CHAPTER 5

Development of Effective Management Strategies

'Two of the identified problems in implementing rat control programs in Penang State, Malaysia, are:

(i) farmers' misconception that rats are 'intelligent' thus successful control is unlikely,

(ii) Superstitious beliefs that rats will take revenge upon their dead friends by causing worse damage.' (Adapted from FAO Evaluation Report, August 1987)

Two main aims of a successful rodent management strategy are to provide increases in agricultural production that are sustainable and to reduce the reliance of growers on chemicals for controlling rats. Principal factors that influence the development of a management strategy for rodents include the nature of the rodent problem, the method of rice production and the ability or will (e.g. financial, sociological, level of training, political will) of the local people to implement the management strategy. These factors are generally interrelated but for ease of consideration we will consider each factor separately. It is unlikely that a generic management strategy can be developed for different agro-climatic zones within a particular country let alone across several different countries.

5.1 Nature of the Rodent Problem

Rodent problems can be broadly categorised as:

(i) Chronic problem of similar magnitude from year to year.

(ii) Acute outbreaks that occur sporadically.

(iii) Acute outbreaks that occur on a regular multi-annual cycle.

(iv) Chronic problems from year to year with high variance in the magnitude of the problem, including occasional outbreaks.

The best strategy for rodent management will depend upon which category of rodent problem occurs in a particular area. The research inputs into developing a successful management strategy will be affected also. For example, categories (ii) and (iv) will require long-term demographic data for the development of good predictive models. Redhead and Singleton (1988b) outline a case study of the decision analyses required in developing a PICA (predict, inform, control, assess) management strategy of rodents that undergo aperiodic acute outbreaks (categories ii and iv). The PICA strategy developed by these authors is distinctly different from a rice-rat integrated pest control strategy (IPC) reviewed by Buckle (1990). Although not clearly stated, the IPC strategy was more tailored for the two categories of chronic rodent problems (i and iv).

5.2 Effect of Magnitude and Frequency of Rodent Problems on Management Strategies.

Perception of the problem plays an important part in the decision making process for rodent management. Farmers, pest control officers, bureaucrats, scientists and politicians all have to believe that there is a pest problem before any action will be taken. Perceptions of the rodent problem are greatly influenced by the magnitude and frequency with which the problem appears. If, for example, rodents are a major problem only every five to seven years then the imperative to control these pests generally diminishes during the intervening years.

With rodent populations that undergo sporadic but severe outbreaks, farmers typically expend considerable time, energy and resources on control operations only when rodents are numerous and causing considerable damage to crops. In essence, by the time the growers perceive they have a major rodent problem it is generally too late and they are forced to take palliative rather than remedial action. Frequently in these situations the action taken is inappropriate and is directed toward 'being seen to be doing something' rather than implementing effective medium or long-term management of the rodent problem. For example, in the southern Philippines, local elected government officials have a large input into rodent control strategies when rodent numbers are high. To be seen to be people of action they organise rat drives and facilitate the distribution of zinc phosphide baits. Both of these actions result in large piles of dead rats. Because everyone sees a tangible result for their efforts, they are satisfied that action has been taken, regardless of the fact that the many remaining rats rapidly reinvade areas where population densities have been reduced. In reality, economic and effective control of irruptive species requires action during the **early stages** of the population build up (Redhead and Singleton 1988a). To enable such a management strategy, rapid increases in rodent population densities must be forecast at least 6 months in advance.

Encouraging farmers to take preventative measures to control any agricultural pest is a worldwide problem. With outbreaking species of rodents the farmer has to be convinced that forecasts of incipient outbreaks are credible and that there is sufficient benefit over the cost of undertaking early control action. With chronic rodent problems the greatest battle is overcoming the acceptance by farmers that rats will eat a certain percentage of their crop each year, regardless of any actions they take. Indeed, the long history of rodent depredations in much of Asia and the attitude of many farmers is summed up by a quote attributable to rice farmers — 'For every 10 rows of rice, we sow two for the rats, one for the birds and the remainder for us'. We came across sayings of similar meaning in most of the Southeast Asian countries that we visited.

