale, data from all farm habitats were pooled. For each night in which the number of recaptures was greater than seven, a capture probability was calculated as the number of recaptures divided by the number of marked mice (if there was more than one night in a trapping session for which this was possible, then a mean capture probability was calculated for the session). For each session which included one or more such nights, a farm-scale estimate of abundance was generated by dividing the mean trap success by the mean capture probability. For the remaining sessions, mean trap success was divided by a seasonal average capture probability. In all cases, the estimate was scaled by trapping effort.

For each annual cycle in the time-series data, a single average rate of population change was calculated over the increase phase and a single average rate for the winter decline. These rates of population change are represented as monthly instantaneous rates of increase, defined as

$$r_{b,t} = \frac{1}{L_t} \ln\left(\frac{N_{end,t+1}}{N_{start,t}}\right) \quad (1)$$

and

$$r_{d,t} = \frac{1}{T_t} \ln\left(\frac{N_{start,t}}{N_{end,t}}\right) \quad (2)$$

where $N_{start,t}$ and $N_{end,t+1}$ are, respectively, indices of abundance at the start and end of the annual increase in mouse abundance that begins in calendar year t and ends in year $t+1$, L_t is the length of time (months) between the start and the end of the annual increase that begins in year t, and T_t is the length of time (months) between the end of the previous annual increase and the beginning of the next. $N_{start,t}$ is defined as the abundance of mice at the last trapping occasion that is less that 9 weeks (the generation time for house mice) after the commencement of breeding. The observed peak in abundance was used to set $N_{end,t+1}$ because there was little correlation between the timing of the observed peak in abundance and the reported end of breeding.

Simulation of fertility control

Fertility control was simulated using the historical time-series data by reducing $r_{b,t}$ (as described below), using a statistical model to predict $r_{d,t}$ (see Figure 1) but retaining the observed values of the date of commencement of breeding and the duration of the increase and decreases phases, L_t and T_t. In the season that fertility control was applied, the observed monthly rate of increase, $r_{b,t}$, was replaced by

$$r_{b,t}(x) = \ln[\phi_t + (1 - x)R_t] \quad (3)$$

where ϕ_t represents the monthly survival of trappable mice during the seasonal increase that begins in calendar year t (estimated from capture–mark–recapture data), x represents the proportion of female mice that are sterile, and R_t is the monthly *per capita* recruitment rate over the breeding season that begins in calendar year t and ends in year t+1 calculated as

$$R_t = exp(r_{b,t}) - \phi_t \quad (4)$$

Simulations began with the onset of breeding and were run for 2 years. The value of $r_{b,t}$ in the second breeding season of a simulation was not changed from its observed value. The demographic rates, R_t and ϕ_t, and the seasonal instantaneous rates all refer to the trappable population. While this population includes some sexually immature animals at some times of the year, we do not attempt to introduce age structure here.

Results and discussion

Rate of increase

The time-series data on the abundance of mice are shown in Figure 1a. There was high between-year variability in the rates of increase during the seasonal increase ($r_{b,t}$). These rates are positively correlated with April–October rainfall, with 45% of the variance accounted for (Figure 1b). Rate of increase, $r_{b,t}$, is *not* correlated with the starting density in spring (Figure 1d).

There was also between-year variability in $r_{d,,t}$. This is negatively correlated with mouse population density at the end of the preceding seasonal increase. It has a stronger negative correlation with both *peak* density during the preceding seasonal increase and *average* density over the seasonal increase. The latter variable explains 84% of the variation (Figure 1c).

Simulation of fertility control

Figure 2 shows a simulation of fertility control for 1983–84, when a mouse plague caused significant losses in crop production, and the consequences of fertility control for the following summer (1984–85). The fertility control agent was assumed to act over the whole of the first breeding season such that $r_{b,t}$ was given by equation (3) with x set to 0.33. For values of x higher than a third, the predicted impact on the abundance of mice is greater than that shown in Figure 2 with trajectories following the same pattern (results not shown). Survival (ϕ_t) over the increase phase in 1983–1984 was set to the maximum observed monthly apparent survival rate of 0.85 (S. Davis, unpublished data).

We have implicitly assumed that:

(i) the survival rates of sterile mice are the same as those for fertile mice;

(ii) the duration of each increase and decrease phase is unaffected by the presence of sterile female mice;

(iii) reproductive parameters such as age at sexual maturity, proportion breeding, litter size and survival of pups are unaffected by the presence of sterile females;

(iv) the fertility control agent is active at the commencement of breeding; and
(v) the fertility control agent affects new cohorts as they appear so that the proportion of female mice that are sterile is constant over the course of the increase phase of the population.

In the simulation of fertility control, compensation did not occur during the seasonal increase but did occur during the winter decline through density-dependent survival. Controlling mice over the seasonal increase resulted in lower densities throughout the increase phase and consequently relatively better survival of mice over winter. This source of compensation can result in higher spring densities the following season than if no control was applied (Figure 2).

This is a potential cause for concern if control of mice in one year results in a high spring density the following year when, if conditions are good, control may need to be

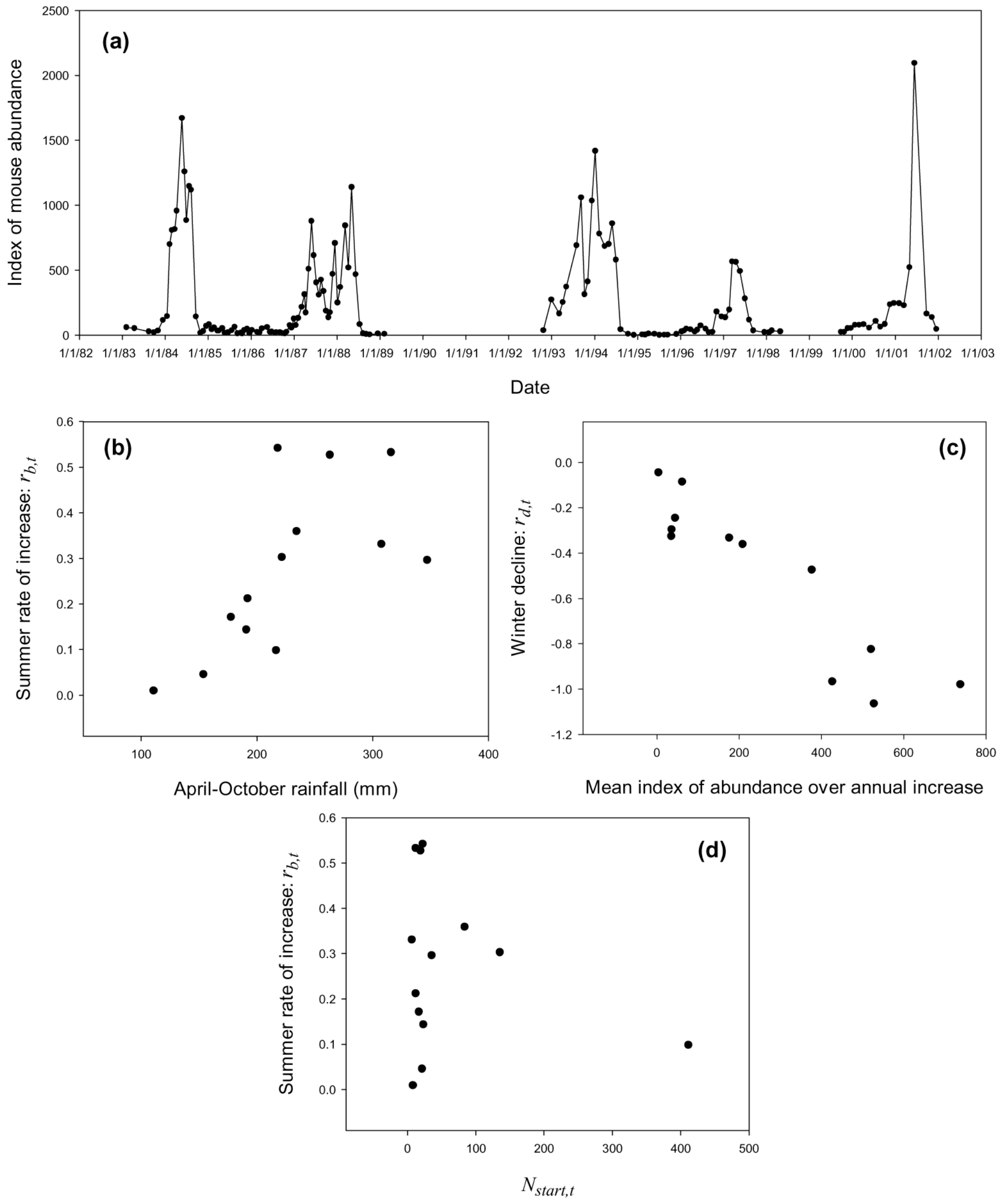

Figure 1. (a) Time-series data on the abundance of house mice (see Methods for definition of the index used). (b) Correlation between the rate of increase during the annual increase phase ($r_{b,t}$) and April–October rainfall (mm) (regression coefficients are –0.1379 and 0.0018 with P values 0.3556 and 0.0121 respectively). (c) Correlation between the rate of increase (decline) over winter ($r_{d,t}$) and mean index of abundance over the preceding increase phase. The linear regression used for simulation purposes was $r_{d,t} = -0.1472 - 0.0013M_{t-1}$, where M_{t-1} is the mean index of abundance over the annual increase phase beginning in the previous year, t–1 (P values for the regression coefficients are 0.0486 and <0.0001 respectively). (d) Lack of correlation between the rate of increase during the annual increase phase ($r_{b,t}$) and starting density in spring ($N_{start,t}$) (regression coefficients are 0.2996 and –0.0004 with P values 0.0004 and 0.4223, respectively).

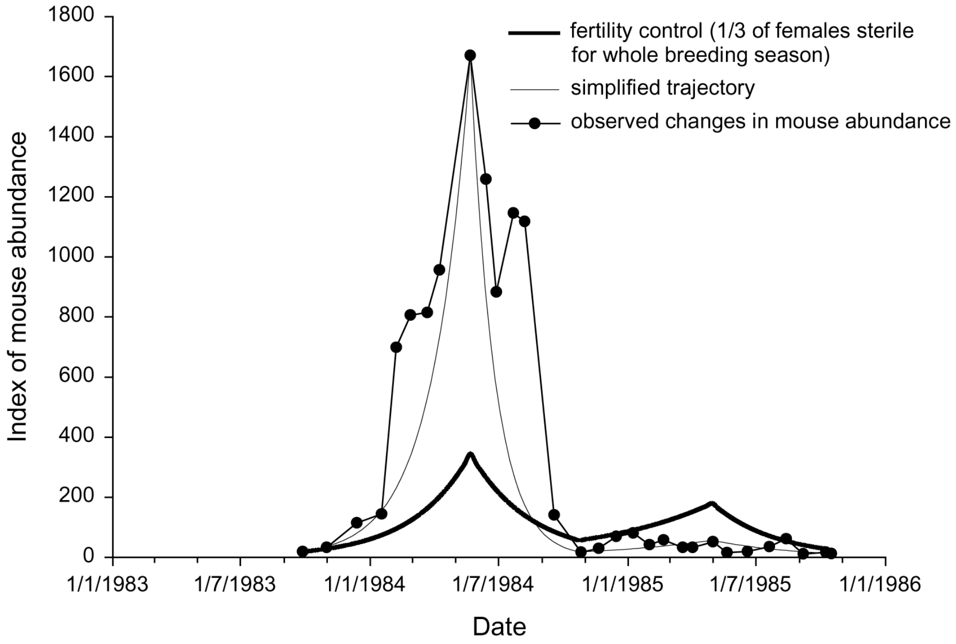

Figure 2. Observed changes in mouse abundance, simplified trajectory (using average instantaneous rates of increase over the increase and decrease phases) and simulation of fertility control, all shown for two annual cycles starting from the beginning of the breeding season in the spring of 1983. Fertility control is modelled as a reduction to recruitment (by a factor of one third) during the whole of the first breeding season but not the second.

repeated in order to prevent an outbreak. This is relevant to all methods of managing mice, rather than being particularly associated with fertility control. Also, if control is highly effective then, despite enhanced winter survival, control in one year may not create management problems in the following year.

The modelled effect of fertility control on house mice populations shown in Figure 2 is similar to that predicted for Brandt's voles (*Microtus brandti*) in Inner Mongolia (Shi et al. 2002). This is because populations of house mice and Brandt's voles have the same seasonal structure in demographic rates: density-dependent survival over winter, and a rate of increase during the breeding season that is independent of density and determined by extrinsic environmental factors.

The simulation may underestimate the true impact of imposing life-long infertility on mouse populations because (a) the maximum observed value for apparent survival was chosen, and (b) in the second year of the two-year simulation, $r_{b,t}$ was not reduced even though a small proportion of over-wintering mice would be infertile.

Conclusion

The predicted impact of fertility control that sterilises a third of the female mice is high in the season that it is applied. This prediction relies on the analyses of the time-series data, which show that the observed rate of increase of house mice during the seasonal increase is independent of density. On this basis, there will be no compensation to fertility control during the seasonal increase phase, at least through density-dependent factors, until the following winter decline. We conclude that achieving high sterility rates is not necessary for effective management of eruptive populations of house mice in Australia.

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Predicting house mouse outbreaks in the wheat-growing areas of south-eastern Australia

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Abstract. Outbreaks of house mice (*Mus domesticus*) occur irregularly in the wheat-growing areas of south-eastern Australia and impact on agricultural production. Prediction of mouse outbreaks has been successful in the central mallee region of Victoria and we have attempted to extend this prediction to a wider region of Victoria and South Australia. We developed two models: (1) a qualitative outbreak prediction from winter and spring rainfall and (2) a quantitative prediction of maximum autumn density of mice from winter and spring rainfall and spring mouse abundance. Both models have achieved some success at prediction. For the qualitative model we can achieve 70% correct predictions from winter and spring rainfall. The quantitative model is less satisfactory, and although it gives some predictability of high autumn densities, it misses too often the severe outbreaks that cause most damage. We highlight the demographic problems that need further analysis to increase our predictive abilities for mouse outbreaks.

Introduction

House mouse outbreaks are an undesirable feature of the wheat-growing regions of south-eastern Australia. Detailed studies of local populations have been carried out at different sites for more than 40 years, and these studies provide a wealth of demographic data for understanding the causes of these outbreaks (Newsome 1969a,b; Redhead and Singleton 1988; Mutze 1989, 1991; Singleton 1989; Singleton and Redhead 1990; Boonstra and Redhead 1994; Pech et al. 1999; Singleton et al. 2001). If one understands the mechanisms behind demographic changes, the next step is to construct models to predict outbreaks. For the house mouse in south-eastern Australia, a detailed modelling effort was undertaken by Pech et al. (1999), concentrating on the data available from one site in the central mallee region of Victoria. The Pech model has been quite successful in predicting changes in mouse numbers in the central mallee, and the objective of this paper is to try to extend this modelling effort to a broader spatial scale. In particular, we ask this question: Can we achieve a predictive model of house mouse plagues that can be used throughout the mallee region of Victoria and South Australia both to assist farmers and to add to our understanding of the ecology of mouse plagues?

Materials and methods

Quantitative house mouse data were available from two main sites: Walpeup in the Victorian mallee (G.R. Singleton, unpublished data) from 1983 to 2002 and Roseworthy in South Australia from 1979 to 2001 (G. Mutze, unpublished data). In addition, quantitative data were available from four other sites in Victoria and South Australia from 1998 to 2002 (Figure 1). Longworth and Elliott live-traps were set in crops (typically 6 × 6 grids, 10 m spacing) and along fence lines (10 m spacing). Mouse abundance was estimated by adjusted trap success, and the general methods are described more completely in Mutze (1991) and Singleton et al. (2001).

Qualitative house mouse data were dichotomised at 0 = no outbreak, 1 = outbreak. These qualitative data were gathered from Saunders and Giles (1977), Mutze (1989), and Singleton and Redhead (1989), and during the last 20 years from direct reporting from farmers and state agricultural scientists. We have used qualitative mouse data from the nine statistical local areas shown in Figure 1 for 1960–2001. Not all areas have data for each year, but there are many more qualitative data available from a larger area than there are quantitative data.

The schematic model for house mouse outbreaks is shown in Figure 2, and is based on the assumption that food supplies drive changes in density. Mutze et al. (1990) and Pech et al. (1999) used wheat yield as a surrogate measure of food supplies, and we have followed their lead in this paper. Wheat yield data from the period 1960 to 2001 were obtained from the Australian Bureau of Statistics for the statistical local areas shown in Figure 1. Monthly rainfall data for the same time period were obtained from the Australian Bureau of Meteorology for sites in or near the areas shown in Figure 1. In a few cases for which rainfall data were missing from one station, we used a nearby station for that time period. In general, monthly rainfall data are highly correlated for nearby sites. In addition to temperature and rainfall, we have computed two weather variables to add in the analysis—actual evapotranspiration and soil water deficit. Actual evapotranspiration (AET) is a complex function of temperature and rainfall in association with potential soil water storage. Soil water deficit measures the shortage of water in the soil, and is maximal under drought conditions. Monthly actual and potential evapotranspiration were calculated for all the rainfall stations from temperature and rainfall data. We used the methods of Thornthwaite and

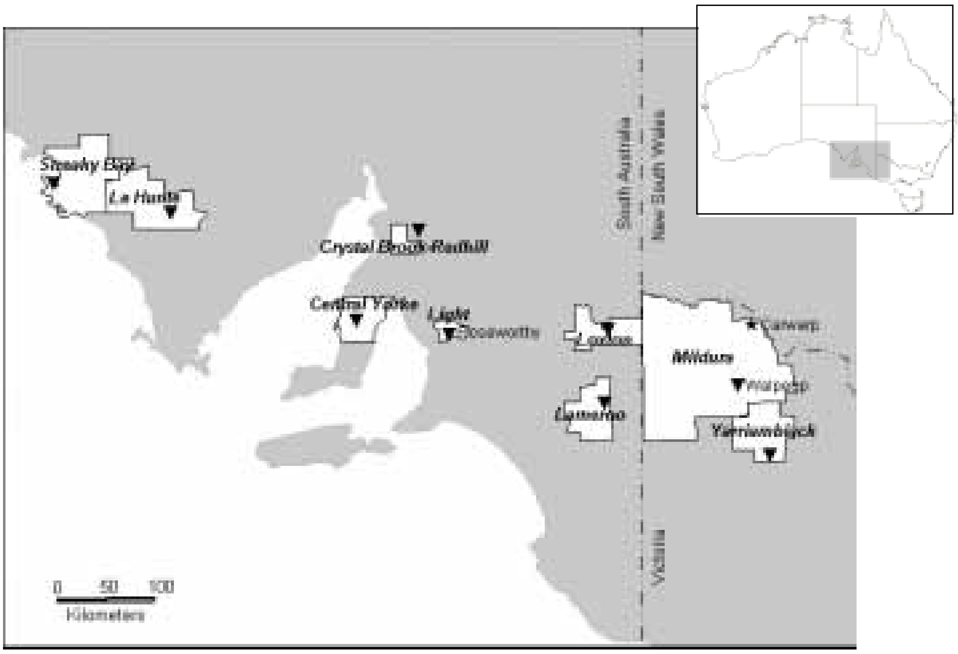

Figure 1. Location of the study areas utilised in this analysis. The nine statistical local areas from which wheat production and qualitative mouse outbreak data were obtained are outlined. The meteorological sites from which rainfall and temperature data were obtained are indicated by a ▼ for each study area. The major long-term study sites of Roseworthy and Walpeup are shown. Quantitative data from 1998–2002 was also obtained from four sites at Loxton, Lameroo, Yarriambiack, and Carwarp.

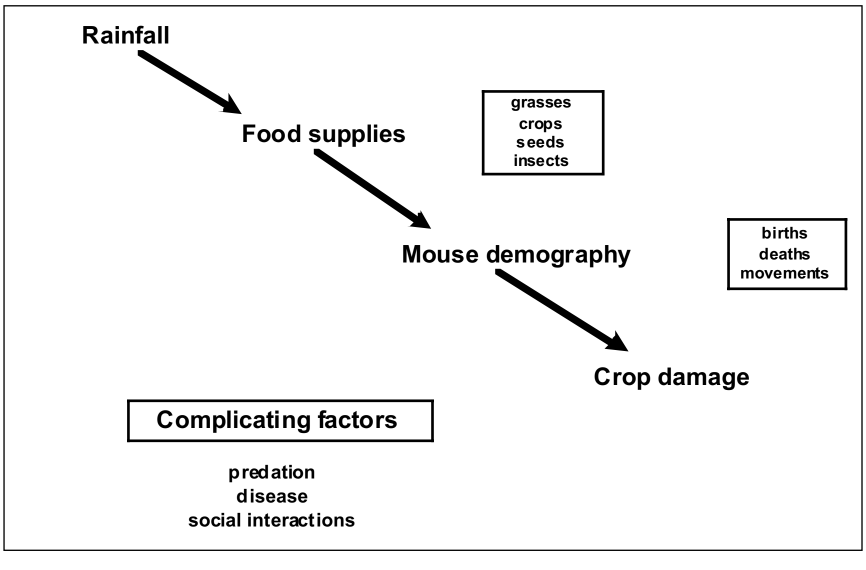

Figure 2. Schematic illustration of the current model for house mouse population dynamics in the grain-growing regions of south-eastern Australia. Food supply is the central variable, but the roles of predation, disease, and social interactions are not clearly understood with respect to how they can modify the basic food-density relationship.

Mather (1957) to estimate actual and potential evapotranspiration and soil water deficit for the areas shown in Figure 1. These estimates agreed with the general maps published by Wang (2001).

These biophysical data were used in logistic regression to estimate the probability of an outbreak for all sites and years for which we had data since 1960 (n = 255 site-years). This approach is similar to that used by Mutze et al. (1990). For sites and years in which we had quantitative data, we used robust multiple regression to attempt to predict the maximum autumn mouse density for that year. The models developed by Pech et al. (1999) and Pech et al. (2001) are based on predicting the rate of increase of mice, so that knowing the starting density of mice and some measure of food resources, one could predict the rate of increase and hence the abundance for the next time step (122 days in the 2001 model). We have adopted a different statistical approach in trying to predict the much simpler qualitative outcome of whether or not there will be an outbreak, and the more difficult quantitative prediction of how large the population will be in autumn, on the assumption that higher abundance in autumn translates into higher crop damage (Caughley et al. 1994).

All statistical analyses were carried out with NCSS 2001 (Number Cruncher Statistical System, Kaysville, Utah, <www.ncss.com>).

Results and discussion

We present our results as a series of questions with relevant data.

Can we achieve a good qualitative prediction of mouse outbreaks?

We used logistic regression to predict the probability of a mouse outbreak using 255 annual observations over the 9 sites. The best predictors were November rainfall and May to September rainfall, and the resulting logistic regression was as in equation (1) below, in which rain is in mm. The resulting logit can be converted to a probability by equation (2).

Classification of the 255 observations was correct 70% of the time (Table 1). We explored many possible alternative predictive models. Adding December rainfall to the above model did not improve predictability. Adding wheat yield to the regression improved predictability but by 3% only. Using wheat yield alone we could predict with 67% accuracy, slightly less than with rainfall alone. Soil water deficit and actual evapotranspiration were of no use in improving predictability. We conclude that the above logistic model based on rainfall is the most useful one at present for predicting qualitatively the chances of a mouse outbreak.

Can we achieve a good quantitative prediction of mouse outbreaks?

We used multiple regression to try to predict the maximum abundance of house mice in autumn from sites with detailed data on mouse abundance. A total of 43 site-years were available, most from the two sites of Walpeup and Roseworthy. The best variables for prediction were December rainfall, April to October rainfall, and September mouse abundance (indexed by adjusted trap success). Equation (3) was obtained, in which rain is in mm and mouse abundance is measured in adjusted trap success. This model, although highly statistically significant, gives an average absolute residual error of 26% in trap success, and is particularly poor in predicting the very highest mouse abundances observed. It is most sensitive to September abundance estimates.

Conclusion

Of the two models, we think the logistic model may be more useful to farmers who need to know in advance when to expect high mouse numbers in autumn. The quan-

Table 1. Classification table for the prediction of house mouse outbreaks in the Victorian and South Australian mallee regions from the logistic regression given in the text for 1960 to 2001. Boldface items indicate mistakes in classification. Outbreaks are classified qualitatively on the basis of moderate or severe damage to crops

		Estimated from model		
		No outbreak	Outbreak	Total
Actual event	No outbreak	149	**62**	211
	Outbreak	**14**	30	44
	Total	163	92	255

Equations:

$$\text{Logit}(Y) = 2.7325 - 0.0277\ (\text{November rain}) - 0.00780\ (\text{May to September rain}) \quad (1)$$

$$\text{Prob(outbreak)} = 1/[1 + e^{\text{logit}(Y)}] \quad (2)$$

$$\text{Maximum autumn abundance} = -27.158 + 0.5308\ (\text{December rain}) + 0.1468\ (\text{April to October rain}) + 1.183\ (\text{September trap}) \quad (3)$$

titative model may be more useful for developing understanding, and could become useful in practice if a simple way of estimating September mouse abundance can be developed.

Future work should involve a more detailed comparison of the relative predictive abilities of the Pech 1999 model, these two models of house mouse dynamics, and that of Mutze et al. (1990). We need to explore what determines the start of the spring breeding season, which is highly variable in house mice. Insects and grass seeds are major components of spring diet (Tann et al. 1991), and the start of breeding could be examined with simple models that predict the onset of insect activity and grass seed production in response to preceding weather patterns. It is clear that rainfall is indeed the driver of mouse outbreaks, as shown in Figure 2, but the exact causal pathway by which this is achieved is not yet clear.

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The non-lethal impacts of predation on mouse behaviour and reproduction: implications for pest population dynamics

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Abstract. In this paper, we report results from an experiment investigating the influence of habitat structure on the non-lethal effects of predation on enclosed populations of house mice. Mice were enclosed in 50 m × 50 m mouse-proof pens that allowed access to free-living predators, and were subjected to various habitat and predator manipulations. Food was provided *ad libitum*. Under high predation risk, mice selectively used areas of dense cover or refuge, but foraged more readily in open areas when predation risk was reduced by the exclusion of predators. These foraging decisions had consequences for body growth rates and the onset of breeding: in pens with little refuge, mice showed low body growth rates and began breeding later in the season, even though the populations were at low densities and there was free access to good-quality food. In pens where refuge habitat provided safe access to food, mice had higher body growth rates and showed an earlier onset of breeding, despite populations being at relatively high densities. Similarly, the total exclusion of predators from pens with minimal refuge also resulted in mice having higher body growth rates and an earlier onset of breeding. These experiments show that in semi-natural systems the non-lethal effects of predation can have large effects on the physiology of mice with flow-on effects to mouse population dynamics, and that these can be mediated by habitat structure. The implications for the development of house mouse (*Mus domesticus*) outbreaks in south-eastern Australia, which are characterised by an earlier onset of breeding compared to non-outbreak years, are discussed.

Introduction

Models of the population dynamics of pest species often assume the influences of extrinsic factors such as food abundance and predation pressure are independent. However, recent evidence suggests the risk of predation can influence the availability of resources, like food, to prey, and hence these factors may interact in determining prey population dynamics (reviewed in Lima 1998). For example, when facing the risk of predation, prey species may reduce their foraging activity, leading to increased risk of starvation (McNamara and Houston 1987) or decreased reproductive output (Peckarsky et al. 1993).

Outbreaks of house mice (*Mus domesticus*), which occur at irregular intervals in the south-eastern region of Australia, are characterised by an earlier onset of breeding than in other years (Singleton et al. 2001), although this is not in itself sufficient for plague formation. A change in food quality is a probable mechanism driving these reproductive differences, i.e. populations increase when the abundance of high-quality food increases. However, it is possible that high predation risk could offset increased food abundance by making food less accessible to mice. There is some evidence that predators can regulate house mouse populations in the irrigated, rice-growing region of New South Wales through direct predation (Sinclair et al. 1990), but the impact of predation risk on mouse population dynamics has not been investigated.

In this paper, we present a subset of results from a study using house mice contained in pens that were accessible to predators (described in detail in Arthur 2001). Three habitat and predator manipulations (A = low refuge; B = high refuge, with wire netting over felled trees providing small areas of absolute protection; C = total exclusion of predators from a subsection of the pen) were used to compare the behaviour of mice in the short-grass habitat common to all pens with their behaviour in patches of absolute refuge (treatment B) or felled trees set out in small grids (treatments A and C). Supplementary food was provided *ad libitum*. The following hypotheses and predictions were tested:

1. If mice perceive high risk of predation, they should selectively use areas under felled trees or areas covered by netting. Exclusion of predators should reduce the selective use of cover.
2. Selective use of cover in low-refuge pens should result in restricted access to supplemental and natural food, which was predominantly in open areas, result-

ing in reduced body growth of mice, compared to high-refuge and predator-exclusion pens where there was safe access to supplemental and natural food.

3. If access to food influences reproduction in mice, then mice with reduced body growth rates in low-refuge pens should have lower reproductive output than those in the other two pens.

Materials and methods

Study site and experimental design

Experiments were conducted in eight 50 m × 50 m pens that allowed access to free-living predators including feral foxes (*Vulpes vulpes*), cats (*Felis catus*) and native raptors. Prey behaviour was assessed in all pens, but due to disruption by feral pigs (*Sus scrofa*), results for mouse body growth and reproduction are presented for five pens only. A full description of the experimental design is provided in Arthur (2001). Populations were subjected to three habitat and predator manipulations: a low-refuge treatment (short grass habitat with a 5 × 5 grid of felled 3 m tall cypress pine trees); a high-refuge treatment (short grass with patches of absolute refuge of wire netting over felled pine covering 10–15% of the area); and a predator-exclusion treatment (short grass habitat but with predators excluded from a 25 m × 25 m subsection of the pen using fencing—a 5 × 5 grid of felled trees equivalent to that in low-refuge pens was placed within the exclosure). Wheat was provided *ad libitum* in four feed stations per pen either in the open (low-refuge treatment), within the refuge (high-refuge treatment), or within the predator-exclusion area (predator-exclusion treatment). The study was carried out on the eastern foreshores of Burrendong Dam on the central western slopes of New South Wales (32°40′S, 149°10′E) in open grassland. Mouse outbreaks occur in nearby areas where agricultural crops are grown (see, for example, Twigg and Kay 1994).

Assessing mouse behaviour

Mouse behaviour was assessed using the giving-up density (GUD) technique, where 20 pieces of cut up sunflower seed (each piece ~1/3 of a seed) were provided in a non-food matrix of sand. The number of pieces remaining after one night of foraging by mice measures the 'quitting harvest rate', which reflects a trade-off between the benefits and risks of continuing to forage at that harvest rate. The prediction is that animals will have a higher GUD (more pieces of food remaining) when facing high predation risk. Perceived predation risk under the three treatments was compared by measuring the GUD in up to 10 trays placed under cover (under a felled tree in the low-refuge and predator-exclusion treatments; or under netting in the high-refuge treatment), with 10 trays placed in the open (1–2 m from cover). Only data from trays visited by mice were used. Data from multiple assessments in replicate pens were analysed as a split-plot repeated-measures experiment using residual maximum likelihood (REML) estimation.

Analysis of body growth rates

Mouse populations were monitored by live-trapping using type A Elliott traps (9 × 10 × 30 cm) baited with wheat. Growth of mice was analysed by comparing the length of trapped individuals between one trapping session and the next (growth = length at session t +1 – length at session t). Initial length was included as a covariate for the analysis. The data were analysed using REML estimation with pen as a random effect. The limited replication of the experimental treatments leaves few degrees of freedom to test for treatment effects. To overcome the low level of replication, further support for conclusions regarding the effect of treatment on growth was obtained by comparing growth rates in pens at different times and under different treatment regimes (e.g. treatment reversals; Arthur 2001), but results for one period only are presented here.

Analysis of reproduction

At the end of the experiment in September 2000 (early spring), reproductive performance was analysed by comparing the proportion of females >79 mm long with embryos and recent uterine scars. This length was chosen because 80 mm was the minimum length of a female that was either pregnant or had recently given birth at the end of the experiment, based on necropsy (unpublished data). Few animals had old scars, and there were too few animals breeding in low-refuge pens to compare the number of uterine scars as a measure of litter size under the different treatments. The data were analysed using a generalised linear model (GLM) with binomial errors and a logit link function.

Results

Mouse behaviour and predation risk

There was a highly significant location by treatment interaction for GUD (F = 9.53, df = 2,8, P = 0.007; Figure 1). In high-refuge pens, the GUD under the netting was much lower than in the open. In low-refuge pens, the GUD in cover was lower than in the open. In predator-exclusion pens, there was a non-significant difference in GUDs between open and closed locations. Also, GUDs in the open in predator-exclusion areas were generally lower than GUDs in the open in other pens. These results were consistent with a number of other trials presented in Arthur (2001).

Growth of mice

Over the winter to early spring period at the end of the experiment (July–September 2000), mice in low-refuge pens grew much less than those in high-refuge and predator-exclusion pens (Wald statistic for treatment effect = 54.2, 2 df, P < 0.001, length by treatment interaction Wald statistic = 5.8, 2 df, P = 0.055; Figure 2). Points with high leverage have been left in the analysis, however it should be noted that if they are removed, the apparent treatment effects are much larger. To show that treatment effects were consistent between pens with the same treatment, lines have been fitted to the five individual pens. Results from other periods, where different treatments were applied in different pens, confirmed that the results were due to treatment effects and not some underlying feature of each pen (Arthur 2001).

Reproduction

At the end of the experiment in spring (September 2000) a much higher proportion of females >79 mm in length was found to be breeding in the high-refuge and predator-exclusion pens than in the low-refuge pens (deviance ratio 13.5, 2 df, $P < 0.001$; Figure 3).

Discussion

The results from this study indicate that predation risk can have significant non-lethal effects on mouse population dynamics under certain conditions. In low-refuge pens, mice showed an unwillingness to forage in the open. This led to reduced body growth rates, and few mice had begun breeding in early spring. In high-refuge pens, mice also showed an unwillingness to forage in the open, but safe access to supplementary food and 10–15% of the natural food provided by the refuge resulted in higher body growth rates and a high proportion of adult females breeding in early spring. When predators were removed, mice were much more willing to forage in the open, and hence had access to the supplementary food and 25% of the natural food in a predator-exclusion pen. As in high-

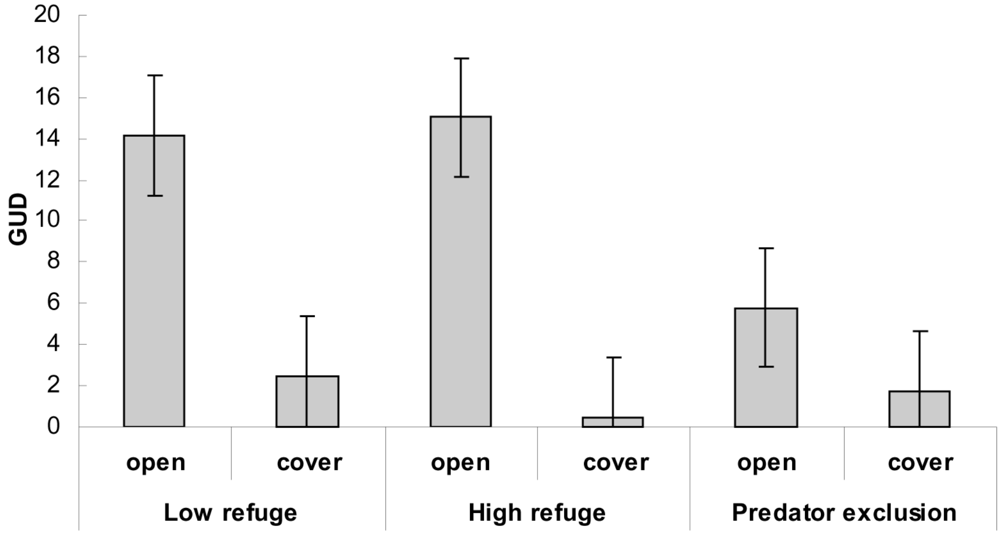

Figure 1. Mean giving-up density (GUD) in open and covered locations under the three different treatment types. Error bars are ± standard errors. Figure redrawn from Arthur (2001).

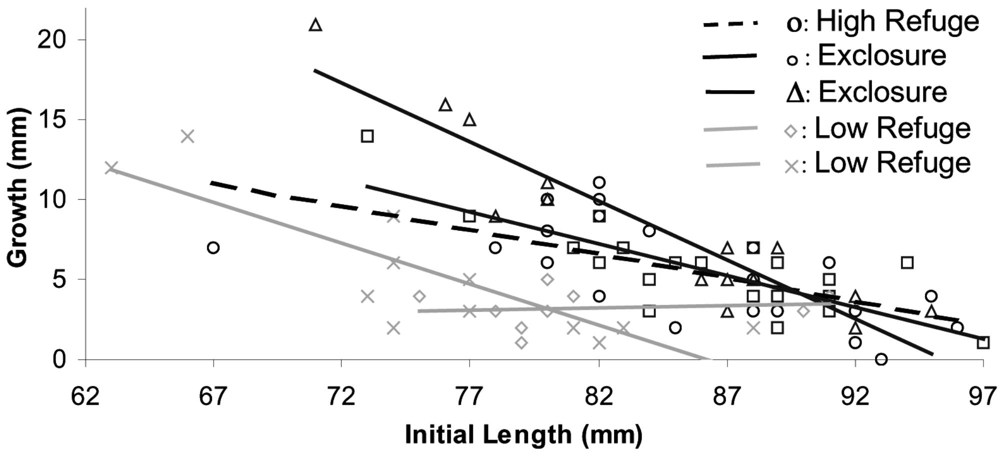

Figure 2. Fitted relationship of growth against initial length of mice for the period July–September 2000, with data grouped by pen. Each data point reflects the growth of one individual over the 84-day period (exclosure = predator exclusion treatment). Figure redrawn from Arthur (2001).

refuge pens, this resulted in higher body growth rates and a high proportion of adult females breeding in early spring. These results occurred despite populations being much higher in the high-refuge and predator-exclusion pens than in the low-refuge pens (Arthur 2001), i.e. the strength of the effect was larger than any effect of population density on mouse reproduction. It is important to note that differences in body growth and reproduction were most evident in winter and spring (Arthur 2001) when cold conditions are likely to result in high-energy requirements for small mammals like house mice. Further results from an experiment conducted in the previous breeding season were consistent with those presented here, and all results are discussed in more depth in Arthur (2001), but here we focus on the implications of these results for rodent management, particularly house mice in Australia.

Populations of house mice in Australia undergo periodic eruptions, with the pattern changing depending on the region (Pech et al. 1999). In the irrigated, rice-growing regions of New South Wales, it has been suggested that mobile predators congregate (Davey and Fullagar 1986) and can regulate mouse populations by direct mortality under certain conditions, preventing eruptions (Sinclair et al. 1990). Populations then erupt due to a combination of wider dispersal of predators and enhanced breeding performance of mice. Based on the results presented here, the latter could be due to a reduction in predation risk associated with the wider dispersal of predators. In the mallee region in Victoria, the availability of high-quality food has been the main focus for models predicting population eruptions of mice, although recent experimental studies have shown that risk avoidance behaviour of mice in areas with short, sparse vegetation is different to those with tall vegetation, e.g. along fence lines (Ylönen et al. 2002). A necessary, but not sufficient, condition for the generation of outbreaks in this region is an early onset of breeding in mid-August (early spring; Singleton et al. 2001). A change in the abundance of high-quality food is a probable mechanism driving these reproductive differences. However, changes in abundance of high-quality food may also be confounded by changes in predation risk. The abundance of high-quality food is influenced by rainfall, which results in extensive vegetation growth along fence lines and other refuge habitats where mouse populations persist between outbreaks. This vegetation growth is likely to greatly reduce the risk of predation of mice by making them less detectable by predators.

Management recommendations for minimising the risk of mouse outbreaks already include controlling vegetation along fence lines to reduce the survival and breeding of mice (Brown et al. 1998). The results presented here suggest that this may also reduce population increases by decreasing the reproductive output of mice due to increased predation risk. However, as the results from the predator-exclusion treatment show, mice will forage willingly in the open if predator activity is low. Hence, we would expect mice to reduce foraging only if predator populations were sufficiently high to generate high predation risk. Future experiments could focus on manipulations of predator abundance and habitat structure to determine whether they interact to influence the build-up of mouse populations in these areas. Studies could assess also whether there is any evidence that mice perceive predation risk at various stages of their population fluctuations.

While habitat and predator manipulations may contribute to management of pests like mice, it is important to note that these manipulations also may have detrimental consequences for other prey species (Pech and Arthur 2001). Predation risk may also be increased for protected native species also, for example. The full impacts of management actions therefore need to be considered carefully before they are implemented.

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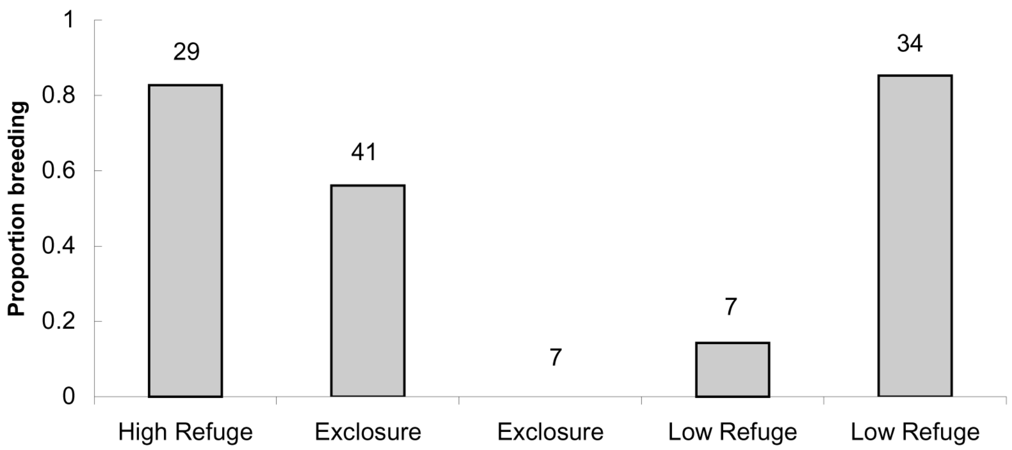

Figure 3. Proportion of female house mice >79 mm in length either pregnant or with recent uterine scars in September 2000 in different pen types. Numbers above columns show sample sizes

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Seed production, predators and house mouse population eruptions in New Zealand beech forests

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Abstract. Periodic heavy seed production in New Zealand beech forests increases the food supply available to both native birds and exotic pests, including the house mouse. We tracked changes in beech seedfall and mouse abundance as well as rats and stoats in two valleys in Fiordland National Park, New Zealand, between 1999 and 2001. Mouse population eruptions occurred only in areas and years where the beech forest was producing large quantities of seed. This autumn injection of highly nutritious food allowed winter breeding by mice, triggering a population eruption. Beech seed is no longer available after spring and mouse populations crash until the next beech seedfall. The presence of stoats (a predator) did not affect the rate of increase of mouse populations, or have any modifying effect on the influence of seedfall.

Introduction

The beech forests (*Nothofagus* spp.) of New Zealand seed heavily at irregular intervals (Wardle 1984). This seed provides an increase in food supply for native birds, but also results in a cascade of pest animal eruptions (King 1983). Immediate (within 3 months) increases in house mouse (*Mus musculus*), kiore (*Rattus exulans*) and ship rats (*R. rattus*) occur after heavy seedfalls, and a delayed increase in stoat populations (*Mustela erminea*) occurs due to their seasonal breeding. This cascade is a concern for New Zealand conservation because stoats and ship rats are predators of ground-dwelling and hole-nesting native birds. Choquenot and Ruscoe (2000) analysed a long-term data set from New Zealand's North Island to assess the relative importance of intrinsic and extrinsic factors in limiting house mouse populations in beech forest. They found that seed availability was the major predictor of house mouse population increase (r), but that this was modified by some unspecified density-dependent mechanism. They also suggested that rat abundance might have had a negative effect on the rate of increase of mouse populations via competition or predation. In this paper, we test the general model of Choquenot and Ruscoe by analysing data collected from Fiordland National Park in the South Island of New Zealand. In addition, we assess the effect of predation by stoats on the rate of increase of mice.