Most pest and disease problems in agriculture are, as rodent pest damage is, extremely patchy in the way in which they affect farmers over a large area. Therefore, a farmer's perception of the problem may be that his chances of sustaining severe damage are low. This is particularly so if he has not suffered any outbreaks of rodents on his farm for several years. Even if neighbours of the farmer have severe losses caused by rats, these are often regarded as 'their problem'. Generally, the farmer will wait until he sees losses occurring before he acts because it is only then that he will believe that control actions will tilt the cost/benefit ratio in his favour.

Despite all the best advice from pest control officers or the willingness by growers to take appropriate action early, socio-political problems often short circuit implementation of control. For example in Laos when a rodent plague occurs in the upland rice-growing regions, requests for rodenticide are processed through an appropriate government channel. Despite all the best will, there is a necessary delay in response because rodenticides need to be imported from another country. Consequently, the rodenticides often arrive too late to alleviate preharvest losses. In the Philippines, the rodenticides are available from within the country but there is a four-tier administrative system which delays the processing of requests and subsequent delivery of the product. Regardless of the reason, if there are delays in response to requests for assistance or in the provision of a recommended rodenticide, growers will quickly become disenchanted and revert to traditional approaches — which often includes no action if losses are less than 20%.

5.3 Effect of Farming Systems on the Nature of Rodent Problems

The type of farming system in place has a profound effect both on the nature of the rodent problem and on the methods for control. Improvements in farming techniques, crop varieties and agricultural management have escalated the battle against rodent pests. Traditionally, there always have been rodent problems, even in rice growing systems that were less intensely managed than they are today and which produced only one crop per year. However, the intensity of these rodent problems in the past appear to have been less severe than those of recent decades. Since the second world war, a progression in the seriousness of rodents as agricultural pests has become widely recognised (Prakash 1988). Several factors in the development of rice production in Southeast Asia and also Indo-China have contributed to this progression. These factors include:

(i) *An increase in the number of crops grown annually to two and in some cases three.* Rats have responded by having two or three breeding periods respectively, rather than one.

(ii) *A marked increase in irrigated cropping.* Irrigated areas provide an increase in the complexity of the habitat surrounding rice paddies and in the moisture content of the soil. Both promote the availability of suitable nesting sites for rats by increasing the area available for burrows and by proving a moister and more pliable soil in which to burrow. Irrigation also allows the growing of crops outside traditional seasons thus providing food for rodents when otherwise there would have been little available. Management of irrigation water also may mean a staggering of crop planting in a region. This leads to asynchronous crop production, which further extends the breeding season and productivity of rats.

(iii) *An increase in the area devoted to intensive cropping.* With increases in the human population more land has been converted to intensive cropping to help feed the extra mouths. This in turn favours those 'weedy' rodent species that thrive in agricultural habitats.

(iv) *Staggering of planting of rice crops over a large area.* Management of crops is often influenced by factors operating at a village or district level. For example the availability of labour to assist in harvesting activities may require farmers from the same village to stagger planting thus allowing labour or machinery to be available to all farmers in a village. The influence of irrigation management on rice crop planting is considered above.

(v) *Shorter rotation of cropped areas in shifting cultivation systems.* In upland areas where slash-and-burn agriculture leads to the clearing of forests for cropping, human population pressure has reduced the time between successive crops on a particular plot of land. In Laos the rotation period used to be between 10 to 14 years, but, recently, this has been reduced to five to eight years. The rodents of a particular area are thus being presented with food on a more regular basis which increases the multi-annual stability of their populations.

(vi) *Increased yields from new varieties of rice.* Increasing yields result in increasing concentrations of food for rodents within a particular area. This in turn may lead to higher population densities of rodents.

(vii) *Increased diversity of the types of crops in an area.* This increases the range of rodent species that can occupy a particular area. For example, *Rattus exulans* is a major pest in rice crops in Sumatra where a diversity of other crops are grown in close association with rice crops. Elsewhere in Indonesia this rodent species is generally only a minor pest of rice crops.

(viii) *Increase in practices such as ratooning.* In the Philippines there is an increase in the practice of leaving the rice stubble in the paddy to be used as fertilizer for subsequent crops. This provides shelter, less disturbance of nest sites, and a greater stability of food supply for rodent populations. Thus these populations survive in greater numbers through to the advent of the next crop. This method is considered in more detail below.

(ix) *Changes in government policies.* In Laos the government is encouraging the upland farmers who practise shifting cultivation to set up permanent villages. In the past, they have moved their entire village every 4 or 5 years after they have cultivated all of the suitable land that adjoins their current village. Permanent villages will result in the same areas being cropped season after season with the consequent development of a permanent food source for rodents in the area. In Vietnam, changes to the countries socioeconomic system for agricultural production have led to three rice crops being produced in some of the main rice producing regions, especially the Red River and the Mekong River deltas. This has led to a corresponding increase in preharvest losses in rice crops to rodents (see Chapter 2).

Case study — ratoon crops in the Philippines

The farmers on Mindoro Island, Philippines, are keen to expand the use of ratoon crops (crops grown from the previous year's crop) but are concerned about the likelihood of high rat damage of such crops. Lock-lodging the previous crop by foot or by use of a modified harvester promotes growth of the ratoon crop from the basal node. The stalks of the previous crop provide a good source of nutrients and ratooning circumvents the need to plough and burn the stubble and to reseed the rice crop. An even crop is produced and yields have been high. ***But*** *ratooning provides excellent harbour for rats. The minimal disturbance of the rice stubble postharvest is likely also to be favourable for rats.*

Any promotion of this 'new' method for ratooning crops should consider the likely impact of rats on yields. No research on rats in ratoon crops has been done.

All of these factors have provided significant short-term benefits to the rice grower but rodent populations have benefited as well. The effects on the rodent populations are unintended and in many cases were not immediately obvious nor were they anticipated by the agricultural managers in the respective countries. The reported responses of rat populations are not surprising to a population biologist. Without exception, changes to agricultural practices on a large scale to increase food supply extend the period during which high quality food is available, or reduce the level of disturbance to nesting sites; and will benefit 'selected' species of rodents that are typically opportunistic breeders and have high emigration rates.

5.4 Constraints on Farmers to Implement Control

Farmers in Southeast Asia face two major impediments to implementing effective rodent control operations. One is the lack of disposable income to buy rodenticides or barrier fences. The other is the lack of adequately trained crop protection officers to provide advice and infrastructure support to the growers. Countries such as Malaysia are notable exceptions to the latter impediment of insufficient trained protection officers.

There have been a variety of systems, implemented by various Asian countries, and aimed at providing affordable management strategies for individual growers. These include the MASAGANA 99 national rice program of the Philippines instigated in the mid 1970s which provided free technical help, and a non-collateral credit program, for the purchase of rodenticides if farmers followed the guidelines of the program. Other programs have been based on the use of subsidies to encourage farmer involvement in control operations. For example both Laos and Vietnam have introduced a bounty for rat tails in recent years.

The inadequacies of current training structures of officers involved in rodent pest management are covered in more detail elsewhere. An example from Laos underlines some of the major shortcomings of current training programs of crop protection staff. In Laos, the only expertise in rat management is in the lowland rice-growing areas. When people from the upland districts are sent to pest management training courses, they are trained in methods for controlling rat populations in lowland irrigated rice crops. These methods are inappropriate for an upland agricultural system based primarily on low nutrient input, shifting agriculture. In the lowland regions, Laotian farmers experience a low level of chronic rat problems. In contrast, farmers from the hill tribes in the upland regions suffer most of their losses from outbreaking populations of rats.

Cultural beliefs may provide another important constraint to the adoption of rodent control programs. The quote at the beginning of this chapter indicates the strength of cultural beliefs concerning rats in Penang State, Malaysia. Unfortunately, similar beliefs are common throughout Southeast Asia. In regions of the Philippines, growers are loathe to kill a rat because they fear that the relatives of the dead rat will invade their house and eat all of their best clothing.