Materials and methods

Study sites

This study was undertaken in two valleys of Fiordland National Park in south-western New Zealand between 1999 and 2001. The Eglinton Valley comprises a forest dominated by red beech (*Nothofagus fusca*) at low altitudes (approx 450 m above sea level) where the trapping grids were located. Stoats were being controlled in the valley as part of a native bird protection program and that provided us with a predator removal treatment. Between January 1999 and June 2001, 792 stoats were removed from the Eglinton Valley (P. Dilks, pers. comm.). The Hollyford Valley comprises a mixed silver beech (*Nothofagus menziesii*)–hardwood forest. There was no predator removal being undertaken in this valley.

Rodent monitoring

Rodent populations were monitored quarterly from May 1999 to February 2002 on two grids in each valley. Each quarter (February, May, August and November), rodent trapping was undertaken on each grid for five successive nights. Each grid was 25,600 m^2, consisting of 81 trapping stations at 20 m intervals in a 9×9 array. At each trapping station, a single Elliott live-capture rat trap was baited with peanut butter and rolled oats and had straw added. All animals caught were tagged with individually numbered ear-tags and given an ear-notch to indicate the trapping session during which they were first encountered. Standard data were collected on all animals caught:

valley, grid, trap location, tag number, notch position, mass (g), head–body length (mm), sex, and reproductive condition.

Beech seedfall

On each grid, four collecting buckets were positioned to catch seed as it fell. The contents of the seed buckets were collected each quarter at the same time as trapping. Seeds (including seedcases) in each bucket were floated in 95% ethanol to determine if they had a kernel (Ledgard and Cath 1983). Only those with a kernel present were used to quantify seedfall (seeds/m^2). Choquenot and Ruscoe (2000) found that seedfall was a significant predictor of the rate of mouse population increase in the autumn and winter months only. In our analysis, seedfall was taken as zero in November and February, while cumulative seedfall was used for May (autumn) and August (winter) within each year. Log (Seedfall+1) was used in the analysis here as was done previously (King 1983; Choquenot and Ruscoe 2000). In laboratory trials, mice open the seed, eat out the kernel, and leave the seedcase (personal observation). An average red beech seed weighs approximately 0.0077g (Lethgard and Cath 1983) of which approximately 50% is kernel weight.

Analysis

Populations were indexed using minimum number of animals known to be alive (*MNA*). Ruscoe et al. (2001), using the first three seasons of this data set, showed that *MNA* was highly correlated with mark–recapture population estimates (r = 0.87). To reduce bias in estimates of mouse population growth between seasons arising from the addition of a constant to mouse *MNA* (N_t), all *MNA*s were transformed using Steen and Haydon's (2000) correction:

$$X_t = N_t + 1 + (0.05\ N_t) \qquad (1)$$

Instantaneous changes in log mouse abundance between seasons (r_t) were estimated from sequential transformed mouse *MNA*s as:

$$r_t = \text{Ln}\ (X_{t+1}) - \text{Ln}\ (X_t) \qquad (2)$$

where time (t) was season. A linear mixed effects model with a first-order autoregressive correlation was used to determine which factors affect mouse r. Valley, Season, log(Seedfall+1), Mouse abundance at the beginning of the quarter, Rat, and Stoat abundance were used as predictor variables and Grid specified as a random factor (S-Plus 6, Insightful, Seattle, USA).

Results and discussion

Effect of seedfall

Mouse abundance on each grid varied with the magnitude of the predominantly autumn beech seedfall (Figure 1). The seedfall represents the density of seed fallen in the 3 months before the trapping date (i.e. May seedfall is that fallen during the February–May quarter). In the Eglinton Valley, there was significant seedfall in both 1999 and 2000, although the magnitude of the seedfall varied

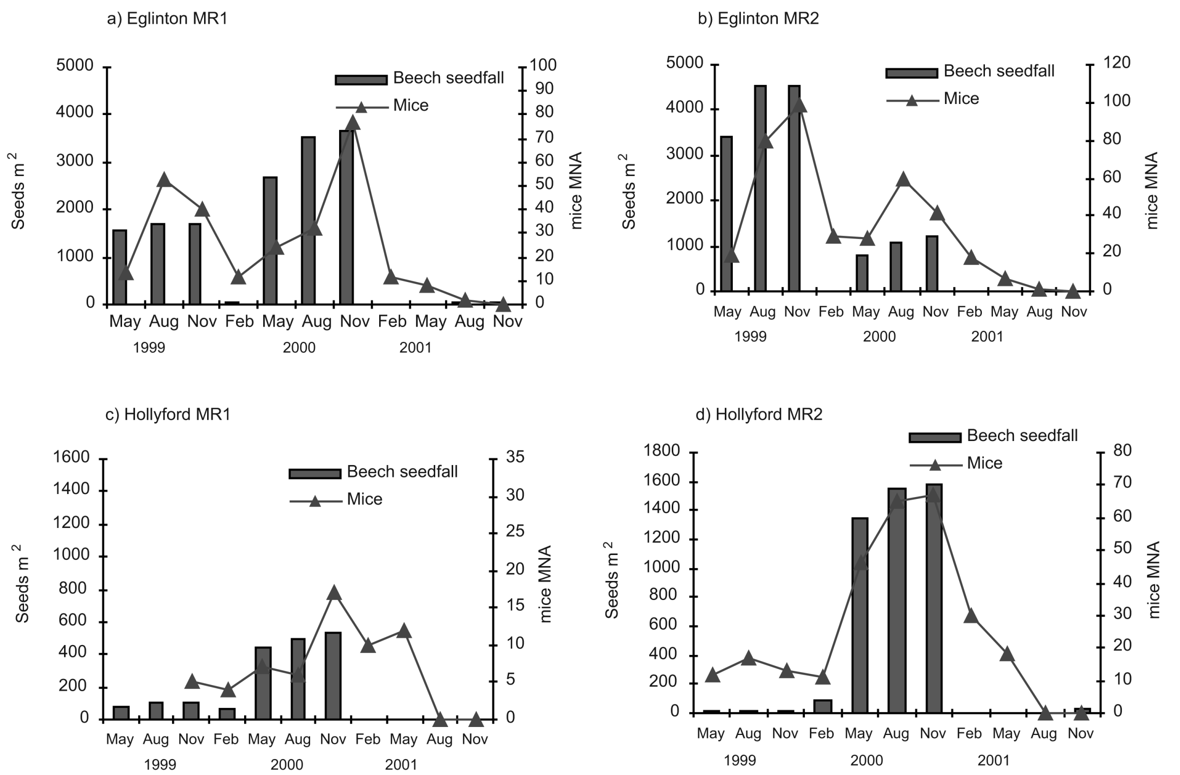

Figure 1. Cumulative within-year seedfall and population size (minimum number of animals known to be alive; *MNA*) on each of the grids in the Eglinton and Hollyford valleys from May 1999 to November 2001. Note different scales on the y-axes.

between grids. Seedfall in the second year was higher than in the first year on Eglinton MR1 grid, whereas the pattern was reversed on the MR2 grid, approximately 4 km away. The silver beech in the Hollyford Valley only produced significant seed in the second year and the quantity produced was markedly higher on the MR2 grid than the MR1 grid.

Mouse population changes appeared to follow the pattern of seedfall. In the Eglinton Valley, the highest mouse population peaks were recorded in the year of highest seedfall at each site. Within the Hollyford Valley, both seedfall and mouse numbers were higher on the MR2 grid than the MR1 grid, despite their being only 2 km apart. Mice were present in the Hollyford Valley in 1999 when there was virtually no beech seedfall. This is probably due to the presence of other seed-bearing plants not present in the Eglinton Valley (King 1983). However, the populations crashed to zero detectable in 2001, as did the Eglinton populations, when there was no beech seedfall in either valley. Annual log (Seedfall) was highly correlated with annual peaks (either in August or November) in log(*MNA*) (r_{10} = 0.957, $P < 0.001$).

The increase in mouse population size in May of each high seedfall year was due to an increase in young animals entering the trappable population. Young animals (head–body length ≤65 mm) continued to make up >25% of the Eglinton population from May to November 1999 but dropped to 10% in February 2000 (Figure 2). Following the next seedfall, the proportion of young animals increased again in May 2000 but then dropped sharply over the following 9 months. The Hollyford Valley populations followed a similar pattern with more small animals in the population in May. Following the failure of beech seeding in 2001, populations crashed toward zero and no young animals were captured after May 2001 (Figure 2). Average head–body length also changed during the study (Figure 3). Lowest averages were recorded in May 1999 and May 2000, with averages increasing from August 1999 to February 2000. In May 2001, with no seedfall, there was no decline in head–body length because only older animals remained in the population.

As a crude measure of the general ‘health’ of the animals captured, a condition index was generated using the regression method of Krebs and Singleton (1993). Figure 4 shows the mean body condition for larger animals (>65 mm head–body length) for each quarter in each valley. Small animals were excluded because juveniles are growing faster in length relative to weight gain and this results in a higher index that may not reflect general health. Likewise, females that were obviously pregnant were excluded. Results are variable, but for Eglinton the general pattern is that animals were in better condition in May when there was seedfall and subsequently lost condition over the following 9 months (winter to summer). In 2001, when there was no seedfall, the average condition index deteriorated and at that time animals were noticeably ‘lean’ in the field. The results for the Hollyford were not as clear. The mice were in good condition from May to November 1999 despite there being no significant beech seedfall that year in the Hollyford Valley. This suggests that mice could be deriving food from another source in this mixed forest.

The effect of food, predation and competition on the rate of increase of mice

Two other mammal species were present on our grids. Ship rats were present on the grids in most trapping sessions, with up to six ship rats caught over the five nights in Eglinton Valley, and up to 17 ship rats or kiore in the Hollyford Valley. Although the study was not designed to index stoat abundance, we did trap stoats on our grids. During the course of the study, seven stoats were trapped in the Eglinton Valley and 19 in the Hollyford Valley. Stoats are kill-trapped in the Eglinton Valley in an attempt to protect threatened birds and therefore are less abundant. We used these trapping indices of stoat and rat abundance (ship rat and kiore combined) as covariates in the model to describe rate of increase of mouse populations in addition to the effect of stoat removal, which is included in the Valley factor effect.

We assessed the interactive effects of Valley and other predictor variables. There were no significant two-way interaction effects of Valley and Season ($F_{3,20}$ = 0.0532, P = 0.614), Seedfall ($F_{1,20}$ = 0.120, P = 0.526), Stoat abundance ($F_{1,20}$ = 0.0001, P = 0.983), or Rat abundance ($F_{1,20}$ = 0.202, P = 0.413) on mouse *r*. Three-way interaction effects were investigated but none were significant ($P > 0.2$). When non-significant effects were eliminated from the model, we were left with the main effects of Seedfall ($F_{1,27}$ = 15.063, $P < 0.001$), Mouse abundance at the beginning of the quarter ($F_{1,27}$ = 31.81, $P < 0.001$), and Season ($F_{3,27}$ = 15.538, $P < 0.001$) and Mouse abundance*Rat abundance interaction ($F_{1,27}$ = 6.050, P = 0.021) that explained 68% of the variation in the data. Examination of the coefficients showed that while seedfall (in May and August only) had a positive effect on *r*, the influence of mouse abundance and rat abundance were both negative.

The lack of significant interaction effects of Rat abundance, Stoat abundance and Seedfall with Valley suggests that, despite the differences in forest type between the two valleys, the effects of these main predictor variables were consistent between the valleys. There was also no main effect of Stoat, or any significant second-order interactions of Stoat with Mouse abundance or Seedfall. Neither Valley (which included the effect of the stoat removal in Eglinton) nor Stoat abundance (as indexed from our trapping) changed the effect that Seedfall or Mouse abundance at the beginning of the quarter, had on mouse *r*. Therefore, we could not detect an effect of predation by stoats on mouse *r*. Mouse population numbers did not reach as high a level in the Hollyford Valley as in the Eglinton Valley. However, it appears that this is more likely due to the differences in food availability between the two valleys than the effect of stoats. Following a high

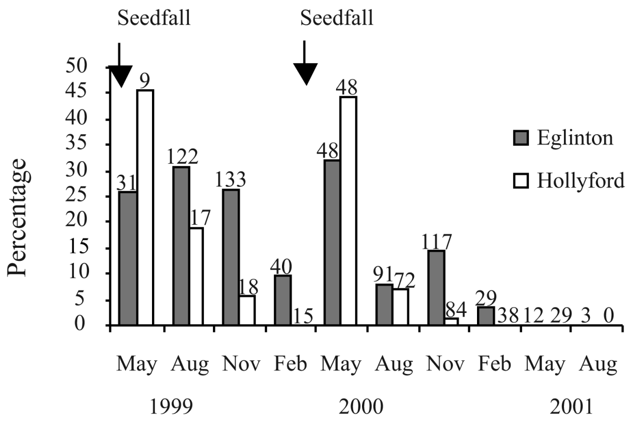

Figure 2. Percentage of small mice (≤65 mm head–body length) in the population for May 1999 to August 2001. Timing of significant seedfall in 1999 (Eglinton only) and 2000 (both valleys) is shown. Sample sizes are shown above bars.

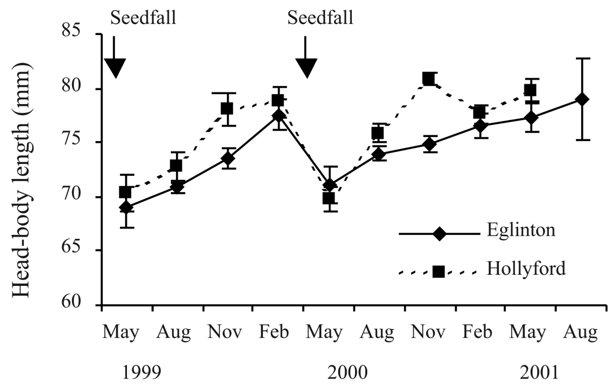

Figure 3. Changes in the mean head–body length (± se) of animals trapped in each valley from May 1999 to August 2001. Timing of significant seedfall in 1999 (Eglinton only) and 2000 (both valleys) is shown.

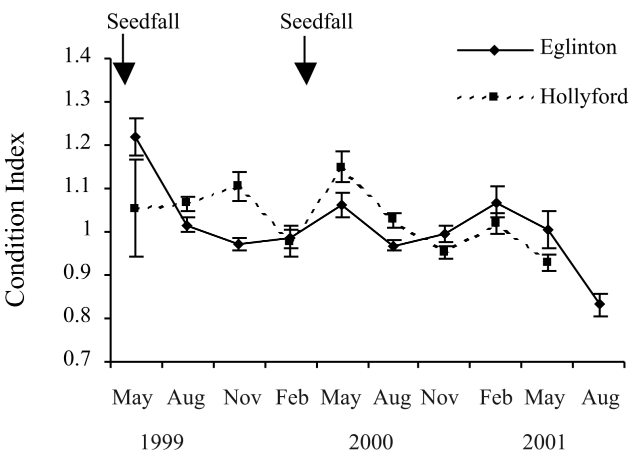

Figure 4. Changes in the mean condition index (± se) of large (>65 mm head–body length) animals in each valley from May 1999 to August 2001. Timing of significant seedfall in 1999 (Eglinton only) and 2000 (both valleys) is shown.

seedfall event, the mouse population decline begins in August or November, and by the following February, mouse populations have fallen to their lowest levels. Stoats only produce offspring in summer (weaned in January–February)—therefore the beginning of the mouse population decline is not related to an increase in stoat numbers. Predators may exacerbate a decline indirectly by influencing the foraging efficiency of prey. We did not find any evidence for stoat abundance affecting the relationship between seedfall and mouse *r* between the two valleys, which suggests that the increased predation pressure in the Hollyford Valley is not sufficient to change mouse foraging behaviour to the extent that it affects population growth and decline.

Conclusion

This study reconfirms the general model of Choquenot and Ruscoe (2000) that the quantity of seed produced by the beeches in New Zealand can be used to predict mouse population growth. We were unable to detect any influence of stoat abundance on mouse population growth during these three years. This leads to the conclusion that these mouse populations are food, rather than predation, limited.

Acknowledgments

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Impact of farm management practices on house mouse populations and crops in an irrigated farming system

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Abstract. House mice cause serious damage to agricultural crops in Australia. A set of farm management practices was developed with farmers, extension officers and scientists for a complex farming system incorporating irrigated winter cereals, rice and summer crops. This paper reports on the effect of baiting and spraying margins of crops on damage to winter crops when mouse densities were low to moderate. Baiting with zinc phosphide reduced the consumption by mice of census cards by 86%, but there was a 35% reduction on unbaited sites. Populations declined further to low levels before harvest and there was no difference in damage to wheat crops before harvest. Spraying margins of winter cereal crops with herbicides to reduce weeds and grasses significantly reduced plant growth by 47% and abundance of mice on sprayed sites by up to 77%. Damage to crops was <5%, and there was no observed reduction in damage to wheat crops. These were two examples of a range of farm management practices. Further analyses are required to look at the impacts over the whole farm and through the combined effects of the recommended practices. A critical test of the recommended practices cannot take place until an outbreak occurs.

Introduction

The house mouse (*Mus domesticus*) is a serious pest to agriculture in Australia. Mouse populations occasionally undergo widespread irruptions (= mouse plagues) in the grain-growing regions of Australia once every four years on average, but their frequency for any particular region is generally one year in seven (Singleton 1989; Mutze 1991). In 1993/94, a mouse plague caused losses estimated at A$64 million (Caughley et al. 1994), while a mouse plague in the Murrumbidgee Irrigation Area in 1994 caused an estimated A$8 million damage to three irrigated summer crops alone (Croft and Caughley 1995). Farmers generally do not perceive they have a mouse problem until densities are >200 mice/ha. The timing of high numbers of mice in relation to the stage of crop development is critical to the level of pre-harvest losses.

Management of mouse population problems in Australia generally has been reactive rather than preventative. During mouse plagues, large amounts of poisons are distributed to control mouse damage and, in one instance, up to 500,000 ha of land was baited with zinc phosphide (see Singleton 2000 for review). There is conflicting evidence about the effectiveness of broad-scale application of rodenticides such as strychnine and zinc phosphide and possible impacts on non-target species (Brown et al. 2002).

Current research is aimed at examining the effectiveness of a range of farming practices to prevent significant damage by mice. These farming practices have been developed from an understanding of the ecology of house mice in the farming system and of how management actions can be integrated into existing farm management. This strategy is based on the concept of ecologically-based management (Singleton 1997; Singleton and Brown 1999). Farm management practices or cultural practices have been used to control a range of rodent pest species throughout the world and include mowing, harrowing, ploughing, irrigating, grazing, application of herbicides to reduce cover and seed set, and baiting when rodent numbers are high (White et al. 1998; Makundi et al. 1999; Jacob and Halle 2000). These practices have proven to be successful where one crop type is grown or when it is mixed with grazing.

Our study draws together data on the responses of populations of mice to farm management practices in New South Wales (NSW), Australia, in a mixed, summer cropping system. We compare the impact of particular farm management practices on mouse population abundance, biomass of plants along crops margins, and damage to crops.

Methods

Study site

The project began in July 1998 and ran for 4 years. Data were collected from 12 experimental sites managed by 7 farmers. Each site was situated within 30 km of Coleambally, southern NSW (34°51'S, 146°05'E; altitude 126 m). The topography of the region is flat to mildly undulating. The soils are predominantly heavy grey-cracking clays. The climate is Mediterranean, with hot dry summers and cool wet winters. The average rainfall at Griffith (40 km north of Coleambally) is 406 mm/year. Rainfall was below average in 1998 (88.6% of the long-term mean, LTM), above average for 1999 and 2000 (124.2% and 108.0% of LTM, respectively) and below average for 2001 (76.4% of LTM).

The main crops grown in the region are winter cereals (wheat, barley and oats, sown early winter, harvested mid-summer), flood-irrigated rice (sown mid-spring, harvested mid-autumn), and pulse-irrigated summer crops (maize, soybean, canola and sunflower, sown mid-summer, harvested mid-autumn). Fifty per cent of paddocks were double-cropped with a winter cereal followed by a summer crop. The average farm size is 250 ha and consists of 6–11 paddocks, each of approximately 20 ha in size. Some farmers also graze sheep.

Farmer actions for mouse control

A list of farm management practices was developed by an advisory panel for controlling the impact of mice on farms (Table 1). The panel consisted of farmers, representatives from the Irrigation Research and Extension Committee, extension officers from NSW Agriculture and scientists from the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The panel met annually to develop, reconsider and make final recommendations on mouse control actions for summer-irrigated cropping systems. These practices were carried out on replicated treated and untreated sites. In this paper we report on the impact of two mouse control practices.

Impact of zinc phosphide baiting

Farmers on two sites considered that they had a significant mouse problem that warranted use of zinc phosphide. Bait was applied at 1 kg/ha by plane on 14–15 September 1999. The mouse populations were monitored using census cards before and after baiting to determine its effectiveness. Census cards are 10 × 10 cm pieces of

Table 1. List of recommended farming practices to reduce the impact of mice in the irrigated summer cropping area of southern New South Wales.

Action	Timing of action
Summer crop	
Cultivate early	May–Sept., spring, before winter
Sow early (on time)	Depends on rainfall
Harvest cleanly	Harvest
Control weeds/Remove food and cover/Spray	Twice (spray) early and follow up
Winter crop	
Pre-sowing stubble management—burn	Depends on weather
Pre-sowing stubble management—incorporate	Early as possible
Control weeds	Before spring
Sow early (on time)	Depends on rainfall
Sow deeper	At sowing
Increase sowing rate	At sowing
Monitor mice	Pre-sowing
Perimeter bait	Pre- or at sowing
Harvest cleanly	Harvest
Rice crop	
Stubble management—no action	
Stubble management—slash early	Soon after harvest
Stubble management—graze	Soon after harvest
Stubble management—burn early	After harvest
Stubble management—burn later	Following spring
Manage channels and banks	Ongoing
Bait stations	Before breeding season
Harvest cleanly	Harvest
Other actions	
Remove and reduce cover around sheds, buildings and silos	Continuous
Monitor for signs of mouse activity	Key times (early spring and autumn)
Clean up grain spills (silos, field bins)	Sowing and harvest
Mouse-proof houses, and grain and stock feed storages	Continuous
Bait key habitats using bait stations	Before spring

white bond paper (photocopying paper) soaked in vegetable oil and pegged to the ground using rigid wire pegs (10–20 cm long). The cards were set for two nights, but checked each day, and replaced on the first day if there was any evidence of chewing by mice. Cards were set in a 5 × 5 grid, 50 m from the edge of the crop, and 2 lines of 10 cards each were set along the edge of the crop, each line being 1 m apart. A 1 cm^2 grid pattern was printed on the cards. The number of cards chewed out of all cards set per site was used as a measure of mouse abundance.

The level of damage to the wheat crop was assessed on all sites 2 weeks before the farmer's expected date of harvest. Four transects were set through each crop. Each transect was separated by 50 m and was set at least 50 m from edges of crops (roads, fencelines etc). On each transect, damage to plants was assessed at five distances into the crop: 10, 20, 50, 100 and 150 m. Ten plants were assessed at each distance. These plants were selected by choosing every second plant on a perpendicular line from the transect. The number of undamaged tillers and damaged tillers were recorded per plant as well as the number of plants damaged per sampling point and reported as the percentage of mouse-damaged tillers.

Impact of spraying weeds

The impact of spraying weeds and grasses around the edge of winter cereal crops on mouse numbers and plant biomass was assessed using live-trapping (Longworth traps) and estimates of biomass from quadrats. Trapping was conducted in 6 × 7 grids placed 50 m into the crops, and from a trap-line along the edge of the crop, fenceline or channel bank. There were 15 trap stations spaced every 10 m, with 2 traps at each station. Traps were set for two consecutive nights. Biomass of weeds and grasses along the edge of the crop was estimated using photographs of known biomass. Reference photographs of known biomass were taken from 1 m^2 sample plots, which were hand clipped at ground level, dried and weighed (converted to kg/ha). Ten 1 m^2 estimates of biomass were taken from each trap line. Mouse damage to the wheat crop was assessed using the same techniques described above. For some farmers, spraying for weeds was conducted routinely around the whole farm, whereas other farmers conducted spraying specifically for this study.

Results and discussion

The application of zinc phosphide on two sites resulted in an 86.2% reduction in abundance of mice (Figure 1). A reduction of 35.2% occurred on untreated sites. Before harvest (November), mouse populations were low on treated and untreated sites (<0.5% census card take), there was little damage to wheat crops and no treatment effect (treated = 1.4% ± 0.8 se, n = 2; untreated = 2.5% ± 0.5 se, n = 6; t_6 = 1.08, P = 0.323). This reduction in mouse abundance after poisoning was consistent to that found in other studies in Australia (Caughley et al. 1998; Brown et al. 2002). However, by November there was a similar reduction in mouse numbers on unbaited sites, hence there was no economic benefit.

Spraying weeds and grasses along fencelines significantly reduced the amount of biomass on the edge of cereal crops compared to unsprayed sites by 46.7% ($F_{1,11}$ = 13.053, P < 0.01) (Figure 2). Furthermore, the abundance of mice was on average 37.3% (up to 77%) lower

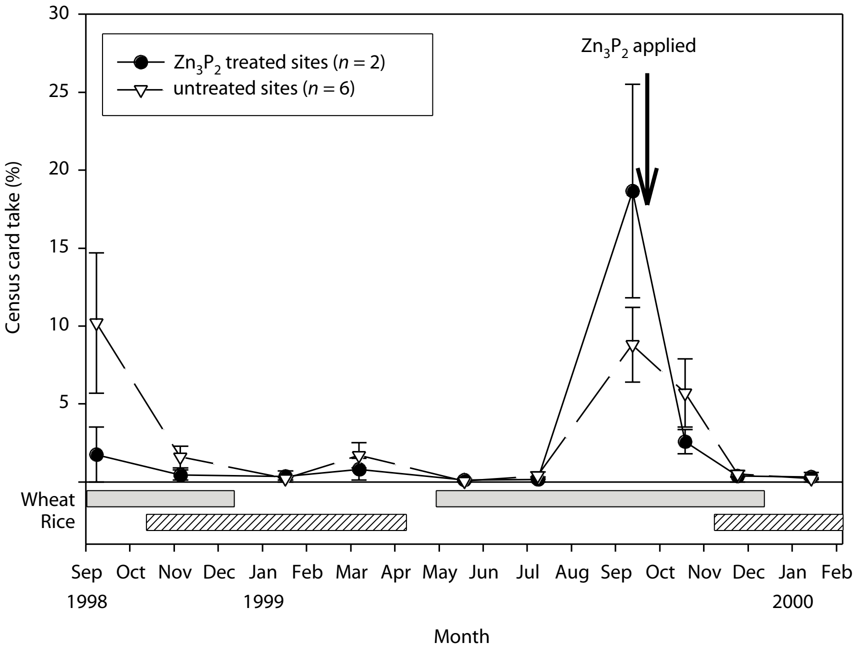

Figure 1. Impact of zinc phosphide (Zn_3P_2) on house mouse abundance measured using census cards on treated and untreated sites (mean ± se). Zinc phosphide was applied aerially on 14–15 September 1999. The horizontal bars represent the duration of the wheat and rice crops.

on sprayed sites compared to unsprayed sites ($F_{1,47}$ = 4.149, $P < 0.05$) (Figure 2). There was no interaction with time ($F_{11,47}$ = 1.005, P = 0.456). Although mouse abundance peaked in June 2000, it was not significantly higher than other months. The average damage to wheat tillers in 1999 was 4.9% (± 0.9 se, n = 3) and 3.6% (± 1.6, n = 3) to sprayed and unsprayed sites, respectively, and for wheat tillers in 2000, damage was 2.3% (± 0.9 se, n = 3) and 0.6% (± 0.3, n = 3) to sprayed and unsprayed sites, respectively. There was no difference in the level of damage between treatments ($F_{1,8}$ = 2.092, P = 0.186), but there was significantly more damage in 1999 compared with 2000 wheat crops ($F_{1,8}$ = 7.221; $P < 0.05$). Farmers generally do not notice this level of mouse damage.

It is possible to reduce the abundance of mice through applying herbicide sprays around the perimeter of crops, however because the abundance of mice was low to moderate and the level of damage relatively low, the impact on damage has not been adequately tested. If mouse populations had been higher, we would have expected to see reductions in damage to crops if these management practices were adopted. Mouse populations decline to baseline levels in November each year in the Murrumbidgee Irrigation Area (P. Brown et al., unpublished data), so damage is generally low before harvest.

Spraying and other forms of habitat manipulation around the perimeter of crops to reduce cover and availability of food have been successfully applied in a range of situations. Black rat (*Rattus rattus*) damage to macadamia orchards in Australia was reduced by 65% through manipulation of adjacent habitats by slashing grasses and applying herbicides (White et al. 1998). In East Africa, environmental manipulation has led to some success in reducing damage caused by rodents, for example, areas that are cleared of bushes or that support grazing usually have a lower carrying capacity of rodent populations, while other practices such as poisoning and trapping remain popular (Makundi et al. 1999).

While individual actions can have positive impacts on mouse populations, it is the combined effect of a range of management practices within a complex farming system that is of interest to farmers. When the study is completed, we will undertake analyses of the responses of mouse populations to a range of farming practices and the associated effects of mouse damage to crops and their yields in both winter and summer crops.

Conclusions

Most of the management of mouse plagues in Australia has been reactive rather than preventative, partly through the availability of broad-acre rodenticides such as strychnine and zinc phosphide. There are a range of farm management practices available that farmers can undertake, or are already undertaking, which can have benefits in terms of reducing mouse abundance and damage to crops. We believe that these could be incorporated within existing management practices for farmers at little cost in terms of time or money, and could lead to significant gains through increased yield, without relying on the use of rodenticides. While the results from this study showed a reduction in mouse abundance, there was no reduction in

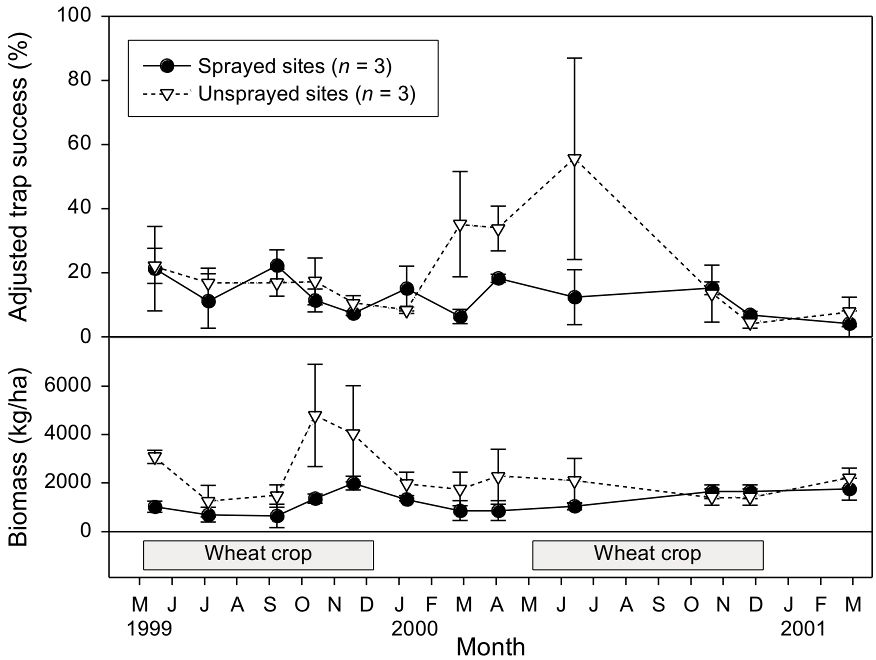

Figure 2. Impact of spraying weeds and grasses around the margins of wheat crops on house mouse abundance (adjusted trap success) and on the biomass of weeds and grasses (kg/ha). Mean ± standard errors are shown. The horizontal bars represent the duration of the wheat crops.

damage to crops when mouse populations were low to moderate. Further work is required when mouse numbers are high and to clarify whether: (1) farmers can do nothing when mice are low and only undertake practices when mice are building up; or (2) farmers that undertake these practices when mouse numbers are low will have less damage when mice are high.

Acknowledgments

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Seasonal differences in bait acceptance by forest-dwelling rats following simulated aerial 1080 possum control operations in New Zealand: interim results

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Abstract. Ship rats (*Rattus rattus*) were trapped following 10 simulated possum (*Trichosurus vulpecula*) control operations using aerially-sown non-toxic baits laced with rhodamine B. These surveys were carried out in different areas and at different times over 3 years in the Whanganui National Park, North Island, New Zealand. Preliminary examination of the data found that between 79 and 100% of ship rats contained traces of rhodamine dye, indicating that they had eaten, or at least handled, baits. Those rats that were caught following winter and spring operations were more likely to contain rhodamine B than those caught in autumn and summer. During these surveys, mice (*Mus musculus*) were incidentally caught in the traps set for rats. The proportions of mice containing rhodamine varied between 40 and 100% and those caught in winter or summer were more likely to have taken baits than those caught in autumn or spring. At the time of writing there was still one more survey to be completed.

Introduction

Aerial 1080 (sodium monofluoroacetate) operations to control possums (*Trichosurus vulpecula*) in New Zealand have traditionally been timed to occur in winter, although they often do not take place until the following spring due to the requirement for a reasonable period of fine weather. Recent work by Landcare Research has shown that there are no seasonal preferences in bait acceptance by possums following simulated aerial 1080 operations (Morgan et al. 2000). This may encourage managers to opt for summer control operations simply because the chances of having predictable periods of fine weather are much higher. Rodent, or at least ship rat (*Rattus rattus*), numbers have been reduced following successful aerial-sown 1080 possum control operations (Innes et al. 1995; Miller and Miller 1995). However, results from aerial 1080 possum control operations in the Pokeka Valley, Wanganui National Park and at Boundary Stream, Hawkes Bay, suggest that rat numbers are not always significantly reduced, even when possums are (McRitchie 2000; J. Campbell, personal observations). Currently, little is known of any seasonal differences in bait acceptance by rats following these aerial 1080 operations. Dowding and Murphy (1994) observed some interesting differences in bait take between male and female rats during an aerial 1080 operation in Northland and suggested there might be seasonal or sexual effects that warrant further investigation. Timing possum control operations to maximise the by-kill of rats, and to coincide with the breeding season of most forest birds, could produce greater conservation gains.

The primary aim of this work was to determine if there were seasonal differences in bait acceptance by forest-dwelling rats following simulated aerial 1080 operations to target possums. In addition, we hoped to determine if there were seasonal differences in bait take between sexes within the sample population of rats. The results from the first 10 surveys of a study conducted over 3 years are summarised here.

Materials and methods

Once each season between October 1999 and July 2002, non-toxic cereal baits (Wanganui No. 7), surfaced-coated with 8% rhodamine B (RB) solution as a marker of bait uptake, were aerially sown at 3 kg/ha over an approximately 90 ha study block in forest in or near the Wanganui National Park, North Island, New Zealand. A new site was selected every season to ensure each survey was independent from previous ones and baits were only sown when we could reasonably predict three fine nights following application. On the fourth day (three nights) after the bait was sown, rats were kill-trapped and possums poisoned using cyanide paste laid near the rat traps for three nights on two randomly-orientated 3.24 ha plots. These plots were separated by an absolute minimum of 200 m within, and no closer than 200 m to the edge of, the 90 ha treatment area. All rats trapped were identified to species, weighed, measured, sexed, and examined internally for the presence or absence of RB (indicating whether or not the rat had eaten non-toxic bait). Usually the RB could be easily detected by eye, however some rodents required inspection under an ultraviolet fluorescent lamp before the marker could be detected.

Statistical analysis

We used an exhaustive CHAID (Chi-squared automatic interaction indicator) analysis to explore predictors (season, sex, year of survey, the night the rat was trapped (1st, 2nd or 3rd night of trapping) and the number of possums poisoned in the survey) that may have affected whether RB was detected in an individual rodent. This algorithm examines all possible splits for each predictor based on chi-square statistics (De' ath and Fabricius 2000) and is implemented in AnswerTree, an SPSS data classification system.

Results and discussion

To date, 10 simulated aerial 1080 operations and trapping surveys had been conducted (two in spring, three in summer, two in autumn and three in winter) and 300 ship rats, two Norway rats (*Rattus norvegicus*) and 98 mice (*Mus musculus*) were caught. The proportion of rats trapped in each survey marked with RB varied between 79 and 100%. We have made two important assumptions with the results from these simulated aerial 1080 operations using non-toxic baits. The first is that the proportions of rodents that would take toxic baits in each season, or within each sex, would be the same as these non-toxic baits. The second is that those animals marked with RB would have consumed lethal doses of a poison and that any sub-lethal doses are not associated with a particular season or sex. CHAID exploration of the pooled data collected to date (Table 1) suggested that those rats that were caught following winter and spring operations were more likely to be marked than those caught in summer and autumn (χ^2 = 8.58, df = 1, P = 0.0034). The CHAID analysis also indicated that those rats caught on the first two nights of trapping were more likely to be marked than those caught on the third night, and that those rats caught on surveys where 124 or fewer possums were poisoned were more likely to be marked than those where 157 or more possums were poisoned (χ^2 = 31.34, df = 1, P = <0.0001 and χ^2 = 9.05, df = 1, P = 0.0026, respectively). Sex or the year that the surveys were carried out did not appear to be important indicators of whether a rat was likely to be marked (χ^2 = 3.13, df = 1, P = 0.0767 and χ^2 = 4.397, df = 1, P = 0.1131, respectively). We used the CHAID analyses in this paper only to provide some indications of the likely predictors of bait acceptance by rats, because at the time of writing there was still one more field survey to be carried out in spring 2002. Also, some of the rodent specimens collected from the 2002 autumn and winter surveys still required examination in the laboratory to confirm that they were not marked with RB, thus the proportions given here are the minimum. Nevertheless, it is interesting to note the apparently higher proportions of rats marked in winter and spring compared to those in summer and autumn. A reduction in ship rat numbers in late winter or early spring following an aerial 1080 operation would provide some relief for those native birds most sensitive to rat predation whilst nesting in spring. Ship rat diet can vary seasonally in New Zealand (Innes 1990) and it may be that there were more alternative foods available during autumn (seeds) and summer (flowers and invertebrates), or the difference was a result of greater competition with possums for the baits in those seasons. The rats caught on the third night of trapping (six nights after the bait was sown) were apparently less likely to be marked than those caught on the previous two nights. In most of the surveys, the baits were no longer observed on the forest floor by three to five nights after they were sown, particularly when there were large numbers of possums poisoned. Those rats trapped on the third night may have been individuals that moved in from outside the treated area and/or represented the more neophobic members of the population. This could also be because the RB marking had worn off, however we suspect this is unlikely because when we did the pilot study for this work we were still able to detect RB in rats caught 2 weeks after the bait drop.

Table 1. Total numbers of ship rats (*Rattus rattus*) caught and proportions (%) of these containing traces of rhodamine B (RB) for each season and for both sexes.

Season/sex	Number of surveys to date	Total number of ship rats caught[a]	Overall % with RB
Spring	2	91	93.7
Summer	3	72	87.5
Autumn	2	51	82.4
Winter	3	86	94.2
Males	All 10 combined	154	89.6
Females	All 10 combined	143	95.1

[a] Three ship rats were scavenged whilst in the trap so could not be correctly autopsied for presence of rhodamine B and the sex of one of these could not be determined.

Mice were not specifically targeted but they were caught incidentally in the rat traps. The proportion of mice trapped in each survey marked with RB varied between 40 and 100%. CHAID exploration of the pooled data collected to date (Table 2) suggested that those mice that were caught following winter and summer operations were more likely to be marked than those caught in autumn and spring (χ^2 = 9.54, df = 1, P = 0.0201). Sex or the year of the survey did not appear to be important predictors of whether a mouse was likely to be marked (χ^2 = 3.19, df = 2, P = 0.203 and χ^2 = 0.6, df = 1, P = 0.4391, respectively). The number of mice caught was quite small, so our results for this rodent should definitely be treated with a high degree of caution. The relatively low bait acceptance (compared to rats) by mice in some surveys, even with this small sample, is nevertheless worth noting and may help explain why mouse populations seem to recover soon after aerial 1080 possum control operations (Innes et al. 1995; Miller and Miller 1995).

Table 2. Total numbers of mice (*Mus musculus*) caught in rat traps and proportions (%) of these containing traces of rhodamine B (RB) for each season and for both sexes.

Season/sex	Number of surveys to date	Total number of mice caught[a]	Overall % with RB
Spring	2	17	47
Summer	3	19	68.4
Autumn	2	31	48.4
Winter	3	31	83.9
Males	All 10 combined	56	69.6
Females	All 10 combined	41	53.7

[a]One mouse was scavenged whilst in the trap so the sex could not be determined.

The main reason that Department of Conservation managers use aerially-sown 1080 is to control possums for forest-canopy protection, not to control rodents. The incidental kill of rodents is usually seen as a beneficial side effect and is occasionally factored into the planning at some conservation sites. The most effective time to control possums using 1080 is when ambient temperatures are lowest and the animals more susceptible to 1080 poisoning (Veltman and Pinder 2001). Our interim results suggest that during winter a high proportion of both rats and mice will eat baits suggesting that this is the season to achieve the greatest knockdown of rodents. So the advantages of doing an aerial 1080 operation in the warmer months when the chances of having predictable periods of fine weather are much higher should be outweighed by the potential for a better knockdown of both possums and rodents in winter.

Interim conclusion

Our interim results indicate that there may be seasonal differences in non-toxic bait acceptance of forest-dwelling ship rats and mice following simulated aerial 1080 operations. Rats trapped in spring and winter were more likely to accept baits than those trapped in autumn and summer and mice trapped in winter and summer were more likely to accept baits than those trapped in autumn and spring. Other factors such as sex or the year of the survey did not seem to be important predictors of whether or not a rat or mouse would take baits, although competition with possums may have influenced what proportion of rats took baits.

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Reproduction and growth in house mice from cold, hot and thermally moderate environments

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Abstract. The house mouse (*Mus domesticus*) is found throughout Australia, and is successful in a wide range of climates. We examined the reproductive success and growth rate of young in differing thermal regimes (13°C, 'cold'; 22°C, 'control'; and 30°C, 'hot') in a laboratory colony of house mice derived from wild stock from Mudgee, New South Wales. Female mice in all groups did not always have a post-partum litter following the birth of their first litter, although post-partum litters were born in subsequent pairings. Litter sizes did not differ between treatment groups, although more young were born from post-partum matings. Young from the 'hot' group were smaller than for other groups, and their growth rates were slower. The observations on post-partum activity, and the differences in growth rates, may be of significance in explaining the sudden plague activities of mice in some parts of Australia.

Introduction

The house mouse (*Mus domesticus*) has been resident in Australia for the past 200 years, and during that time has radiated throughout the continent. While successful throughout Australia, it is less common in desert regions. However, unlike its counterpart in Europe, the Australian house mouse is more widely dispersed in the environment than around farm buildings and houses.

The adaptation of the house mouse to the Australian environment has been a topic of study for at least 30 years, with much of the focus centering on how mice increase their population size at times to plague proportions. Plague activity is found in some North American and European rodents (Bronson 1979), but is not known for the house mouse in Europe (Singleton and Redhead 1990). Australian studies have demonstrated that house mouse populations increase in response to rainfall, although other factors also seem to be important (Singleton 1989; Pech et al. 1999). One important factor may be temperature, and so our aim was to investigate the influence of temperature on some basic reproductive parameters in laboratory-bred house mice that originated from a wild population.

Materials and methods

Ten house mice (6 females, 4 males) were captured at Mudgee, New South Wales (NSW) (32°36'S, 149°35'E) and transported to the laboratory to establish a captive colony. Mudgee was selected because a previous study had demonstrated that mice from this site were 'average' for a broad range of morphological parameters (Crowther et al., this volume).

Animal husbandry

Mice were housed in standard cages 300 × 200 × 450 mm and provided with wood shavings, a nest box with nesting material, and a variety of toys or novel objects which were changed weekly. Laboratory mouse cubes and drinking water were available *ad libitum*, and animals were weighed weekly, at which time their cages were also cleaned. The disturbance caused by cleaning days was rewarded with a handful of mixed parrot seeds on the day.

When females were at least 12 weeks old, they were placed with unrelated males for breeding purposes. A second nest box with nesting material was provided at all times. When young were born, the parents were left together for a few days longer to allow the opportunity for post-partum mating to occur, and then males were removed from the cage and housed separately. Females observed to be pregnant at the weekly monitoring session were checked more frequently to determine the date of birth of the young. Females with young were housed together in large cages (450 × 600 × 450 mm), and provided with two nest boxes with nesting material, and, when the young were a few weeks old, toys and novel objects. If a post-partum litter was observed, the young of the first litter were removed and housed together in the larger cages in same sex groups until used for breeding, or for other physiological experiments. Young were weighed weekly for 12 weeks. Post-breeding animals were housed individually. Litter size, survivorship to weaning, evidence of post-partum reproductive activity, and body mass were recorded. All experiments were performed with permission from the University of New England Animal Ethics Committee and NSW National Parks and Wildlife Service.

Temperature treatments

The laboratory colony was established initially under the natural photocycle of Armidale, NSW, and at 22 ± 2°C, in September 2000. When sufficient numbers of mice were available, animals were divided into three treatment groups, with offspring of all founder individuals distributed evenly across the groups. Animals were housed in temperature-controlled rooms at either 13 ± 2°C, 22 ± 2°C, or 30 ± 1°C. All animals were placed under broad-spectrum fluorescent lighting of 250 Lux (mean value at cage lids) for light:dark 13:11 h. During the scotophase, animals were exposed to a dim red light.

Data analysis

Litter sizes between experiments were compared by analysis of variance (ANOVA) followed by Tukey's pairwise tests. Partial and complete losses of litters before weaning were compared between treatments by Chi-squared test. Growth rates were plotted, regression lines calculated for each group, and data were analysed by multiple regression and ANOVA of the Y-intercept and slopes (Zar 1996).

Results and discussion

Mating outcomes

Post-partum matings occurred in approximately half the pairings in all treatment groups (control, 48%; 'hot', 53.4%; 'cold', 47.5%). However, pairings that produced no post-partum litter occurred more often in females that were young, or had not previously had a litter (i.e. it was their first opportunity to have a post-partum oestrus) (control, 71.4%; 'hot', 71.4%; 'cold', 73.3%) compared to pairings which produced a post-partum litter (control, 53.8%; 'hot', 40.1%; 'cold', 57.1%; $\chi^2 = 3.91$, $P < 0.05$).

Litter outcomes

Overall, there were no differences in numbers of young born in each litter for the different treatments (Table 1), although there were differences in the numbers

Table 1. Reproductive success for each of the treatment groups of mice. Data are expressed as means ± se (except for percentages). For mean litter sizes, all treatment effects were not significant.

Groups	Mean litter sizes born (range)	Mean litter sizes weaned (range)	% of litters with all young lost before weaning	% of litters with some young lost before weaning
Control (22 ± 2°C) All litters (*n* = 36)	5.53 ± 0.25 (3–9)	5.17 ± 0.31 (0–8)	2.8	13.8
'Hot' (30 ± 2°C) All litters (*n* = 42)	5.48 ± 0.20 (3–8)	4.72 ± 0.31 (0–8)	9.5	28.6
'Cold' (13 ± 2°C) All litters (*n* = 55)	5.58 ± 0.27 (1–10)	5.00 ± 0.34 (0–10)	12.7	29.1
Control (22 ± 2°C) Litters with no post-partum mating (*n* = 11)	5.36 ± 0.53 (3–9)	5.18 ± 0.48 (3–8)	0	18.2
Control (22 ± 2°C) Litters with a post-partum mating (*n* = 12)	5.33 ± 0.38 (3–7)	5.33 ± 0.38 (3–7)	0	0
Control (22 ± 2°C) Product of post-partum mating (*n* = 13)	5.85 ± 0.71 (3–9)	5.00 ± 0.71 (0–9)	7.7	23.1
'Hot' (30 ± 2°C) Litters with no post-partum mating (*n* = 13)	4.62 ± 0.33 (3–6)	3.84 ± 0.39 (0–5)	7.7	38.5
'Hot' (30 ± 2°C) Litters with a post-partum mating (*n* = 14)	5.67 ± 0.25 (5–8)	5.00 ± 0.43 (0–7)	7.1	21.4
'Hot' (30 ± 2°C) Product of post-partum mating (n = 15)	6.00 ± 0.37 (4–8)	5.19 ± 0.65 (0–9)	13.3	33.3
'Cold' (13 ± 2°C) Litters with no post-partum mating (*n* = 21)	5.16 ± 0.53 (1–9)	4.79 ± 0.61 (0–9)	14.3	23.8
'Cold' (13 ± 2°C) Litters with a post-partum mating (n = 17)	5.65 ± 0.41 (3–9)	4.53 ± 0.63 (3–9)	17.6	41.2
'Cold' (13 ± 2°C) Product of post-partum mating (*n* = 17)	6.00 ± 0.45 (3–10)	5.75 ± 0.50 (0–10)	5.9	29.4

of young produced from different mating activities (no post-partum mating, 5.05 ± 0.28 (n = 45); with post-partum mating, 5.57 ± 0.20 (n = 43); product of post-partum mating, 5.96 ± 0.23 (n = 45); F = 3.25, P < 0.05). All treatment groups lost complete litters before weaning, and all treatment groups had litters that lost some young before weaning (Table 1). Significantly fewer young were lost from the control group (χ^2 = 34.85, P < 0.001). Growth rates were significantly different between groups up to 35 days (immediately post-weaning, Figures 1 and 2). After weaning, the growth rates were also significantly different between groups; young grew at a different rate than before weaning (Figure 2), although the regression r^2 was low, and thus the regression equations are not presented (see Figure 2). The lines of best fit from 0–35 days were control body mass =1.38 + 0.293Days (r^2 = 88.2%, P < 0.001, n = 540); 'hot' body mass (g) =1.26 + 0.266Days (r^2 = 85.0%, P < 0.001, n = 562); and 'cold' body mass (g) 1.52 + 0.276Days (r^2 = 87.4%, P < 0.001, n = 844). The slopes of the regression equations of all treatment groups were significantly different from one another (F = 8.919, P < 0.05).

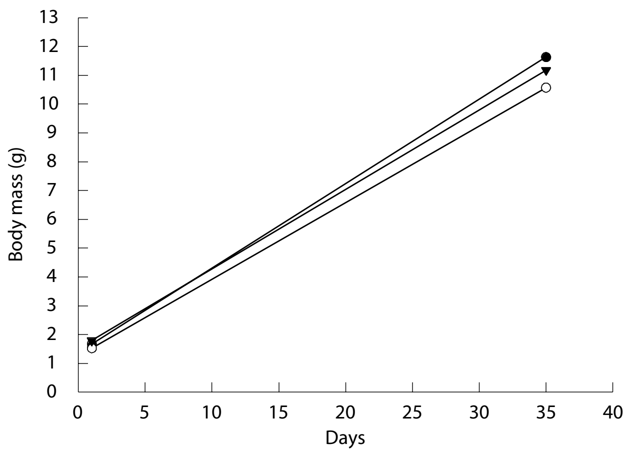

Figure 1. Regression lines for the growth data for the three treatment groups. Closed circles indicate 'control' treatment (22 ± 2°C), open circles indicate 'hot' treatment (30 ± 1°C), and closed triangles indicate 'cold' treatment (13 ± 2°C).

Temperature appears to have an effect on reproductive outcomes for the Australian house mouse. Overall litter sizes were similar between treatment groups, and our data are consistent with other studies (Pelikán 1981; Singleton et al. 2001). However, more young were lost from litters born to females in 'hot' and 'cold' environments, similar to results found in other studies on cold-exposed mice (Barnett and Widdowson 1965; Barnett 1973). A more significant effect of temperature was seen in the growth patterns of the litters. Young from the 'hot' group grew more slowly, and were smaller than young from other groups—this trend continues throughout the post-weaning period (see Figure 2; and Crowther et al., this volume). Young from 'cold' environments also grew more slowly than control young, although their body mass increased after the post-weaning period, again similar to other studies (Barnett and Widdowson 1965; Barnett 1973; Marsteller and Lynch 1987). The differences between 'cold' and control treatments in these parameters are notable because many other studies observed the same differences in cold temperatures of 5°C and –3°C (Barnett and Widdowson 1965; Barnett 1973; Marsteller and Lynch 1987), significantly colder than our study. There are few studies of higher than room temperatures on reproduction and our data suggest that, for the house mouse, hotter temperatures may be more physiologically stressful than colder temperatures.

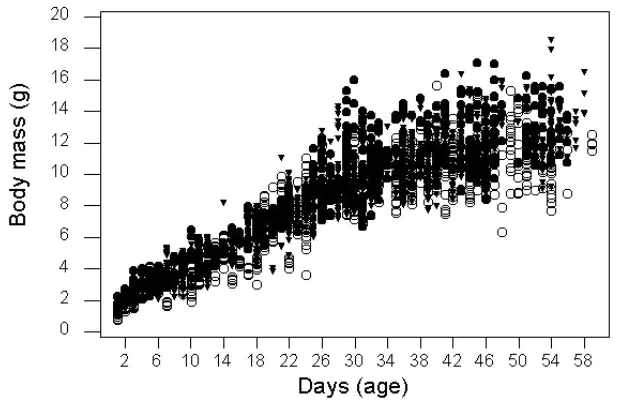

Figure 2. All growth data from 0–60 days for animals from each treatment group. Closed circles represent data points from the 'control' group (22 ± 2°C, n = 767), open circles represent data points from the 'hot' group (30 ± 1°C, n = 828), and closed triangles represent data points from the 'cold' group (13 ± 2°C, n = 1208).

While overall litter sizes were similar between treatment groups, in all groups fewer young were born in litters from females that did not have a post-partum mating and consequent litter. Many of these females were young, first-time mothers, indicating that maturity may influence reproductive outcome in house mice. The larger litter sizes in post-partum litters also may be due to the increasing age of the mothers, and it has been observed that older Australian house mice have larger litters (Singleton et al. 2001). In Australia, plague activity occurs after rainfall and is believed to be closely linked to food availability (Singleton and Redhead 1990). Our study suggests that temperature and the age of the mothers may also have an overall effect on reproductive outcome. Survivorship of older females under more favourable conditions, influenced by both temperature and rainfall, could mean a sudden explosion of young as these older females are producing more young and more post-partum litters. If followed by reproductive recruitment of younger females as suitable conditions continue, the mouse population could rapidly increase.

Conclusion

The thermal environment significantly influences reproductive output, with both 'cold' and 'hot' temperatures affecting litter losses and growth of young. The more deleterious effects of hotter temperatures may explain why mice are sparse in the interior of Australia. The complex interactions between temperature and reproductive success of 'younger' versus 'older' mothers may contribute to the population explosions of house mice seen in Australia.

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Morphological variation within Australian populations of the house mouse: an observational and experimental approach

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Abstract. Morphological variation within Australian populations of the house mouse (*Mus domesticus*) was evaluated using measurements of head–body length and relative tail length. In order to examine the effects of temperature on these characters, and to attempt to experimentally replicate this variation, mice from one of the wild populations were raised under three different temperature regimes in captivity (13 ± 2°C, 22 ± 1°C and 30 ± 1°C). There was considerable variation between wild populations in both head–body length and relative tail length. Comparisons with estimated values of mean annual temperature at study locations found that mice were smaller in cooler climates (opposing Bergmann's Rule), but no real climatic trends were found for tail length. In contrast, mice bred at different temperatures within the laboratory displayed very large differences in morphology, with those raised at the warmest temperature being the smallest in size and having relatively longer tails. These results corresponded with both Bergmann's Rule and Allen's Rule. The differences between the treatments were more apparent in younger mice (6 weeks of age) than those at 12 weeks and 24 weeks. It is apparent that just a few degrees difference in temperature has a major effect on the morphology of house mice. However, comparison with the wild populations shows that many other factors must have a role in shaping mouse morphology. The research presented in this paper and continuing work on internal organ systems has major implications for taxonomy and adaptation of house mice, and could help explain the success of mice in colonising the wide range of habitats within Australia and other parts of the world.

Introduction

House mice (*Mus domesticus*) in Australia have a continent-wide distribution and are found in an extremely wide range of temperature and rainfall zones. This includes arid areas which receive as little as 100 mm of rainfall per year to very mesic areas that receive as much as 8350 mm per year. The life history of house mice is typified by rapid population turnover and small demes, enabling swift colonisation of new areas (Berry 1981). Thus, mice can rapidly diverge from their founder populations (Berry 1981). Since European people probably introduced house mice into Australia a little over 200 years ago (Singleton and Redhead 1990), Australia is the perfect place to study the changes that this species makes in new environments. Studies of Australian *M. domesticus* on limitation to growth, niche invasion and morphological variation in non-Australian mice have been made, but there are very few studies to date on morphological variation within Australian mice.

Morphological characters such as tail length have been used to diagnose and distinguish between species of *Mus*. Short tails are believed to be the preserve of *M. musculus* and long tails of *M. domesticus* (Marshall and Sage 1981). However, in the laboratory, tail length is significantly modified by environmental temperature. When mice are reared at low (–3°C) temperatures, the tail length is shorter by up to 10% than in mice reared at room temperature (22°C) (Barnett 1965; Barnett et al. 1975).

In this study, we examined variation in cranial and dental characteristics, external measurements, coat colour, vertebrae number, and renal and adrenal structure in wild-caught mice. The populations came from a range of climatic and habitat types throughout Australia. To examine for the effects of temperature on morphology and attempt to replicate the variation found in the wild populations, mice from the wild were bred in captivity under different temperature regimes and then the same measurements as from the wild mice were taken. For the purposes of this publication, only relative tail lengths and head–body lengths will be reported.

Materials and methods

Sampling areas

Mice were collected from 18 localities around Australia to represent a variety of habitat and climate types. The populations presented here are Jindabyne (36°24'S, 148°37'E), Emerald (37°53'S, 145°27'E), Broken Hill (31°58'S, 141°27'E), Ouyen (35°4'S, 142°19'E), Mudgee (32°36'S, 149°35'E), Kangaroo Island (35°45'S, 137°37'E), Hattah-Kulkyne (34°42'S, 142°17'E), Millicent (37°35'S, 140°21'E), Mildura (34°11'S, 142°09'E) and Woodcroft (35°06'S, 138°33'E). All mice were collected between April and May 1999 in order to reduce seasonal variation. Further locations covering the breadth of Australia are currently being processed. Animals were judged to be adult based on tooth wear, cranial development and reproductive condition.

Data acquisition and analysis

Head–body (HB), tail (TV), ear, and hind foot lengths were measured with vernier calipers on dead specimens to the nearest 0.05 mm, and body mass with electronic scales to the nearest 0.001 g. Carcasses were then placed in buffered formalin for internal organ measurements and skulls were cleaned for cranial and dental measurements. Skull and dental dimensions were taken with digital calipers to the nearest 0.01 mm on the right side of the skull, except in damaged specimens. Kidneys, adrenal glands and reproductive tracts were dissected out of the mice and weighed using electronic scales to the neared 0.001 g. Localities for each collection were assigned coordinates for latitude, longitude and elevation. The mean annual temperature at each locality was estimated using the program BIOCLIM within the ANUCLIM package (e.g. Crowther 2002). Differences between populations were compared using a one-way analysis of variance (ANOVA) (males and females treated separately), and regressions of the mean of each character (weighted by sample size) versus the estimated mean annual temperature were computed.

Laboratory mice were selected from wild founders from Mudgee, New South Wales (32°36'S, 149°35'E) and placed in different rooms using one photoperiod regime (13:11 h light:dark) and three different temperatures (13 ± 2°C, 22 ± 1°C, 30 ± 1°C). Non-breeding animals were housed individually. When females were 12 weeks old, they were placed with unrelated males for breeding purposes. Refer to McAllan et al. (this volume) for more details of captive protocols. Offspring of these groups of mice were then killed at 6 weeks, 12 weeks or 24 weeks. In order to minimise pseudoreplication, each age class of treatment was replicated over time. Measurements were taken as for the wild-caught mice. Differences between sexes, ages and temperature treatments were compared using a three-way ANOVA.

Results and discussion

Wild caught animals

Thirty to 40 specimens were obtained from each locality. There was large variation in most characters measured between localities, including relative tail length (Figure 1a; $F_{9,201}$ = 8.87, P < 0.001) and head–body length (Figure 1b; $F_{9,203}$ = 2.34, P < 0.001). There was a significant trend for mice from cooler regions to be smaller (HB = 68.5 + 0.6*Temperature, R^2 = 0.86, $F_{1,8}$ = 50.7, P < 0.001), in contrast with the predictions of Bergmann's rule. Relative tail length showed no significant relationship with mean annual temperature (R^2 = 0.35, $F_{1,8}$ = 4.31, P = 0.07).

(a)

(b)

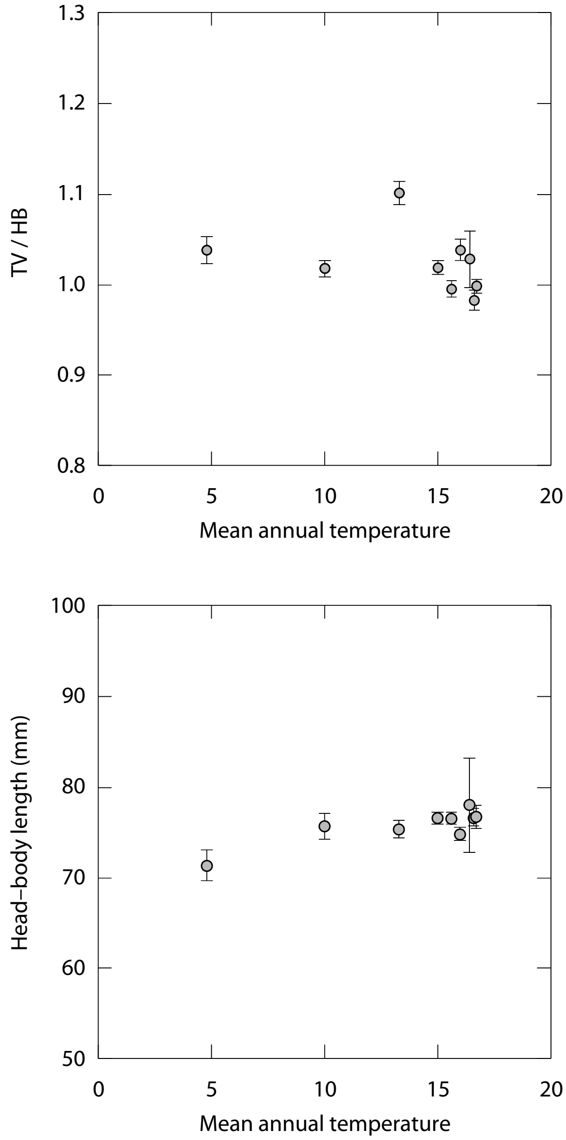

Figure 1. Relative tail (TV/HB) (a) and head–body lengths (b) for Australian populations of house mice versus mean annual temperature (°C) at collection localities (as estimated by BIOCLIM). Means are shown ± standard errors. Only males are shown—while there are sex differences in the data, the patterns of change are the same.

Laboratory trials

There were large differences between the three treatments in both relative tail length and head–body length. Mice raised at warm temperatures (30 ± 1°C) were significantly smaller than those raised at 22 ± 1°C and 13 ± 2°C (Figure 2b, Table 1), and had significantly longer tails (Figure 2a, Table 1). Tail lengths appear to get relatively shorter (compared with the head–body length) as the animals grow older, and the differences between animals raised at different temperatures appear to reduce (hence the significant interactions between age and treatment; Tables 1 and 2). However, the animals raised at 30 ± 1°C still maintain a relatively longer tail than those raised at other temperatures, even after 24 weeks.

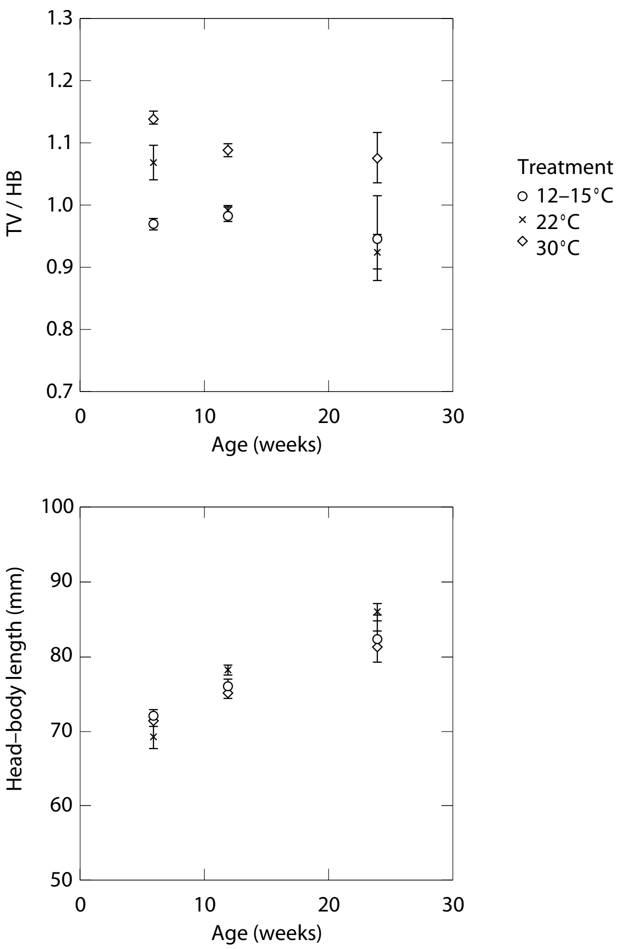

Figure 2. The effects of temperature on relative tail length (TV/HB) (a) and head–body length (b) for mice raised at three different temperatures (means and standard errors). Mice were killed at 6 weeks, 12 weeks or 24 weeks. Only males are shown—while there are sex differences in the data, the patterns of change are the same.

Singleton and Redhead (1990) suggested that the ratio of head–body length to tail length was not variable in Australian mice. They stated that tail length was generally longer than head–body length and also that the difference was rarely greater than 5%. In contrast, this study found much variation in tail length, with some populations having tails much shorter than head–body length (Figure 1). However, most tails were greater than 73 mm, indicating *M. domesticus* rather than *M. musculus* (Marshall and Sage 1981).

Differences between head–body lengths and tail lengths have implications for the thermoregulatory performance of house mice. A smaller body size and relatively longer extremities should assist in heat dissipation. Why the Australian wild mouse populations appear to contradict Bergmann's rule is not easily explained, especially when they appear to follow it under laboratory conditions. Other studies of small mammals, including mice, have found similar trends opposed to Bergmann's rule. Rowe-Rowe and Crafford (1992) found that mice on Gough Island were smaller at higher than lower altitudes. They suggested that the high altitude population was smaller since the mice bred later at higher altitudes. It is also possible that food quality and quantity are a larger determinant of body size than temperature in house mice, although this is yet to be tested. It is also possible that wild mice use behavioural responses to offset the thermoregulatory losses caused by other factors affecting morphology.

Table 1. Results of three-way analysis of variance (ANOVA) for relative tail length of house mice raised at different temperatures.

	SS	df	MS	F	P
Sex	0.033	1	0.033	9.778	0.002
Treatment	0.608	2	0.304	89.277	<0.001
Age	0.103	2	0.052	15.147	<0.001
Sex*Treatment	0.029	2	0.014	4.206	0.016
Sex*Age	0.017	2	0.008	2.484	0.085
Treatment*Age	0.060	4	0.015	4.400	0.002
Sex*Treatment*Age	0.025	4	0.006	1.841	0.121
Error	1.158	340	0.003		

Preliminary work on the skull and dental morphology, and kidney and adrenal size, has shown similarly large degrees of variation between populations of wild house mice. Measurements of these and other organs in the laboratory populations have shown that temperature also appears to have a major effect on their size. Completion of this section of the project promises to produce exciting results for the study of morphological plasticity in house mice and to have major implications for taxonomic

Table 2. Results of three-way ANOVA for head–body length of house mice raised at different temperatures.

	SS	df	MS	F	P
Sex	450.832	1	450.832	29.241	<0.001
Treatment	1.03.608	2	51.801	3.360	0.036
Age	4478.488	2	2239.244	145.239	<0.001
Sex*Treatment	56.305	2	28.152	1.826	0.163
Sex*Age	24.652	2	12.331	0.800	0.450
Treatment*Age	215.770	4	53.943	3.499	0.008
Sex*Treatment*Age	43.812	4	10.953	0.710	0.585
Error	5550.337	360	15.418		

research. For example, characters such as tail length, and cranial and dental characters are often used to diagnose species when in fact they could be just the result of environmental variation within a single plastic species.

Conclusion

Temperature has a dramatic effect on many morphological characteristics of house mice, including size and relative tail length. The differences between mice raised at different temperatures appear to be of different magnitudes at different ages, the largest differences being in the younger animals. Captive-reared mice conform with both Bergmann's rule (mice raised in warmer temperatures are smaller) and Allen's rule (mice raised in warmer temperatures have relatively longer tails). The differences in temperature need to be only a few degrees to produce large changes in the morphology. Morphological variation between wild populations was high, but the effects of temperature on this variation remain uncertain. There was a trend for wild mice to be smaller in cooler localities, contradicting the laboratory results, suggesting that factors other than temperature affect their body size. Current research on other features of Australian populations of house mice (e.g. the kidneys and cranium), both in the field and the laboratory, is producing exciting results and may help unravel the limits of morphological plasticity and adaptation in house mice. Care must also be taken in taxonomic studies, particularly within *Mus*, that morphological differences between taxa are not the result of phenotypic plasticity. The ability for mice to display such high levels of variation and to respond quickly to environmental conditions may help explain their broad distribution within Australia and throughout the world.

Acknowledgments

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The impact of age on the breeding performance of female rice-field rats in West Java

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Abstract. The reproductive performance of rodent pest populations is partially determined by the age composition. The rice-field rat (*Rattus argentiventer*) is the major pest rodent in lowland irrigated rice fields in Indonesia. Their populations have pronounced intra-annual fluctuations due to the strong association between female breeding performance and the stage of the rice crop. We collected data from 1995 to 1998 in Sukamandi, West Java and estimated the age of rats based on the dry weight of their eye lenses. The reproductive status of rice-field rats was assessed by necropsy. The age composition fluctuated during the planting seasons. Recruitment of young occurred twice a year—once in the dry season and once in the wet season. The number of embryos per litter in rats 5–8 months old was higher than in younger and older rats. Rat control may be particularly efficient if conducted at the tillering stage of the rice crop—before reproduction commences and when there is a large cohort of medium-aged rats with high reproductive potential.

Introduction

Understanding how animal populations function is fundamental for successful management and conservation. For managing rodent pests, the focus is usually on increasing mortality, and culling is applied with variable success where rodent problems occur (Singleton et al. 2002). In lowland irrigated rice fields in Indonesia, the rice-field rat (*Rattus argentiventer*) is the only mammalian species that causes widespread pre- and post-harvest damage (Singleton and Petch 1994). Most farmers there control rodents by hunting, flooding burrows and trapping (Sudarmaji, Rochman et al., this volume), and by poisoning with alternative pesticides such as endosulfans and organophosphates because legal rodenticides are difficult to find or are too expensive. Another approach for reducing the density of unwanted species is the inhibition of fertility in females, which has been successfully applied in r-selected species (e.g. Twigg and Williams 1999).

Populations of rice-field rats may be particularly prone to the manipulation of female fertility because breeding occurs only in the presence of a rice crop and for only 6–8 weeks per cropping season (Leung et al. 1999). Their reproductive performance is thought to be highest early in the breeding season (Jacob et al. 2002). Two processes may cause a decrease in reproductive performance on the population level during the cropping season: (1) young females, which start reproducing in the same season they are born, may not have the physiological maturity to produce as many embryos as older females; and (2) a higher density of rats and diminishing resources at late stages of the cropping season may be limiting for the production of high litter sizes.

If resources restrict the reproductive performance in rice-field rats, the maintenance of low densities by fertility control could lead to increased reproductive output in young females and partially compensate for the effects of fertility control. If the reproductive performance in rice-field rats is limited by age, compensation may be limited and short-term anti-fertility effects may suffice to prevent high densities of rice-field rats.

We studied populations of rice-field rats in lowland irrigated rice fields in West Java, Indonesia during the wet seasons in 1996/97 and 1997/98 and the dry seasons in 1995–1998 to examine the relationship between the age of female rats and the number of embryos produced per litter.

Material and methods

The study took place in irrigated rice fields at experimental fields of the Research Institute for Rice and the Sang Hyang Seri seed farm in Sukamandi (06°20'S, 107°39'E), West Java in 1995–1998. For a detailed description of the study sites, see Singleton et al. (1998) and Brown et al. (2001). The climate in the region is tropical with an average temperature of 28°C and annual rainfall of 1450 mm. One rice crop is planted in the wet season (November–April) and one in the dry season (May–October).

Rice-field rats were collected by fumigation with sulfur gas and digging and by using multiple-capture wire-cone live-traps (20 × 20 × 50 cm) in rice fields and along the edge of rice fields. The traps were placed along drift fences to maximise trapping success. Traps were set in the evening and checked every morning at sunrise for 3 days in August, September, November and December 1995, January 1996, May–November 1997 and April, May and August 1998. Trapped rats were transferred to the laboratory and killed with CO_2 gas.

For age estimation, we used the weight of the eye lens and the age curves developed by Murakami (1992) for the rice-field rat based on rats collected within 20 km of our study site. Pregnant females were autopsied and the number of live embryos counted.

Results and discussion

We collected 1932 rats for age estimation. Of the 870 female rats caught, 67 were pregnant. Most rats were caught during the fallow stage post-harvest, possibly due to high trappability at that time (Jacob, Sudarmaji and Singleton, this volume). The number of rats was usually low during the tillering and flowering stage of the rice crop.

Age composition

The average age of the rats was 3.8 months (se ± 0.1 month) and the oldest rat collected was 34 months old (Table 1). Young (<2 months old) rice-field rats were present at almost all crop stages, the only exceptions being during ploughing and tillering in the wet season 1995/96 (Table 1). At that time, older rats (5–8 months old) dominated the population. The proportion of young rats in the population tended to be high from after late tillering until harvest but sometimes also during fallow (1997/98).

The predominance of 1–3-month-old rats in August and September 1995 indicated that most births occurred during the booting (June) and heading stage (July) of the previous crop. A high proportion of these rats survived for 5–8 months (Table 1). These animals also bred in January 1996 (1996/97 wet season) and their offspring survived until May 1997; none were recorded in June and thereafter. Interestingly, peak recruitment in the 1997 dry season occurred in June, consisting of young rats (66% were 1–2 months old) that were offspring of the January cohort.

A second bout of recruitment occurred at the end of the dry season (August–September 1997) because all rats caught in October 1997 were 1–2 months old. These rats were probably offspring of rats born earlier in that year (Table 1). Some of the rats born in the dry season 1997 survived until the end of the following wet season but the irregular trapping in 1998 did not allow for further tracking of these cohorts.

In 1995 and 1997, when rats were trapped more frequently, a shift from relatively young rats (1–4 months old) to older rats (5–10 months old) was evident post-harvest. This also indicated that few females bred during the fallow period and that there was no immigration of young rats from other areas where reproduction might have continued.

The presence of young rats at later stages of the rice crops confirmed earlier findings that the breeding of rice-field rats starts about 2 weeks before maximum tillering of the crop (Leung et al. 1999). If the first litter was conceived about then, young rats would enter the trappable population approximately 5 weeks later, which is

Table 1. Age composition of rice-field rats (%) in lowland irrigated rice fields of West Java, Indonesia. Rats were live-trapped in the wet and dry seasons 1995–98 and age estimated from eye lens weight.

Season	Year	Month	Crop stage	*n*	Maximum age (months)										
					2	4	6	8	10	12	14	16	18	20	>20
dry	1995	Aug	fallow	866	53	26	4	7	4	4	4	1	1	0.5	
		Sep	fallow	249	21	59	2	7		2	3	1	0.5		
wet		Nov	ploughing	48		8	54	15	10	4	6	2			
		Dec	tillering	34			50	35	15						
	1996	Jan	booting	73	15		12	26	21	12	3	4	4		3
dry	1997	May	planting	22	27	59	9	5							
		Jun	tillering	47	66	34									
		Jul	tillering	19	47	53									
		Aug	flowering	16	63	31	6								
		Sep	harvest	56	46	54									
		Oct	fallow	30	100										
wet		Nov	ploughing	275	44	46	6	3	0.5	0.5	0.5				
	1998	Apr	ripening	75	84	5		4	4		1			1	
dry		May	fallow	65	97	3									
		Aug	booting	57	75	12		9		2		2			

reflected in the age structure data. The generally low percentage of young rats at transplanting and early tillering confirms earlier reports that the breeding activity of rice-field rats ceases shortly after harvest (Lam 1983; Leung et al. 1999).

Substantial proportions of rats older than 6 months were present in the wet season 1995/96 (Table 1). These rats must have survived the dry season 1995 and some of them also the previous wet season. Almost no rats older than 6 months were caught in the dry season 1997. This was surprising because the relatively long fallow (10 weeks) between dry and wet seasons in the region should have led to low survival rates entering the 1995/96 wet season because of the lack of food and shelter during the extended fallow period. The fallow between wet and dry season in West Java is short (4–6 weeks) and survival should have been higher. Although the data set is incomplete, these results indicate that the length of the fallow seemed to have limited importance for the survival rate of rats. This does not support the recommendation by Leung et al. (1999) that the longer fallow between the dry and wet seasons be maintained to reduce the population size of the rice-field rat. Other factors such as population density and intensity of rat control may have been of greater importance during 1995/96. However, because there was no consistent trapping effort during this period we could not assess density effects. These findings need further study, in particular a detailed study of survival rates of marked rats during the fallow period.

Good survival of rats to the next breeding season results in a large founder population that may create high densities with the potential to cause high levels of crop damage and yield loss. From a management perspective, targeting these rats before they reproduce may lessen their negative impact on the rice crop.

Relationship between age and embryo number

Counts of the number of embryos are closely correlated with litter size at birth because intrauterine mortality is low in rice-field rats (Lam 1983). The breeding history (number of preceding litters) has an effect on litter size in female rice-field rats in laboratory colonies (Lam 1983). Our study showed a parabolic relationship between the age of the mother and the number of young produced per litter (analysis of variance, ANOVA, $F_{6,48}$ = 3.61, p = 0.005) (Figure 1). There was a lower number of embryos in 1–2-month-old rats (7.8, se ± 0.4) than in 5–8-month-old rats (10.8 ± 0.8 – 11.3 ± 0.8) (post-hoc test, t = 3.37, $p \leq 0.001$). Similarly, the number of embryos was lower in rats older than 9 months (6.5 ± 0.5 – 9.0 ± 1) than in 5–8-month-old rats (although sample sizes were small for the older age classes). We could not determine whether there was a parity effect influencing this relationship or whether there was a pure age effect. Either way, if young rats are less likely to produce large litters than older rats, it could be beneficial for the application of anti-fertility agents to manage rats. Fertile offspring of rats not responding to anti-fertility agents had limited potential to compensate for decreased reproductive output of the population. Field trials using or simulating fertility control are desirable to test this further.

In other rodent species, younger females do not have the physiological maturity to have large litters (Ingram et al. 1958). This may be due to physiological constraints. Very young, and therefore small, females may not be able to produce large litters and the effects of senescence in old females may prevent them from having high reproductive output. In addition, the occurrence of medium-aged rats may coincide with low rat density at the beginning of the breeding season and the abundance of food at that time

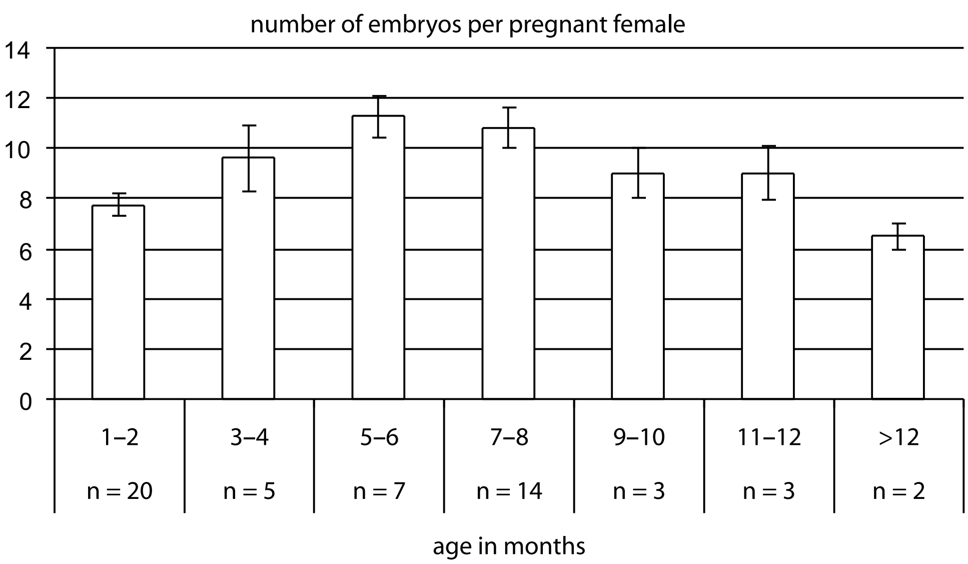

Figure 1. Mean number of embryos for pregnant female rice-field rats of different ages. Rats were sampled in lowland irrigated rice fields of West Java, Indonesia. Rats were live-trapped during the 1995 to 1998 wet and dry seasons and age estimated from eye lens weight. Embryos were counted at necropsy. Error bars are standard errors.

may promote high numbers of embryos. The abundance of 3–5-month-old rats could be high after the 10-week fallow between dry and wet seasons. Larger samples are needed to test whether age, as well as population density, affects litter size in rice-field rats.

Conclusions

The seasonal breeding of rice-field rats with little or no reproduction during the fallow period leads to an accumulation of 3–5-month-old rats at the beginning of the dry season. These rats have a higher reproductive potential compared to younger and older rats. Rat control at the beginning of the cropping season could minimise the size of the founding population and consequently reduce the rate of increase of the population. This may lead to decreased damage to rice crops and thus increased yield. Our results indicate that there was reduced reproductive performance of young rats. Therefore, young rice-field rats may have limited potential for compensation if anti-fertility agents were used to manage rice-field rats. More detailed studies are desirable to validate our data that were pooled over several years and seasons.

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A bioeconomic model for the management of *Mastomys natalensis* mice in maize fields

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Abstract. The existing stochastic population dynamics model for *Mastomys natalensis*, an important field rodent pest in sub-Saharan Africa, is extended with a number of extra components:

- a submodel for maize growth and yield as a function of rainfall and fertiliser;
- functions linking rodent population density to maize damage at planting and harvest;
- simulation of rodent control with poison (simulated by increasing mortality); and
- an economic model expressing costs related to maize growing and poison application and benefits from selling produced maize with net profits for the farmer summed and discounted over a chosen planning horizon.

This bioeconomic model is implemented numerically and used to simulate the effects of different control strategies, not only on the population dynamics of the rodents, but also on a farmer's income. The results show that strategies with only a few months of control, chosen at the appropriate time of the year, are the most economical, even though they have little effect on rodent population dynamics.

This model demonstrates how important it is to combine both ecology and economy when discussing management strategies, with results that are not always intuitive.

Introduction

Field rodents are a very serious concern in agriculture throughout eastern Africa. Farmers consider rodents as the most important pest organism in their staple crops and, after drought and soil fertility, as the biggest impediment to higher yields. Besides the usual annual losses, irregular rodent outbreaks occur during which damage to crops can increase to over 80% (Leirs et al. 1996). Most rodent control is organised in an ad hoc approach, either at a small scale by local farmers, or at a wider geographical level by a government agency (Mwanjabe et al. 2002). Such approaches often come too late, when the damage has already reached high levels. There is a need for better strategies that prevent damage.

Ecological models allow us to investigate which factors contribute to fast population growth, predict outbreaks, or simulate control strategies to evaluate which approach would be most effective in keeping a rodent population at low levels. A number of models for African rodent populations exist (Leirs 1999). Stenseth et al. (2001) used a population dynamics model for *Mastomys natalensis* mice from Tanzania to investigate a number of different control approaches. They showed, for example, that a sustained control strategy, applying poison every month, would be efficient even when the poison was not very toxic (i.e. only had a limited effect on mortality). On the other hand, using highly toxic poisons (i.e. with a strong effect on mortality), but only under high mouse density conditions, was not successful in reducing the mouse population numbers. Interestingly, the latter reactive approach is what most people do in practice.

Ecologically based rodent management should focus on the reduction of damage levels, rather than the mere reduction of population numbers (Leirs et al. 1999). In this paper, we take the argument even further than consideration of damage and include the net economic benefit of damage reduction (i.e. the difference between the reduction of losses due to rodent damage and the cost of the control strategies). We investigate how this affects the strategies that were proposed as useful by Stenseth et al. (2001).

Materials and methods

We used an existing demographic model for the population of *M. natalensis* mice. This model is based on estimates of reproduction, survival and sexual maturation obtained from a capture–mark–recapture (CMR) study in fallow land in Morogoro, Tanzania. Basically, it is a Leslie-matrix type of model in time steps of one month with juvenile, subadult and adult age classes and with demographic processes dependent on rodent population density and on rainfall in the past three months (Leirs et al. 1997). The model's reliability and precision were investigated by Leirs (1999); it is this same model that was used by Stenseth et al. (2001).

We expanded the population dynamics model with a number of new components. They are briefly described here—more details can be obtained from the authors.

- A submodel for maize growth and yield as a function of rainfall and fertiliser, based on data collected in a nearby region in Tanzania (McDonagh et al. 1999). Maize yield increases up to a maximum with better rainfall during the cropping period; the slope of the increase and the level of the maximum are dependent on the application of fertiliser. Although the actual parameter estimates may be different in Morogoro, we assume that the general form of the functions is similar. For the simulations presented here, we simulated fields where 40 kg nitrogen fertiliser per ha was added.
- Functions linking rodent population density to maize damage at planting and harvest. These are based on observations of damage in experimental fields in Morogoro, Tanzania, for which also the rodent population size was calculated, based on closed-model CMR estimates. The relationship between rodent population density and proportional damage at planting is sigmoidal and based on field observations of actual damage and rodent densities in 21 study fields in Tanzania (L.S. Mulungu et al., unpublished data). At harvesting we assume a linear relationship between number of rodents and amount of maize that is actually damaged by the mice during the month preceding harvest (0.270 kg/mouse).
- A simulation of rodent control with rodenticide, increasing the natural mortality up to a maximum of 95% per treatment with poison, depending on the quantity and quality of the applied poison. In this study, a fixed amount of 2 kg of warfarin bait per ha was used for all simulations. We assumed that poison baits remain available to the rodents in a field for a single month after application, after which the bait has disintegrated.
- An economic model expressing costs related to maize growing (for example, preparing fields, buying and sowing seeds, buying harvesting bags) and poison application and benefits from selling produced maize. Net profits for the farmer are summed and discounted over a chosen planning horizon of several years. (See Table 1 for the values used in the model.)