In other places, cultural practices have evolved with rat control in mind. For example, in Javanese village life, rat tails are used as a token of goodwill when permission is sought from a village head for marriages and other celebrations to take place. Rat tails are also used as a sign of good faith by those seeking election to local positions. A gesture of several thousand rat tails to be presented to the village may be required by someone seeking local office.

One can also use the strong cultural and social ties of villagers to advantage. An effective rat control program cannot be conducted by a single farmer. Rats are highly mobile and will quickly reinvade a small patch of land where rat numbers have been reduced. To counter this mobility, rat control programs need to be adopted by a majority of farmers who grow crops in the same district. The village, therefore, needs to be the minimum unit for establishing a rat control operation.

5.5 Concluding Remarks

Many factors need to be considered during the development of effective management strategies for rodents in Southeast Asia. There are good reviews of the 'decision analysis/system analysis' approach to vertebrate pest management (Norton and Pech 1988) and of the principles and strategies of vertebrate pest management (Braysher 1993) in Australia. This chapter has highlighted how social, cultural, political and economic factors plus the rapid widespread adoption of major changes to agricultural practices, further complicate the management of rodents in Southeast Asia.

Understanding the technical and socioeconomic factors that affect the development and adoption by farmers of rat control practices is only part of the background investigations that need to accompany field research programs directed at managing rat populations. The difficulties that cultural beliefs pose for rodent pest operations in some regions emphasises the importance of determining how farmers perceive and react to pest problems (Norton and Heong 1988). The need for community-based programs (see van Elsen and van de Fliert 1990) and multi-media programs tailored specifically for the target audience (Posamentier 1994) are further integral parts of an effective rodent management program.

We finish this chapter by identifying two important challenges to pest managers that have not been mentioned. Whatever management strategy is developed, it will be unacceptable to the international community if, firstly, it does not promote ecologically sustainable control and, secondly, does not provide humane methods for control. Both are extremely important issues that are low on the priority of pest control officers and farmers in Southeast Asia. The underlying fact is that many farmers live on the borderline of poverty and therefore have little concern for the welfare of animals that compete for their food. Similarly, farmers are generally only concerned with obtaining the highest possible yield from their next crop, regardless of whether particular practices may cause deleterious effects on later crops or on the surrounding environment (an example is the use of diesel oil in irrigated crops affected by rats). Adoption of ecologically sustainable farming practices will require a major effort in education and extension. It is for this very reason that it is contingent on wildlife managers to take the responsibility of imposing both of these requirements — ecologically sustainability and humaneness — on the outputs of their research programs in this region.

CHAPTER 6

Rodents as Carriers of Zoonotic Disease: a Southeast Asian Perspective

'Whether in rural settlements or cities, there is often little public awareness of the presence or of the magnitude of diseases with rodent reservoirs and, consequently, relatively little action is taken to prevent their transmission; this is especially the case in the tropical developing countries.' —N.G. Gratz (1994)

Rodents are well known as carriers of a variety of diseases that can infect both humans and livestock. The large number of rats present in and around the rice fields of Southeast Asia exposes both humans and animals to a significant risk of contracting many of these diseases. Regular contact with rodents appears to occur quite frequently, therefore the control of rodents is a requirement not only for the economic risks these pests pose through their destruction of crops, but also through their ability to inflict harm upon humans and livestock via the transmission of infective disease.

Many rodent control activities require the handling of live or dead animals. Also, the housing arrangements for humans and livestock often lead to accidental contact as rodents share the same accommodation; and the use of rodents as food by humans and domestic animals such as dogs and pigs, compounds the problem of exposure to rat-borne disease.

There is only a small body of literature on the incidence of rodent-borne disease in Southeast Asia. This probably reflects a general inadequacy in the knowledge of the epidemiology of human and animal disease in the region. In the present study, it was clear from anecdotal evidence from rice farmers that disease rates were higher when rodent numbers were higher. However, there was no hard evidence for these observations and any claim of a causative link would be speculative.