We simulated different control strategies by varying the number of months in which rodenticide was applied. In the present study, we did not compare alternative methods of population reduction, the application of different rodenticides, or the intensity of rodenticide applications. The major variable to change in the model was whether to apply rodenticide in a given month or not. Different strategies included:

- never applying rodenticide;
- applying rodenticide every month;
- applying rodenticide in fixed months only (e.g. every February or every May); and
- applying rodenticide in months matching pre-set conditions of rodent population density.

All simulations were first run for 20 years (240 time steps of one month) to reduce the effect of initial conditions. After that, control strategies were simulated during a period of 10 years and the net benefits to a farmer calculated. The area unit for the model simulations was a maize field of one hectare. In the model, planting always happened in March, replanting was not provided as a possibility, and the maize was harvested in August.

Table 1. Values, prices and costs (in Tanzanian shillings; Tsh) used for the economic part of the model.

Component	Value
Net price of maize	100 Tsh/kg
Price of fertiliser	220 Tsh/kg
Price of poison	6500 Tsh/kg
Fixed costs per ha of maize field	10 000 Tsh/ha
Planning horizon	10 years
Discount rate	0.07

The model was implemented numerically using Stella Research, version 5.1.1 (High Performance Systems, Inc., Hanover, NH, USA). Monthly rainfall in the simulations was bootstrapped from rainfall values measured between 1971 and 1997, adding environmental stochasticity to the model. Every simulation run was repeated 100 times with different rainfall series.

Results and discussion

Figure 1 shows an example of simulations with different control strategies. In this example, all simulations were run with the same rainfall series, i.e. the same environmental conditions. The simulation with no rodent control shows a strongly fluctuating rodent population, an average harvest, and a low income for the farmer. In years with many rodents, the harvest is so poor that it cannot cover the production costs and farmers may have a net loss (negative income). In the scenario with permanent rodent control, the rodent population is completely exterminated. This result was also obtained by Stenseth et al. (2001) who thought this to be the ecologically most rewarding method. Indeed the harvest is very much better and also the farmer's income increases. The third scenario, control under high-density conditions only, corresponds to what is often seen in practice: farmers only perform control actions when they actually perceive high numbers of rodents. Although this strategy does not exterminate the rodent population, and the yield is lower than under the previous control strategy, the farmer's income is considerably higher.

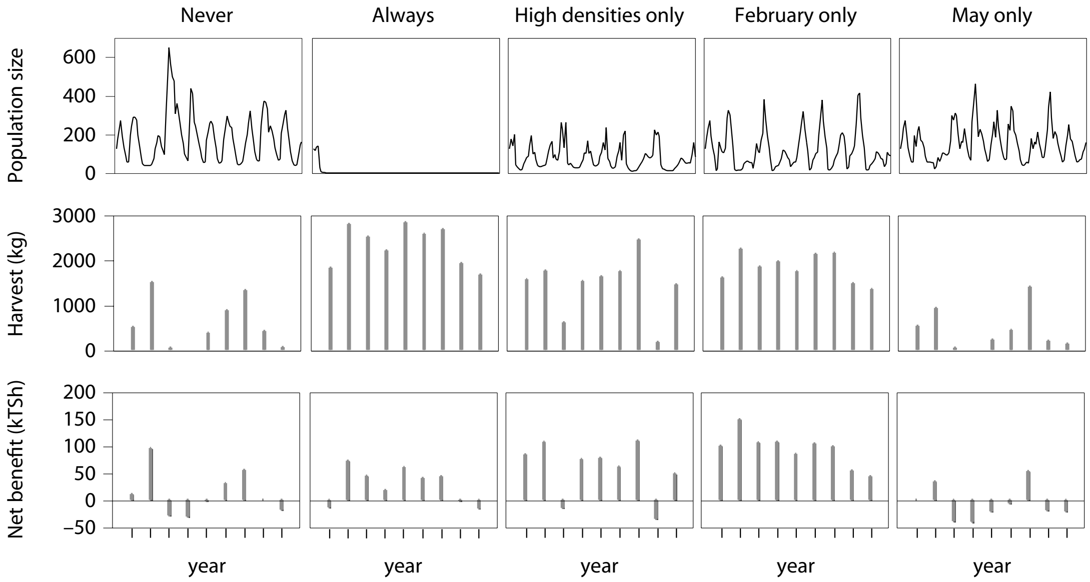

Figure 1. Examples of simulations run with different rodent control strategies for a 1 ha field of maize. From left to right, simulations in which rodenticide was applied: (1) never; (2) every month; (3) in months with a density of over 150 animals/ha; (4) in February every year; and (5) in May every year. The top row of graphs shows the rodent population size per ha over a time period of 10 years, the middle row shows the predicted annual harvest from 1 ha during the simulated period, and the bottom row shows the corresponding net annual benefit to the farmer (in 1000 × Tanzanian shillings per ha), after reduction due to all costs, including those of rodent control. All simulations were run with the same environmental conditions.

The lower harvest is offset by the much lower costs for rodent control, since under this scenario rodent control will be performed in a limited number of months only. The next scenario, controlling every year in February, just before planting, is the most economically rewarding. The population fluctuations of the rodents are not affected very much, but the crop is protected during the most sensitive period of planting and, therefore, the harvest is good. Since only a limited amount of resources must be spent on rodent control (only one month per year), the net income is maximal. In contrast, the last scenario—control in May every year—results in a poor harvest and a very low net income. Money is spent on rodent control at a time when the crop is not at risk, the rodent population is hardly affected and thus the money is basically wasted. It is worth noting that the two latter scenarios have very different results for the farmer's income, although apparently similar outcomes for the rodent population dynamics.

Of course, the results shown in Figure 1 could be due to the specific rainfall series. Repeating the same simulations under different environmental circumstances, however, shows the same pattern (results not shown here). It is interesting that prophylactic rodent control in February corresponds to a certain degree to what some farmers do in Tanzania, but is very different from the government's ad hoc control programs. Comparing more strategies shows that the most rewarding one is a strategy in which control is performed every year in January, February and November regardless of population density of rodents. Changing fertiliser input may affect the relative benefit of different control strategies (results not shown here).

Conclusions

Clearly, a model's output is only as good as the model itself is. The present model does not include movements between fields or flexibility in the rodent management strategies (e.g. replanting, habitat alteration, fertility control). Therefore, the results should be treated with caution and used to guide, but not prescribe, what is done in practice. However, the model allows us to obtain new insights into how the timing of control determines the net benefit to farmers.

Too often, ecologists tend to ignore economics, economists typically have a simplistic understanding of ecology, and pest control managers commonly underrate both. The simulations with the presented bioeconomic model show optimal strategies are sometimes counter-intuitive and rodent population dynamics is not the only factor that must be taken into account.

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Spatial heterogeneity of seed predation on wild apricot by small rodents

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Abstract. In 2000 and 2001, we studied seed predation on wild apricot (*Prunus armeniaca*) by small rodents in three habitat types (forest, shrub and grass) in a mountainous area (40°00'N, 115°30'E) near Beijing, China. Seed predation of wild apricot by small rodents was intense. All the seeds in three habitat plots were removed or consumed within 18 days of seed placement. The seeds disappeared most rapidly from the forest habitat. The number of 'seed remaining days' (SRDs) was negatively correlated with rodent population abundance of the three habitats. Seed predation on wild apricot by small rodents was spatially heterogeneous. This predation affected seed fate and the natural regeneration of wild apricots. Rodent density, predation risk and seed availability may be the key factors affecting seed disappearance of wild apricot. We suggest that grass habitats are more suitable for re-forestation of wild apricot by sowing seeds.

Introduction

Seed predation by animals may affect plant fitness, population structure and dynamics, community structure (Harper 1977; Clark and Clark 1984; Schupp 1988, 1990; Willson and Whelan 1990), natural selection (Janzen 1971) and maintenance of species diversity (Janzen 1970; Connell 1971; Grubb 1977). Previous studies have suggested that rodents ate most seeds and only very few seeds were able to become seedlings (Sork 1984; Miyaki and Kikuzawa 1988; Herrera 1995). On the other hand, rodents are also regarded as an important agent for some types of forest regeneration because they disperse and bury seeds (Jensen and Nielsen 1986). Vander Wall (1994) reported that pine seed predation by vertebrates was helpful to understanding forest regeneration. Some studies have shown that habitat heterogeneity may affect seed removal by animals, especially small mammals (Willson 1992; Burkey 1994). Predation risk may be one important factor influencing the space use and foraging by small mammals (Kotler 1984; Lima and Dill 1990; Gill and Marks 1991; Wada 1993; Schupp 1995). Crawley (1992) reported that post-dispersal seed predation by animals was variable in space and in time. Seed mast years might lead to seed predator satiation (Janzen 1971) since the huge production exceeds the number of seeds that can be consumed by the total predator population.

Wild apricot is one of the common shrubs or low forest species in mountainous areas near Beijing (Chen 1997). Each seed of the wild apricot weighs about 1.5 g and its coat is very hard. Seeds become mature usually in mid-June and sprout into seedlings in the following spring. Apricot seeds are of economic significance, since they are the source of some medicines and are used for a kind of soft drink. Wild apricot can survive in harsh conditions with poor soil quality and low rainfall, and thus is planted in degraded areas to reduce soil erosion. The impact of rodents on seed predation of wild apricot has not been studied and may be critical to understanding plant regeneration. The link between rodents and the regeneration of wild apricots in the study region was first investigated by Zhang and Wang (2001) using tin-tagged seeds. They suggested that rodents were an important factor affecting the natural regeneration of wild apricot. However, the spatial heterogeneity of seed predation has not been studied. The purpose of this study was to investigate how rodent seed predation is influenced by habitat type. The main aim of this series of studies is to propose practical methods for enhancing seeding reforestation of wild apricot.

Methods

Study site

The study site is located at 40°00'N, 115°30'E, about 120 km north-west of Beijing. It is in the Dongling Mountain region, a mountainous area near the Liyuanling, Mentougou district, and has a warm temperate continental monsoon climate. The study area is highly disturbed due to extensive human activities over most of the last century. The common shrubs include oak (*Quercus liaotungensis*), wild walnut (*Juglans mandshurica*), wild apricot (*Prunus armeniaca*), *Vitex negundo* and *Prunus davidiana*. Larch (*Larix principis-rupprechtii*) and Chinese pine (*Pinus tabulaeformis*) are planted in small areas by local forestation farmers. The main rodent species are the field mouse (*Apodemus speciosus*), white-bellied rat (*Rattus confucianus*), striped field mouse (*A. agrarius*), rat-like hamster (*Cricetulus triton*), gray-sided vole (*Clethrionomys rufocanus*), white toothed shrew (*Crocidura lasirua*), striped hamster (*C. barabensis*), long-tailed hamster (*C. longicaudatus*), chipmunk (*Tamias sibiricus*), red-backed vole (*C. rutilus*), house mouse (*Mus musculus*), and gray squirrel (*Sciurotamias davidianus*). In the study area, the rodent density is lowest in spring (usually in May) and reaches a peak in August as a result of summer breeding. Seed production of the wild apricot was normal in 2000 but very low in 2001 due to a spring drought. The mean density of fallen seeds was 13.58 seeds/m^2 in 2000 and 5.26 seeds/m^2 in 2001.

Spatial patterns of rodent population abundance

Wooden snare kill-traps baited with fresh, ripe seeds of wild apricot were used to determine the rodent species removing seeds, as well as the spatial patterns of rodent population abundance. To minimise the effect of trapping on the rodent community in the plot where seeds of wild apricot were released, the trapping plot was placed about 400 m away from the seed-spreading transect, but on the same slope. In each trapping plot, four transects were selected and 25 traps at intervals of 5 m were set along each transect for two consecutive nights. The traps were checked every morning and the rodents captured were recorded. To investigate the spatial pattern of rodent population abundance, trapping was carried out near the three habitat plots (see below) in May 2000 and 2001. Rodent population abundance was measured as the proportion of trap success.

Impact of habitat type on seed disappearance

In May 2000 and 2001, three plots representing three different habitats (forest, shrub and grass) were selected. The forest habitat was a planted larch forest in which *Larix principis-rupprechtii* was the dominant species, with sparse representation of *Q. liaotungensis* and *Ulmus laciniata*. In the shrub habitat, *V. negundo* and *Spiraea pubescens* were the dominant species. In the grass habitat, *Calamagrosis aundinacea* and *Carex rigescens* were dominant species. A transect line was selected in each habitat plot. Five sites were set at intervals of 10 m along each transect line. All sites were located in areas of limited natural seed production. At each site (1 m^2), 20 apricot seeds were placed evenly on the ground surface and then monitored for their loss. Three categories of seed states were defined for seeds or their fragments:

1. intact *in situ*—the seed was intact and remained *in situ*;
2. disappearance, but consumption i*n situ*—in this case, there is a gnawing hole opened by a rodent on the seed coat. The seed coat was left as litter *in situ* and the inside kernel of the seed was removed. The number of seeds consumed in situ was recorded according to the number of seed coats left in the litter; and
3. disappearance with the seed removed to other another location for consumption or burial.

Statistics

The loss rate of intact seeds *in situ* was measured as seed remaining days (SRDs) (one SRD = one intact seed remained *in situ* for one day). Kruskal-Wallis tests were used to identify the difference between SRDs in the three habitats. Pearson correlations were used to identify the relationship between SRDs and rodent abundance in the three habitat types.

Results and discussion

Spatial patterns of rodent population abundance

A total of 99 rodents were captured, and included the field mouse, white-bellied rat, rat-like hamster, striped field mouse and house mouse. The field mouse was the dominant species. Trap success in 2001 (13.5%) was significantly higher than that in 2000 (3%). The average trap success in this study area between 1993 and 1995 was 5.38% (Ma et al. 1999). These results suggest that 2001 was a peak year for rodent populations. The spatial distribution of rodents as revealed by trapping suggested that rodent density was highest in forest habitats (6.0% in 2000, 20.0% in 2001), followed by shrub habitats (2.0% in 2000, 5.5% in 2001) and grass habitats (0.4% in 2000, 2.0% in 2001).

Each of the captured species, with the exception of the house mouse, will consume apricot seeds in the laboratory (unpublished data). Thus, they are likely to be the key species affecting wild apricot seed disappearance. Further, in laboratory feeding trials, the appetite of the field mouse for wild apricot seeds was much greater than that of the white-bellied rat, rat-like hamster and striped field mouse (unpublished data). Previous studies have shown that the field mouse is the dominant species in the rodent community (Zhang et al. 1998). Thus, the field mouse was probably responsible for the disappearance of most of the wild apricot seeds in the study area. In addition, some rodent species such as the Norway rat, gray-sided vole, gray squirrel and chipmunk may be involved in seed removal (Ma et al. 1999) but are not likely to be captured by snare-traps. Some of these species are also rare. Birds were never observed to eat seeds of apricot, probably due to the hardness of the seed coat.

Impact of habitat on seed disappearance

The removal rate of seeds of wild apricot in all three habitats was very high in 2000 and 2001 (Figure 1). Within 18 days after seed placement, all seeds were removed or consumed. The number of SRDs (seed remaining days) of forest habitat was much lower than that of shrub and grass habitats in 2000 ($p = 0.045$) and in 2001 ($p = 0.004$). The number of SRDs was negatively correlated with population abundance of field mouse in three habitats in 2000 ($r = -0.761$, $P = 0.001$) and in 2001 ($r = -0.713$, $P = 0.003$). Nearly all seeds were carried away from the original placement sites. Only one seed was consumed *in situ*—this occurred in the shrub habitat in 2001.

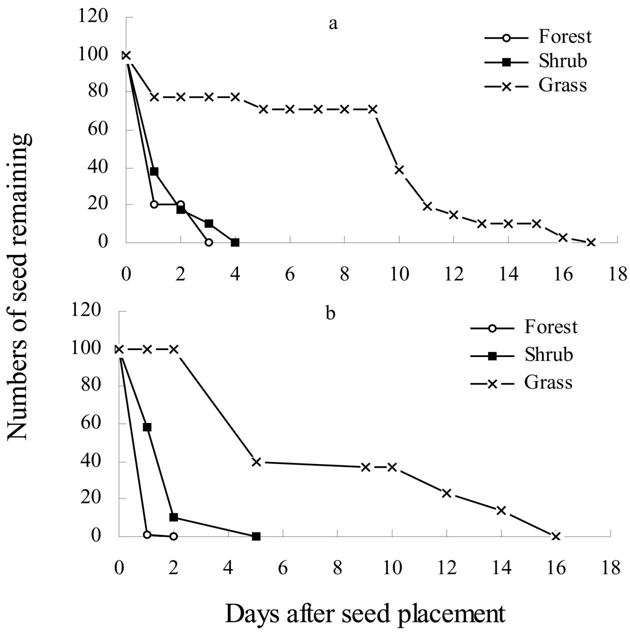

Figure 1. Spatial heterogeneity in the survivorship curves for the seeds of wild apricot (*Prunus armeniaca*) remaining in three habitats (forest, shrub, grass) in (a) 2000 and (b) 2001.

These results indicate that seed predation of apricot by small rodents is very intense in this region. Previous findings have shown that rodents consumed most seeds, with only a few seeds being able to germinate and become seedlings (Sork 1984; Miyaki and Kikuzawa 1988; Herrera 1995). Habitat heterogeneity may also affect seed removal by animals, especially small mammals (Willson 1992; Burkey 1994), and the rates of seed predation by animals are different in different micro-environments (Gill and Marks 1991; Wada 1993; Schupp 1995). In our study, the rate of seed disappearance was also different in the three habitat types, and this showed that seed predation by rodents was spatially heterogeneous. The spatial pattern of seed disappearance showed similar trends in 2000 and 2001, that is, the seeds of wild apricot disappeared most rapidly from the forested sites with a closed canopy. This was probably a consequence of high rodent densities in the forest habitats. The spatial pattern of seed predation by the small rodents was also probably related to the vegetation characteristics of different habitats. In the forest habitat, because of the sparse cover of grass, the ground surface was open—probably making it easier for rodents to find food. In contrast, the dense grass in the grass habitats may limit the ability of rodents to find seeds, as previous studies have suggested that seedling recruitment rates are higher when seeds are planted in the grass habitats (Zhang and Wang 2001). It may therefore be preferable to target reforestation efforts on grassland habitats where seeds will not be at such a great predation risk.

Compared to other seeds (e.g. acorns), very few apricot seeds were consumed *in situ*. This was perhaps related to predation risk. The seed coat of wild apricot is much harder than that of acorns, and a small rodent takes a longer time to open it, so the predation risk will be higher.

Conclusion

We conclude that seed predation by small rodents was spatially heterogeneous. This affected seed fate and consequently the natural regeneration of wild apricots. The rodent population abundance, habitat characteristics and seed availability appear to be the key factors affecting seed disappearance of wild apricot. We suggest that to achieve reforestation of wild apricot, seeds sown in the grass habitats would be more likely to lead to success.

Acknowledgments

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The role of interspecific competition in determining macrohabitat use by the black rat and brown rat at Bradley's Head, NSW

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Abstract. We investigated macrohabitat use in populations of the black rat (*Rattus rattus)* and the brown rat *(Rattus norvegicus)* at Bradley's Head, New South Wales. The study site included a zoological park and surrounding bushland reserve on a headland of Sydney Harbour. These two environments provided quite different macrohabitat types. The bushland reserve contained a dense mix of native and introduced plant species, while more open and disturbed habitats were located within the zoo. Between December 2000 and June 2001 we found a clear difference in the habitat use patterns of the two species. Only 3 of 30 *R. rattus* trapped were caught within the zoo grounds. For *R. norvegicus*, 51 of 82 individuals were trapped within the zoo grounds, revealing a preference for an area that contained a large food source in the form of a refuse pit. The removal of approximately 73% of *R. norvegicus* from within the zoo grounds by poisoning failed to elicit a change in habitat use by *R. rattus*, as measured by both trapping and radio-tracking. Of the 12 radio-collared *R. rattus* tracked after the removal, none moved into the zoo grounds. Perceived predation risk may play an important role in determining the habitat use patterns of *R. rattus* at Bradley's Head.

Introduction

Both the black rat (*Rattus rattus*) and brown rat (*Rattus norvegicus*) are introduced pest species of the Sydney region. Since European settlement, *R. rattus* has extended its range to cover most of the temperate areas of eastern Australia where the habitat has been disturbed by people (Cronin 2000). *R. rattus* is common to both disturbed bushland and urban areas where it prefers dense understorey vegetation and deep leaf litter in forested areas, and lives a partly arboreal existence (Key and Woods 1996; Cox et al. 2000). In urban areas, black rats will often occupy buildings, nesting in wall cavities and roofs. Both species of rat are omnivorous generalists that are easily able to adapt their feeding habits to the available food types (Macdonald 1984). *R. norvegicus* primarily is found in highly disturbed habitats, such as around the Sydney Harbour foreshore (Cronin 2000). *R. norvegicus* has been found to occupy sewers, drains, and tips and is not noted as a climber, preferring to move between areas through drains and crevices in rocks rather than by climbing through trees (Taylor 1978; Key and Woods 1996).

Interspecific competition can be an important determinant of small mammal macrohabitat use, resulting in restriction or exclusion of the subordinate species from particular habitat types where the dominant species has a competitive advantage (Dickman 1984; Maitz and Dickman 2001). *R. norvegicus* has previously been found to be competitively dominant to *R. rattus* in laboratory experiments (Barnett 1958). In the present study around Bradley's Head in Sydney, we examine interspecific competition between these two commensal rat species. We hypothesise that the Norway rat excludes the black rat from its preferred habitat, so that if the Norway rat is removed from an area, black rats will quickly colonise the empty area.

Materials and methods

During a pilot study in December 2000 and January 2001, 100 traps were spread throughout the Taronga Zoo and surrounding bushland at Bradley's Head. Two trapping sessions were conducted, each for three nights. Wire possum cage traps were used for the capture of rats. The purpose of the trapping conducted at this time was to gauge the abundance and species diversity of small mammals at Bradley's Head. A mixture of oats, wheat grain and fish sauce was used to attract animals to the traps.

We found in these preliminary studies that few *R. rattus* lived on the zoo grounds. On trapping trips in May and June, 2001, we focused on the southern section of the zoo, which allowed more intensive sampling of an area that contained a diverse range of habitats. Sixty traps were set for five consecutive nights in May, and again in June. This smaller study area was broadly divided into two markedly different macrohabitat types: the bushland reserve outside the zoo, and a refuse pit and water treatment works inside the zoo. The bushland reserve extends approximately 500 m between Sydney Harbour and the southern zoo boundary. It is 100 m wide on average and slopes down steeply to the harbour, with the reserve including a headland and small beach 150 m long. The reserve contains many large trees with Moreton Bay figs (*Ficus macrophylla*) and Sydney red gums (*Angophora costata*) the dominant species. The area has a multitude of weeds including blackberry (*Rubus fruticosus*), wandering Jew (*Tradescantia albiflora*) and lantana (*Lantana camara*). Further to the east is a small national park, while to the west is suburbia. The zoo grounds included within the trapping area are largely open. The refuse pit is located approximately 20 m from the zoo boundary and consists of a 25 m diameter concrete floor with a crumbling 4 m high brick wall on its northern side. Hay, chaff, seed, animal waste, and plant clippings are tipped into this area and may remain for a week or more. The northern half of the study site includes treatment ponds, buildings for water treatment, and some small garden beds. North of the refuse pit is a vegetated slope dominated by *T. albiflora*. Beyond the study area to the north are the main animal exhibits.

To test the role of interspecific competition on macrohabitat use, most individuals of the putatively dominant species were removed. In the absence of any suitable replicate sites, individual radio-collared rats were used as replicates. This provides a response of individuals to reduced interspecific competition (Dickman and Woodside 1983). We had planned to remove *R. norvegicus* through extensive trapping. However, in the 6 weeks between trapping sessions, the zoo undertook an extensive baiting campaign around the refuse pit. There was no baiting in the bushland reserve beyond the zoo boundary. This meant that the goal of removal of a large majority of *R. norvegicus* was met at the zoo site. Moreover, if the numbers of *R. rattus* dramatically decreased over this period then it would suggest they had been feeding within the zoo grounds.

During the pre-removal trapping session conducted in May 2001, six *R. rattus* and seven *R. norvegicus* were radio-tracked using single-stage transmitters (Sirtrack NZ). All radio-collared rats weighed over 100 g in order to keep the transmitter weight less than 5% of the animal's body weight. All individuals were still alive and being tracked at the completion of the radio-tracking period on the 9 May 2001. For the post-removal radio-tracking session, 13 new individuals were radio-collared of which eight were *R. rattus* and five were *R. norvegicus*. Two *R. rattus* were unable to be tracked for a sufficient time to allow their home ranges to be calculated. This session was completed on the 28 June 2001.

Results and discussion

Fifty-five rats were live-trapped at Bradley's Head between December 2000, and June 2002 (Table 1). Of these, 82 were *R. norvegicus* and 30 were *R. rattus.* Twenty-seven of these *R. rattus* were caught in the bushland reserve, beyond the zoo walls. The three trapped inside the zoo were caught amongst thick vegetation in the aviaries and gardens located centrally within the zoo. This contrasts strongly with *R. norvegicus*, of which 62% of individuals were trapped within the zoo grounds. *R. norvegicus* was trapped over a range of habitat types including open areas, such as along paths and in animal enclosures. They were observed to congregate in large numbers at food sources, such as around the refuse pit, in animal enclosures where food had been spilt, as well as around kiosks and bins where zoo patrons had discarded food. The observations of this species suggested that *R. norvegicus* may be excluding its smaller congener from an area rich in food. The restriction of *R. rattus* within the zoo grounds to thick vegetation suggests that they may be able to persist in the presence of *R. norvegicus* only where there is ample cover. This is consistent with observations that *R. norvegicus* is competitively dominant to *R. rattus* (Barnett 1958). The arboreal habit of *R. rattus* in dense bushland (Cox 2000) indicates that they may be able to partition their use of the landscape to avoid *R. norvegicus*.

Table 1. Total number of captures from four trapping trips conducted between December 2000 and June 2001. The zoo fence is the boundary that divides the two macrohabitat types. Only three male *R. rattus* were trapped inside the zoo grounds during this period.

	Rattus rattus		*Rattus norvegicus*		Total captures
	Zoo	Bush	Zoo	Bush	
Males	3	12	24	19	58
Females	0	15	27	12	54
Total	3	27	51	31	112

The trapping during May and June revealed an even clearer pattern of habitat use by *R. rattus*. Of the 40 rats trapped, 10 were *R. rattus* and all of these were trapped outside the zoo grounds within the bushland reserve. *R. norvegicus* was found in approximately equal numbers inside and outside the zoo. The refuse pit was a key feature of the southern section of the zoo and it contained a wide range of suitable rodent food. Large numbers of *R. norvegicus*, up to 20 in 10 m^2, were observed to feed from the refuse pit each night. We expected an area containing such a varied and ample food supply would be frequented by both rodent species. Yet trapping suggested that *R. rattus* avoided this area. The area is relatively open and *R. rattus* may avoid it because of a greater perceived risk of predation. This area is fenced to minimise access by cats, dogs, and foxes, hence the emphasis on perceived predation risk. We know of no other study that has reported similar habitat partitioning by these two rat species in an urban landscape dominated by vegetation and open access to food waste.

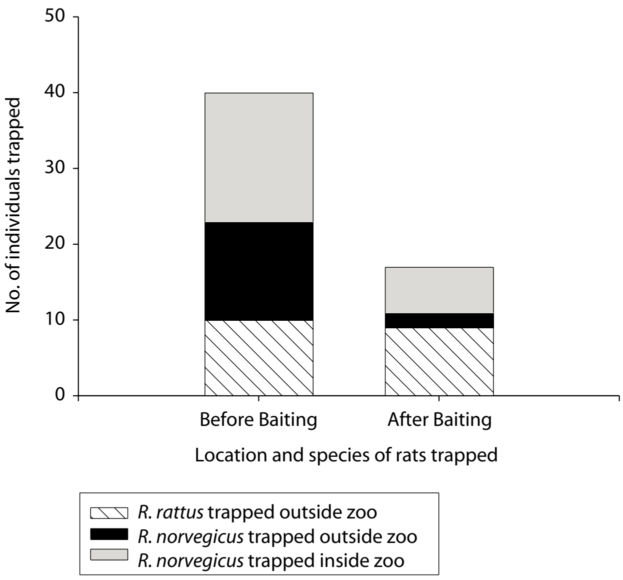

Figure 1. Response of both *Rattus rattus* and *Rattus norvegicus* to baiting conducted around the refuse tip within the grounds of Taronga Zoo between 9 May and 20 June 2001. A reduction of 73% in *R. norvegicus* numbers was observed, with numbers reduced both inside and outside the zoo. No *R. rattus* were trapped within the zoo grounds. The absence of a significant reduction in the number of *R. rattus* further supports the hypothesis that *R. rattus* does not venture into the zoo grounds to feed.

The baiting of *R. norvegicus* from around the refuse pit reduced the population by 73% in 6 weeks (Figure 1). The amount of bait laid out by zoo staff around the refuse tip increased five-fold during this period. The dramatic reduction in *R. norvegicus* numbers and the apparent lack of an effect on the numbers of *R. rattus* suggests that few, if any, *R. rattus* consumed bait. While this may reflect an aversion to bait stations, this finding, combined with the trapping data, suggests that *R. rattus* rarely venture from the bushland reserve into the adjacent zoo grounds.

Immigration into the study area over the 6-week period during which the numbers of *R. norvegicus* decreased appeared to be low. Few *R. norvegicus* were observed feeding from the refuse pit at night during the final trapping session. This is despite the observation that *R. norvegicus* numbers remained high in other parts of the zoo. This may be due to an abundance of food in animal enclosures in other parts of the zoo. With such resources available elsewhere, there may have been no incentive for migration to take place. Dickman (1991) found that subordinate species of small mammal might respond within hours to the removal of a dominant species, so the possibility of a delayed response to the removal of the majority of *R. norvegicus* is unlikely. The large decline in *R. norvegicus* numbers was most likely due to the change in baiting regime rather than intrinsic demographic factors because it occurred when the rats were still breeding and high rodent densities were observed elsewhere in the zoo.

In May and June, radio-tracking of 12 *R. rattus* yielded a total of 373 location fixes, with each of these rats having their position recorded not less than 28 times. No difference was found in habitat use patterns following the removal of *R. norvegicus*. On no occasion was any *R. rattus* observed to occur on zoo grounds (Table 2). By contrast, approximately two-thirds of all locations recorded for *R. norvegicus* were within the zoo grounds. The 12 radio-tracked *R. norvegicus* were all documented entering the bushland reserve and all visited the refuse pit. Therefore, *R. rattus* appeared to be restricted to areas of dense vegetation, whereas *R. norvegicus* moved freely between the two habitat types and fed from the refuse pit.

Table 2. Total number of fixes recorded in the two macrohabitats for 24 radio-collared rats between May and June 2001. No *Rattus rattus* was found to enter the zoo grounds, while *Rattus norvegicus* moved freely between the two macrohabitat types.

Rattus rattus				*Rattus norvegicus*			
Sex	Fixes in zoo	Fixes outside	Total	Sex	Fixes in zoo	Fixes outside	Total
Male (M)	0	32	32	M	31	1	32
M	0	32	32	M	29	3	32
M	0	31	31	M	24	8	32
M	0	33	33	M	11	21	32
M	0	34	34	M	9	25	34
M	0	28	28	M	9	25	34
Female (F)	0	32	32	M	11	20	31
F	0	31	31	F	31	1	32
F	0	30	30	F	30	2	32
F	0	31	31	F	7	22	29
F	0	31	31	F	29	2	31
F	0	28	28	F	25	3	28
6M, 6F	0	373	373	7M, 5F	246	133	379

Conclusion

The two commensal rodent species showed markedly different patterns of habitat use at Bradley's Head. *R. rattus* strongly favoured areas of dense bush, whereas *R. norvegicus* occurred in both the zoo grounds and in the bush adjacent to the zoo. We suggest that more marked predator avoidance behaviour by *R. rattus*, rather than interspecific competition, is responsible for the perceived difference in habitat preference. There is mounting evidence that predators can strongly influence the habitat use of rodents (Banks 1998; Ylönen et al. 2002; Arthur and Pech, this volume). The strength of this effect on habitat use by *R. rattus* in urban settings requires further investigation, as does the apparently weak effect that it may have on *R. norvegicus*. A practical recommendation from this study is that pest control at the zoo should be focused on *R. norvegicus*, with invasion by *R. rattus* appearing unlikely even in the absence of its larger congener. Control methods at the zoo should initially address the problems of food spillage, animal waste, and the storage of these in a location that is not open and easily accessible for *R. norvegicus*.

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SYMPOSIUM 6: SOCIOLOGY AND ECONOMICS OF RODENT MANAGEMENT

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Modelling the structure of non-linear and non-additive climatic forces in small rodent population dynamics

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Abstract. Understanding the role of interactions between intrinsic feedback loops and external climatic forces is one of the central challenges within the field of population ecology. For rodent dynamics, the seasonal structure of the environment involves changes between two stages: reproductive and non-reproductive. Nevertheless, the interaction between seasonality, climate, density-dependence, and predators has been generally ignored. In this study, we analysed the combined effects of non-linear feedback and non-linear, non-additive climatic forces on population dynamics of small rodents. We studied population time series of several small rodent species inhabiting different continents: (i) southern temperate forests of Chile, (ii) a desert in south-western United States of America (USA) and (iii) a deciduous forest in eastern USA. We analysed the numerical fluctuations exhibited by these small rodents using theoretically based models of population dynamics. Recent climatic changes seem to account for dramatic perturbations of the rodents' dynamics. Direct and indirect climatic effects and their non-linear structure are likely to have important effects on rodent dynamics. Assuming such interactions to be typical of ecological systems, we conclude that appropriate predictions of the ecological consequences of climate and global change on small rodent populations will depend on having an in-depth understanding of the community–weather system.

Introduction

The numerical fluctuations exhibited by small rodent populations have fascinated ecologists during the last 80 years. Since Elton (1924), the study of regular cyclic oscillations of arvicoline rodents (lemmings and voles) has been influential for understanding animal population dynamics (Hanski et al. 1993; Stenseth 1999). The emphasis of these studies has been the search for the underlying feedback structure (first- and second-order) representing the individual interactions (within- and between-level trophic interactions). By contrast, the population dynamics of non-cyclic small rodents have been less studied. While studies focusing on cyclic rodent dynamics have emphasised the role of direct and delayed density-dependent feedback and seasonality as the important factors driving numerical oscillations, the influence of climatic forces on fluctuations of small rodent populations has received less attention.

For decades, the role of exogenous and endogenous factors in determining population dynamics has been hotly debated in population ecology (Nicholson 1933; Andrewartha and Birch 1954). Today, there is a growing body of empirical evidence supporting the joint effects of endogenous and exogenous forces on the dynamics of natural populations (Leirs et al. 1997; Forchhammer et al. 1998; Grenfell et al. 1998; Lima et al. 1999). However, in most of the studies, it had been assumed that the endogenous and exogenous effects are linear and additive. As a consequence, the existence of non-linear and non-additive climatic effects has been much less studied (but see Sæther et al. 2000; Mysterud et al. 2001; Stenseth et al. 2002).

The inclusion of climatic forces in population dynamic models represents an interesting challenge for small rodent ecologists (Stenseth et al. 2002). Two factors contribute to this challenge: first, because the signature of the climatic forces on population dynamics depends on the underlying feedback structure (Royama 1992); and second, because there are complex interactions between the feedback structure and climate. For example, climate can affect the maximum per capita growth rate, or the food supply, or even the intra- and inter-specific interactions. In this case, climate affects the system in a non-additive manner because the feedback structure parameters are a function of climate (Stenseth et al. 2002). In this study, we analysed the combined effects of non-linear feedback and non-linear, non-additive climatic forces on the population dynamics of small rodents. We studied population time series of several small rodent species inhabiting different continents: (i) southern temperate forests of Chile, (ii) a desert in south-western United States of America (USA) and (iii) a deciduous forest in eastern USA. We analysed the numerical fluctuations exhibited by these small rodents using theoretically based models of population dynamics.

Material and methods

Small rodent data

We used time series data of three small rodents from Chile, six species of small rodents from eastern deciduous forests in Pennsylvania, USA, and 12 species of small rodents from south-western semi-arid USA.

Climatic data

For characterising the climate in Chile, we used the annual rainfall from Illapel station (31°30'S, 71°06'W) and Valdivia town (39°38'S, 73°07'W) (NCDC 2002) the Southern Oscillation Index (SOI) (DNRM 2002) and the Antarctic Oscillation Index (AAOI) (Climate Prediction Center 2002).

For characterising the climate in Pennsylvania, USA, we used different climatic variables to represent environmental conditions: the North Atlantic Oscillation (NAO) index, the yearly rainfall, the average winter and summer temperatures and the average snow depth for Powdermill Biological Station (40°10'N, 79°16'W).

For characterising the climate in south-western USA, we used data for the summer and winter rainfall from the Portal study site.

Statistical models of population dynamics

Population dynamics of small rodents are the result of the feedback structure and climatic (also stochastic) influences. To understand how these factors determine population fluctuations, we consider the scenario of Figure 1. The arrows define the potential ecological interactions between rodents, plants, predators and climate: the first-order intraspecific feedback within the rodent population is defined by the partial derivative, ($\partial f_N/\partial N$). The trophic interactions between rodents and plants are given by the partial derivatives, $\partial g_N/\partial P$ and $\partial g_P/\partial N$, respectively, and the trophic interactions between rodents and predators by the partial derivatives $\partial j_N/\partial Y$ and $\partial j_Y/\partial N$ and the direct climatic effects are given by $\partial h_N/\partial C$ and $\partial h_P/\partial C$ (Figure 1).

One way to simplify the system is when rodents have no effects on plant dynamics (i.e. $\partial g_P/\partial N = 0$) and there are no effects of predators on rodent dynamics (i.e. $\partial j_N/\partial Y = 0$) Under this scheme, we can represent these ecological relationships from the small rodent perspective using a very general model in terms of reproduction and survival of individuals (Berryman 1999), which represents a variant of the Ricker (1954) discrete-time logistic model influenced by climate and stochastic forces.

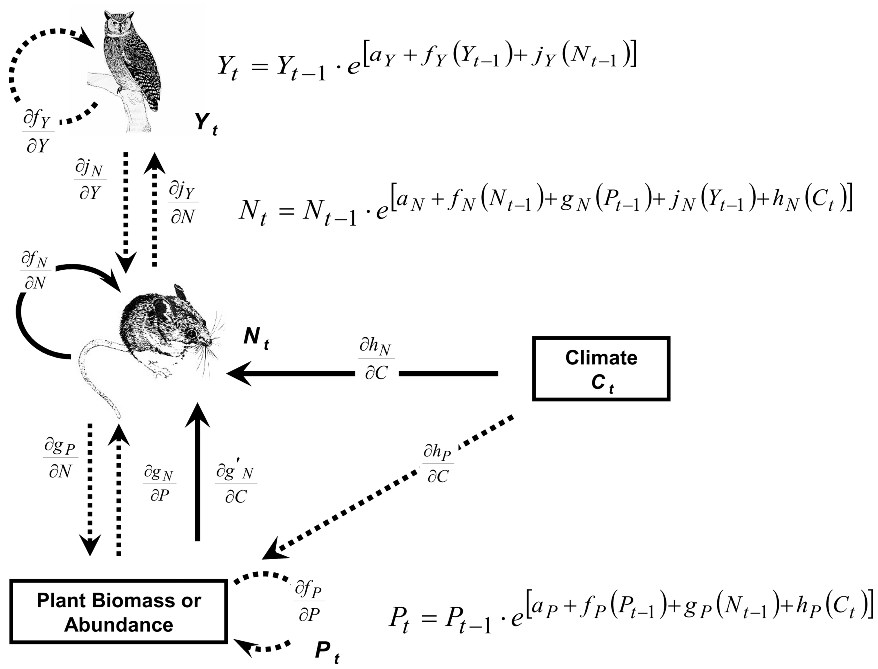

Figure 1. A schematic model illustrating the potential interactions between plants, small rodents, predators and climate. Y_t, N_t and P_t give abundance of predators, small rodents and plants respectively, while climate denoted by C_t. The ecological functions $f_Y(\bullet)$ and $j_Y(\bullet)$ in Y_t, $f_N(\bullet)$, $g_N(\bullet)$, and $h_N(\bullet)$ in N_t and $f_P(\bullet)$, $g_P(\bullet)$, and $h_P(\bullet)$ in P_t describe the changes in predator, rodent and plant populations following the ecological interactions given by the arrows and defined by the partial derivatives. The dotted arrows indicate the relationships that were not explicitly considered in our modelling of the population dynamics. See text for details.

$$N_t = N_{t-1} \cdot e^{[A_N + f_N(N_{t-1}) + g_N(P_{t-1}) + h_N(C_t) + \varepsilon_t]} \quad (1)$$

where N_t and P_t are the small rodent and plant abundances at time t, C_t is the variable representing the climate state. The term A_N is the maximum per capita growth rate and the functions $f_N(N_{t-1})$, $g_N(C_{t-1})$, and $h_N(C_t)$ represent the effects of rodent abundance, plant abundance and climate on rodent population dynamics and ε_t represents normally distributed stochastic perturbations. Direct effects of climate on rodent population dynamics may be produced by mortality due to freezing temperatures or snow depth, and also by flooding. On the other hand, plant abundance is directly influenced by climate. In consequence, from model 1 and in the absence of data about plant biomass or abundance, we can represent the small rodent population dynamics as a single equation with lagged climatic effects (see Royama 1992; Forchhammer et al. 1998):

$$N_t = N_{t-1} \cdot e^{[A_n + f_N(N_{t-1}) + g'_N(C_{t-1}) + h_N(C_t) + \varepsilon_t]} \quad (2)$$

(where N_t denotes the small mammal abundance at time t, C_{t-1} is the lagged climatic effect due to delays in interactions with the lower trophic level (plants biomass) (see Forchhammer et al. 1998), C_t is the direct effect of climate (for example, snow, freezing temperatures, rainfall and floods) and $f_N(N_{t-1})$, $g'_N(C_{t-1})$, and $h_N(C_t)$ are unknown functions which have to be estimated from the data. The lagged climatic effect ($g'_N(C_{t-1})$) is a compound function of three ecological processes—the direct effects of climate on plants ($\partial h_P/\partial C$), the self-regulation term of plants ($\partial f_P/\partial P$), and the positive effects of plants on rodent dynamics ($\partial g_N/\partial P$) (Figure 1). An alternative way to express equation 2 is in terms of the instantaneous *per capita* population growth rates, which represent the processes of individual survival and reproduction that drive population dynamics. This is the *R*-function (sensu Berryman 1999). Defining R_t = log (N_t) – log (N_{t-1}) equation 1 can be expressed as:

$$R_t = A_n + f_N(N_{t-1}) + g'_N(C_{t-1}) + h_N(C_t) + \varepsilon_t \quad (3)$$

This model represents the basic feedback structure, without explicit representation of the plant trophic level, and includes the climatic and stochastic forces that drive population dynamics in nature.

On the other hand, climatic effects can be non-additive. The non-additive effects of climatic variables can be modelled in different ways. For example, the climatic effects on plant dynamics may have a logistic demand/supply structure where C_{t-1} is an index of the effect of food availability on rodent population dynamics:

$$R_t = A_n + f_N\left(\frac{N_{t-1}}{C_{t-1}}\right) + h_N(C_t) + \varepsilon_t \quad (4)$$

or the climatic effect may be a factor of the feedback structure, that is, the feedback function depends on climate:

$$R_t = A_n + f_N(N_{t-1} \cdot C_{t-1}) + h_N(C_t) + \varepsilon_t \quad (5)$$

The basic idea for population analysis is to choose a family of functional forms to fit time series data. This treats equations 3, 4 and 5 as non-parametric non-linear models (see Bjørnstad et al. 1998 for an ecological example). The choice of the functional forms for *f*, *g* and *h* can be approximated using natural cubic splines (Bjørnstad et al. 1998). The complexity of the curve (the number of degree of freedom) was 3 and the number of terms was tested by using the Schwarz's Bayesian criterion (SBC) (S-PLUS 2000). The SBC is obtained as the –2*log-likelihood + npar*log(nobs), where npar represents the number of parameters and nobs the number of observations in the fitted model.

Results and discussion

The numerical fluctuations observed in these small rodent species appear to be the result of strong non-linear climatic effects combined with negative first-order feedback, which were strongly non-linear in some species. In addition, some species showed non-additive climatic effects.

For example, in northern Chile, population growth rates of the leaf-eared mouse (*Phyllotis darwini*) exhibit a clear seasonal structure, i.e. factors influencing population growth rates are clearly different between breeding and non-breeding seasons. In addition, we detected non-linear density-dependence. The seasonal structure and the factors influencing population growth rates were able to capture the observed temporal variation in these rates, including their structural variation over time (Figure 2).

The long-haired field mouse (*Abrothrix longipilis*) in southern temperate forests of Chile was characterised by a second-order feedback (N_{t-1} and N_{t-2}) and a non-linear effect of SOI on the per capita growth rates. This climatic effect can be a proxy for the influences of climate on food (fungus in autumn and winter, and fruits and plants during summer) (Figure 3).

Long-tailed rice rats (*Oligoryzomys longicaudatus*) were characterised by first-order dynamics and a negative non-linear effect of SOI on per capita growth rates, that means that El Niño years have a negative impact on the population dynamics of rice rats. This negative impact may be associated with the relationship between SOI and summer rainfall in southern Chile. Also, the non-linear and negative effects of rainy winters may be the effect of high over-winter mortality produced during very rainy winters due to cold weather or flooding. The non-linear effects of rainfall and SOI on population growth rates represent a new and interesting finding for understanding population dynamics of this rodent (Figure 4).

Strong non-linear and non-additive effects of winter weather were observed in the population dynamics of small rodents from Pennsylvania (USA) (Figure 5) and Chihuahuan desert in Airzona, USA (Figure 6). This finding emphasises the importance of interactions between climate and feedback structure for understanding the population dynamics of small mammals. Although several studies have shown effects of climate in different ecological systems (see Ottersen et al. 2001 for a review), in this study we describe for the first time effects of the NAO on small rodent populations inhabiting North America and non-linear effects of rainfall on kangaroo rats. The NAO is primarily a winter phenomenon influencing air temperatures, winds, and precipitation over the North Atlantic areas. In the same vein, strong non-linear and non-monotonic effects of winter and summer rainfall on small rodent population growth rates were observed in time series from south-western USA.

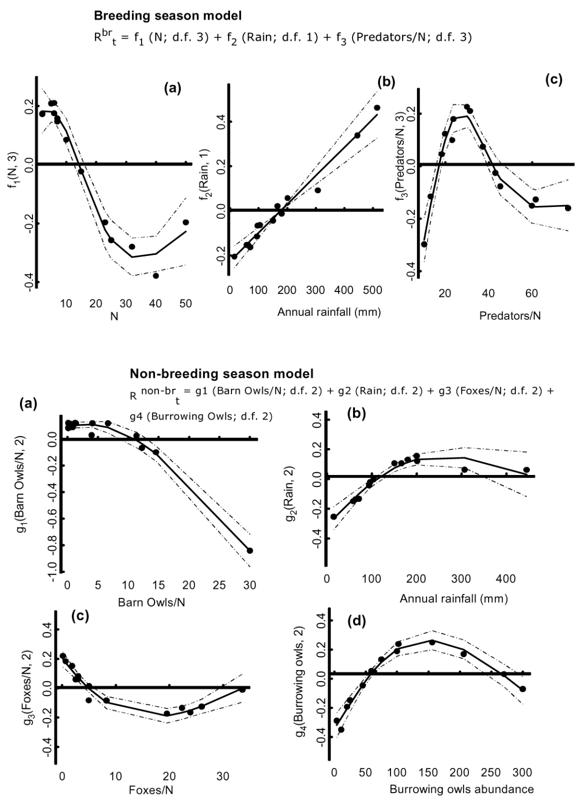

Figure 2. Best generalised additive model (GAM) representing the breeding R-function for leaf-eared mouse dynamics (breeding season model): (a) partial non-parametric regression line for the population density (N_t–1); (b) partial non-parametric regression line for annual rainfall; and (c) partial non-parametric regression line for the ratio (total predator abundance index)/(leaf-eared mouse abundance). The model was fitted by using natural cubic splines with 3 df. Dashed lines are 95% confidence intervals; $R^2 = 0.97$.

Best GAM model representing the non-breeding R-function for leaf-eared mouse dynamics (non-breeding season model: (a) partial non-parametric regression line for the ratio (barn owl abundance index)/(leaf-eared mouse abundance); (b) partial non-parametric regression line for annual rainfall effect; (c) partial non-parametric regression line for the ratio (culpeo fox abundance index (foxes))/(leaf-eared mouse abundance); and (d) partial non-parametric regression line for the effect of burrowing owl abundance index (burrowing owls). The model was fitted by using natural cubic splines with 2 df. Dashed lines are 95% confidence intervals; $R^2 = 0.98$.

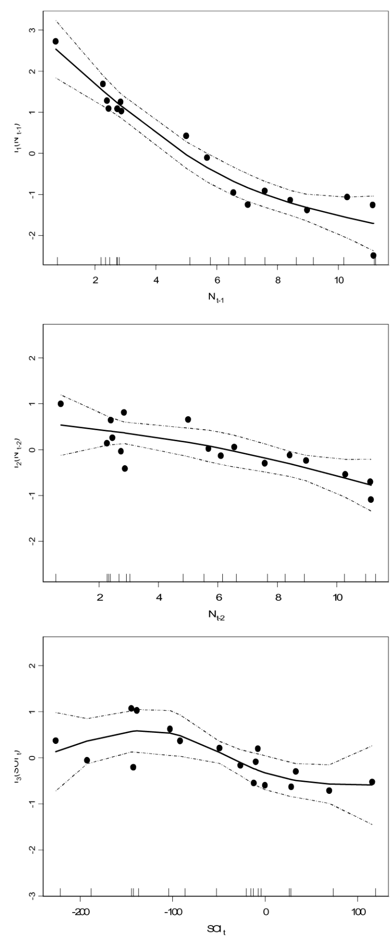

Figure 3. Statistical population dynamic model representing the per capita population growth rates [(R_t = Log $(N_t/N_{t–1})$ or R-function] for long-haired field mice (*Abrothix longipilis*). (a) Partial non-parametric regression line for first-order feedback ($N_{t–1}$). (b) Partial non-parametric regression line for the second-order feedback ($N_{t–2}$). (c) Partial non-parametric regression line for Antarctic Oscillation Index (AAOI). The model was fitted by using natural cubic splines with 3 df. Dashed lines are 95% confidence intervals and explain 94% of the variance.

Consequently, we suggest that the interactions between direct and indirect climate effects, and non-linear density-dependence, are the key elements in understanding the dynamics of many small rodent populations. The principle that emerges from this study is that predicting responses to global change of natural populations may be confounded if non-linearity and non-additive effects are not clearly assessed. The existence of both non-linearity and non-additivity has profound implications for understanding natural population dynamics and food web structure. We contend that one cannot predict the responses of natural systems (populations and communities) to climate changes unless the particular non-linear structure of these systems is fully understood.

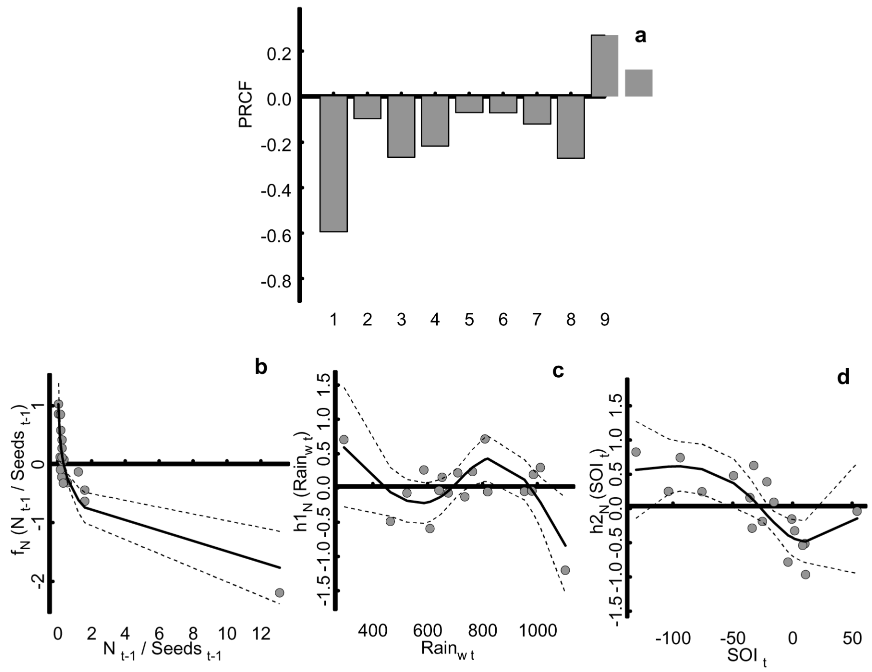

Figure 4. (a) Partial rate correlation function (PRCF) for the rice rat time series. (b) Best model representing the *R*-function and the climatic co-variables for rice rats (*Oligoryzomys longicaudatus*). Partial non-parametric regression line for the ratio between population density and seed density (N_{t-1}/Seeds$_{t-1}$); partial non-parametric regression line for winter rainfall (c) and partial non-parametric regression line for Southern Oscillation Index (SOI) (d). The model was fitted by using natural cubic splines with 3 df. Dashed lines are 95% confidence intervals.

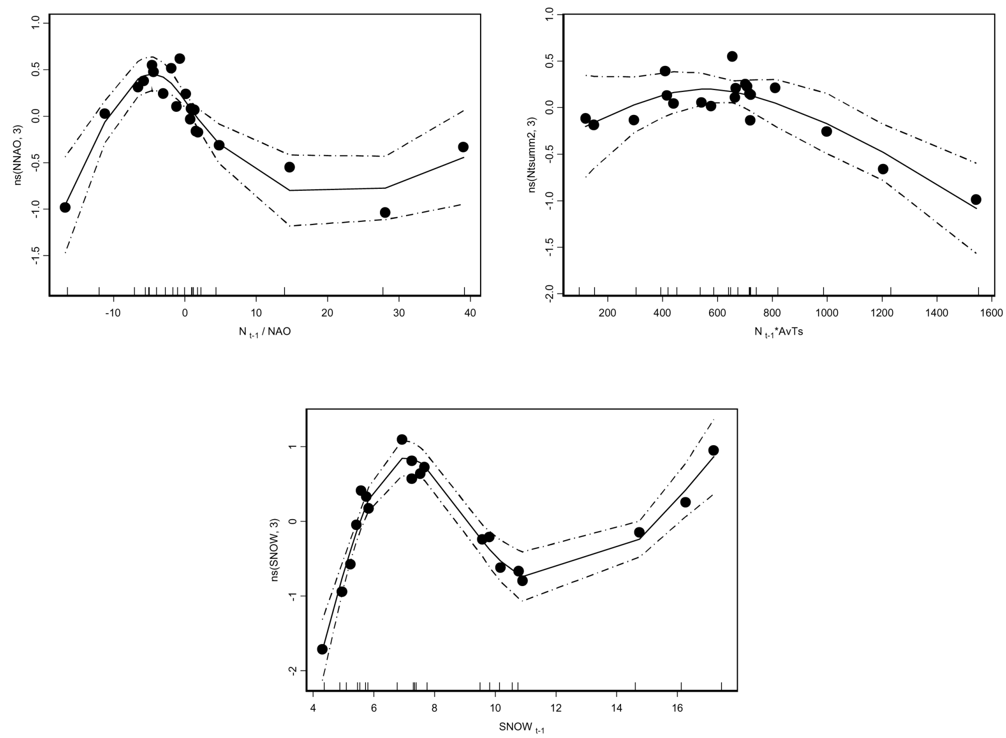

Figure 5. Best model representing the *R*-function and the climatic co-variables for southern flying squirrels (*Glaucomys volans*) at Powdermill Biological Station, Pennsylvania, USA. Partial non-parametric regression line for population density (N_{t-1})/North Atlantic Oscillation (NAO); partial non-parametric regression line for population density (N_{t-1}) * Average summer temperature (*AvTs*); and partial non-parametric regression line for direct snow depth effects. The model was fitted by using natural cubic splines with 3 df. Dashed lines are 95% confidence intervals.

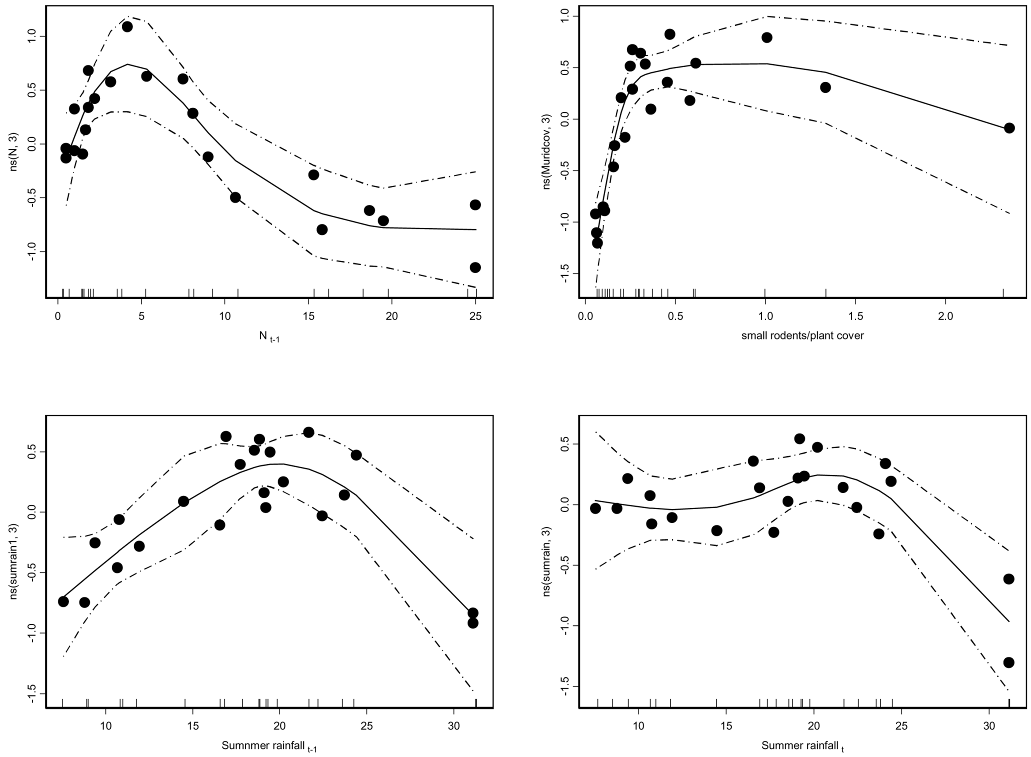

Figure 6. Best model representing the *R*-function and the climatic co-variables for Banner kangaroo rats (*Glaucomys volans*) at Portal, Arizona, USA. Partial non-parametric regression line for population density (N_{t-1}); partial non-parametric regression line for the interation between small rodent abundance/plant cover; and partial non-parametric regression line for lagged and direct summer rainfall. The model was fitted by using natural cubic splines with 3 df. Dashed lines are 95% confidence intervals.

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A sociological perspective on the community-based trap–barrier system

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Abstract. The community-based trap–barrier system (CTBS) is a relatively new technology for the non-chemical control of rodent pests in rice fields. There has been substantial biological work conducted on the CTBS but relatively little anthropological work. This paper develops a framework for understanding the CTBS by redefining the CTBS as a common property resource (CPR) and thus subject to many of the same constraints and opportunities as other CPRs. The paper shows that many of the documented threats that other CPRs have are also present in the CTBS, principal among these are the free rider, issues of transparency and equity, and the use of existing institutional structures for resource management. We begin by applying a typical CPR framework to the CTBS—demonstrating the links between the two systems. This is followed by an analysis of a set of threats to CTBS derived from our understanding of CPRs. We conclude with a set of testable hypotheses for those interested in applying this framework to other CTBSs or CPRs in general.

Introduction

The community trap–barrier system (CTBS) is a relatively new technology for the management of rodents in rice fields (see Singleton et al. 1999 for review). We have made an effort to define the CTBS in sociological terms to better understand the social dynamics of management. This in turn allows us to make better recommendations regarding how to improve the overall effectiveness of the system.

In this paper we draw on our experiences of the adoption of the CTBS in the Mekong Delta to present a theoretical framework for understand the sociological component of the CTBS, followed by a selection of threats to the sustainability of the CTBS, considering only sociological aspects. Based on these threats, a set of mechanisms for improving the likelihood of the sustainability of CTBS is suggested. Finally, we identify a set of hypotheses that can be used to test the CTBS in different cropping systems.

Technical background to the CTBS

A CTBS for rodent control in rice fields has an early planted ‘trap crop’ within the CTBS, which lures rodents to the traps. Ideally, the trap crop should be planted about 20 days before the surrounding rice fields. The trap crop has a plastic barrier around it, placed along the margin of a rice crop, and small holes are made in the fence just above the irrigation water. Adjacent to each hole is a multiple-capture trap suspended on bamboo above the water level (on the crop side of the fence). A mud mound provides access to the hole and thence to the trap. Rats are attracted from an area beyond the field of one farmer. This area is referred to as the ‘halo’, or the area of effectiveness, and may cover an area of 10–15 ha (Singleton et al. 1999). One distinct advantage to the CTBS is that no poisons are used, although management and labour costs may be higher than in typical baiting systems.

Theory

Frames of reference

There are at least two analytical frames possible in a CTBS. First, the CTBS is a common property resource (CPR), created with the establishment of the system by community labour and shared cash inputs. Second, the CTBS is a private resource, where the outputs of the CTBS, e.g. low rat damage, is considered a positive externality of individual behaviour.

Property rights are understood as the “*sanctioned behavioural relations* among men that arise from the existence of goods and pertain to their use” (Furubotn and Pejovich 1974). Theorists typically recognise four sanctioned behavioural relations: private, communal, state, and open access (Feeny et al. 1990). State control of resources and open access rights regimes will not be considered here since they are not generally relevant to the management of a CTBS. Of interest here are the various costs, benefits, and general utility of private and common property in the management of rodents.

A rice field is typically owned privately by the farming household. This means that the right to manage, sell, or lease the property is determined by the household itself, without any undue encumbrances laid upon it by either the government or other households. Common property exists where a group of users cooperate in the management and disbursement of the resource, and thus share in the benefits 'stream'. Users share the 'rights' of resource use and 'duties' of resource management (Bromley and Cernea 1989).

Typically, no common property exists in a rice field since rice is the sole property of the owner. But when a CTBS is established using shared resources, such as materials and labour, a common property is created. In this case, the shared resources are reduced rodent damage to rice, any consumable rodents, and other consumable animals caught in the trap. The shared costs include the cost of the fence, and the labour to erect it, and any costs incurred related to early establishment of the rice crop and daily monitoring of the traps and the fence.

In some cases, the TBS may operate as a private property system with a stream of positive externalities. In this case, a family may decide to establish TBS on their own. They receive the full benefits of reduced rat damage and the control of all the live animals caught in the traps. Those farmers outside the immediate family yet still within the halo of protection are the beneficiaries of what is referred to as a positive externality—they receive benefits at no cost.

The difference between the private and common theoretical frames can be described according to two dimensions: the number of participating households within the closed system and the degree to which participating members feel burdened by non-participants who benefit. In the pure case of the common CTBS, all members pay equal costs and receive equal benefits. For all practical purposes, this can never be achieved due to the complex nature of the transactions and the importance of perceptions of equity in the allocation of resources.

In farming communities where the average farm size (most are <2.5 ha in Southeast Asia and South Asia) is at least a quarter of the halo of protection (10–15 ha), it is unlikely that many farmers will willingly establish a TBS alone (the private option). This is because the trap–barrier system is costly, and usually beyond the means of individual farmers. The main costs for Mekong farmers are draining the field before direct seeding, especially in the wet season, and purchasing the poles and plastic of the fence. A farmer may, on the other hand, build a CTBS with their own funds for the benefit of their neighbours, particularly where these neighbours are relatives. However, since exchange in extended households often changes form, e.g. weeding labour may be exchanged at a later date for a cash loan, the establishment of a CTBS would be considered a common good for his extended family. The main difference here is the degree to which these decisions turn on the expectation of return. Within a household, all members contribute resources and receive benefits according to some culturally determined set of principles.

For a typical common property resource (CPR), the attributes are important in determining the management strategy employed for optimum use (McCay and Acheson 1987). There are four important aspect of a CPR: (1) the technical attributes; (2) the decision-making arrangements; (3) the patterns of management interaction; and (4) the outcomes of various management decisions and options (Oakerson 1986).

Technical attributes

One important technical attribute is subtractability, which is the degree to which one resource user limits the use of another (Oakerson 1986). This is important because most resources are limited in time and space, thus too many users would mean both higher costs to obtain resources and the potential for degradation of the resource over time. Neither of these are problems necessarily, because the main benefit of a CTBS is actually the *absence* of a problem (rat damage), creating a *presence* of a resource in the form of a public good (improved rice yield within the halo). Sharing the trapped rats can be dealt with through institutional cooperation. One community group came up with the idea that those who check the traps also receive the rats inside ("check the traps, keep the rats").

Excludability, the degree to which entitled users can keep out other potential users is another important technical issue. Like subtractability, this is important because the benefits of the resource are limited, so the presence of unentitled users would mean less benefit for all entitled users. Excludability in a CTBS is very low—all entitled users (paying and within the halo) of the CTBS would receive the full value of their investments. Others outside the halo, who are not required to pay, may also receive benefit. However, if this causes no concern on the part of the entitled users, then no problem exists. On the other hand, if the halo is determined not theoretically, as in "200 metres in every direction from the trap crop", but practically by assuming that all those who have no rat damage are within the halo, then subtractability may be an important issue. This view redefines those outside the halo as free riders, and thus makes them problematic for the community group.

Finally, divisibility, the ability of users to divide common property into private sub-units, is indeed a threat to the CTBS. The process of privatisation of the CTBS could involve either an individual voluntarily constructs a TBS and others benefit from that, or a small group of local users could develop their own CTBS, whereby only those individuals in this smaller group benefit. In the former case, a private property system has emerged, while in the latter case it is simply a selective form of CTBS.

Decision-making arrangements

Decision-making arrangements are as important as the technical attributes in determining the sustainability and effectiveness of a CTBS. These arrangements are typically made up of a set of rules or guidelines to structure the behaviour of members. The majority of the rules are unwritten, and they govern how decisions are made, and the content of these decisions. In addition to rules, other management tools include incentives for cooperation, structures for the dispersal of benefits, and allocation of labour among households.

Group decisions in resource management are based on individual understanding of the dynamics of resource use. In the case of the CTBS, this includes an understanding of the fundamental link between the creation of a CTBS and a reduction of rodent damage. If this understanding is limited, participation will also likely be limited because the link between individual costs and benefits are not understood.

Patterns of interaction

A third important element is the patterns of interaction or interrelationships between actors, in relation to the resource. These include the behavioural outcomes of the rules and technical attributes of the resource (Figure 1). For instance, if one farmer opts out and becomes a free rider, others will see this and it will cause friction within the group. This will give members a negative expectation of the behaviour of the group as a whole, thus reducing the amount and enthusiasm of their own investment. Alternatively, if reciprocity is the norm, the CTBS is more viable and transaction costs are lowered. Transaction cost in this case is the time, effort, and other resources needed to search out, negotiate, and carry out the operations of management.

In 1968, Garrett Hardin proposed the concept of the "tragedy of the commons" (Hardin 1968), which has since become a standard feature of any discussion on common property resource management. The tragedy of the commons refers to the destruction of a common resource due to individual pursuit of resources to the maximum, in spite of obvious resource degradation. This individual pursuit is characterised as the free rider (Hardin 1968). Hardin's analysis has been often cited as a reason to privatise the commons, thus linking the maintenance of resources with the benefits derived from them.

Ostrom (1990) has shown that successful CPR systems are usually the result of "factors internal to the given group" Unsuccessful CPRs may be marred by the inability of members to communicate with each other or to develop trust in the institutions. Also, factors "outside the domain of those affected", e.g. lack of local autonomy to change the given institutional framework, can also have detrimental effects on the effectiveness of CPRs (Ostrom 1990).

Internal factors are important for successful CPRs because they determine how members of a given group interact with one another. The size of the governing group is critical in determining the likelihood of successful cooperation in achieving group aims (Olson 1971), and group size is not determined by the number of actors, but the relative degree of their transparency of action (Ostrom 1990). Moreover, the actual patterns of interaction among members cannot be dictated from outside, nor should criteria for success be presumed at the outset.

Reducing costs and increasing benefits to individual members or the group as a whole will increase the likelihood of maintenance of the institutions responsible for continuation of the CTBS. Alternatively, holding meetings and talking with neighbours about the CTBS can be presumed to be a (transaction) cost, regardless of how small. Therefore, the relative ease with which people can meet and discuss the CTBS will determine the likelihood of success. We recommend that the CTBS group be made up of people who will generally talk to each other often anyway, e.g. kin, to reduce transaction costs.

This begs the question: what (or who) is the community in community trap–barrier system? Generally, the community is a default set of individuals who happen to share fields within a halo. The community in a CTBS can either be created, by vested local leaders (e.g. village head, or extension worker), or through the adoption of an existing community for a CTBS, such as a kin group described earlier. Our research shows that both types of communities exist: the communities in a CTBS may be a community in other terms, either through integrated pest management or farmers' club, or related by kin in some way.

These are important considerations, because farmers' commitment to the community relates directly to feelings

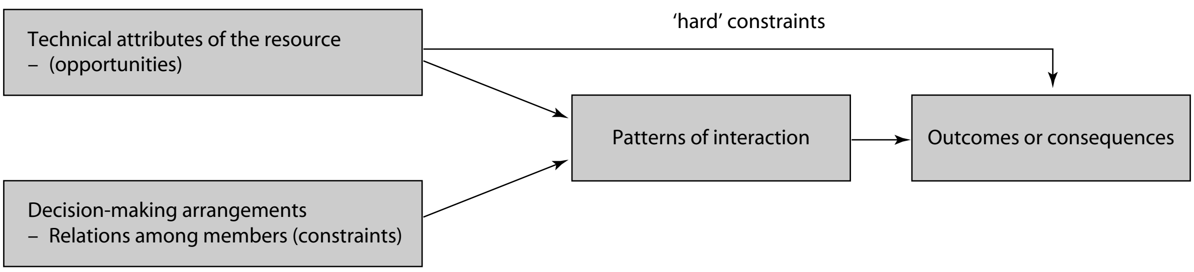

Figure 1. Model of common property resource interactions.

of obligation and the likelihood of active participation in maintenance of the CTBS. The anthropological CPR literature is replete with examples of how the problem of free riders has been avoided through active, vital community involvement in resource management (Netting 1976; McCay and Acheson 1987; McCabe 1990; Ostrom 1990). The basic thrust of this work is to demonstrate that the tragedy of the commons is avoidable through historically relevant institutional arrangements and local culture.

Outcomes of the community resource management system: equity and efficiency

There are two important considerations regarding the outcomes of a community resource management system: whether the system efficiently allocates resources for optimal gains to users and whether these allocations are made equitably. Both equity and efficiency can be understood at the group and individual level. Group efficiency arises from an overall reduction in the damage due to rats within the entire halo area, and whether total CTBS costs are less than those of rodenticides and other control measures. Individual efficiency may be understood as a function of individual costs of the CTBS (including labour) in relation to other control methods. For instance, some farm households may have excess labour, but less capital, therefore preferring to contribute more labour than cash to the CTBS.

Equitable individual division of the benefits of CPRs and CTBS are especially difficult to implement and monitor. Because costs and benefits must be defined both internally, i.e. within the household, and externally, the precise benefits to the individual user could vary widely in an otherwise successful rodent control program. This is exacerbated by the inexact size and shape of halos, which are presumed to be more or less circular, although factors may exist (e.g. rat breeding hot spots: heterogeneity of source and sink habitats for rats in the landscape), which would skew this distribution pattern. Indicators of inequity include variable rat damage between farms, lower yields within the trap crop, and absence from the construction teams.

If inequity is too great, farmers will be less likely to continue working with the CTBS. Whether the inequity is real or imagined, it is important in regards to methods for mitigating the inequity. Transparency and communication can solve the problem but technical solutions would be ineffectual. For real problems of inequity, such as random rat damage in a rice field, technical solutions are possible and should be pursued. These may include a change in the location, size or design of the trap crop or associated management actions to reduce the number of breeding hot spots. It is important to determine whether inequities are borne out by demonstrable facts or due to improper perceptions of the on-the-ground case.

Equity is very difficult to manage because it is based on many factors. Most importantly perhaps is the unpredictability of rodent damage and the effect this will have on farmers' perception of CTBS equity and effectiveness Farmers know that rat damage can be very heavy one year and light the next, but they do not know what effect CTBS will have on this annual variability. Farmers must be able to properly assess the causes of damage to determine whether they can modify social and physical mechanisms. Therefore some understanding of rodent ecology is critically important. A technical or sociological solution needs to be found if inequity in equity exists.

The shape that a halo takes has important implications for the equitable distribution of benefits in a CTBS (Figures 2 and 3). In Figure 2, the halo is well defined for the 10 farmers. All five CTBS members are within the halo and all five non-members are outside. The relationship between benefits and costs is well defined, and reality (i.e. damage) will support this understanding of the distribution of goods. Figure 3 illustrates a poorly defined halo. Two non-participating farmers are found within the halo, and thus defined as free riders, and three participating farmers are outside the halo, giving a total of five people who are not properly described by the halo concept.

This membership by benefit scenario, which will be indicative of the likelihood of the sustainability of the CTBS, suggests that members who receive benefits will remain within the CTBS. Non-members who receive benefits are likely to encourage the members to continue the system, since they are free riders. Members who do not receive benefits are likely to quit.

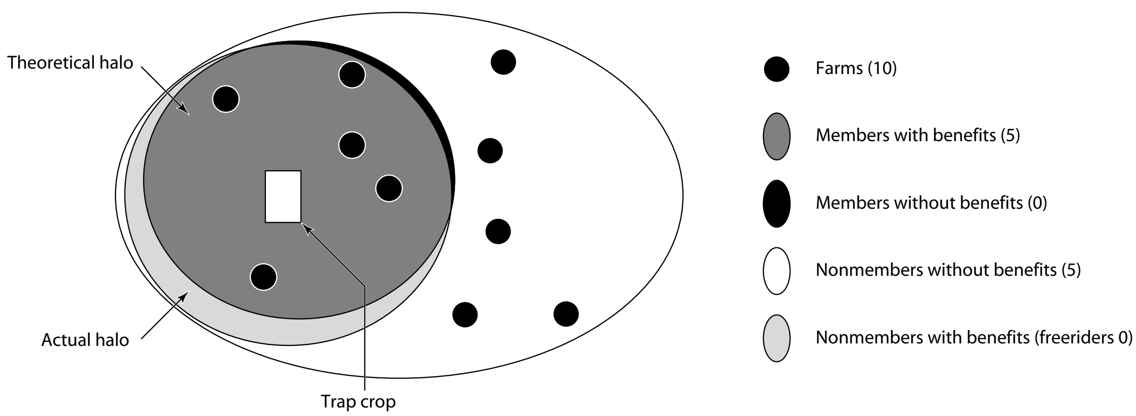

Figure 2. Equity: actors in a well-defined community-based trap–barrier system.

Benefit–cost in technology assessment

In economics, everything used in the productive process has calculable value, including family labour. However, because family labour is not sold, it has an imputed value based on the concept of opportunity costs. Opportunity cost is defined as the value of any resource when put to its best alternative use (Doll and Orazem 1984). Let us consider the opportunity cost of the farmer's time. If they have a job off the farm which they have to give up temporarily to check if there are rats caught in the rat traps, then we say that the opportunity cost of their time in checking rat traps is the wage which they would have been earning if they had stayed in the job instead. Normally, and in our case, the imputed wage for family labour is the average agricultural wage.

One measure of assessing the viability of the CTBS is through the marginal benefit–cost ratio (MBCR). This is the ratio of additional benefit due to adoption of the TBS and additional costs due to adoption of the CTBS.

The potential benefits of the CTBS are:

1. reduction in the cost of rodent control other than TBS, i.e. rodenticide, labour;
2. value of the incremental yield due to less rodent damage; and
3. value of rats caught (in this case, there is a market price for live rats caught).

There is also the environmental benefit from reduced chemical use, but this is difficult to valuate.

The potential costs of the TBS are:

4. materials and labour to build the fence;
5. material cost of rat traps;
6. labour to check the traps daily, remove rats from the traps and maintain the fence;
7. reduction in the trap-crop yield;
8. reduction in field size due to the creation of a buffer around the trap crop; and
9. increased crop protection costs in the trap crop from other pest infestation.

The result of our benefit–cost analysis is presented in Table 1.

Case study: threats to the sustainability of the CTBS

Based on research with previous CPRs, two threats to the sustainability of a CPR are transaction costs and costs associated with maintenance of the institutional and physical infrastructure. Private property regimes improve resource management systems in these two areas. Considering that privatisation is not yet an option for the CTBS, we must consider ways to improve the efficiency within the CPR. This can be achieved by considering two of the main costs of the CTBS: the labour associated with daily maintenance of the traps and fence; and the transaction costs associated with establishing and running the CTBS.

In October 2001, an informal survey was conducted examining the characteristics of members of the trial CTBS in the Mekong Delta, Vietnam. The leaders of the CTBS were asked to list the members of the CTBS, their relationship to other members, and the distance from the trap crop to the members' residences. We found that there was a dense network of interrelationships among members of the CTBS, shown in Table 2, in which all but one of the farmers were related by affinity (marriage) or consanguinity (blood) to someone else within the CTBS (defined as the area presumed to be protected by a CTBS). According to the CTBS leader[1], this pattern resulted from the historical sharing of plots among extended kin. The inheritance preference among Vietnamese parents is for the youngest son to have first rights because he will help his parents as they get older. The youngest son will also bring a wife into the family. If the youngest son cannot inherit, preference is given to any son, and lastly to a daughter. The daughter is not preferred because she will marry and give part of her inheritance to the family she marries into, thus reducing the landholding of the corporate group. This also illustrates why so few women landholders are part of this study (Table 2).

This means that the CTBS has a good prospect of being successful in Vietnam because there is a large group

1. The CTBS leader, unless otherwise noted, is the same person who owns and maintains the trap crop.

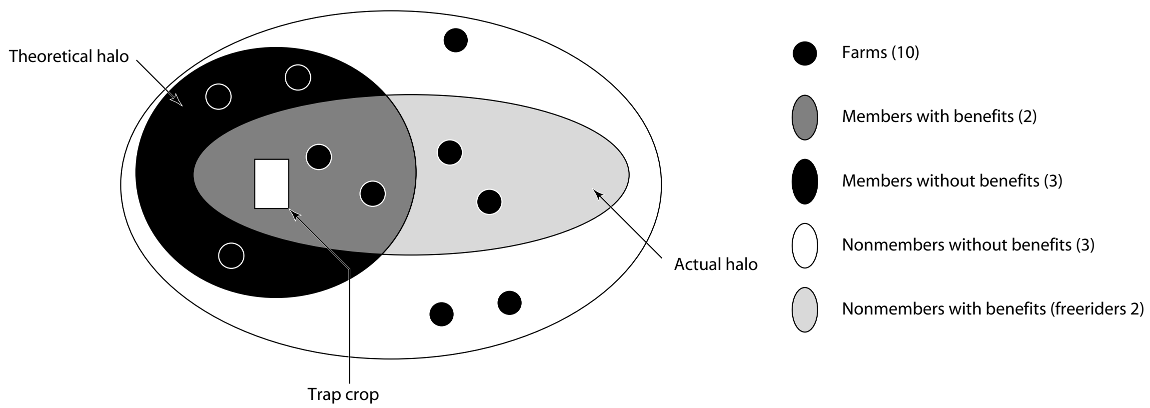

Figure 3. Inequity: different actors in a poorly-defined community-based trap–barrier system.

of potential workers who are related and have neighbouring fields. As kin, they share labour and other resources on a routine basis, particularly among and between men. In the CTBS illustrated in Table 2, the trap-crop owner said he relied mostly on two of his nephews, or junior male kin (farmers represented by numbers 12 and 15), to help him build the CTBS fence. This reduces transaction costs, helps to ensure equity in the distribution of resources, increases transparency, and it increases the perception of equity, i.e. participants are less likely to assume a relative is a free rider than a neighbour, and a relative would be less likely to cheat on transactions such as sharing of benefits.

A number of trap-crop owners said they will continue to operate their CTBS, at some cost to themselves, because it serves a useful purpose that they can share. As we can see from the list of relationships in Table 2, the goods described in this case are, to some degree, private goods, with sharing occurring within a defined kin group. This conceptualisation, however, blurs the distinction between private and common property. Nearly everyone in Table 2 is related to someone else within the CTBS.

A final threat to the sustainability of CTBS is low cash flow. Many farmers commented that they are just too poor to actually pull together the cash at the right time to effectively use the CTBS. This may imply that there is not

Table 1. Marginal benefit–cost ratio (MBCR) from taking part in a community-based trap–barrier system (CTBS) for individual calculation. (The exchange rate at the time of the survey was approximately Vietnamese dong (VND)14,500 to US$1.)

Factor	Cost (VND)	Benefit (VND)	MCBR
Additional cost due to TBS			
TBS materials and labour (VND1.35 million/10 farmers)	135,000		
Additional benefit due to TBS			
Rats caught 100/4 (rats/kg) * 6000 (VND/kg)		150,000	
Yield due to TBS 500 kg/ha * 1500 (VND/kg)		750,000	
Reduced/eliminated rodenticide expenditure		16,000	
Total cost	135,000		
Total benefit		916,000	
MCBR			6 (916,000/135,000)

Table 2. Relationships of community-based trap–barrier system (CTBS) members and their household distances from the trap crop, Thuan Hung village, My Tu district.

Number	Family name of farmer	Relationship 1	Relationship 2	Relationship 3	Distance to trap (m)
1	Nguyen	Leader	Related throughout		150
2	Nguyen	Cousin of leader	Younger brother of 3		Other village
3	Nguyen	Elder brother of 2	Cousin of leader		Other village
4	Nguyen	Brother-in-law of leader			700
5	Truong	Cousin of leader			700
6	Trinh				700
7	Nguyen	Son of 8	Cousin of leader	Brother of 10	700
8	Nguyen	Uncle of leader			700
9	Nguyen	Son of leader			300
10	Nguyen	Son of 8	Cousin of leader	Brother of 7	700
11	Quach	Nephew of leader			500
12	Truong	Son of 5	Nephew of leader		300
13	Quach[a]	Cousin-in-law of leader			300
14	Huynh	Son-in-law of leader			5000
15	Truong	Son of 5	Nephew of leader		300

[a]Denotes a female farmer, otherwise all are male.

sufficient interest in it to make it work, because farmers can usually bring resources together when there is need and determination. It is also possible that there is competition for cash—farmers generally believe in the CTBS but do not, at the time of trap construction, have the necessary cash for purchasing the fence, stakes, and fuel to pump the water of an area for transplanting the early trap crop.

Mechanisms for improving the sustainability of the CTBS

The threat of privatisation, abandonment, or simply disintegration of social networks are significant hurdles to the widespread adoption of CTBSs in Southeast Asia. Therefore, it is important to address these threats in the design of the system to minimise or to eliminate them. We have identified eight decision factors that should be taken into consideration when establishing a CTBS.

Factor 1: keep the social relationships among participants within the halo as 'dear' as possible

Typically, the topography of the rice field is the main criterion in where to establish a CTBS, with preference given to open, mostly flat areas. This assumes that the social grouping that constitutes the membership within the halo is of secondary importance. Our contention is that topography is important, but not as important as the people running the CTBS. It is our belief that the social grouping should be given an equal weight when considering where to locate a CTBS. Ideally, the CTBS should be located where both topography is adequate and social relationships close.

We first must assume that, as a general rule, kin will work for other kin more than they will for non-kin. With this assumption, we can make the statement that the density of kin relations within the group is positively associated with level of altruistic behaviour. Where many kin relationships exist, there will be a greater sense of altruism and actions consistent with the survival of the group over individual benefit. Where these kin relations are lacking, the degree of cooperation will be reduced, although never absent.

There are other ways to ensure that members act in ways that are group rather than individual oriented. Among them are strict agreements at the outset regarding behaviour, high levels of transparency, and strict allocation of costs and benefits. The advantage of using the density of kin networks is that many of these mechanisms are already present and do not need to be legislated or explicitly stated. Principal among these unstated rules is the capacity to allocate rights and duties within the CTBS. In many CPRs, the eldest, or the most respected in the group, will allocate labour and the nature of the benefit stream.

There are ways to ensure greater density of relations, kin or otherwise. One is to use it as a basis for selection of the CTBS in the first place. Halos of various sizes and shapes, and trap crops of various configurations, have to be explored. It is our belief that slight losses in the efficiency of the system to capture rats can be exchanged for a greater likelihood in creating a socially sustainable system. Using existing institutions, such as integrated pest management (IPM) clubs, is another way to ensure greater internal cohesion. This saves the CTBS organisers from building new institutions, which can be very difficult and time-consuming and are likely to fail.

Factor 2: determine as accurately as possible the size and shape of the halo

It is important to know the shape of the effective halo because this represents the good being distributed. This has practical benefits because it will suggest how the costs should be shared and it is a theoretical question because, at present, it is presumed that halos are generally circular (in the absence of a hot spot). The shape of halo also will show who is a free rider and who is not, within the effective halo. This is especially important in rodent control, considering that damage is spatially and temporally variable.

Factor 3: keep the trap crop close to the homes of the people who are required to check it

Checking traps is a simple, necessary activity. Unfortunately, it must be done every day. The labour costs associated with checking traps increased proportionally to the distance needed to travel to the trap crop. In our informal survey, we found that average distances ranged from around 200 to over 1500 m from home to the trap crop. In such cases, the trap-crop owner has no choice but to allow those living a long distance from the trap to check it less often. This places a greater burden on those close to the traps for contributions to labour.

Factor 4: use the CTBS in seasons or areas known to have high rat populations

The CTBS, like most agricultural technologies, will not work in every place for every season. Therefore, identifying where and when it will work enhances the positive image farmers will maintain of it. If it is used too often in the wrong places or seasons, farmers will begin to distrust it. Therefore, CTBSs ought to be implemented in places where rodent damage is a major constraint to rice production.

Factor 5: choose farmers whose labour and cash availability are not severely limited

If farmers are overburdened with the labour requirements of rice farming, the addition of another labour-intensive technology will not be well received. In addition, low-income farmers would prefer to use their available cash for food rather than investment in a CTBS, where the probability of success is uncertain and the payoff is not immediate.

Factor 6: choose locations where post-capture markets or consumption habits make rat collection a profitable chore

Farmers in Vietnam and elsewhere eat rice-field rats. Although their market value per rat may be low, there is an emerging rat-meat market in southern Vietnam (Khiem et al. 2002). This creates an incentive for farmers to capture and sell clean, live rats. Farmers refuse to eat rats killed by rodenticides, so the CTBS offers an alternative income source. Elsewhere, rats are cooked and then used as a source of protein for fish or livestock.