6.1 Viral Diseases

Haemorrhagic Fever with Renal Syndrome (HFRS) (Hantaan virus)

Haemorrhagic fever occurs in many parts of the world (Childs et al. 1988) where it has been known by a variety of names; Korean haemorrhagic fever, epidemic haemorrhagic fever, nephropathia epidemica, far eastern nephroso-nephritis and Tula fever. The World Health Organisation standardised the name to Haemorrhagic Fever with Renal Syndrome in 1983 (WHO 1983). The many strains of this virus give rise to a wide variety of symptoms and there is considerable difference in the virulence of different strains. This virus was first isolated during the Korean war when some 3000 soldiers stationed in the demilitarised zone developed a new disease which caused the deaths of some 10 to 15% of those infected. As the first cases were reported from near the Hantaan River, the virus derived its name from this locality. It was only in 1976 that the causative agent was isolated in the Korean rodent *Apodemus agrarius*. Serological surveys have since shown that the virus is almost cosmopolitan, with the most virulent strains occurring in east Asia. In general, Hantaan virus has been found in urban populations of rodents, particularly in *Rattus norvegicus*. More recently it has been isolated from *R. rattus* and *Mus musculus* as well as a variety of other rodents (Childs et al. 1988).

The virus is passed from host to host via infected saliva, urine and faeces. The virus may persist for months outside the body of the host and can infect further hosts if they inhale the dust formed from dried infected faeces. Grain stores, in particular, present an ideal locality for the transmission of HFRS to take place.

6.2 Rickettsial Diseases

Tick typhus (Fièvre boutonneuse)

This disease, caused by the microorganism *Rickettsia conori*, results from the bite of an infected tick. The disease is found through Asia, the Middle East, and north and central Africa. It has been reported from Vietnam and Malaysia (Gratz 1988).

The principal reservoir of this disease is believed to be the dog, however rodents are an important reservoir of infection (T-W-Fiennes 1978). Marchette

(1966) reports that strains of this rickettsia have been isolated from *R. argentiventer* and *R. diardii.* Gratz (1988) proposed that rodents form the principal reservoir of this disease in the wild, whereas dogs serve to maintain the disease in the domestic environment.

Scrub typhus

Scrub typhus is found throughout Asia and has very serious implications for those infected. Spread by mites of the genus *Leptotrombidium*, the disease is primarily caused by infection with *Rickettsia tsutsugamushi*. While mortality rates are low if treatment is sought early, the mortality rate from this disease can be as high as 60%. Rodents are the principal reservoirs of this disease in Southeast Asia (Traub and Wisseman 1973) although other small mammals have been found to be infected with *R. tsutsugamushi* (Gratz 1988).

Studies in Indonesia have isolated *R. tsutsugamushi* from several common rodents (Nalim 1980). Table 6.1 presents a summary of those findings.

During this study, rats were collected also from other localities on Java, and from Kalimantan, Sulawesi, Timor, and Flores. All these specimens were found to be negative. Unfortunately Nalim (1980) does not give an indication of the numbers of rats examined. Thus we do not know the prevalence of infection by *R. tsutsugamushi.* It is evident however, that the disease does occur amongst rodents in Indonesia, that it is relatively widespread geographically and a variety of rodents can act as reservoirs of the disease.

Table 6.1 Results of a survey examining the preva lence of *Rickettsia tsutsugamushi* in various species of rodents from Indonesia (from Nalim 1980).