Factor 7: select large landholders to achieve an economy of scale

An alternative approach to the CTBS is to target large landholders, whose decision-making processes, institutional frameworks, and capital needs are much less complicated than the community's. Indeed, in West Java, Indonesia, a company that produces certified rice seed for sale to farmers has been using the CTBS successfully on its 2000 ha farm since 1998. The annual schedule for construction and management of the CTBS has varied little during the period 1998–2002.

Factor 8: determine, and make known to farmers and extension workers, the profitability of the CTBS

The CTBS is likely to be adopted if the benefit is greater than the cost. Table 1 shows marginal benefit–cost ratio (MBCR) for individual participants in a CTBS in southern Vietnam. The MBCR was 6, which suggests that for every one Vietnamese dong (VND) additional investment, a farmer in that village or region gets VND6 additional return. The high profitability of participating in the CTBS is encouraging for farmer adoption. However, this individual calculation of MBCR assumes that all participating farmers will bear the costs and that the benefits will be equally distributed (or randomly over time).

A high MBCR is not always returned (Palis et al., this volume); benefits depending on a number of local conditions.

Hypotheses for research

Hypothesis 1

The social distance between halo members is closely associated with the likelihood of continuation with the CTBS as a system of rodent control (assuming equal efficacy of the system to control rodents).

This hypothesis requires measurement of the social distance between members and some measure of the likelihood of continuation of the CTBS. One important ranking criterion would be the likelihood of cooperation in labour activities. For instance, a brother–brother relationship would be ranked closer than a brother–cousin. Father–son or brother–brother relationships may have the highest ranks, whereas 'uncle–niece-in-law' may be lowest. In the latter case, the relationship crosses three recognised social boundaries: gender, generational/age, and marriage. The lowest-ranked case would be non-relatives. The assumption that non-kin have the lowest rank may have to be tested in its own right.

Hypothesis 2

A more tightly integrated CTBS organisation will demonstrate generally less transparency.

Oftentimes, the methods of sharing resources in families, and their inherent equity, are not immediately clear. This is because family members usually have a shared understanding of the meaning of given behaviours, and thus these need not be explicitly stated. Therefore, within families, the concept of transparency is not a good measure of the degree of openness in institutional decision-making or power. To test this, a measure of integration must be compared to some notion of transparency, perhaps through knowledge tests.

Hypothesis 3

In situations where there are wide divergences in labour investments in the CTBS, there will also be greater likelihood of the free rider.

If free riders openly flaunt the system, they can be quite disruptive. However, in those cases where the free rider has no choice in deciding whether to be a free rider, e.g. if they live a great distance from the trap crop and cannot easily check the traps, the degree to which this is perceived as negative will change. They are still a free rider, however. In order to test this hypothesis, interviews can be conducted which evaluate members of the CTBS in terms of both their contribution to the group and the overall evaluation of that person's role in it.

Hypothesis 4

The severity of a rodent problem is directly related to the likelihood of CTBS acceptability and sustainability.

In situations where rodents are a highly significant constraint to production, farmers would be more likely to adopt a CTBS. This may happen regardless of the existing social relationships in the community, particularly in the farm neighbourhood. One measure of this is whether a CTBS is adopted for each of the rice crops in a year or only for the crop or crops that typically have greater losses to rats.

Conclusion

The CTBS is an effective means for controlling rodents in rice fields. It shows a high rate of return on investment and individual labour costs remain relatively low. It is sustainable in both the short and long term. Farmers appreciate the ingenuity and complexity of the system and have suggested effective alternatives to the system to fit their local conditions.

Farmers will determine the success of CTBS for their particular farming systems. We have suggested eight factors that will generally encourage success in the application of the CTBS. Gone are the days when a single technology will solve the same problem for all rice farmers; there is just too much between-farm diversity for this ever to occur. This is why it is imperative that the CTBS be applied judiciously where it has the greatest likelihood of success. The CTBS will not work everywhere, but we have found that it does work in the Mekong Delta region of Vietnam. There are certainly other locations where it will work.

Like many technologies, the CTBS will work best where farmers understand the technology and have the social and institutional background to effectively apply it. Scientists, particularly biologists, can help in this process by explaining to farmers the biological details necessary to effectively apply the technology (such as the link between the birthing cycle of rats and the rice crop).

Defining the CTBS as a common resource is a productive and effective analytical tool for understanding the social relations of CTBSs. We have uncovered important sociological constraints and opportunities to CTBSs and suggested means to overcome them. We have also made suggestions for future researchers should they wish to apply the same analytical framework to their CTBS or CPR.

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Farmers' perceptions and practices in rat management in West Java, Indonesia

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Abstract. Pests are one of the major constraints to rice production in Indonesia. We examined the perceptions, knowledge and current rat control practices of 120 farmers, 40 from each of three villages (Pasirukem, Sukatani, and Tegalurung) in the Cilamaya subdistrict, of Karawang district in West Java. The survey was conducted in November 1999. The respondents were aged 20 to 70 years, and most had only 1 to 6 years of schooling, a mean of 18.9 years in rice farming, and a mean farm size of 2.13 ha. Rats were reported as the most important pest to manage in this region. Controlling rats was important for 98.3% of farmers. There was divided opinion as to when it was best to conduct rodent control: approximately 60% thought it should be done during land preparation and 40% thought only during the rice-growing seasons. However, early rat control was conducted by 87.2% of farmers, with most effort during the land preparation–seedling stage. Most respondents (80.7%) agreed that by controlling rats they could increase rice yields, and 83.3% of respondents believed that rats could be controlled successfully. Cooperation between farmers was identified by 76.7% of farmers as important for successful rat control, although 13.8% of farmers prefer to do rat control by themselves because they were more satisfied with the results. Usually, local government officers coordinated group activities. Individual expenditure on rodent control per hectare ranged from US$0.3 to US$45. The common rat control methods were plastic barriers to protect rice seedlings (100%), rodenticides (98.3%), mass hunting (79.7%) and flooding rat burrows or fumigation/digging (44.1%). Most farmers used alternative pesticides such as temik (aldocarb; carbamate) (78.5%), akodan (endosulfan) (77.6%) and azodrin/guzadrin (monocrotophos; organophosphate) (12.9%), because legal rodenticides were difficult to find and/or were more expensive. These are all broad-spectrum poisons and some were mixed with oil before applying to the flooded crop. Although these poisons are of major environmental concern, a majority of farmers did not consider these to be environmentally unsafe.

Introduction

Important constraints to increasing rice production in Indonesia are the losses caused by pests and diseases, which occur every season. One of these pests is the rice-field rat, *Rattus argentiventer.* This pest causes the largest pre-harvest damage to rice crops (Geddes 1992; Priyono 1992; Singleton and Petch 1994). There are chronic low levels or rat damage (5–10%) in the rice fields of Java, with some villages experiencing high damage in most years. During the decade 1989–1998, a mean of 93,908 ha per year was identified as having severe rat problems, with a mean damage intensity of 19.3%. The largest losses were in 1998, with severe damage reported over 159,057 ha and a mean damage intensity of 24.8% (unpublished report from Direktorat Perlindungan Tanaman Pangan, 1999).

The rice-field rat is a pest of various agriculture commodities, such as food crops, horticulture and plantations, and it causes significant losses across a wide range of agro-ecosystems (e.g. lowland irrigated rice, rainfed rice in elevated areas, tidal swamp area). This rat species is also a vector for a number of human and animal diseases (Singleton and Petch 1994). Farmers in Southeast Asia use several rodent control methods, such as mechanical/physical control, chemical control and biological agents (see Fall 1979 and Singleton et al. 1999 for reviews). In many cases, the rodent control efforts by farmers in Indonesia and elsewhere in Southeast Asia have not given satisfactory results (Singleton and Petch 1994). The socioeconomic conditions and culture of farmers are thought to influence the success of pest management practices compared to other factors, such as the technology availability to manage the problem (Untung 1992). Information therefore needs to be collected on farmer beliefs, perceptions and practices associated with pest management (Heong and Escalada 1999). This study reports on information on rodent pest management gathered through farmer surveys conducted in the Karawang District in West Java, Indonesia.

Materials and methods

In November 1999, a farmer survey was undertaken at three villages (Pasirukem, Sukatani and Tegalurung) in Cilamaya subdistrict, Karawang district, West Java province, Indonesia. A structured questionnaire was developed and then pre-tested through field interviews. One hundred and twenty farmers (40 per village) were interviewed on their knowledge, perceptions and practices of rat control. The questionnaire consisted of 43 questions, which were divided into three sections and focused on the previous 1999 dry-season crop. The first section summarised demographic and farming information. The second section began with a general question on the main pests of rice during the previous crops and then considered rat control only. Farmers were asked what methods they used to control rats, how often, when and where they were applied, the time spent on control and its cost. The structure of rodent control activities (individual, groups, how groups were organised and their structure) was recorded also. The third section considered beliefs associated with rodent control with 13 questions that each had five descriptors from which the farmers chose the one that best described their belief. In this overview paper, the five categories were collapsed to three. The data were coded and are presented as percentages. Respondents were chosen at random from a list of farmers in each village provided by local extension agencies. Six people, with each conducting three or four interviews per day, conducted the surveys.

The villages were selected as part of a larger study on ecologically based management of rats using a farmer participatory approach that was imposed in two of the villages for the 1999/2000 wet season. All respondents are to be re-interviewed after the rodent management project has been operating for three years.

Results and discussion

Farmer characteristics

The age of respondents ranged from 20 to 70 years: 14.7% were 20–30 years old, 23.3% were 31–40 years old, 29.3% were 41–50 years old, 20.7% were 51–60 years old, and 12.0% were 61–70 years old. Only two of the respondents were female.

The formal educational background of the farmers varied considerably: 18.6% had not attended school, 61.2% had attended elementary school (1–6 years of schooling), 8.5% had attended junior high school (7–9 years of schooling), 10.2% had attended senior high school (10–12 years of schooling), and 1.7% had more than 12 years of education.

Farming was the main occupation for the people living in these villages in Cilamaya (92.1%). The farmers had a mean of 18.9 years of farming experience (range 2 to 59). The mean farm size was 2.13 ha. (range 0.3 to 15 ha). The respondents either owned their farm (60.2%), had a fixed rental (4.2%), were share-tenants (22.9%), or had another arrangement (2.5%). A high proportion of respondents had additional jobs (42.4%) such as trader of goods, local government officer or a driver. This often led to responses such as "we have no time" or "we do not only work in the field", when questioned on their field activities for controlling rats.

Farmer knowledge

During the 1999 dry-season rice crop, the common pests and diseases were rats, golden apple snails, brown planthoppers, stemborers, worms and ragged stunt. The most important pest for that season was brown planthopper (46.4%), followed by the rice-field rat (29.5%) and the golden apple snail (15.2%). A few farmers (1.8 to 3.6%) also identified stemborer, worms, and ragged stunt damage as their most important pest. Although the brown planthopper was identified as causing the largest amount of damage during the 1999 dry-season crop, farmers ranked rats as the most important pest to be controlled. The farmers indicated that insect pests were relatively easy to control by using available insecticide, whereas rodenticide use was not sufficient to control rodent pests. Rodent management also required technical and mechanical control. Moreover, brown planthopper damage was mainly restricted to the generative stage of the crop, whereas rat damaged occurred during the whole growing season.

Farmer perceptions

Perceptions of farmers were determined from their agreement or disagreement to a series of specific questions. There was an interesting spread of responses regarding the timing of rodent control: 54.3% were strongly of the opinion that the control should be done before transplanting, whist 39.1% thought that control should only be implemented when the crop is growing. Almost all of the respondents agreed that rat control is important (98.3%), can increase rice yields (80.7%), and that it is important to increase yields by controlling rats (94.9%). Most farmers believe that rats can be controlled (83.9%) and that it is important to do so (94.9%) (Table 1).

The respondents realised that cooperation among farmers on rat control is required (76.72%) and important (92.3%), although some farmers were not sure and disagreed. Half of the respondents (55.5%) agreed that the rat control should be done after harvest and it was considered to be an important activity (75.99%).

Rat control was important for the farmers, although there was variation as to the best time for control and the preferred methods of control. Some farmers had the opinion that early rat control was not important. The success of rat control was identified as requiring cooperation among the farmers. Nevertheless, some farmers prefer to do rat control by themselves.

Rat control practices

During the 1999 dry season, farmers in Ciliamaya adopted many methods for rodent control (Table 2). The main physical methods of control were mass hunting

(79.7% of respondents), flooding rat burrows (44.1%), fumigation (using sulfur dioxide) and digging of burrows (44.1%), and plastic fences around rice nurseries (100%). Fumigation and digging were usually conducted individually or in small groups of farmers. Mass hunting is less expensive and is conducted in large groups, usually coordinated by local government extension staff as a control activity at the village scale. The paternalistic hierarchy of farmer groups influences coordination of rodent control; some farmers delay control until activities are coordinated by the head of a farmer group or by local government officials (Untung 1992).

Almost all of the farmers used rodenticide (98.3%), however, no farmers used anticoagulant rodenticides, which are readily available in the stores in Cilmamya subdistrict and are the only rodenticides registered for use in rice fields

Table 1. Perceptions of farmers on rodent control in Cilamaya subdistrict, West Java.

Perceptions	Agree		Do not know		Not agree	
	Number	%	Number	%	Number	%
Rat control must be done once rice is growing	41	39.05	7	6.67	57	54.28
Controlling rats is important	116	98.30	0	0.0	2	1.69
By controlling rats, a farmer can increase his rice yields	92	80.70	10	8.77	12	10.53
The yield losses caused by rats is important	112	94.91	4	3.39	3	1.70
Rats can be controlled	99	83.90	11	9.32	8	6.78
Rat control is important	111	94.86	4	3.42	2	1.71
Rats can cause severe yield losses	109	93.97	2	1.72	5	4.31
These severe yield losses are important	96	82.05	1	0.08	20	17.09
Rats can only be controlled if farmers work together with other farmers	89	76.72	11	9.48	16	13.79
It is important for farmers to work together to control rats	108	92.30	6	5.13	3	2.56
Rats should be controlled after harvest	65	55.55	22	18.80	30	25.64
To control rats after harvest is important	89	75.99	3	2.56	25	21.36

Table 2. Methods of rat control, and frequency of application, by farmers in Cilamaya subdistrict, during the 1999 dry-season rice crop.

Rat control method	Farmers		Mean number of times action is applied per season (range)
	Number	%	
Physical/mechanical (*n* = 118)			
Mass hunting	94	79.7	3.57 (1–16)
Flooding rat burrows	52	44.1	3.33 (1–8)
Fumigation/digging	52	44.1	4.1 (1–12)
Fencing for seedlings	118	100	1
Rodenticide (*n* = 116)			4 (1–6)
Temix (acute poison)[a]	91	78.5	
Phosphit (zinc phosphide; acute poison)	10	8.6	
Klerat (anticoagulant poison)	0	0	
Other pesticides[b]			
Azodrin, Gusadrin (monocrotophos)	15	12.9	
Akodan (endosulfan)	90	77.6	
Bait used (*n* = 105)			
Broken rice	79	75.2	
Unhulled rice	11	10.5	
Crab	12	11.4	
Fish	1	1.0	
Dedak	2	1.9	
Biological method/Predator	0	0	0

[a]A nematocide that is not registered for use in Indonesia as a rodenticide.
[b]Insecticides not registered for use in Indonesia as rodenticides.

in Indonesia. Temix, a nematocide, was widely used and is available in small plastic satchets without instructions for its use (e.g. concentration for its application). Temix is a potent aldocarb that has been banned in the United States of America since the 1940s. Of particular concern is the high use of the organophosphate ‘azodrin’ (monocrotophos) and the endosulfan ‘akodan’ because they are mixed with vehicle oil and spread on the flooded rice paddies. Rats that enter the paddies get the chemical on their fur and die when they ingest the chemical through preening themselves. Both chemicals affect the central nervous system and are broad-spectrum poisons. Although monocrotophos is rapidly degraded and does not persist in the environment, water birds (White et al. 1983; Flickinger et al. 1984), aquatic invertebrates, bees, fish, and mammals are particularly susceptible to monocrotophos and it is moderately toxic to fish and earthworms (WHO 1993). The World Health Organization states that this is a highly toxic chemical and care should be taken to avoid contamination of soil, water and the atmosphere. Endosulfans usually break down in crops over a period of a few weeks, however they stick to soil particles and may take years to completely break down. Endosulfans can also accumulate in animals that live in contaminated water (Agency for Toxic Substances and Disease Registry 2001). Farmers used these ‘alternative’ rodenticides because they are considered easy to use and are cheap to purchase.

Therefore, the usage pattern by farmers in Ciliamaya of these chemicals is a major environmental concern. The respondents used akodan because they believed it was very effective (3.6%) or effective (60.9%). Only 33.3% of farmers considered akodan not to be environmental safe to use (Table 3). It is clear that these farmers do not know the harmful effects of these pesticides on the environment. Interestingly, the respondents who considered akodan not to be safe reported dead chickens, ducks and fish around the rice plots treated with the akodan and oil mixture.

Farmers generally conducted rat control from land preparation through until harvest (Figure 1). Most of respondents conducted rat control during land preparation–seedling (87.3%), and there was also a concentration of effort at this time of the crop cycle with control activities conducted an average of 13.1 times (range 1 to 27). Rodent control activity decreased during the panicle stage and during ripening–harvest (Figure 1). After harvest, the farmers did not conduct rat control. Therefore, most of the farmers in Cilamaya conduct early rat control and realise the importance of early management action. Farmers also reported that after the vegetative (tillering) stage, rat damage seemed to be lower and so they reduced their rat control activities accordingly.

The time of application of rat control methods varied among farmers (Figure 2). Farmers used rodenticide from land preparation until the panicle initiation of the rice crop, with high usage during the seedling, transplanting, and tillering stages. Mass hunting started from land preparation until the booting stage, and the focus was especially on seedlings and recently transplanted rice. Night hunting of rats with torches was only conducted around the rice

Table 3. Opinions of farmers on the environmental safety of using akodan (an endosulfan) plus oil and its effectiveness in controlling rodent populations.

Opinion	*Is it effective?*		*Is it safe?*	
	Number of respondents	%	Number of respondents	%
Very effective/safe	4	3.6	2	1.9
Effective/safe	67	60.9	50	46.3
Not sure	19	17.3	20	18.5
Not effective/not safe	20	18.2	36	33.3
Highly ineffective/not safe	0	0.0	0	0.0

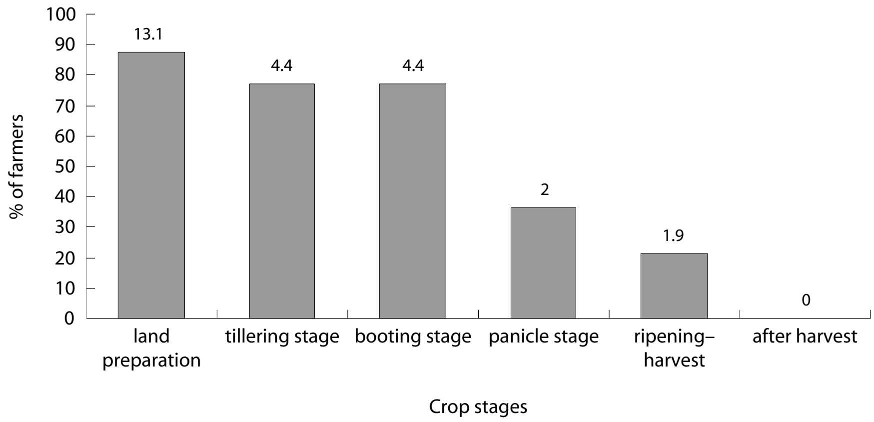

Figure 1. Percentage of farmers who conducted rat control at different crop stages in Cilamaya during the 1999 dry season. The mean number of rodent control activities for each crop stage is shown above each bar.

nurseries. Flooding of rat burrows was conducted on large banks or irrigation channel banks, with the sanitation or clearing of these banks conducted from land preparation until the booting stage. During land preparation until the ripening stage, the farmers fumigated rat burrows using sulfur dioxide. Plastic fences were only used to protect seedbeds of rice.

Table 4. Profile of rat control activities and access to tools to conduct rodent control in Cilamaya subdistrict, West Java.

Details	Number of farmers	% of farmers
Implementation of rat control		
Alone	14	12.07
Group	18	15.52
Combination (individually and group)	79	68.10
Hired labour	5	4.31
Coordinator		
Village/local government officer	87	81.31
Farmer group	10	9.34
Extension officer	10	9.34
Farmer themselves (neighbours)	10	9.34
Ownership of rat control tools		
Yes	47	40.52
No	69	59.48
Reason for no rat control tools		
Expensive	15	23.81
Not required	22	34.92
Could borrow/hire	24	38.09
Difficult to find	2	3.17

The farmers from the three villages owned land in one of four cropping areas where rice is grown as a monoculture. For the 1999 dry season, the mean cost per hectare of rodent control for these four areas was US$6 ($n$ = 27), US$6 ($n$ = 22), US$4 ($n$ = 26) and US$4 ($n$ = 26), respectively. However, there was a high amount of variation between farmers, with individual expenditure per hectare ranging from US$0.3 to US$45. This variation confirms the patchy nature of rodent damage that is often reported for rice cropping systems in Southeast Asia (Fall 1979; Buckle 1988; Singleton and Petch 1994).

Cooperation among farmers played an important role for rat control: 12.1% prefer to work alone, 15.5% only in groups, and 68.1% used a combination of both. Only a few farmer hired labourers to control rats (Table 4). Village or local government officers generally coordinated mass control actions and were an important source of information on rat control practices. Access to tools such as a fumigator and nets also influenced rat control activities (Table 4). Only 40.5% of farmers owned their fumigator or net.

None of the farmers used the trap–barrier system with an early-planted crop to manage their rat problem.

Conclusion

In the Cilmaya subdistrict, West Java, farmers identified rodents as a major pre-harvest pest, which is consistent with previous reports on the important impacts of rodents in rice agricultural systems in Indonesia (Geddes 1992; Singleton and Petch 1994). A wide range of physical and chemical methods of rodent management was adopted and farmers used a combination of these methods. Most effort in rodent management occurred during the land preparation–seedling stage, which is consistent with our understanding of the ecology and biology of the rice-field rat in West Java (Leung et al. 1999).

Most farmers agreed that by controlling rats they could increase rice yields, and believed that rats could be controlled successfully. Cooperation between farmers was identified as important for successful rat control, although 13.8% of farmers preferred to do rat control by themselves because they were more satisfied with the results.

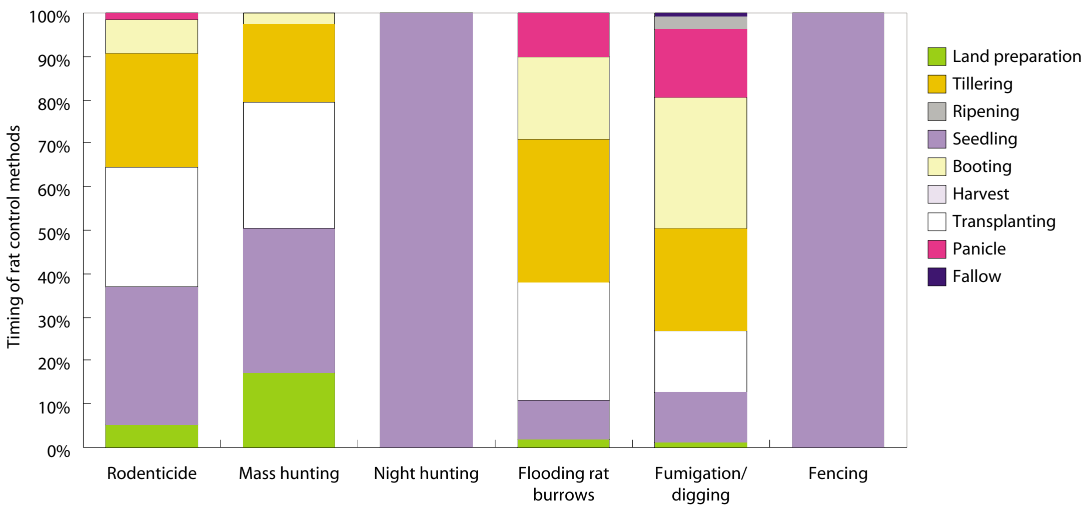

Figure 2. Rat control methods in different rice crop stages in the 1999 dry season in Cilamaya.

A major environmental issue emerged from the survey; over 75% of farmers used broad-spectrum poisons that are not registered for use against rats. Some were mixed with oil before applying to the flooded crop—an environmental disaster. A majority of farmers did not consider these to be environmentally unsafe. This is an area of education that needs to be urgently addressed.

None of the farmers had used the environmentally friendly trap–barrier system (TBS) to control their rodent populations. This simple technology is new to West Java (Singleton et al. 1998) and was implemented in two of the three villages, beginning with the 1999/2000 wet season crop. A follow-up survey will be conducted in late 2002 to examine the impact of this technology on chemical usage and whether the farmers are likely to continue with the use of the TBS technology.

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Community costs and benefits of rodent control in Cambodia: a first-round analysis of adaptive management

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Abstract. This case study examines the first round of experience from the Farmer-based Adaptive Rodent Management, Extension and Research System (FARMERS) Project. The project involved the introduction of a trap–barrier system (TBS) for rodent pest management across 11 villages in Samrong Commune in Kampong Cham province in Cambodia. This system has been trialled with some success in other countries and elsewhere in Cambodia. Participatory research methods were employed in the FARMERS Project, engaging the farming community in planning, managing, monitoring and evaluating the TBS. This article describes the process and outcomes of the first round of research, conducted in association with the dry-season crop in the early part of 2002. Farmer groups operated the TBS under social agreements that recorded the details of group responsibilities, entitlements and obligations.

After trialling the system on the dry-season crop in 2002, the farmers were firmly committed to the second-round establishment of the TBS for the wet-season crop. This indicated that TBSs were perceived as an improvement to rodent control strategies, although the test for sustainability was yet to occur.

There was a tendency for free-riding behaviour in the community, placing the burden of the cost of the TBS on the persons who owned the lure crop for the TBS. Nonetheless, the processes embodied in the social agreements for the TBS have been shown to be an effective mechanism for community education and the evolution of arrangements to counter free-riding behaviour.

Introduction

This case study is based on work conducted at Samrong Commune in Kampong Cham province in Cambodia. The work was a component of the Farmer-based Adaptive Rodent Management, Extension and Research System (FARMERS) Project; jointly undertaken by the community of Samrong, the Kampong Cham Office of Agricultural Extension (OAE), the Cambodian Agricultural Research and Development Institute (CARDI) and researchers from the University of Queensland. The FARMERS Project was aimed at developing and implementing rodent pest management strategies consistent with the ecological, technical and socioeconomic constraints faced by the community.

Rodents are considered a major pest of rice in Cambodia, particularly for dry-season crops (Jahn et al. 1999). The FARMERS Project introduced a trap–barrier system (TBS) for rodent pest management that has been trialled with some success in other countries and elsewhere in Cambodia (Jahn et al. 1999; Singleton et al. 1999). The TBS requires community cooperation and coordination to achieve a broad pattern of rodent control. The FARMERS Project sought to create the conditions for cooperation and coordination in the 11 villages of Samrong Commune. Monitoring work was also conducted in the neighbouring L'vea Commune, as a prelude to further involvement by that community.

The study of the socioeconomic conditions under which the project operates requires an assessment of both costs and benefits borne by farm households and a framework for the analysis of social costs and benefits. The TBS provide a limited *public good* in the form of relative freedom from rodent damage. The public good is limited in geographical extent by the ranging nature of the rodents, their reproductive patterns and ecology. A public good has attributes of *non-exclusivity* and *non-rival consumption*. These characteristics are commonly associated with *free-riding* behaviour. The characteristics of public goods and the consequences of free riding are widely discussed in the literature of environmental economics (Tietenberg 1996).

Participatory research methods (Martin and Sherrington 1997) were employed in the FARMERS Project, engaging the farming community in planning, managing, monitoring and evaluating the TBS. This paper describes the process and outcomes of the first round of research, conducted in association with the dry-season crop in the early part of 2002. CARDI's growing involvement in participatory research has previously been discussed by Cox and Mak (1999) and Lyons (2001).

This paper does not report results in the format of a scientific field trial. It was a trial conducted with the farming community and involved the dynamics of the agro-ecosystem of the commune. It was an action research project rather than a scientific experiment. There was no replication and no control. There was considerable variation in the timing of implementation, the surrounding landscape, and construction, management and monitoring of the TBS in the rice fields.

The economic impact of rodent pests in rice production in Cambodia is not well known. However, farmers and researchers alike confirm that rodents are a major pest and can be particularly damaging under certain conditions leading to population explosion. Singleton et al. (1999) report on cost–benefit analysis of the TBS in controlled studies in West Java and Vietnam. They found that the TBS generally enjoyed positive cost–benefit ratios and this was particularly apparent when rodent densities and crop losses in surrounding areas were high. Singleton et al. (1999) identified a challenge in transferring this technology readily and effectively to farmers. They observed that the small size of the rice fields in Southeast Asia would lead to neighbours enjoying the benefits of the 'halo of protection' of the TBS, without the need for bearing any of the costs. Thus, they concluded that the TBS would be most effective if implemented as part of a community-based approach to rodent pest management.

Earlier work by CARDI (Cambodia–IRRI–Australia Project 1998) in Svay Rieng province in Cambodia found that the TBS was not an effective mechanism for rodent control due to the need to monitor traps regularly, the high cost of the materials involved, the danger of theft of the traps, and the capture of non-target species. They observed that the major limitation of the TBS appeared to be the high cost of materials relative to the value of the losses associated with rodent damage.

Methods and results

Participatory planning processes

The initial introduction of the ideas for the FARMERS Project involved participatory methods of information collection and planning. Seasonal calendars were used to gather information to assess the significance of rodent pests in rice production. With the assistance of project staff, the farmers from the 11 villages in Samrong Commune formed 20 groups, each of approximately 10 farmers, to implement a commune-wide system using the TBS to protect the dry-season crop early in 2002. Social agreements were used to record the group membership and to formalise the social arrangements for the groups, their responsibilities, shared benefits and costs, and expectations of others. The agreements revealed that the majority of the farmers who intended to establish the TBS on their rice plots were also the group leaders. This pointed to likely farmer perceptions that the TBS would bring material benefit to the person who sited it in their own field.

Rice production budgets

The irrigated dry-season crop in Samrong Commune is grown mainly for sale and is exclusively IR66—a high-yielding, short-duration variety. Samrong has a total of 573 ha of dry-season rice (Powell 2002). A survey was conducted to develop a detailed rice production budget using in-depth interviews of key informants. This approach is based on Powell (2002) who estimated a return of US$199 per ha from dry-season rice production after all costs, including family labour, were deducted. In this study, 16 farmers from 4 villages in Samrong Commune were interviewed to gather detailed information on their rice production budgets. All farmers owned land and their dry-season fields varied from 2.3 ha down to 0.13 ha, with an average of 0.82 ha. Rice yields were in the order of 2.5 t/ha on average, returning an average gross income from rice of approximately US$160 per ha. Costs and returns were highly variable, with one of the farmers interviewed suffering a complete crop failure due to water shortage.

The training and materials for construction of the TBS in Samrong were provided by CARDI and OAE, and the labour for construction was provided by the farming community. Demonstration TBSs were constructed at the CARDI research station and cost US$40 for labour and materials. The farmers at Samrong received approximately $30 worth of materials for each 25 × 25 m TBS. They contributed labour and used local materials for the bamboo supports for the plastic sheeting.

Although 20 TBSs were planned and groups formed for each TBS, two TBSs were reported not functional, principally for lack of water for the crop. Assuming a 200 m radius of protection around each TBS (Singleton et al. 1999), the TBS in Samrong offered the potential to protect approximately 226 ha of rice. However, the TBSs were dispersed according to a complex of both physical and social conditions, rather than a simple grid system. Some of the TBSs were separated from the commune by a broad stream, where farmers owned fields located in an adjacent district. These conditions might significantly influence the area protected by the TBS.

Social and environmental costs and benefits

There was no anecdotal evidence of yield loss in the TBS lure crop beyond the levels experienced in adjacent crops and the farmers with lure crops made no claims for compensation for yield loss. The detailed monitoring of yield loss through cut tiller counts, visual estimates and calculations of grain dry weights produced highly variable results that limited bio-physical and economic analysis. The project team reviewed data collection techniques in an effort to learn from the problems encountered in the first round. The first round of yield loss measurements was based on the differential between an estimate of the yield from an undamaged crop and the actual yield. The estimate of potential yield was based on a calculation of the yield from undamaged hills, multiplied by the number of hills per square metre. The choice of undamaged hills allowed for subjectivity in sampling and the amount of variability in the results was unsatisfactory. This technique had been devised to eliminate the need for the construction of rat barriers and exclusion plots.

Farmers raised both intra-group and inter-group issues relating to the cost of the TBS. Intra-group issues primarily concerned the elimination of free riding. Many group leaders (who also tended to be TBS 'owners') complained that the commitment of group members tended to fall away after TBS construction. They also felt that the location of the TBS on their field exposed them to higher risk through the early planting of the lure crop. The group leaders felt that they bore a burden of labour in monitoring traps and in packing up and storing the TBS materials. Their major concern before commencement of the second round was for access to a secure water supply to prepare the field for transplanting the lure crop and for raising seedlings. The cost of crop failure was highly significant for the individuals concerned. Some villagers considered the conditions so difficult in their locality that they asked for cooperation from other villages to provide seedbeds or seedlings.

After their first experience with the TBS, it was reported by farmer representatives that other farmers were reluctant to work on the TBS because they perceived that the benefits of the TBS were enjoyed by the TBS 'owner'. This indicated that they believed that the benefits of the TBS were associated with the physical protection provided by the barrier, as opposed to the wider-scale protection the research team envisaged would accompany reduced rodent numbers. This indicated a need for more information on the function of the TBS to be provided to the community.

The farmers identified a number of factors that would show whether the project was successful. These included: reducing the number of rodents and yield losses; improved standard of living; adoption of the techniques by other communities; the ability to buy the materials for the traps and to set them up themselves; and the generation and sharing of new ideas for rodent management. Cost-effective management for rodents was considered a critical indication of success by all other elements of the project team.

Farmers at Samrong Commune rated the effectiveness of various rat control methods using a scoring matrix under the guidance of farmer facilitators from the project team. The results of the farmers' ratings in Samrong Commune are presented in Table 1. The matrix shows the TBS scores poorly (☹) in terms of the requirement for labour, monetary outlays and materials. It was rated very highly (☺) on environmental friendliness and effectiveness. Despite the perception that the TBS was environmentally friendly, it was apparent that some farmers continued to use rodenticides, even around the paddies containing a TBS.

In the first round of trapping during the 2002 dry-season crop, 349 rodents, comprised predominantly of two forms of *Rattus rattus* and *Rattus argentiventer* (K. Aplin, pers. comm., August 2002), were caught in the 18 functional TBSs in the fields farmed by Samrong Commune farmers. Project team members considered this number indicated a relatively low population of rodents in the dry-season crop. Farmers agreed that rat problems were relatively low for that particular crop and understood that the number of rodents caught would fluctuate in accordance with seasonal variations.

Gender issues

Although there has been wide interest in the field activities associated with the project on the part of men, women and children, all of the TBS group leaders are men, and women had minimal representation in the groups and at formal meetings concerning the project. A few women were listed in the social agreements as group members, but other women involved in work were described as the wives of group members. A workshop evaluation before the first-round implementation of the TBS specifically identified the involvement of women farmers as an issue for improvement for further workshops. However, the CARDI field facilitator reported that the women farmers considered the TBS to be the work of the men.

Estimates of the division of labour were gathered on several separate occasions using different techniques, from both men and women in Samrong Commune. Powell's initial (2002) findings were verified by focus groups involving women in Samrong and by the construction of

Table 1. Matrix scoring table for the evaluation of various rat control methods in Samrong Commune (rating by farmers from low favourability = 1, ☹; to high favourability = 5, ☺).

Methods	Chemical control	Trap	Hoe	Community rat hunt	Dogs	Trap–barrier system
Evaluation criteria						
Labour	5	4	4	1	5	1
Money	1	3	2	5	4	1
Materials	4	3	3	4	5	1
Environment	1	5	5	5	5	5
Effectiveness	5	3	3	5	3	5

division of labour pie diagrams by the project team and the predominantly male farmer representatives during workshop sessions at CARDI and in Samrong. The breakdown of labour inputs (Table 2) reflects other research into the traditional division of labour for rice production in Cambodia (Catalla et al. 2001) and is representative of the other opinions collected in this study.

Table 2. Breakdown of labour inputs for rice production by gender (% contribution).

Activity	Male	Female
Land preparation	90	10
Seedbed	70	30
Seedlings and transplanting	30	70
Crop management	50	50
Harvest	30	70

Discussion and conclusions

The commitment of the farming community to the second-round establishment of the TBS for the wet-season crop indicates that TBSs are perceived as an improvement, although the test for sustainability is yet to occur. This will be evident when the community action is self-funded and directed. The continued adoption or adaptation of the TBS is the critical test for each round of cropping in the project area. The initial provision of materials from project funds and the assistance from the project team at that stage limits any judgement of the sustainability of the TBS.

The first-round experience showed that the social agreements had not fulfilled the role that they might have done in curbing free-riding behaviour. The groups were encouraged to review their social contract on the basis of new knowledge and experience, rather than to abandon the tool. The guidelines for forging the social agreements for the second round were modified to account for inter-group obligations and more definitive contractual arrangements for the intra-group arrangements. Plans for better communication with the wider farming community were also devised.

It was clear from the results of the first round that a better flow of information was required. A notice board was subsequently erected at the commune centre for information and photographs to stimulate community interest in the TBS. Regular meetings with TBS groups were planned, along with educational activities in the four commune schools to coincide with the second round of TBS activity.

The TBS did not appear to impose a major change in the division of labour by gender. The increase in workload appears to have been borne mainly by men. The main implication for labour was that the burden of work associated with the TBS fell unevenly between households. There was a tendency for free-riding behaviour in the community to place the burden of the cost on the person whose field contained the TBS. Nonetheless, the processes embodied in the social agreements have been shown to be an effective mechanism for community education and the evolution of arrangements to counter free-riding behaviour. More information on the benefits of the TBS will consolidate this process. There is considerable scope for improving the research process, particularly through the development of a better flow of information, in successive cycles of investigation.

The intention of the OAE to extend the TBS technology and social organisation to another district is a promising sign of their confidence in the system. The relative success of the system in the new environment and under the sponsorship of the Provincial Government staff will provide valuable information for the evaluation of sustainability.

Acknowledgments

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Farmers’ perceptions and practices in rat management in Vinh Phuc province, northern Vietnam

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Abstract. A survey of farmers was conducted in Vinh Phuc province, Vietnam, to examine the knowledge, attitudes and practices for rodent management near the beginning of a village-level study to examine the impacts of a range of rodent management practices. Thirty farmers were interviewed from four study sites. There are three main crop seasons during the year, two rice crops and a winter crop. Over 20 different vegetable crops were grown throughout the year. Most farmers believed that rats caused the most damage to their crops and that rats were the most important pest species to control. Most farmers identified kohlrabi then rice as the crops that suffered most damage. Most farmers identified crop damage through damage to plants and fruits rather than tracks, droppings or burrows. Trapping was the most common method used to control rats in the fields, followed by use of chemicals and plastic barrier fences. An average of 16 days labour was spent controlling rats in the previous season, and Vietnamese dong (VND)16,000–18,000 (~US$1.2) was spent per day of labour. On average, farmers spent VND130,000–170,000 (~UD$10) in the previous season on controlling rats. The farmers estimated a loss of about 40% of their rice yield if they were not to implement any rat control practice. Nearly all farmers stated that rat control must be carried out and that it is very important. Many farmers believed rats can severely reduce their rice yield and that rats can be controlled if all farmers work together and throughout all stages of the growing season. A follow-up survey will be conducted towards the end of the project to examine changes in farmers’ perceptions and practices.

Introduction

An important constraint to rice production in Vietnam is significant yield loss by pests and diseases both in the field during growth and in post-harvest storage. Rodent pests have been identified as causing severe damage to rice plants in the field and rice grain in storage (Singleton and Petch 1994; Brown et al. 1999), and have been described as one of the three most important pests of rice crops (Huynh 1987). The rice-field rat (*Rattus argentiventer*) and the lesser rice-field rat (*Rattus losea*) are the two major species found in rice fields in Vietnam (Brown et al. 1999; Brown, Tuan et al., this volume).

There is a range of management practices available for farmers to control rodents, but the level of damage suffered by farmers can still be significant. An experimental study is being conducted to test a range of rodent management techniques within a village scale in Vinh Phuc province, Vietnam (for details, see Brown, Tuan et al., this volume). Among the practices being tested are the community trap–barrier system (CTBS) (for details, see Singleton et al. 1998, 1999), field sanitation, synchronising of planting and harvesting, reducing the size of bunds within fields, and conducting bounty systems at certain times during the crop (Brown, Tuan et al., this volume). It is valuable to learn what other methods are used by farmers for rat control, not only to learn new methods, but to establish some basis for an analysis of the success of the CTBS and other methods. Furthermore, information on the amount of time and money used by farmers for controlling rats would enable an analysis of the benefits and costs.

In an effort to determine the success of rodent management at the village-level, a preliminary survey of the knowledge, attitudes and practices of the farmers in four villages was conducted. Similar surveys have been used to assess changes in rice farmers’ pest management in the Mekong Delta (Huan et al. 1999), for quantifying farmers’ decision-making for stem borer control (Heong and Escalada 1999), and on farmers’ practices and perceptions for rodent control in Indonesia (Sudarmaji, Singleton et al., this volume). The initial survey was conducted 18 months after the commencement of the project, which was 9 months after implementation of the treatments. A follow-up survey will be conducted towards the end of the four-year project. This paper reports on the initial survey.

Materials and methods

A questionnaire was developed specifically for farmers in the Vinh Phuc province, 40 km north of Hanoi in the Red River Delta. The questionnaire was modelled on several other questionnaires that have been conducted in the Mekong Delta, southern Vietnam (Sang et al., this volume), the Nakuru district, Kenya, West Africa (N. Oguge, 2000 unpublished data) and West Java, Indonesia (Sudarmaji, Singleton et al., this volume). It was designed to gather information on general farming practices and farm characteristics and, more specifically, rodent pest problems, management and farmer attitudes.

Four sub-villages (sites) within the Vinh Phuc province, which are currently being managed for a study on ecologically based rodent management, were used in this study. Farmers within these sites were surveyed to gain information on their knowledge, attitudes and practices for rodent management. Surveys were conducted in October 2000. Thirty farmers were interviewed from each site and were chosen at random from the field at the time of the survey, including some important members of the farming cooperative. A cooperative is set up in each sub-village (~150 families) and consists of a few smaller 'groups', each having leaders and various management positions held by farmers. The cooperative is responsible for major village farming decisions.

Results and discussion

Of the 120 farmers interviewed, 47% were female and 53% male, and the average age of farmers interviewed was 36 years old. The average overall level of education was 8 years and on average the farmers had 17 years of rice-growing experience. The average farm size was 0.3 ha (8.4 sao; 1 soa = 360 m^2), and rice was normally grown on 0.19 ha (5.2 sao) and vegetables on 0.13 ha (3.6 sao). The average rice yield for the area was 5.17 tonnes/ha (±0.18 se).

Crops and pests

The farmers surveyed at four sites in Vinh Phuc grew over 20 different crop types. Rice was the most commonly grown crop in the spring and summer seasons at all four sites. Tomato, squash and melons were grown commonly in the summer and spring seasons. Kohlrabi, onion, tomato and beans were the most frequently grown crops, respectively, in the winter season, at all sites.

Most farmers at each site believed rats caused the most damage to their crops (Figure 1). Farmers across the four sites identified 17 different pest types and pest categories; rats, insects and fungi being the three main pests identified. Stem rot, plant disease and a range of insects also were identified by a few farmers as important pests and some farmers indicated that climate or 'nature' was their biggest crop enemy.