Location	Species	No. of animals	%+ve
N. Jakarta	*Rattus argentiventer*	12	9
	R. r. diardii	15	7
	Bandicota indica	36	3
S. Jakarta	*R. norvegicus*	12	17
Cikuray (Java)	*R. argentiventer*	9	22
Situgunung (Java)	*R. exulans*	25	8
Panel (Java)	*R. tiomanicus*	3	33
Owi (Irian)	*R. exulans*	2	50
Biak (Irian)	*R. exulans*	2	50
	R. r. septicus	2	50

Murine typhus

Murine typhus is caused by *Rickettsia typhi* and is also known as flea-borne or endemic typhus. It is considered by the WHO to be 'grossly underestimated in importance' (WHO 1982). Murine typhus is spread by bites from the flea, *Xenophylla cheopis* and has a mortality rate of less than 2% (Gratz 1988). The disease causes a wide range of symptoms including; myalgia, headache, nausea and vomiting, abdominal pain, constipation and seizure (Silpapojakul et al. 1993). This disease has been reported from throughout Southeast Asia where Traub et al. (1978) report that the primary mammalian reservoirs are *Rattus norvegicus* and *R. rattus* spp. The route of rickettsial transmission is still uncertain. Flea bites may be infective, but contact with infective faeces or crushed fleas is considered the most likely passage of the disease from host to host (Traub et al. 1978; Farhang-Azad and Traub 1985). What is certain is that rodents are a principal carrier and reservoir of this disease.

6.3 Bacterial Diseases

Leptospirosis

Caused by the spirochaete, *Leptospira* spp. leptospirosis is one of the most prevalent of the zoonotic diseases carried by rodents in rice fields. In fact, one of the names for this ailment is rice field worker's disease. The infection has symptoms not unlike influenza and the illness may last from several days to three weeks. Mortality is generally low, however some serovars can cause mortalities up to 20%. Infection occurs when an open wound, break in the skin or one of the mucous membranes comes in contact with water, moist soil or vegetation contaminated by the urine or faeces of infected animals, particularly that of rodents. Although the disease is widespread amongst mammals in Southeast Asia, those serotypes posing a threat to humans appear to be more common in commensal rodents (Nalim 1980).

Studies undertaken in Indonesia have indicated that almost all rodent species found in Southeast Asia can act as a host for *Leptospira* spp. (Table 6.2).

In Malaysia, leptospirosis has been reported to be particularly common among oil palm estate workers who come into contact with *R. jalorensis* (Smith et al. 1961). *Rattus argentiventer* is also a common reservoir of this disease in Malaysia.

Studies in Thailand (Harinasuta et al. 1976; Thanongsak et al. 1983), have shown *R. rattus* and *Bandicota indica* and *B. savelei* in the north east of

Table 6.2 *Leptospira* spp. isolated from kidneys of rodents from Indonesia. (From van Peenen et al. 1971).

Location	Host species	Serotype
Jakarta	*Rattus norvegicus*	*Leptospira bataviae*
	R. norvegicus	*L. javanica*
		L. tarassovi
West Java	*R. norvegicus*	*L. bataviae*
	R. diardii	*L bataviae*
		L. bangkok
	R. bartelsi	*L. javanica*
		L. celledoni
	R. argentiventer	*L. australis*
Sumatra	*R. diardii*	*L. javanica*
Sulawesi	*R. hoffmani*	*L. australis*

the country to be seropositive for *Leptospira autumnalis*, and *L. javanica*. These studies found negative responses for a range of other rodents including *R. losea*, *R. berdmorei* (sic.), *R. argentiventer*, and *R. exulans* as well as *Tupeia glis*.

In the Philippines, Carlos et al. (1970) trapped 730 rats in and around Los Baños, Makati, Manila and Sangley Point Naval Base. He found some 20% to be seropositive. No indication was given of the species of rat. Basaca-Sevilla et al. (1986) report the presence of *Leptospira* in rats but give no indication of the species of rodent.

Leptospirosis has also been widely reported from Burma, Vietnam and Taiwan. Rodent species responsible have not been identified, though it could reasonably be assumed that the species commonly found in the rice fields are involved in the transmission of the disease. In Southeast Asia, agricultural workers account for more cases of leptospirosis than any other group of workers (Tan 1973). Working with bare feet in rice paddies exposes the workers to considerable risk from infection. Leptospirosis also poses a significant risk for the animals that inhabit the rice paddy or nearby areas. Cattle and pigs are the main livestock affected by leptospirosis and in these, it causes renal problems and abortion.