The majority of farmers at all sites identified rats as the most important pests to control and the pests that caused most damage to crops (Figure 1). Most farmers at sites 1, 2 and 3 identified kohlrabi, then rice, to be the crops most damaged by rats. Farmers at site 4 believed the crops most damaged by rats to be green beans, then onion and kohlrabi (Table 1).

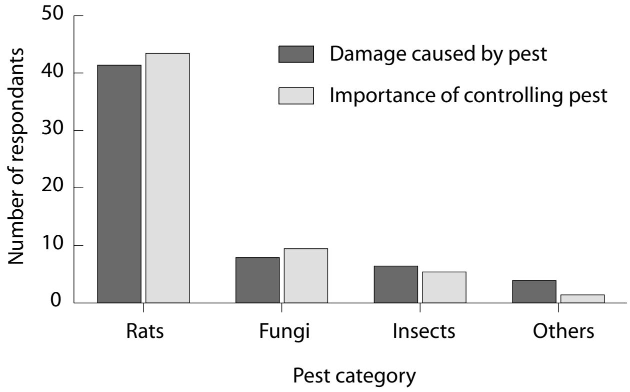

Figure 1. Responses by farmers to questions about which factors cause the most damage to their crops (black bars), and which pests they should control (white bars).

Table 1. Crops suffering the most rat damage (% respondents) ($n \approx 30$).

Crop	Site 1	Site 2	Site 3	Site 4
Rice	31	21	17	16
Green beans	0	0	0	40
Tomato	0	7	0	4
Onion	0	3	0	20
Kohlrabi	69	69	83	20
Others	0	0	0	0

Farmers at each site had similar methods of assessing crop damage. The farmers looked at plant and fruit damage more often than the direct evidence of rat presence such as tracks, droppings and burrows. Many farmers detected rats in their vegetable plots through evidence of chewing and biting marks on their growing fruits and tubers. The damage to vegetables was more commonly mentioned than damaged rice plants.

Nearly all farmers at all sites said that rat damage was 'regular', occurring every season. This corresponds with their belief that rats are a major pest animal and one that is important to control.

For rodent management in the fields, trapping was the most popular method of rat control at all sites (Table 2). Chemicals were the second most popular control method at sites 1 and 4 while plastic barrier systems were the second most popular control methods in sites 2 and 3. Digging was carried out frequently at all sites, then to a lesser degree hunting, cat predators, trap–barrier systems, fumigation, flooding and some other methods used very infrequently at all sites (Table 2).

Farmers were aware of safety in their control methods, many believing chemicals to be unsafe. This did not deter widespread use of a variety of chemicals, most commonly an unknown Chinese chemical believed to be highly toxic. It was commonly used because it is effective, cheap and easily obtained.

Physical control methods were highly favoured and trapping was the most commonly employed method with a few different traps being used. The most popular traps used were kill-traps (metal and wood mechanical traps) and sticky-traps (sheets of sticky substance that physically trap rats). Sticky-traps were favoured for use in the house and kill-traps for use in the field.

A barrier system (BS) was commonly used in all sites except site 4 where only 50% of surveyed farmers used a BS (Table 2). Many farmers incorporated traps with their BS or would hunt around its borders at night. Most other activities were quite similar across sites, with similar methods and timing of application.

Families were primarily responsible for their own rodent and pest management but the farming cooperative organised some pest control activities. Leaders from site 4 told us that their cooperative has provided funding for a rat bounty system in the past, with most farmers using digging and hunting. They would put aside money to pay local people in a concentrated rat-hunting effort.

In all sites, an estimated 16 days labour was spent controlling rats in the previous season and on average between Vietnamese dong (VND)16,000 and 18,000 (~US$1.2) was spent per day of labour. Overall, farmers at all four sites claimed to have spent between VND130,000 and 170,000 (~US $10) in the previous season on controlling rats. The farmers estimated a loss of about 40% of their rice yield if they did not implement rat control practices.

Farmers at all sites believed that controlling rats was most effective at the booting and tillering stages of rice growth (Figure 2). This belief corresponds with research carried out at the National Institute of Plant Protection, indicating that rats are most attracted to rice seedlings at these stages of development. This means that for physical control practices, there will be high densities of rats to control at these times.

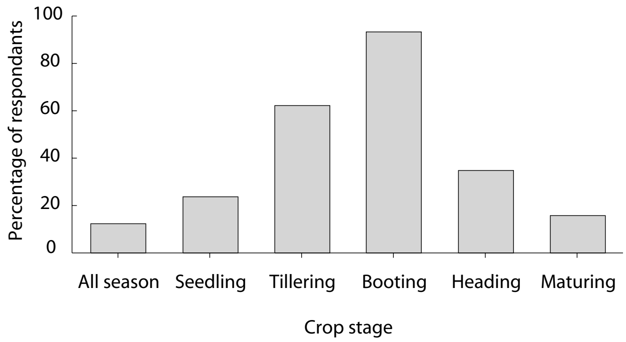

Figure 2. Responses by farmers concerning the best time for rat control throughout a rice-growing season (*n* ≈ 120 due to incomplete surveys).

Rats in the Red River Delta have a breeding cycle which follows the availability of food, and this is cued to specific times in the rice-growing season (Brown et al. 1999). Some farmers indicated that it is important to control rats at the time that vegetable plants develop fruits and tubers. Some farmers said they control rats when they see damage to their crops or rats in their fields, or in particular seasons, while some practised rat control continuously all year.

Nearly all farmers stated that rat control must be carried out and that it is very important (Table 3). Many farmers believed rats can severely reduce their rice yield and that rats can be controlled if all farmers work together and throughout all stages of the growing season. Some farmers were less convinced that rats could be controlled and seemed indecisive about when and how to control them (Table 3).

Most farmers believed that rat numbers had increased over the past 10 years to high numbers of rats in the past 2 years. This corresponds with national data for rodent damage, which indicate a steady increase in rodent

Table 2. Summary of all rat control methods used at four sites in Vinh Phuc province, indicating their rank order of use (rank) and the percentage of farmers (%) that use each method.

Control method	Site 1		Site 2		Site 3		Site 4	
	rank	%	rank	%	rank	%	rank	%
Chemical	2	87	3	77	3	77	2	83
Trapping	1	100	1	96	1	100	1	97
Hunting	4	47	4	47	4	59	4	57
Digging	3	76	3	77	2	79	3	80
Flooding	–	0	6	3	6	0	6	20
Trap–barrier system	6	10	6	3	5	3	6	20
Barrier system	1	100	2	80	1	100	5	50
Fumigation	7	3	6	3	6	0	8	7
Cats	5	33	5	13	5	3	7	10
Other	–	0	6	3	–	0	–	0

damage to rice crops over the past decade (Ministry of Agriculture and Rural Development 2000).

Table 3. Farmer responses (%) to a series of statements about rat control (average for all sites).

Question	Always true	Maybe true	Definitely not true
Rat control must be carried out	100	0	0
Controlling rats is important	98	2	0
Rat damage can severely decrease rice yield	58.5	39.5	2
Rats can be controlled	16	78	6
Rats can only be controlled if farmers work together with other farmers	73	24.5	2.5
Rats should be controlled at all stages of the growing season	46.5	51.5	2

Conclusions

The study site at Vinh Phuc supports a complex cropping area, with over 20 different crops being grown across three distinct growing seasons, experiencing quite different climatic characteristics. Farmers in the area primarily grow rice, but nearly all of them grow other vegetable crops concurrently. This mixed cropping structure can create difficulties for crop management, especially pest management. Farmers at Vinh Phuc identified nearly 20 different crop pests they considered important to control. Rats were considered as an important crop pest, not only for rice, but for some vegetable crops. Farmers use a variety of control methods including chemicals and plastic barrier fences.

With three growing seasons overlapping, there is always a food source for pests, especially for opportunistic pests such as rats. Farmers seemed more concerned about protecting their vegetable crops than their rice crops. They often built barrier systems around vegetable crops, especially when plants developed fruits and tubers and especially around kohlrabi crops, and used large amounts of chemicals to control rats.

Farmers in the Vinh Phuc province have a broad understanding of the pest management issues in their complex, mixed cropping farms. Most farmers believe that pest management, especially of rodent pests, is extremely important for the viability of their crops and that a range of different pest control methods implemented throughout the growing season is required for effective pest management.

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Adaptive management: a methodology for ecosystem and community-based rodent management in Cambodia

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Abstract. There appears to be no easy solution to reducing crop damage caused by rodents in Cambodia and other parts of Southeast Asia. Agricultural and pest management scientists focusing on technological improvements have expressed frustration with the apparent slow uptake of management options produced from an 80-year history of research. In Cambodia, rats destroy an estimated average 0.1% of the total rice production area annually. This may sound barely perceptible, but damage is often very patchy and locally severe. An outbreak in 1996 was reported to have destroyed rice sufficient to feed over 50,000 people for one year. Typically, farmers' rat management efforts have had poor success. There is an increasing awareness that traditional research, development and extension (RD&E) approaches have frequently led to inappropriate, irrelevant and unequally distributed technologies and unrepresentative decision-making. This paper provides an overview of one approach, adaptive management (AM), which aims to overcome these problems. An example of the application of AM to improve Cambodian RD&E in rodent management is also presented. We propose that the management of rodent problems in lowland rice could improve dramatically if approaches are community-based and if the concept of uncertainty is incorporated as an integral part of the decision-making process.

Introduction

Although traditional research has advanced the understanding of rodent ecology, the predominant extension model has been the transfer of technology (ToT) approach. After decades of using the ToT model, extension theorists and practitioners began to notice that the ToT approach proved successful only under certain conditions. These conditions are described by Jiggins (1993) as "homogenous production environments, for larger commercial farming units, wherever field conditions and interactions can be replicated in the laboratory and research station, and where innovation is driven by strong market forces which signal demand for tightly specified, discrete and specialised products". Where the approach had been inadequate, however, had been in more complex situations, particularly heterogeneous environments (e.g. varied soil types, unpredictable seasonal distribution, mixed cropping systems) and where social and cultural factors (e.g. division of labour, market forces, individual preferences) influenced and were influenced by changes in farming practices. In this light, it is easy to see why the ToT approach has not been successful to the small-scale, often unpredictable (due to poor food distribution, rat outbreaks and food shortages), and subsistence nature of Cambodian rice-farming systems.

In the 1970s, to deal with the inadequacies of ToT, the importance of developing technologies within the context in which they were to be used (both environmental and social) made its way into the research, development and extension (RD&E) agenda under the label of 'farming systems research' (FSR). This approach was seen as a more holistic approach to prior reductionist research approaches and had researchers conducting experiments and developing technologies in farmers' fields. However, FSR (in its early forms) still retained many of the assumptions of ToT, in that scientists still retained control over the research agenda. That is, FSR seemed a subsidiary of ToT, albeit a more effective way of doing it.

The 1980s saw a new approach in the RD&E arena referred to as 'participatory technology development'. In this setting, the extension agencies, particularly non-government organisations (NGOs) began to focus on issues of power and equity, introducing the notion of social justice into their framework for thinking about agricultural development. In the social justice agenda, participation was not only seen as a way of developing better technologies in relation to context, but also a right of individuals and communities in shaping and determining their own destiny. Extension theorists and practitioners began to pose questions such as "Whose knowledge for whom?" and "Who are the beneficiaries of development projects?"

Community-based approaches and participatory methods were developed accordingly.

By the 1990s, extension science (if not extension practice) had become concerned increasingly with rural people's sense-making activities (i.e. how people make sense of the activities in which they are engaged) and extension agents took on the role of facilitators and coordinators of these multi-stakeholder forums. However, the notion that farming systems (as we might view them) are embedded in larger systems that provide context and meaning for decision-making was often neglected in RD&E efforts. This caused projects to expand their focus toward multi-disciplinary and inter-disciplinary research. Mak (1998; see also Cox and Mak 1999) advocates, in the context of rodent management, that unless research on rodent ecology is matched by parallel research in the social sciences, gains in understanding rodent ecology will not be transformed into development outcomes.

In conjunction with this change, RD&E approaches that could also allow for the recognised complexity of and uncertainty within systems were being sought. What were needed were new approaches that would allow knowledge and understanding to emerge from the process. This led to the application of learning and action based participatory approaches, such as action learning, action research, participatory action research, soft systems methodology, and adaptive management. The success of these in agriculture and resource management is well documented through the 1990s (Hamilton 1995; King 1997, 2000; King et al. 1999). Success factors include strengthening community capacity, generating innovation and communication, enhancing organisational and research capacities, and developing and adapting technologies to local agroecological and socioeconomic conditions.

Today, the current trend in agricultural and resource management extension is for practitioners to facilitate multi-stakeholder participatory methodologies that allow for uncertainty and surprise (Röling and Wagemakers 1998). This may be at the 'soft', as well as 'hard' system level, as King (2000, p. 269) explains:

> There are a variety of reasons why a participatory learning process does not flow according to a blueprint plan or is not as effective as one might imagine. Issues of power, hidden agendas, expectations, past experiences, different world views and the fact that people are intentional beings, makes group learning processes and outcomes unpredictable at the level of praxis. Facilitating participatory learning processes is inherently complex, requires a wide range of skills and has many implications. It is not as simple as following a 'recipe' but requires an alternative, responsive approach to the flux of process.

This paper provides an overview of *one* particular approach, adaptive management (AM), which aims to allow for uncertainty and surprise. An example of the application of AM to improving Cambodian RD&E in rodent management is also illustrated. We propose that the management of lowland rice could improve dramatically if uncertainty were not only acknowledged, but also incorporated as an integral part of the decision-making process.

Adaptive management: what is it?

Adaptive management has a 25-year history in the natural resources literature. It was first introduced by Hilborn and Walters in 1976 in a fisheries paper that discussed how scientific research conducted separately from management was not producing useful predictions for fisheries managers (Walters 1995). The term itself was coined in 1978 by an inter-disciplinary team of biologists and systems analysts under the leadership of the Canadian ecologist Clarence Holling (Lee 1993). Walters (1986) and Lee (1995) further expanded ideas on AM, treating natural resource management as deliberate experimentation as well as advocating the methodology as a means of conducting better habitat management over time. Jiggins and Röling (2000, p. 3–4) illustrate the impetus for AM:

> AM has been gaining ground in response to a widely perceived sense of societal crisis. This perception is essentially concerned with the relations between people and their physical and biological environment, and the ways in which those relations are changing the function and capacity of the ecological processes on which human existence depends. The nature of change is seen as generating fundamentally new kinds of irreducible uncertainty. The conventional tools of risk assessment, planning and design, and the methodological and explanatory reductionism of conventional science are held to constitute an incomplete, inadequate, and an inappropriate toolbox for the construction of the future in situations in which surprise becomes increasingly determinant of outcome.

The formulation of AM was based on detailed studies of complex ecosystems such as the Florida Everglades, the Columbia River, the New Brunswick spruce forests, the Baltic Sea and others in which humans play a dominating role. Jiggins and Röling (2000) acknowledge the work of Gunderson et al. (1995), Holling and Sanderson (1996), Walters (1986), and Birkes and Folke (1998) in bringing together the concepts of AM in relation to these studies.

Definitions of adaptive management

There are now many definitions of adaptive management. To illustrate a few:

- AM is a heuristic process coupling science and social values to promote the sustainable management of natural systems (Holling 1978).
- AM aims to base management decisions on site-specific information gained through experimentation with management. Experimentation with management serves to combine information collection and policy design into a single process, in which policy is both informed by, and designed to yield, information (Blumenthal and Jannink 2000)
- A key aspect of AM is acknowledgment of uncertainty about what policy or practice is 'best' for the particular management issue, noting that AM has a sequence of steps including (1) problem assessment, (2) project design, (3) implementation, (4) monitoring, (5) evalua-

tion, and (6) adjustment of future decisions (Nyberg 1998).

- AM entails identifying areas of scientific uncertainty, devising field management activities and real-world experiments to test that uncertainty, learning from the outcome of such experiments, and recrafting management guidelines based on the knowledge gained (Walters 1995).
- AM is 'learning by doing' (Walters and Holling 1990).

While there are several approaches, Farr (2000) suggests that the following are key attributes of an AM approach:

1. Decision-makers, scientists, and other stakeholders work together and seek to enhance the understanding of the system that they manage
2. Identification of:
   - indicators (i.e. quantitative measures of the state or dynamics of the system that are relevant in the analysis of trade-offs among management alternatives);
   - actions (management activities or policies that will affect the system); and
   - ecological processes (that link actions to changes in the indicators).
3. Explicit predictions of outcomes of potential management actions on a suite of indicators, using simulation models or other projection tools. Exploration of trade-offs among alternative approaches.
4. Identification of key uncertainties and knowledge gaps. These are prioritised based on how reducing these uncertainties will help in the trade-off analysis (i.e. if we know X, would it help us to choose among management alternatives A and B?).
5. Active AM typically involves (management) experiments implemented at an operational scale, designed to test hypotheses or qualitative relationships between management actions and changes in indicators.
6. Monitoring of indicators.
7. Evaluation of observed and predicted changes, diagnosis of reasons for differences, and assessment of whether newly acquired knowledge justifies modification of the management plan, e.g. based on new projections of consequences of proposed actions with new relationships between actions and indicators. Other reasons for changes in plans include new objectives of stakeholders.

Two points raised by Holling (1978) that illustrate the difference between AM and traditional research are that at least as much effort must go into communication as goes into the analysis, and that there exists a serious trade-off between designs aimed at preventing failure and designs that respond and survive when that failure does occur. Taylor et al. (1997) suggest that AM differs from traditional research in three important ways:

1. managers play an integral and often lead role;
2. polices are implemented at an operational scale, in an operational setting; and
3. monitoring is less detailed, and the focus is on understanding the response of the system as a whole (rather that on detailed understanding of parts of the system).

Challenges to implementing adaptive management

Halbert (1993), Walters (1997) and Jiggins and Röling (2000) analyse the constraints to the effective implementation of adaptive management from a sociological and institutional perspective as follow:

- Under the experiential learning-based AM model, data are generated, analysed and interpreted over time periods that often exceed project time frames and political tenure. The process of learning is the primary objective rather than reaching an anticipated goal or output.
- As a methodology, AM has been questioned as to whether it is applied to the appropriate situation. It has been suggested that AM is most useful in situations in which environmental change is driven by high human activity, which threatens to undermine essential ecological functions and capacity.
- Computer-supported simulation models, although seen as an important tool for AM, are typically too complex to be easily understood by the stakeholders themselves. In addition, the overall objective of learning is often traded-off when scientists are focused on establishing 'true' models.
- Temporal scale is difficult to address, particularly where there are inter-generational differences in future equity stakes and differences in the articulation of action among different scale levels. Solving problems at one level does not automatically add up to solving problems at another system level with different emergent properties.
- A key assumption of AM is that social learning will lead to concerted action at the scale of the ecosystem being managed. In the case of large ecosystems, it has so far been difficult to establish effective management regimes (as opposed to the scale at which common property regimes have been successfully established).

Halbert (1993) suggests that although formal adoption and institutionalisation of AM is critical, this alone is insufficient to ensure successful implementation, which further requires that:

- management takes risk-prone actions while providing institutional patience and stability;
- managers and politicians redefine success so that learning from errors becomes an acceptable part of the learning process;
- managers set clearly established goals and decision-making criteria that will allow for accountability and effective evaluation;
- the goals must be compatible with natural processes, existing or achievable technology, and social norms; and
- the definition of adaptive management itself needs to be negotiated and agreed upon.

The application of adaptive management to Cambodia's rat problems

Rice production is the basis of food security in Cambodia. In some areas, rodent pests cause chronic and acute damage to rice crops and jeopardise food security for subsistence farmers and their families (Jahn et al. 1997, 1999). For example, Jahn et al. (1999) reported an outbreak in 1996 that destroyed rice sufficient to feed over 50,000 people for one year. The Cambodian government recognises the seriousness of the rodent problem and has in the past instituted bounties for rats, free distribution of rodenticide, and rodent pest awareness campaigns. Leung (1998, 1999) evaluated the Cambodian government campaigns for rodent pests and found that they were ineffective for crisis management or involved poorly timed routine activities without a sound ecological or socioeconomic basis. Leung (1999) also concluded that, while farmers had some knowledge of local rat populations, their ability to transform this knowledge into better management actions was limited by:

- a lack of community-based learning and actions;
- a lack of understanding of the ecological and socioeconomic issues; and
- some technical problems of rodent control methods.

The trap–barrier system (TBS) is a novel technological solution that holds considerable potential to control rodent problems in lowland rice systems (Leung 1999). While much has been learned of the *ecological* properties of the TBS, the *economic and social aspects* of this technology are poorly understood. However, what is clear is that the use of the TBS will be less than socially optimal if managed by individual decision-makers acting in isolation. Management of the TBS as a common property resource (i.e. at a community level) may provide a means to overcome this problem. This also means that the technical aspects of the technology and the social arrangements that support it have to be melded together.

'FARMERS' (Farmer-based Adaptive Rodent Management, Extension and Research System) is a collaborative project between farmers of Somrong Village, the Office of Agricultural Extension (OAE), the Cambodian Agricultural Research and Development Institute (CARDI) and The University of Queensland (UQ), funded by the Australian Centre for International Agricultural Research (ACIAR). Figures 1–6 illustrate aspects of the project. The project is based in Kampong Cham province, Cambodia, and has been in operation since July 2001. Details of the study location and TBS implementation are provided by Russell et al. (this volume).

Figure 1. The Australian Centre for International Agricultural Research (ACIAR) project team.

Figure 2. Rat damage to a rice field.

Figure 3. Rats, rat traps and a trap–barrier system.

Figure 4. Map of common property resources and trap–barrier system locations.

Figure 5. Participatory matrix for exploring gender and seasonal labour.

Figure 6. Participatory pie chart for assessing different control options.

The benefits expected from the project include:

- greater understanding of the technical, economic and social aspects of rodent management;
- development of appropriate social institutions for managing the TBS technology as a common property resource at a village level; and
- greater familiarity of community-based technology development approaches at CARDI.

The definition of adaptive management within the context of the FARMERS project is based on an action research model and is *an integrated, problem-solving approach, which operates on continuous learning and action cycles, with community participation in all phases of the planning, implementing, monitoring, interpretation and evaluation of the research*. Key aspects to the facilitation of AM in this project have been:

- The AM cycles coincide with cropping seasons to better link learning with ecological processes and the project includes social, economic and biophysical aspects to optimise learning about ecosystems management.
- Participatory planning has included farmers, scientists, extension agents and managers at the whole project level. This in itself is innovative, as farmers are typically involved in activity-level decision-making but excluded from decisions made at the whole project level.
- Research is carried out on-farm and involves the facilitation and coordination of a number of stakeholders that have formed their own 'research' community to explore more effective strategies together.
- Interactive participatory tools are used to bring out the stakeholders' different perceptions of reality.
- AM is seen as an overarching approach, but the emphasis in planning meetings has been on foundation concepts such as systems thinking, participation and action research.
- Spatial-scale issues are being addressed through mixes of processes allowing stakeholders to conceptualise and 'vision' their environment in a systemic way and to become aware how their own context fits into a larger picture.
- Monitoring and evaluation (M&E) is participatory, and the core project team (including farmers) uses, critiques and adapts the M&E methods before using them with farmers in the community. These tools can also be reframed as projection tools for future planning. Social aspects are incorporated into these methods, thereby surfacing and acknowledging the complex nature of introducing different management strategies.
- Indicators have been developed that reflect anticipated changes at both the farming systems level and the project team and management level. Indicators also reflect biophysical, economic and social phenomena.
- The AM approach is being used also to develop the learning and understanding of the project team itself. That is, the team is also facilitated through the process of planning, implementing, monitoring, interpretation and evaluation; and then reflects on this process.
- Negotiations and agreements are seen as dynamic rather than static, allowing for re-negotiation as learning by all participants increases.
- The inclusion of management in the core team aids in linking understanding to policy and redefining learning as a valid project outcome. The inclusion of farmers in the core team moves a step closer to ensuring the sustainability of the learning process in communities. It also acknowledges the value of farmer process knowledge as well as farmer technical knowledge.
- The learning focus and reflective nature of the team and community activities aim to sustain the learning process itself (beyond project time frames). Facilitated learning about learning also anticipates an increased understanding about the process of learning and its relationship to uncertainty and surprise.

Conclusions

Traditional RD&E approaches have frequently led to inappropriate, irrelevant and unequally distributed technologies and unrepresentative decision-making. Adaptive management is one methodology that may overcome many of these problems in complex ecosystems management. It is community-based, allows for the inherent uncertainty and surprise associated with complex systems, has a strategic learning focus, and links policy to practice change. Although further understanding of the complexities in facilitating such a process is needed, the application of AM to managing the lowland rice rats in Cambodia is showing promise.

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Gathering indigenous knowledge as a tool for rural research, development and extension: case study on rodent management in Cambodia

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Abstract. Many researchers and facilitators acknowledge the value of farmer participation in rural research, development and extension (RD&E), both for problem recognition and for problem solving. Although the intention to include farmers in the RD&E process may be genuine, implementation is often complicated by the fact that researchers, facilitators and farmers have very different perceptions of the natural and human environments and the complex interactions between them. This can lead to fundamental misunderstandings and act as a barrier to effective exchange of knowledge and ideas between project partners. This paper emphasises the need for researchers and facilitators to first explore the knowledge and beliefs of the farmers with whom they are working. It reports on research carried out to gather indigenous farmer knowledge and perspectives on rodent management in a rice-growing community in Cambodia.

Introduction

The population of Cambodia is over 85% rural, with most people involved in lowland rice production. Rodents are reported as a major cause of crop losses in many parts of Cambodia (Jahn et al. 1999) and farmers typically use rodenticide at times when rat damage is observed. This method is rarely, if ever, cost-effective, and may be harmful to the farmers' water supply and the environment. Since the end of 2001, researchers and extension agents have been introducing farmers of Somrong commune in Kampong Cham province to alternative, ecologically sustainable methods of rodent control, based primarily on the use of a trap–barrier system (TBS; Singleton et al. 1999). In brief, the TBS uses a lure crop (usually a rice crop planted 3 weeks ahead of surrounding fields) to attract and trap rodents before the surrounding fields reach booting stage. In theory, this leads to a reduction in rodent populations before the onset of breeding activity. The TBS method is best applied in a coordinated fashion across large cropping areas, but this requires a high level of community involvement and cooperation. In Cambodia, the willingness to work as a community was eroded during the Khmer Rouge time and consequently it is perhaps more than usually difficult to raise a community effort (Meas Nee 1995).

For the introduction of any new agricultural method to be successful, farmers must genuinely *believe* that it works and that it is cost-effective. In the case of the TBS method, this poses a considerable challenge, as the method works through subtle manipulation of ecological processes and, unlike the current practice of rodenticide use, does not result in large numbers of dead rats. Adoption and future cost-effective application of the TBS method is thus likely to hinge on farmers acquiring quite a high level of understanding of rodent ecology, including aspects of breeding biology, population cycles and seasonal movements, as well as a firm grasp of the way in which TBS acts to mitigate rodent population growth and crop damage.

Adult learning and indigenous knowledge

Adults tend to learn more effectively when the knowledge is problem-oriented (Rogers 1992), i.e. when they can relate the new information to real life situations. A study on adult learning involving farmers in Queensland, Australia, showed that the learning process is enhanced when the facilitator can relate the new knowledge to the individual experience of the farmer (King 2000). Other important points in relation to adult learning include those suggested by Malouf (1994), that learners must: set their own learning goals; participate actively; build upon their own experiences and knowledge; and see learning as desirable. In addition, the learning environment needs to be perceived as a mentally and socially safe space, and must allow effective, interactive communication. An understanding of the dynamics of adult learning is particularly relevant to farmer participatory research, where scientists and farmers come together (typically in farmers' fields) to collectively learn about and address problem situations.

Where cultural backgrounds differ substantially, the dynamics of adult learning may take on a new dimension. Farmers may have a fundamentally different world view that is difficult to reconcile with the Western scientific paradigm held by researchers or trainers, with different concepts of causality and contrasting modes of explanation. Such differences can lead to fundamental misunderstandings and may act as a barrier to effective exchange of knowledge and ideas between the project partners. In such situations, it is imperative that researchers and facilitators take time to explore the knowledge and belief systems of the farmers with whom they are working.

The idea that indigenous knowledge and scientific knowledge can be complementary in the research process is not new. Parallels between indigenous knowledge and sustainable development within particular situations are well documented (Agrawal 1994; Scoones and Thompson 1994). Indigenous knowledge has been introduced into development projects primarily in recognition that (i) it has been developed in context, (ii) it is generated over time through experience and trial and error, and (iii) it can incorporate the ideas and constructs of the end users of technologies.

Researchers and facilitators have most often gathered farmer knowledge as a means of quickly identifying problems and issues related to a specific topic. This is typically done through the use of structured questionnaires and semi-structured focus groups (Escalada and Heong 1997). In some cases, insights gleaned from such activities can also lead to the rapid development of effective solutions, building on traditional pest management practices. The gathering of indigenous knowledge might also assist a researcher or facilitator to understand how farmers are likely to respond to a possible solution, and how best to structure and present information in a way that will make sense to end users.

In addition, the *process* of gathering indigenous knowledge can itself produce benefits:

- informal discussions with farmers can build trust;
- talking about what *they* know can give farmers confidence to participate in discussions;
- incorporating *their* knowledge into development can give farmers a feeling of empowerment; and
- discussing *their* knowledge helps farmers to articulate new ideas and can lead to an enthusiasm to test these in the field.

Methods and study area

An initial focus-group interview was conducted with a small group of about 15 farmers (in this case, all men) to explore their knowledge about rodents and rodent ecology. Several open-ended questions were prepared by the facilitator in order to cover topics pertinent to the problem, but a general discussion was also encouraged. Visual tools including skulls, skins or bodies and a map of the commune proved useful to focus the discussion. Hall and Hall (1996) quote Fielding (1993) who describes semi-structured interviews as an ethnographic process where "the interviewer asks certain, major questions…but is free to alter their sequence and to probe for more information". Hall and Hall add that open-ended questions allow informants to discuss the issues more freely than they could with the closed or forced-choice questions of the structured questionnaire.

The diversity of opinions expressed during the focus-group meeting suggested that knowledge about rodents is not uniformly shared among all members of the Somrong community. As in any society, individuals have different personal experiences, they have been exposed to different bodies of wisdom, either within families or other social groups, and they may have varying levels of interest in particular topics. For this reason, the interview has been supplemented with numerous discussions with individuals or small groups of farmers, probing for information about their rodent problems, their personal observations of rodents and their understanding of the dynamics of rodent populations. This is an ongoing process, and almost every new conversation with farmers brings to light new information and insights. The information presented here is thus a composite of many conversations, although, so far, conducted exclusively with men, and is very much a preliminary account of farmer indigenous knowledge in the Somrong community.

Somrong commune supports approximately 7000 people living off a total cropping area of c. 700 ha. The cropping area is divided into distinct cropping areas: the dry-season cropping area (DSCA) and the wet-season cropping area (WSCA). The DSCA supports a mosaic of low scrubby vegetation and cultivated rice fields during the period November to February, but this area is inundated from June to November every year by the rising floodwaters of the Mekong River. The DSCA is progressively replanted as the floodwaters recede. The WSCA is located above the high-water level. It lies fallow during the dry season, but is planted with rice during the wet season as water becomes available either through local rainfall or by pumping from the rising floodwaters via a system of canals. A total of 11 densely settled villages are scattered across the WSCA. Vegetables are grown in small gardens within the village complexes.

Rodent specimens collected during this study were identified through comparison with reference material in the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Australian National Wildlife Collection in Canberra.

Results

The farmers of Somrong generally enjoy discussing their knowledge of rodents and the chance to share their observations. As noted above, the level of knowledge is quite varied within the commune, most farmers saying that they learnt their knowledge partly from their older relatives and partly from observation. During the focus-group discussion, farmers voiced a range of opinions on every question, although two or three individuals generally led the group. The responses to some questions were very specific, however on other topics they admitted to having more limited knowledge. The forest patches and the villages feature in the farmers' responses as important habitats for rodents. Similar general observations apply to the many individual discussions carried out subsequent to the group meeting.

Rodent taxonomy

Most farmers recognise three types of rats: *kondol preing, kondol promeh* and *kondol bie,* with the names *kondol ot mien chmua* and *kondol propeh* mentioned as alternative names for *kondol bie*. *Kondol prieng* refers to the largest of the local rodents, members of the genus *Bandicota*. There are two species of *Bandicota* present in Somrong: *B. indica* and *B. savieli*, but these are apparently not distinguished; they differ mainly in maximum adult size. *Kondol promeh* and *kondol bie* refer to the smaller rats of the genus *Rattus*. There are at least four *Rattus* species in Somrong: *R. argentiventer, R. losea,* and two members of the *R. rattus* complex (an endemic southeast Asian form and the 'European' black rat). *Kondol bie* is said to be slightly bigger than *kondol promeh* but is mainly recognised by its reddish colour. Specimens of *R. argentiventer* were frequently identified as *kondol bie* but if a specimen lacked the reddish colouring typical of that species, then it was sometimes referred to *kondol promeh.* One *Rattus* specimen was identified by a farmer as a baby *Bandicota* because of its greyish colouring. In general, it seems that pelage colour is the most important feature in Somrong for identifying the type of rat, followed by its size.

Two species of *Mus* have been collected at Somrong, *M. caroli* and *M. cervicolor.* Some farmers in Somrong believe mice to be the babies of the larger rats and do not consider them to be important targets for control in their own right. However, other farmers know that they are fully grown and can provide details as to when and where they breed, and describe how they can climb the rice plants to cut ripening panicles. These farmers consider mice to be major pests of their rice fields. The extent of farmer knowledge of particular rodents may be proportional to the crop damage that they experience from any given species.

Jahn et al. (1999) stated that farmers in Cambodia recognise two to six kinds of rats, however this was not referenced to area. The number of different kinds recognised may reflect the importance of rodents as pests in a particular area. However, it might also reflect farmers' perception of their ability to control any of the rodent species. The fact that the farmers in Somrong ascribe only three names to what are at least seven species may also reflect their belief that all rats are pests of rice and that all should be targets of control (see below).

Rodent habits and breeding

Somrong farmers believe the habits of the three types of rodents are essentially the same. In their view, the same kinds of rodents inhabit the villages and the fields. In the villages, rats eat rice stored under the houses. They mainly come out at night but are sometimes active during the day. During the dry season, they live in burrows in the DSCA, but when the flood comes, many rats move up to the WSCA. However, some remain in the flooded forest areas for up to 3 months. Although during the wet season rats can be found through all parts of the WSCA, they prefer to live in the 'forest' or in the villages. For this reason, more damage is expected in rice fields situated adjacent to these habitats. The farmers also claim that rats prefer to stay close to the flooded zone during the wet season, rather than moving into the more distant parts of the WSCA. This belief affected their placement of TBS units for the 2002 wet-season crop, the majority of which were positioned near the flooded area. At the end of the wet season, rats are said to move back down to the DSCA where they attack the recession rice crop.

Rats are said to breed all year round but with most young appearing at the end of the dry season. The number of pups per litter is said to vary but an average of six pups was generally given for all types of rats. Some farmers believe that rats can breed three times in one month. Rats are said to have their pups under the ground.

Rodent numbers and crop damage

Somrong farmers claim that the largest numbers of rats are present during harvest time in the dry season from February to April; and in the wet season from July to September, after the flood has reached its upper limit. They mentioned that rats tend to aggregate around the last fields to be harvested. Poison baits are generally placed at this time, sometimes resulting in observations of large numbers of dead rats around these fields. This is generally regarded as a sign of effective treatment.

Rats are thought to attack all stages of rice but mainly the booting stage. However, during the 2001–2002 dry season (the first TBS season), they claim that rats were attacking mainly the flowering stage, because this was when they caught the most rats in the TBS. One farmer explained this by saying that the flowers produce a good smell that attracts the rats. This was seen as a benefit of using an attractant crop inside the TBS and also as a reason why the TBS crop needed to be ahead of the surrounding crops.

All types of rats are said to eat rice, but *kondol promeh* and *kondol bie* (*Rattus* spp.) are believed to do more damage than *kondol preing* (*Bandicota* spp.). Rats do not store rice in their nests but they sometimes take it back to their nests if they live in the forests. Farmers mentioned that damage in the fields tends to be concentrated toward the centre rather than around the edges. The degree of damage is reported to be much higher in fields located near the villages and forests. Within the WSCA, damage is highest in fields close to the flooded zone, and generally very slight in fields that are distant from this zone. In most years, the highest-level damage is said to occur to the dry-season crops.

Farmers mentioned that rat numbers fluctuate from year to year. They also claim that the number of rats present during the dry season can be predicted from the amount of rain and the extent of flooding during the previous wet season. Before planting the 2001–2002 dry-season crop, farmers predicted that there would be fewer rats than usual and little damage, and attributed this to the high flood and heavy local rainfall of the 2001 wet season. This prediction was borne out by the results of the first TBS season—few rats were caught and there was relatively little damage other than in fields located close to major forest patches.

Discussion and conclusion

There is little comparative data from Southeast Asia against which to assess the extent of indigenous knowledge of Somrong farmers in regard to rodents. Although they clearly have a good understanding of many aspects of rodent biology, there is a tendency to view all rodents as having similar habits and as posing similar threats to rice crops. The number of different rodents distinguished is much fewer than the true number of species, but this is not surprising, given the very slight differences in size and morphology that separate some of the species. At an ecological level, Somrong farmers clearly appreciate the impact on rodent numbers of the annual flooding and cropping cycles, and they also appreciate the importance of refuge habitats (forest and villages) as potential 'source' habitats. Trapping studies at Somrong over coming years should reveal to what extent the farmers' concept of cyclic movements and refuges matches up with the ecological reality, however for the present, their views would appear to be reasonable in view of the general landscape ecology.

A more important observation in the context of the rodent management project is that Somrong farmers not only form a clear conceptual link between rat numbers and crop damage, but also appreciate that rodent numbers are unevenly distributed, both within the landscape and through time. These dual pillars of understanding may well have a strong influence on their ability to independently assess the effectiveness of the TBS and ultimately may help them decide whether or not the TBS will be cost-effective for any particular location, or for any particular season before the start of that season.

Our improved understanding of farmers' perceptions about the localised distribution of rats, the pattern of migration during flooding, and the relative damage to crops in different areas allows for:

- an appreciation by scientists and facilitators of the farmers' logic in application of the TBS;
- a more purposefully designed and facilitated future research process; and therefore
- the development of an improved rodent management strategy.

Although farmer knowledge of rodent biology and ecology is extensive, particularly in relation to rodent distribution and movement, our results suggest that knowledge about rodent life cycles is limited. Providing farmers with some additional information in this area may help them formulate a more accurate picture of rodent ecology. An understanding of the present limits to knowledge also enables the facilitator to develop a more strategic and focused learning process revolving around rodent life cycles (e.g. the breeding cycle of rats, and which species are present and important to target).

The farmers involved in the research presented here were all men. In the future, it would be useful to hold similar discussions with women, as they are concerned with different aspects of rice cultivation and may well have additional and alternative knowledge and ideas to contribute. King (2000) documented the complementary contributions of men and women's knowledge to understanding complex systems, noting, however, that women are often conspicuously absent from research, development and extension (RD&E) activities.

Recent interest in the contribution and incorporation of farmer knowledge in scientific research has tended to focus on what can be termed 'indigenous technical knowledge' (ITK), i.e. the knowledge farmers possess about technical aspects of their farming system and biophysical environment. Scoones and Thompson (1994) suggested that this interpretation of local people's knowledge and abilities is too narrow, and introduced the concept of 'rural people's knowledge' in which ITK is seen as only one of many components of a knowledge system. This notion was taken a step further by King (1998) who demonstrated the significance of 'indigenous process knowledge' (IPK), especially in the context of participatory research and complex systems management. In the present case study, the data-gathering process was initially focused on ITK. However, many of the farmers' 'ecological' observations stray outside of this sphere and qualify as elements of IPK. As mentioned earlier, indigenous knowledge is generated in context, often learnt from experience, and reflective in nature. It is these characteristics that articulate so well with the adaptive management methodology used to drive the participatory research in the Somrong rat management project. Close attention to both indigenous technical and indigenous process knowledge is a key component in the development of appropriate rodent management strategies and, more importantly, in their adoption by end users.

Gathering indigenous knowledge should be seen as an ongoing process. Knowledge is often diffuse within rural communities and it is important to try to gain as broad an understanding as possible of both the knowledge available within a complex farming community and of the social context of that knowledge. The new understanding that emerges from this process will facilitate the learning process and help build a better relationship between researchers, facilitator and farmers. A variety of semi-structured and casual methods must be used to obtain a complete understanding. Farmers may have issues, problems, information or ideas that will not surface within the confines of a structured survey. Adult learning theory also suggests that farmers may be better able to grasp or assimilate a new idea if it is related to their personal experiences or existing knowledge base. Without a prior understanding of indigenous knowledge as a baseline for planning, new knowledge or ideas presented to a farmer may be misunderstood or lost. Gathering indigenous knowledge and incorporating indigenous knowledge into the research process also increases the confidence and interest of farmers and this, in itself, is a successful outcome for any RD&E project.

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Economic factors influencing integrated rodent management in rural areas of Yunnan, China

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Abstract. Integrated rodent management (IRM) was adopted as a scientific control method in 1985 in some counties of Yunnan province in China. After 10 years, there is significant success in some counties (e.g. Tonhai and Daili), but in most other counties of Yunnan, there are still many problems with IRM. Many questions need to be addressed regarding under what conditions IRM would be successful. Why is IRM not successful in some places? Are there economic factors that affect IRM? In this study, three townships, six villages, and 100 farmers in Tonhai, and one township, one village, and 197 farmers in Qijing were selected for sampling information on benefits and costs of IRM. Farmers generally had a good understanding of the benefits and costs of IRM while the government tended to overemphasise the benefits. From our surveys, we conclude that the government needs to support the organisation of IRM by providing financial inputs and training courses for farmers. Efforts by the government should be distributed across all government levels to increase awareness and competence in IRM. Correctly estimated benefit–cost ratios provide proof of effective IRM to both government and farmers and can help in the decision-making process in IRM.

Introduction

Yunnan is a province in the south-west of China where 80% of the population engages in agriculture (Anon. 1992). About 85% of land is mountainous and only 19% is forested. Rice, wheat, corn, potato and soybean are the major food crops. Cash crops include tobacco, sugarcane and tea. Every year, greater than 10–20% of the agricultural production is damaged because of pests. Among the four major pests—disease, insects, rodents and weeds—rodents are a serious problem, causing an average 1–3% loss of crops in Yunnan province. In recent years, rodents damaged about 0.2–0.6 million t of food every year and there is also the problem of disease transmission from rodents to humans and livestock.

Integrated rodent management (IRM) is an ecological approach to rodent suppression. The goals of IRM are to reduce loss in crops and foodstuffs caused by rodents and to increase net profits to the farmer. Methods that cause minimal environmental damage and pose little or no risk to human health are selected, e.g. trapping rodents, digging out burrows, using cats to catch rats, integrating the use of rodenticides, and improving food storage technology (wood store, bamboo store etc.).

IRM was adopted in 1985 in a few counties of Yunnan province, and after 10 years, there has been significant success in some places (e.g. in Tonhai and Daili counties), but in most other places in Yunnan there are still many problems with IRM. Although IRM still needs to be improved (Zhang 1999), it is potentially a good method for controlling rodents, but it is still not widely adopted. Many questions need to be addressed as to conditions under which IRM could be successful. Why is IRM not successful in some places? Are there economic factors that affect IRM? Although it has been estimated that 30% of success and failure is determined by technical factors and 70% is determined by organisation (Wan and Den 1984), more detailed studies are needed to reveal those important factors and relationships.

The aims of this study were to:

- compare and analyse the IRM performance between successful and unsuccessful counties;
- identify important economic and organisational factors affecting the adoption of IRM; and
- determine the economic factors that affect the effectiveness of IRM once adopted by farmers.

Methods

We compared socioeconomic aspects between areas that were successful or unsuccessful in implementing IRM. All problems were approached from a socioeconomic viewpoint, i.e. the distribution of crops and cultivating practices, the benefit–cost, including the comparative net benefit, control cost and net benefit from rescuing losses, and benefit–cost of different methods in different places.

We compared successful IRM in Tonhai county to places where there are many problems with IRM, such as in Qijing county. Random sampling techniques were used when choosing the villages and farmers. Most of the indices used belong to the unified standards of the official rodent control agency for IRM inspection: (1) benefits–costs of IRM, e.g. the direct benefits (the value in avoiding losses), and the external benefits (potential value of public health); (2) perceived IRM benefits, from interviewing farmers and from official sources (government)—these perceptions were used to estimate the expected benefits of IRM; and (3) the monetary costs of IRM.

Three townships, six villages, and 100 farmers in Tonhai and one township, one village, and 197 farmers in Qijing were selected for sampling information. Tonhai is one of the counties in Yunnan that adopted IRM early. It has about 245,000 people and 26,230 ha of cultivated land. The elevation is 1793 m. Qijing is located in the northern part of Yunnan province, with 301,000 people, 38,560 ha of cultivated land and an elevation of 1860 m.

Results and discussion

IRM performance

IRM in these two counties, as in other parts of Yunnan province, depended on good organisation, financial support, and concerted actions which, when operating together, carried through to good results. There are still many problems with IRM as practised in Qijing county. These include: (i) the difficulties of IRM actions in large rural areas; (ii) the lack of financial support for practising IRM; and (iii) the different levels of organisation of IRM, i.e. the shortage of recognition of IRM at the different levels of prefecture, county, township, village and farmer. Also, in Qijing county the low quality of rodenticides, the confusion associated with marketing of rodenticides, and the farmers' attention to IRM combined to create problems for putting IRM into action. In a survey of people from different levels (province to farmer) in both counties, it seemed that the adoption of IRM was most likely to be inhibited at the local level (farmer and village) (Table 1).

Socioeconomic factors influencing IRM

In the two counties sampled, the total financial input was highest at the village and farmer levels (Figure 1). The inputs at village and farmer level were mainly the grain for rodenticides and the labour required support IRM. These two components amounted to more than two-thirds of the total input in Tonhai and in Qijing.

Farmers have different perceptions of benefit–cost than the government (Table 2). There was a significant difference between the farmers' opinion and the government's opinion of the benefit–cost ratio of IRM ($t = 6.13$, $P < 0.01$). The estimation of farmers' benefit–cost ratio may not be exact, but this will determine the IRM adoption rate by farmers. In Huanlong, Wanjiai and Qiling townships, we began to investigate a more objective benefit–cost ratio:

$$B/C = (B_n + B_p)/C \quad (1)$$

Table 1. Perceived source of problems for integrated rodent management as seen by respondents from Tonhai county (T) and Qijing county (Q).

Respondents see source of problem in:	Respondents represent					
	Province	Prefecture	County	Township	Village	Farmer
Province			TQ			
Prefecture	TQ	Q	T			
County	TQ	Q	TQ	TQ	TQ	TQ
Township	TQ	TQ	TQ			
Village	TQ	Q	TQ	TQ	TQ	TQ
Farmer	TQ	TQ	T	TQ	TQ	TQ

Table 2. Benefit–cost ratio perceived by government authorities and farmers (farmers in brackets) in Huanlong and Wanjiai townships in Tonhai county and in Qijing and Qiling townships in Qijing county.

County	Township	Year						
		1994	1995	1996	1997	1998	1999	Mean ± se[a]
Tonhai	Huanlong	4 (3)	7 (2)	10 (1)	15 (13)	13 (3)	10 (2)	9.8 ± 3.9 (2.2 ± 0.8)
	Wanjiai	5 (2)	7 (1)	15 (3)	9 (1)	8 (1)	10 (1)	9.0 ± 3.4 (1.5 ± 0.8)
Qijing	Qijing	7 (1)	6 (1)	6 (2)	3 (2)	2 (1)	5 (2)	4.8 ± 1.9 (1.5 ± 0.5)
	Qiling	6 (3)	10 (2)	15 (1)	10 (1)	7 (1)	6 (5)	9.0 ± 3.5 (1.6 ± 0.8)

[a] Average perceived benefit–cost ratio for Tonhai is 9.5 by government authorities and 1.9 by farmers, and for Qijing is 6.9 by government authorities and 1.55 by farmers.

where: B_n is the benefit of IRM; B_p is the potential control of IRM, e.g. effects of disease control (B_p is >0 but undetermined); and C is the total costs (material, labour).

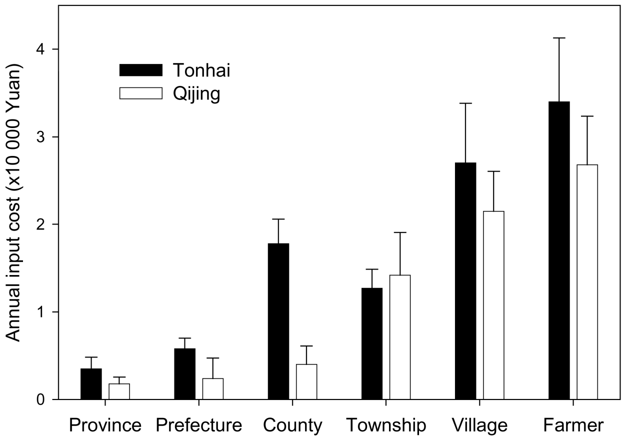

Figure 1. Mean annual input (yuan) for integrated rodent management (1993–1998) for Tonhai and Qijing counties.

We assumed that a rodent, on average, destroys 9 kg of crops per year and that the average value of a 1 kg crop is about 2.2 yuan (¥) (US$1 = ¥8.2). The social and health benefits of IRM are unknown, but thought to be substantial.

A questionnaire survey of 200 farmers in Huanlong, Wanjiai and Qiling townships revealed B_n values of ¥1300–2800, and C values of ¥860–1560. Although B_p remains undetermined, we can calculate B_n/C for farmers and government authorities. There was a significant difference between the government's perception of benefit–cost ratios and the benefit–cost ratios calculated by us (t = 5.44, $P < 0.01$). There was no significant difference between the farmers' perception of benefit–cost ratios and the benefit–cost ratios calculated by us (t = 2.18, $P > 0.1$). It seems that the farmers' perception of benefit–cost ratios is a reliable estimate of real IRM benefit–cost ratios.

Other socioeconomic factors

Monitoring benefits and costs is an important factor in evaluating the results of IRM and in encouraging the adoption of IRM practice by farmers. However, monitoring is rarely conducted, especially at the local levels of township and farms, where only 30% of the surveyed units did monitoring. Public places (e.g. toilets, storage rooms, fallow fields, ditches, canals) were always ignored regarding management actions by both the government and the farmers. This will certainly interfere with the effects of IRM control action because in these habitats pest rodents are sheltered and offspring generated there may invade crops.

Conclusions

Howard (1984) has pointed out 39 factors that could interfere with IRM. In this study, we found that four economic factors have a key influence on the practice of IRM in Yunnan province.

4. The government needs to support the organisation of IRM by providing financial inputs and training courses for farmers.
5. The efforts by the government should be distributed over all government levels (province to farmer) to increase awareness and competence in IRM.
6. Correctly estimated benefit–cost ratios provide proof of effective IRM to both government and farmers and can help in the decision-making process in IRM.
7. Increased yield is only one positive outcome of rodent control in agro-ecosystems. Farmers will also have a benefit if the time spent controlling rats decreases, even if the yield does not increase. The farmers can use the time gained for other cash-generating activities or for leisure. If IRM can be conducted without or with little use of chemicals, the environmental benefits may be considerable.

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Developing a rodent management strategy for South Africa's Limpopo province

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Abstract. A crop post-harvest needs assessment was conducted in the Limpopo province, South Africa. Six villages from three districts were surveyed using participatory methods to assess the livelihood constraints of subsistence farmers. Farmers indicated that rodents were a serious agricultural constraint, and were often ranked as the most important post-harvest constraint for a range of stored crops. In addition to damage to stored staple crops, rodents were noted also to feed on the crop in the field, cause damage to buildings, and bite people in their homes. Farmers knew little about the source of these rodents or how to control them, and they had little faith in any of the available rodenticides. A follow-up pilot trial with kill-traps in homesteads showed a catch rate ranging from 2% to 48%, trapping *Rattus rattus*, *Rattus norvegicus* and *Mastomys* spp. Newly initiated research in Limpopo province is focused on developing more sustainable and ecologically based rodent management strategies for both pre- and post-harvest rodent problems. The aims of these farmer participatory trials are to determine the: (1) population dynamics and breeding ecology of the main pest species; (2) impacts of rodents on crop losses and other livelihood issues; (3) effectiveness of trapping on rodent populations and the damage they cause; and (4) incidence of rodent-borne diseases and the risks they pose to humans.

Introduction

The Limpopo province (formerly the Northern province) is historically comprised of three 'homeland' areas with 91% of the population settled in rural areas. Per capita income is the lowest in South Africa, with an average disposable income of 2112 rand. A study by Rwelamira (1997) estimated that three quarters of the rural households subsist below the poverty line of 900 rand per month, while one in four households managed on less than 800 rand per month. Agriculture is the second largest sector of the province's economy (after mining) and is characterised by subsistence production of staple crops and vegetables.

A project funded by the Crop Post-Harvest Programme of the United Kingdom Department for International Development was initiated to determine the potential for integrating post-harvest technologies available in other African countries into the small-scale food production systems in Limpopo province. The aims of this study were to improve household food security by analysing the post-harvest constraints and opportunities and how these influence the livelihood strategies of rural households. It was expected that the outputs of this study would lead to new projects aimed at addressing the constraints identified.

Materials and methods

A participatory rural appraisal (PRA) survey was implemented in six villages during the out-of-season period after harvesting was completed and before the rainy season when planting commences (July to September 2000). The six villages were randomly selected from the three districts (two villages per district) of the province with the highest populations of small-scale or resource-poor farmers (Lowveld, Northern and Southern districts). The survey used PRA tools with groups of the community to determine agricultural activities and constraints, survival strategies, information pathways and the role of different stakeholders. A questionnaire with individual households focused on activities related to the production and storage of the main crops. Information from each village surveyed was compiled in a report that was presented at workshops attended by representatives of the farming communities and other role players.

Results and discussion

Results of the survey showed that agriculture and income from government pension grants were perceived by the communities as their most important survival strategies. Few farmers produced enough surplus food for sale.

Table 1. Agricultural constraints as listed and ranked by the six villages surveyed in Limpopo province. Shaded areas were not listed as constraints. Men (W) and women (W) in each village ranked the constraints separately by apportioning 100 stones among the constraints identified by the entire community ('0' indicates it was scored as 0, while '–' indicates it was not scored because it was not listed). (Source: von Maltitz et al. 2001.)

Constraint	Lowveld district				Northern district				Southern district			
	Basani		Nkomo-B		Mapate		Vhurivhuri		BBkloof		Ga-Phaahla	
	M	W	M	W	M	W	M	W	M	W	M	W
Physical												
Lack of tractor/implements	34	21	13	20	18	17	16	31	11	8	10	9
Lack of fences	15	21	10	10			11	6	19	5	8	5
Lack of thresher											14	7
Lack of mills									–	10		
Lack of co-op									–	8		
Transport: field to home	6	8			6	5			7	6	8	4
Transport: home to market					4	6			8			
Distance to mill	5	11										
Distance to market							9	0				
Lack of market			4	0					7	7	0	7
Lack of grazing							6	0				
Lack of dip tank			4	6								
Lack of irrigation			11	0								
Lack of storage											0	7
Susceptible hybrid seed	3	2										
Natural												
Insect pests and diseases			7	8	10	12	4	4	4	13	11	5
Insect pests in storage	3	7					6	19	2	5	3	6
Termites							7	11			11	7
Diseases									5	–		
Damage by birds									5	–	11	9
Rodents	6	5	6	11							2	5
Witch weed							4	10	5	–	13	8
Drought							7	7				
Wild animal damage									–	6		
Soil erosion							5	6				
Infertile soil											3	9
Lack of water/irrigation			30	38	7	3			–	11		
Waterlogging											4	4
Human												
Lack of information			14	7					9	7		
Lack of info processing									–	3		
Labour to fence	2	4										
Labour shortage	3	2			7	7						
Labour to clear fields	17	9										
Weeding laborious					8	8						
Theft	1	4									4	5
Harvesting laborious					7	5			8	–		
Shelling laborious					5	8						
Poor agricultural practices											2	5
Financial												
Transport cost	5	6										
Lack of pesticides					8	–			–	4		
Lack of seed			7	10	9	14	9	8	7	3		
Lack of fertiliser			4	0	11	15	9	10	–	4		

Table 2. Methods used by farmers in Limpopo province to protect their stored crops from rodent damage. (Source: von Maltitz et al. 2001.)

Method of rodent management cited	Village name						Total
	Basani	Nkomo-B	Mapate	Vhurivhuri	BBkloof	Ga-Phaahla	
Rattex (difethialone)	7	12	3	5	5	12	44
Cats	5	2	1	2	1	5	16
Traps	1	2	1		1	1	6
Sticky glue	1	1					2
Carbaryl/gamma-benzene hexachloride	1						1
Pour hot water in rat holes	1						1
Mud/cattle dung for sealing entry holes in granary				1			1

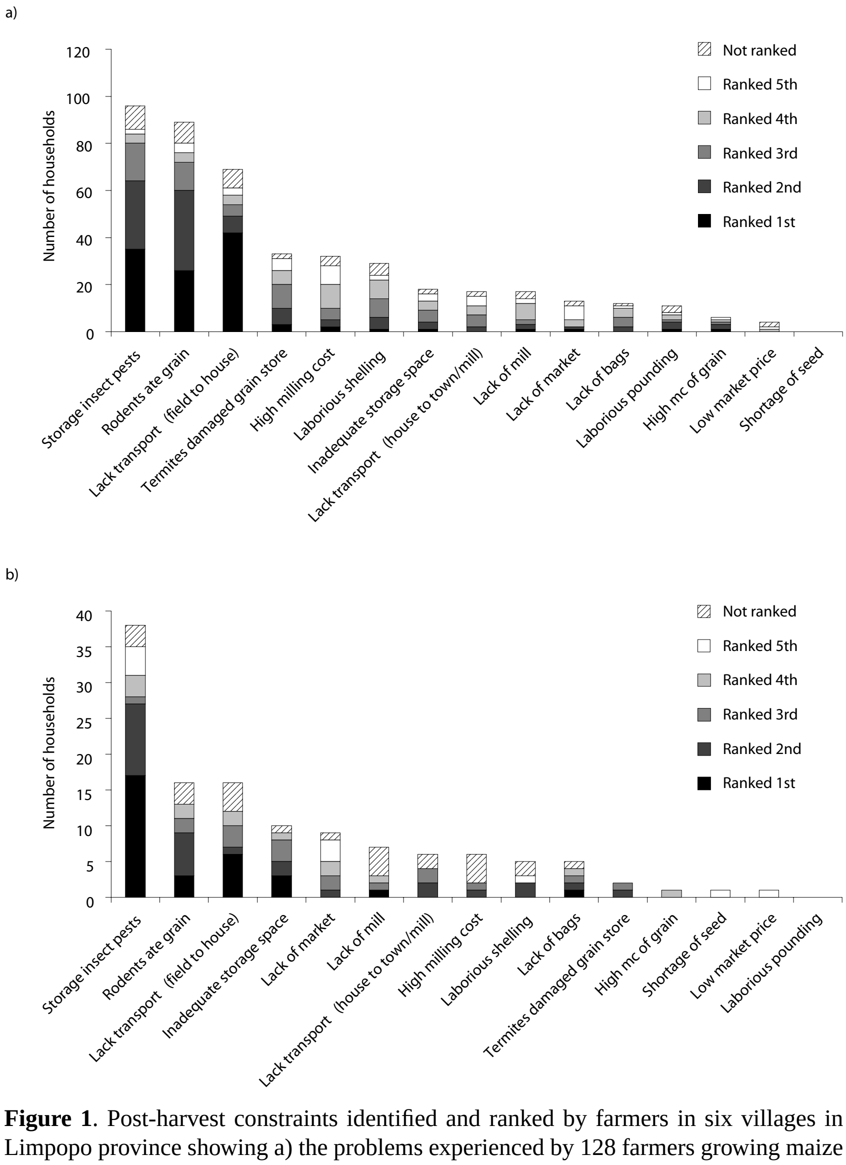

Figure 1. Post-harvest constraints identified and ranked by farmers in six villages in Limpopo province showing a) the problems experienced by 128 farmers growing maize as their staple crop and b) the problems experienced by 40 farmers growing sorghum as their staple crop (mc = moisture content).

Open-pollinated maize varieties were the major staple crop, while sorghum and millet were the staple crops in the more arid southern area. Groundnuts and legumes were major crops in the northern and eastern areas. Nearly all crop yield was stored on-farm, with maize cobs stored in granaries and all the other crops threshed for bag storage in the home.

Each community was asked to list their agricultural constraints, which were then ranked separately by the men and women in the community (Table 1). Natural constraints, particularly insect and rodent damage in storage, were considered the most important in all communities, as shown by farmers growing maize and sorghum as their main crops (Figure 1). Rodent damage to stored millet, groundnuts and legumes was ranked as the first and/or second most important problem. Surveys that specifically dealt with rodent problems indicated that 40% of respondents used a preventative method against rodent damage—the most common method was the occasional single-dose use of a chronic rodenticide in and around the house and food store (Table 2). Rodents were noted also to feed on the crop in the field, cause damage to buildings, granaries, furniture and household belongings, and bite people at night in their homes. Farmers knew little about the source of these rodents, how many types there were, or how to control them. Post-harvest hygiene and waste management was a problem in the villages surveyed, and agricultural waste was often left in the yard, providing shelter for rodents. Open-structure granaries used for maize storage were raised less than 1 m from the ground, allowing rodents free access.

A pilot trial with kill-traps placed inside people's homes and stores showed that capture rates per trap night varied between 2% to 48% over 3 days of trapping. The rodent species trapped were *Rattus rattus*, *Rattus norvegicus* and *Mastomys* spp., with *R. rattus* being the dominant species at the time of the survey (November 2001). A new project to develop rodent management strategies for pre- and post-harvest rodent problems has recently commenced with a view to understanding the rodent ecology and control options that can lead to reductions in rodent impacts on people's livelihoods.

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Socio-cultural and economic assessment of community trap–barrier system adoption in southern Vietnam

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Abstract. The community trap–barrier system (CTBS), an ecologically based rodent management strategy, was introduced to rice farmers in the Mekong Delta in 1997 to facilitate farmer adaptation and eventually adoption on a large scale. This paper explores factors for, and constraints to, CTBS adoption. Southern Vietnamese farmers are likely to adopt the CTBS considering their perceptions of the technical effectiveness, profitability, assuming the cost is shared among the members within the protected area, reductions in chemical usage to control rats, and their social and cultural practices. Major constraints to its adoption are the high initial costs for establishing one TBS and the uncertainty of farmers within the protected area to equally share these costs. To ensure large-scale adoption of CTBSs in southern Vietnam, it is suggested that the government should subsidise farmers by providing them with TBS materials. The farmers would provide labour equity. Improvements to the CTBS technology suggested by farmers are presented.

Introduction

A farmer's choice of action—adoption of a new technology—is mainly influenced by his/her evaluation of the new technology. That evaluation is largely based on his/her perceptions on the effectiveness of the technology and the feasibility of the technology for farmer use. Technological feasibility may include economic profitability, technological simplicity, and social and cultural acceptability. A technology is likely to be adopted if the economic advantage is superior to the existing and alternative technologies. Likewise, to ensure that the technology is likely to be accepted by the target users—the rice farmers—it should be simple to implement and compatible with their culture, such as their norms, beliefs, and practices.

The use of a trap–barrier system (TBS), with an early-planted crop within the barrier, has shown promise for controlling rodent pest populations in lowland irrigated rice crops (Singleton et al. 1999). The adoption of this simple technology requires community participation and so has been described as the community trap–barrier system (CTBS). This paper aims to explore factors influencing CTBS adoption, and the constraints to its adoption, for controlling rodent pests in the Mekong Delta region of Vietnam.

Materials and methods

This study had two treatments: with CTBS and without CTBS, with a total of 24 TBSs established. One TBS was established in each of six hamlets in Cai Be and Cai Lay districts, Tien Giang province, and My Tu and Long Phu districts in Soc Trang province. Another two hamlets from each of the two provinces were chosen to serve as the control group. Key informant interviews, focus group discussions, and a partial input–output survey on rice production using semi-structured questionnaires with personal interviews, were conducted to elicit information on farmers' rodent pest management practices, farmers' perceptions of rodents as a constraint to rice production, profitability of the CTBS, and to assess the potential factors and constraints to farmer adoption of the CTBS. In all, 233 farmers were interviewed: 114 from the 12 treatment hamlets (six from each province), and 119 from the control hamlets.

The establishment of TBSs in the treatment sites was financed by the project, and included materials, including fences, rat traps, seeds for the planting of the trap crop, labour for pumping water because the trap crop was planted early, and establishment labour. Farmers' equity was in the form of labour, such as checking the rat traps daily and keeping records of the total numbers of rats caught. Those farmers who had crops within the area protected by a CTBS were responsible for the maintenance and management of their CTBS. Different dynamics and institutional arrangements in the management of the CTBS were noted. A marginal benefit–cost ratio (MBCR) was estimated to assess the economic viability of the CTBS.

Results and discussion

Farmers' perceptions on the technical effectiveness of the CTBS

Adoption of the CTBS among southern Vietnamese farmers can be assessed from the following angles: technical, economic, social and cultural. In terms of technical acceptability, it should be perceived as an effective rodent control method. Table 1 shows farmer ranking of the effectiveness of different rodent control methods, as well as ranking of other attributes, such as labour and cost requirements. Farmers perceived CTBS as the most effective control method, and recognised that it requires low labour, and its use can be sustained in all three cropping seasons. However, the establishment of a TBS is perceived as the most costly because it requires high initial investment in terms of the plastic fence, rat traps, labour, and land preparation.

Farmers further perceived the CTBS as an effective rodent control method in terms of percentage rodent damage (Table 2). Farmers observed a marked damage reduction after CTBS implementation: from 12% before to 4% after CTBS implementation in My Tu, and from 21.4% before to 16.5% after CTBS implementation in Cai Be. In contrast, farmers in the control group perceived that rat damage had increased or remained the same. CTBS farmers from the other two districts, however, perceived that damage due to rats remained the same. It is surmised that the technical effectiveness would be more apparent if CTBSs were established in areas of known high rodent damage.

Economic viability

One measure for assessing the economic viability of a CTBS is through the marginal benefit–cost ratio (MBCR), which is the ratio of additional benefits and additional costs due to adopting CTBS. Additional benefits due to CTBS adoption equal the sum of the value of yield difference between CTBS and non-CTBS users, reduction in rodenticide costs, including the cost of baiting and labour, and the value of rats caught from the traps in CTBS (Table 3). Most of the CTBS farmers did not use rodenticides (70–97%), while most of control farmers were still using them (70–80%). This is an important finding because often the chemicals used in this region are not those recommended by the Plant Protection Department and are therefore likely to have a high negative environmental impact, including poisoning of non-target species. Also of concern is that people consume rats caught in this region.

The additional costs of adopting CTBS technology is estimated to be Vietnamese dong (VND)135,000 (US$1 = VND14,500), which largely included material costs and labour.

From the four villages, three had positive MBCRs, ranging from 2–6. This indicates that a farmer participating in a TBS would incur a minimum additional return of VND2 and a maximum return of VND6 for every VND1 invested. There was one village, Long Phu, which had a negative MBCR, implying a negative return (Table 3). One of the reasons for this negative MBCR was that at Long Phu there was a late start to the summer–autumn season because of drought. This led to significant crop losses due to disease affecting the late-planted crop. However, the control site was minimally affected.

Table 1. Ranking by farmers from Tien Giang, southern Vietnam, of the effectiveness of their different rodent management practices (1 = most effective, 7 = least effective). Also shown are some key factors that influence the decisions of farmers to adopt management practices (H = high, M = medium, L = low; Y = method adopted, N = method not adopted; I = individual, C = community). In this region there are three rice-growing seasons each year.

Control method	Effectiveness ranking	Consume rats caught?	Costs	Labour	Season			Community or individual action
					1	2	3	
Trapping	5	Yes	M	H	Y	Y	Y	I
Using rodenticides	6	NO	M	H	Y	N	N	I
Catching by hand	6	Yes	L	H	Y	Y	Y	C
Hunting by dog	3	Yes	L	H	Y	Y	Y	C
Smoking the holes	8	Yes	L	H	Y	Y	N	C
Sound of machinery, then digging	4	Yes	M	H	Y	Y	N	C
Wood trap	2	Yes	M	M	N	N	Y	C
Circling with grass	4	Yes	L	H	N	N	Y	C
Sling shot	7	Yes	M	M	N	Y	Y	C
Long pole at night	3	Yes	M	M	N	Y	Y	C
Community trap–barrier system	1	Yes	H	L	Y	Y	Y	C

Table 2. Mean values of farmers' perception of rodent damage (%) before and after community trap–barrier system (CTBS) implementation, summer–autumn season 2001.

Village	With CTBS		Without CTBS (control)	
	Before	After	Before	After
Tien Giang				
CaiBe	21.44a	16.55b*	12.87a	15.57a
CaiLay	14.95a	17.06a	12.87a	15.57a
Soc Trang				
MyTu	11.86a	3.59b**	11.79a	7.56a
LongPhu	18.74a	19.82a	9.28a	11.03a

Note: means of the same letter in a row are not significantly different at the 0.05 level; * = significant at the 0.10 level; ** = significant at the 0.01 level.

Table 3. Marginal benefit–cost ratio (MBCR) associated with using community trap–barrier system (CTBS) technology in four districts in southern Vietnam. Values (in Vietnamese dong, VND) are estimated through comparing costs of actions on treated and control sites.

Village	Yield (kg/ha)		Value of yield difference (VND)	Value of rats caught (VND)	Reduction in cost of rodenticide, bait and labour (VND)	Additional benefit (VND)	Additional costs (VND)	MBCR
	With CTBS	Without CTBS						
Tien Giang province, winter–spring 2000								
Cai Be	6969	6882	120,060	154,500	18,416	292,976	135,000	2
Cai Lay	5589	5124	641,700	147,000	73,532	862,232	135,000	6
Soc Trang province, summer–autumn 2001								
My Tu	6120	5763	399,840	222,000	–6050	615,790	135,000	5
Long Phu	5432	5986	–620,480	186,000	44,870	–389,610	135,000	–3

Social and cultural practices

Community action for rodent control is not new to Vietnamese farmers. Eighty per cent of the existing rodent control methods are done as a group (Table 1)—only rodenticides and small traps are used by individuals without consideration of the actions of their neighbours. Thus, the CTBS, which calls for community participation, is likely to be feasible for widespread implementation for controlling rodents. In Cai Be, the integrated pest management (IPM) 'club' is strong. Checking the rat traps was done according to schedules prepared by the members of the club and those within the area protected by a CTBS. Also, farmers prefer CTBSs to rodenticides because the latter are hazardous to both animals and human health.

In southern Vietnam, rat meat is part of the food culture. Millions of rats are caught each year, especially during the months of February, March and April (Khiem et al., this volume). Rat meat is a particular delicacy, which is an added incentive to farmers to use live-traps (i.e. CTBS) instead of poisons. One can buy live rats at VND6000/kg.

Constraints to CTBS adoption

Constraints to farmer adoption of the CTBS are high initial investment and the sustainability of CTBS management. At VND135,000, the CTBS is expensive for one farmer to bear all the costs. Farmers acknowledge the difficulty in getting others to share the costs. It is therefore suggested that the government should subsidise farmers by providing CTBS materials. In this case, farmers' equity would be the labour for establishing the CTBS and the daily monitoring of the rat traps. In terms of managing the CTBS, it requires daily checking of the rat traps. One way to improve sustained checking of traps is to place the trap crop near the houses of the trap-crop owners and members of the CTBS group (Morin et al., this volume). Another way is to place the CTBS where those who have crops within the protected area are related.

Farmers' suggestions for improving the CTBS

Currently, the TBS materials are replaced every season. The farmers suggested that the plastic should be thicker so that it can be used for more than one season. One way to reduce TBS investment is to reduce the height of the plastic fence and to use smaller traps. Furthermore, farmers suggest that traps should be placed inside the trap crop, so that if some rats get inside the TBS fence, they will be trapped, minimising the damage done to the trap crop.

Conclusion

The CTBS is likely to be adopted by southern Vietnamese farmers considering farmers' perceptions of the technical effectiveness of the CTBS as a rodent control method, the profitability of the CTBS—assuming the cost is shared among the members within the protected area, the reduction in chemical usage, and their social and cultural practices. The major constraints to farmer adoption of the CTBS is the high initial investment or expenditure and the difficulty in getting farmers to share the costs. It is therefore suggested that the government should subsidise farmers by providing them CTBS materials to ensure large-scale adoption of CTBSs in southern Vietnam.

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Farmers' beliefs and practices in rat management in the Mekong Delta, Vietnam

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Abstract. A survey of 400 farmers in four villages in the Mekong Delta showed that they considered rats as the most important yield constraint to rice production. A variety of control methods were being used, most common among them rat poisons such as zinc phosphide and warfarin, and crudely constructed electric fences. Generally, farmers spent 5–8 days per season on rat control, spending about US$17. They believed that if they did not control rats, crop losses amounting to about 700 kg (or US$63) per ha would be incurred. Most farmers believed in a group-based approach to rat management, but few practised it. These observations provide important information for facilitating the introduction of a non-chemical community-based trap–barrier system.

Introduction

Rats are important yield constraints to rice production in Vietnam. Crop losses have been estimated at 300,000–400,000 t of rough rice each year (Brown et al. 1999). In the Mekong Delta, there are two main rat species attacking rice, namely, the rice-field rat (*Rattus argentiventer*) and the lesser rice-field rat (*Rattus losea*). Farmers generally resort to the use of poison baits to kill rats. The efficiency of baiting is unreliable and rat poisons are also highly hazardous to human health. The trap–barrier system (TBS) introduced in Malaysia has been found to be an effective, non-chemical system (Singleton et al. 1999). To facilitate adoption of this system, a baseline survey on farmers' knowledge, attitude and practice was conducted to provide information on farmers' beliefs and practices in rat management in Tien Giang and Soc Trang provinces.

Materials and methods

Treatment, study sites and sampling procedure

The survey was conducted in two provinces, namely, Tien Giang and Soc Trang. These provinces have a history of significant rat problems in rice crops. In each province, two villages about 10 km apart were selected and a sample of 100 farmers was selected randomly for interviews. One of the villages was designated as treatment (cTBS) where the TBS was introduced to a community of 30 farmers. Here, farmers were trained to construct and maintain the TBS and monitor rats caught. The other village was designated as the control where a TBS was not introduced. The survey was conducted in March and April 2001 when the TBS training was provided but before the farmers had used the technology. Two focus-group discussions were conducted in the survey areas to obtain information for drafting of the questionnaire. The draft questionnaire was then translated into Vietnamese and pre-tested among 10 farmers individually and revised accordingly. Trained agricultural technicians administered the questionnaire.

Measuring beliefs

Twelve attributes developed from focus group meetings were used in the questionnaire to assess farmers' beliefs in rat management. Beliefs were scored using a response cue card with descriptor phrases in Vietnamese expressing their degree of agreement. Each point was assigned a numerical value from 1 to 5 following a Likert scale. The descriptors were: 1 = definitely not true; 2 = in most cases not true; 3 = may be true; 4 = in most cases true; and 5 = always true.

The responses of the farmers from within each village were combined to form a control group of 100 and experimental group of 100 for each province.

Results and discussion

Respondents' profile

The profile of the sample farmers is shown in Table 1. Most of the farmers in Tien Giang and Soc Trang were about 40 years old and had about 5–7 years of education, which was similar to previous surveys by Mai et al. (1997). Farmers in Tien Giang cultivated about 0.9 ha (range 0.2–7.0 ha) of rice while in Soc Trang they tilled about 1.2 ha (range 0.2–6.0 ha). Respondents' characteristics between the experimental and control villages, except rice area cultivated, were not significantly different. In Tien Giang, farmers in the experimental village had rice areas of 1.1 ha, while farmers in the control village had 0.7 ha. In contrast, in Soc Trang, farmers in the experimental village had 1.2 ha, while those in the control village had 1.7 ha.

Rat management practices

Farmers in Tien Giang reported 12 rodent control measures (Table 2a) while those in Soc Trang mentioned nine (Table 2b). The popularity of the methods used varied among farmers between provinces. In Tien Giang, cleaning the field was found to be the most common (64% on average), followed by digging (59%) and use of chemicals (54%). In Soc Trang, 75% of farmers used chemicals, followed by cleaning the field (51%) and digging (47%). Electrocution was used commonly by farmers in Soc Trang (41%) but had never been applied by farmers in Tien Giang. Electrocution is a rat control method that presents a dangerous hazard to human health. Its use in Soc Trang may be due to lack of information because extension and Plant Protection Department (PPD) technicians and the mass media seem to have had little influence on farmers' rat management methods in this province.

Table 1. Profile of respondents in treatment (cTBS) and control villages. The *t*-test was used to compare mean values between villages. The *t* values were used to determine significance. Probability (*p*) indicates the level of significance, with * = significant and ** = highly significant.

Category	Control (N = 100) (mean)	cTBS (N = 100) (mean)	t	p
Tien Giang				
Age (years)	41.4	42.1	0.436	0.66
Years of schooling	6.0	6.7	1.860	0.06
Rice farming experience (years)	19.1	17.9	0.910	0.36
Rice area cultivated in dry season 2001 (ha)	0.7	1.1	2.570	0.01*
Rice area cultivated in wet season 2000 (ha)	0.7	1.1	2.360	0.02*
Soc Trang				
Age (years)	43.3	43.5	0.160	0.87
Years of schooling	4.9	4.6	0.910	0.36
Rice farming experience (years)	19.4	20.4	0.380	0.70
Rice area cultivated in dry season 2001 (ha)	1.7	1.2	3.540	0.00**
Rice area cultivated in wet season 2000 (ha)	1.7	1.2	3.580	0.00**

Table 2a. Rat control methods used by farmers (% farmers using) in Tien Giang province, comparing treatment (cTBS) and control villages.

Control method	Wet season 2000		Dry season 2001	
	Control (n = 100)	cTBS (n = 100	Control (n = 100)	cTBS (n = 100
Use chemical	60	43	64	47
Trapping	6	26	5	20
Hunting	39	66	39	63
Flooding the field	50	25	48	30
Cleaning the field	69	64	65	59
Digging	39	78	45	75
Rat round-up	7	3	8	1
Trap–barrier system	0	4	0	3
Biological	4	14	4	14
Plastic strip barrier	1	6	1	7
Wood trap	0	1	0	1
Fumigation	0	0	0	1

Table 2b. Rat control methods used by farmers (% farmers using) in Soc Trang province, comparing treatment (cTBS) and control villages.

Control method	Wet season 2000		Dry season 2001	
	Control (n = 100)	cTBS (n = 100	Control (n = 100)	cTBS (n = 100
Use chemical	73	70	78	78
Trapping	11	5	10	8
Hunting	36	33	35	35
Flooding the field	14	11	14	12
Cleaning the field	47	54	47	54
Digging	53	39	54	42
Rat round-up	2	1	3	2
Biological	2	1	1	1
Electrocution	39	42	42	40

Farmers in Tien Giang and Soc Trang used two groups of chemicals to control rats. The first group included the rodenticides warfarin (anticoagulant), zinc phosphide (acute poison), and one from China whose active ingredient was not known. The second group consisted of insecticides, such as cartap and methamidophos although the Ministry of Agriculture and Rural Development has banned the latter for use in agriculture.

There was a slight difference in rodenticide use between the two provinces. In Tien Giang, the most common rodenticide used was warfarin (trade name: Rat–K), which accounted for 63% of usage followed by zinc phosphide (trade name: Fokeba) (37%). The Chinese rodenticide was not so widely used in this province (Table 3a). In Soc Trang, however, the most commonly used rodenticide was zinc phosphide (43%), followed by warfarin (33%) and the Chinese rodenticide (30%) (Table 3b). No clear difference in rodenticide use was found between control and experimental villages in the two provinces.

Table 3a. Rodenticides used by farmers (% farmers using) in Tien Giang province, comparing treatment (cTBS) and control villages.

Chemical name	Wet season 2000		Dry season 2001	
	Control	cTBS	Control	cTBS
Rat-K (warfarin)	60.7	67.4	57.8	64.4
Fokeba (zinc phosphide)	31.7	39.5	32.8	44.4
Chinese rodenticide	10.0	2.3	10.9	2.2
Padan (cartap)	0.0	0.0	1.6	0.0

Table 3b. Rodenticides used by farmers (% farmers using) in Soc Trang province, comparing treatment (cTBS) and control villages

Chemical name	Wet season 2000		Dry season 2001	
	Control	cTBS	Control	cTBS
Rat-K (warfarin)	31.5	35.7	32.1	32.1
Fokeba (zinc phosphide)	49.3	35.7	47.4	38.5
Chinese rodenticide	21.9	35.7	25.6	37.2
Monitor (methamidophos)	0.0	2.9	0.0	3.8

Farmers' choice of particular rat control methods did not differ between wet and dry season. Farmers in both provinces used more than one method to control rats; they believed that no single method would be effective. However, more than 50% of the farmers mainly relied on chemicals in both wet and dry seasons. Among farmers' reasons for using chemicals to control rats, 73.6% specified their high efficiency, followed by labour saving (28.7%), low cost (15.4%), and ease of use (14%).

Different rat management actions should be conducted at the right time during a growing season based on the ecology of the rodent pest species in the area (Brown et al. 1999). Although our survey did not record the timing of application for each method, we collected data on control measures used for particular growth stages of the crops (two or three crops are grown in this region each year). Farmers in Tien Giang and Soc Trang took rat control action at various rice growth stages, from seedling to maturing. However, most control actions were targeted at booting stage in both provinces (Table 4). This was consistent also with farmers' perception of the critical stage for rat control as shown in Table 5. Perhaps farmers focused their control efforts at this stage due to the visible symptoms of rat damage.

To assess the economic benefits of rat control, we computed farmers' actual expenses on rat control and their estimation of loss. Farmers spent between 5–8 days/ha/season controlling rats (Table 6). Cost of chemicals and other materials for rat control was highly variable, with a mean of US$5.90/ha/season in Tien Giang and US$6.29/ha/season in Soc Trang. On average, the total cost of rat control/ha/season was about US$19.20 in Tien Giang and US$14.00 in Soc Trang. Farmers' perceived benefits from controlling rats were about 792 kg and 617 kg of paddy/ha/season in Tien Giang and Soc Trang, respectively. With the farm-gate price of US$0.09 per kg, the perceived benefits were computed to average US$73.45 and US$56.70/ha/season in Tien Giang and Soc Trang, respectively. Thus, the perceived cost–benefit ratio would be 1:3.8 in Tien Giang and 1:4.0 in Soc Trang. No difference in the number of days spent and labour cost for rat control was found between control and experimental villages in both provinces. However, the cost of chemicals and other materials for rat control was significantly higher in the experimental village in Tien Giang (Table 6).

With regards to the mode of implementing their rat control efforts, 82% of control village farmers in Tien Giang did it alone, while only 40% in the experimental village controlled rats individually. The remaining 60% in the experimental village said that they worked together with other farmers. In Soc Trang, more than 90% of farmers interviewed said they controlled rats alone and very few controlled rats as a group.

Farmers' beliefs in rat management

Most farmers in Tien Giang and Soc Trang believed that rats are important yield constraints and that controlling rats would maintain rice yields. The belief that rats can only be controlled if they worked together with other farmers was stronger in Tien Giang than in Soc Trang. However, most farmers in both provinces strongly believed that the cost of control could be reduced if farmers worked together with other farmers.

The belief that rats can be controlled effectively only by the use of chemicals was low in both provinces. However, there was a difference in the degree of belief about the environmental concern when using chemicals between farmers in Tien Giang and Soc Trang. More farmers in Soc Trang (65.5%) than in Tien Giang (20%)

believed in the statement that it does not matter whether use of chemicals to control rats will harm the environment, as long as rats are killed. In both provinces, most farmers evaluated the efficiency of rat control as more important than its cost.

Conclusion

Farmers in both provinces strongly believed in the need to control rats as well as in the advantages of a group-based control approach in terms of efficiency and cost reduction.

Table 4. Timing of rat control efforts of farmers (% farmers) in Tien Giang and Soc Trang, comparing treatment (cTBS) and control villages (DAS = days after sowing).

Crop stage	Wet season 2000		Dry season 2001	
	Control	cTBS	Control	cTBS
Tien Giang province				
Seedling (0–15 DAS)	51.0	60.6	46.0	45.5
Tillering (16–40 DAS)	49.0	69.7	51.0	61.6
Booting (41–60 DAS)	96.9	81.8	97.0	80.8
Heading (61–70 DAS)	61.2	41.4	58.0	44.4
Maturing (>70 DAS)	15.3	11.1	13.0	12.1
Soc Trang province				
Seedling (0–15 DAS)	73.0	66.0	76.0	81.0
Tillering (16–40 DAS)	21.0	17.0	16.0	28.0
Booting (41–60 DAS)	80.0	81.0	87.0	81.0
Heading (6–70 DAS)	57.0	47.0	64.0	59.0
Maturing (>70 DAS)	21.0	7.0	22.0	7.0

Table 5. Rice growth stage perceived by farmers (% farmers) to be most effective for controlling rats, comparing treatment (cTBS) and control villages.

Crop stage	Tien Giang		Soc Trang	
	Control (*n* = 100)	cTBS (*n* = 100)	Control (*n* = 98)	cTBS (*n* = 98)
Seedling (0–15 DAS)	16.0	20.0	24.5	15.3
Tillering (16–40 DAS)	5.0	18.0	0.0	6.1
Booting (41–60 DAS)	73.0	57.0	56.1	68.4
Heading (61–70 DAS)	2.0	2.0	18.4	10.2
Maturing (>70 DAS)	4.0	3.0	1.0	0.0
Total	100.0	100.0	100.0	100.0

Table 6. Farmers' rat management expenses (in US$) and their estimation of loss (on a per ha basis, based on the arithmetic mean).

Crop stage	Wet season 2000		Dry season 2001	
	Control (*n* = 100)	cTBS (*n* = 100)	Control (*n* = 98)	cTBS (*n* = 98)
Tien Giang				
Number of days spent on rat control	5.1	8.7	5.6	8.0
Labour cost for rat control	10.91	15.91	12.04	14.88
Cost of chemicals and other materials for rat control	2.44	8.74	2.70	9.23
Total cost of rat control	13.34	24.65	14.73	24.11
Perceived loss if no rat control (kg of paddy)	704.79	782.83	965.20	715.58
Cost of perceived loss (VND) if rice was sold at VND1300/kg	65.44	72.69	89.63	66.45
Soc Trang				
Number of days spent on rat control	4.3	3.2	4.9	4.6
Labour cost for rat control (VND)	8.04	5.55	9.14	8.04
Cost of chemicals and other materials for rat control (VND)	4.82	6.20	5.68	8.28
Total cost of rat control (VND)	12.87	11.85	14.82	16.40
Perceived loss if no rat control (kg of paddy)	655.20	373.90	810.5	629.30
Cost of perceived loss (VND) if rice was sold at VND1300/kg	58.27	34.72	75.26	58.44

This presents an opportunity that could facilitate the introduction of community control actions, such as required for the use of TBS technology. Farmers' reliance on chemical measures and their lack of concern for their environmental impact suggest a need to educate the masses of farmers on non-chemical rat management methods in the region.

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