Plague

Of all of the zoonotic diseases, the plague is most closely associated with rodents. Although no longer occurring in pandemic proportions such as those that occurred in 14th century Europe, this disease nevertheless still presents a very serious public health problem in many parts of the world. The plague was once very common in Southeast Asia and the western Pacific (Gratz 1990). Outbreaks of plague have been recorded in several Southeast Asian countries including Indonesia (Nalim 1980), Thailand (Tongavee et al. 1990), Burma, Vietnam and China (Gratz 1990)

The cycle of this disease is mammal–flea–mammal. The causative agent is the bacterium *Yersinia pestis*. Rodents are the primary hosts and human infection tends to be accidental. Brooks et al. (1977) report that the most common rodent reservoir species in Burma are *Bandicota bengalensis* and *Rattus exulans*. Velimirovic (1972) reported that *R. exulans* is the principal reservoir of the plague in Vietnam, however he claims that cases of the plague in China are not associated with rodents.

Work in Indonesia has revealed several species of rodents acting as carriers of the plague in central Java (Turner et al. 1974). This work is summarised in Table 6.3.

The above work reveals that plague is still a threat in Indonesia. Recent work there has concentrated on the eradication of the flea rather than the rat (Nalim 1980) however the presence of rats still poses a great threat with respect to the potential transmission of this disease.

Rat bite fever

This disease, which is found throughout the world, is caused by the spirochaete *Spirillium minor* which is transmitted through mucous which invades the infected individual after a rat bite. Incubation takes several weeks from the time of the rat bite and symptoms usually appear after the wound caused by

Table 6.3 Results of isolates from organs of rodents from central Java tested for presence of the plague bacillus *Yersinia cheopis* (after Turner et al. 1974).

Mammalian host	General habitat	Result of isolate
Suncus murinus	house	negative
Rattus rattus diardii	house	positive
	field	negative
R. exulans	house	positive
	field	negative
R. tiomanicus	house	negative
	field	negative
R. niviventer	house	negative
	field	negative

the bite has healed. Mortality is generally low, however, it can reach 10% in untreated cases.

Salmonellosis

Many different serotypes of the genus *Salmonella* have been reported to cause disease throughout the world. Humans are usually infected by ingesting water or food contaminated by faeces from an infected person or animal or through the eating of incorrectly prepared foods. A very large number of animals can act as reservoirs for this disease and rodents are certainly not the primary carriers. They can, however, be very effective in causing the spread of salmonellosis. Ngyen et al. (1974) found isolates of *Salmonella* in *Rattus exulans* and *R. norvegicus* from areas around Ho Chi Minh City. It is reasonable to assume that this disease occurs in rodents in most areas of Southeast Asia.

Salmonellosis also affects most livestock and causes gastroenteritis — in severe cases with septicemia. Given the high probability of contamination of livestock food by rat faeces, saliva and urine, this disease must pose a particular threat to domestic animals throughout Southeast Asia.

6.4 Helminth and Protozoan Diseases

Paragonomiasis

Caused by flukes of the genus *Paragonimus*, this disease has as its reservoir a large number of domestic mammalian hosts including cats, dogs, pigs and rats as well as man. Paragonomiasis is widespread throughout eastern and southeastern Asia (Cabrera 1977). Infected rodents have been found in the Philippines and flukes have been recovered from *Rattus norvegicus* (Cabrera 1977). In Taiwan they have been found in *R. norvegicus* and *R. coxinga* (Chiu 1962), and in Thailand, in *R. rattus*, *R. beardmorei*, and *R. rajah* (Vajrasthira 1969).

Toxoplasmosis

Toxoplasmosis is a cosmopolitan infection caused by the coccidian *Toxoplasma gondii*. Although the definitive host is the domestic cat, many other mammals, including rodents, can act as intermediate hosts and as significant reservoirs of the disease (Jackson et al. 1986; Jackson and Huchison 1989). It is reasonable to assume that many rats of all species in Southeast Asia are infected with this disease.

Leishmaniasis

Flagellates of the genus *Leishmania* cause this disease which has been reported from most areas of the world. There are many different forms of the disease, not all of which have been reported from Southeast Asia. A wide variety of symptoms result from infection with the different forms of *Leishmania* which vary widely in their pathogenicity. Rodents are important reservoirs of Leishmaniasis which affects both wild and domestic animals as well as humans (Gratz 1988). The exact role that rodents play as reservoirs of the disease is not clear.

Hymenolepiasis

The cestodes *Hymenolepis* spp. infect humans throughout much of southern Asia. The role that rodents play in the transmission of this disease is uncertain, however, it appears they may have a role in maintaining its existence in the absence of other hosts (Gratz 1988). In Malaysia, Singh et al. (1987) found infections of *Hymenolepis diminuta* in the forest rat *Leopoldamys sabanus*.

Raillietiniasis

Raillietiniasis is caused by a cestode for which rodents are the definitive hosts and the infection is spread by ingestion of food contaminated with the intermediate host — presumed to be an arthropod (Gratz 1988). Little is known of this disease which, in Southeast Asia, is caused by the cestode *Railletinia celebensis*. This parasite was found to occur in India in *Bandicota bengalensis* and *Rattus rattus* by Niphadkar and Rao (1969), however, little information exists to confirm its presence in Southeast Asia.

Schistosomiasis

Infection by trematodes of the genus *Schistosoma* is one of the most serious public health problems in the developing world. Several different species of this parasite cause very serious disease in those infected, however only one of these diseases, that caused by *S. japonicum* is endemic in Southeast Asia. Although man is the primary host for this trematode many wild and domestic animals also act as reservoirs for the disease and rodents are one of the prime carriers (Mitchell et al. 1991). Studies in China (Gratz 1988), the Philippines (Cabrera 1976; Pesigan et al. 1958) and Indonesia (Carney et al. 1974; Sudomo 1984) have reported the presence of *S. japonicum* in rodents (Table 6.4).

In Indonesia, schistosomiasis is endemic only in two very isolated areas, the Lindu and Napu valleys in central Sulawesi (Sudomo 1984). In these areas infection can be widespread with a number of primary hosts involved. Carney et al. (1974) found positive indications of infection by *S. japonicum* in at least four species of *Rattus* (Table 6.4).

Table 6.4 The results of a survey of several species of rats examined for *Schistosoma japonicum* in Indonesia (after Carney et al. 1974).

Species	No. Examined	No. Positive	% Positive
Rattus exulans	2183	439	20.1
R. marmosurus	41	4	9.8
R. hoffmanni	180	43	23.9
R. chrysocomus rallus	54	5	9.3

Carney also found one specimen of *Rattus celebensis* which was positive for *S. japonicum.* Thus, although they are not the principal host for this disease, they are nonetheless important reservoirs of infection.

Angiostrongyliasis

Angiostrongyliasis, or eosinophilic meningoencephalitis causes symptoms typical of meningitis, and as its name suggests, is characterised by the presence of eosinophilic leucocytes in the cerebrospinal fluid. First reported in 1944 on Japanese occupied Taiwan (Beaver and Rosen 1964), angiostrongyliasis is believed to have been restricted to eastern China until it was spread via the Japanese occupation of much of south and southeast Asia and the Pacific.

The disease is caused by the third-stage larvae of the rat lungworm *Angiostrongylus cantonensis.* The adult worm lives in the lungs of the primary host, a rodent. Eggs laid by the worm develop into first stage larvae which crawl up the trachea of the rodent and are swallowed and pass out in the faeces. A variety of molluscs act as true intermediate hosts by ingesting worm larvae after feeding on rodent faeces. Several weeks development in the mollusc leads to high levels of infection with third-stage larval *A. cantonensis*. Ingestion of the infected mollusc leads to infection with the parasite. After infecting the primary host, whether it be rodent or human, the parasite enters the circulatory system of the gut, and is carried passively to the heart. Some larvae migrate via the pulmonary artery to the lungs, others reach the brain and accumulate in the grey matter of the brain, spinal cord and nerve roots. The worms undergo two moults in this tissue then leave the brain for the lungs via dilated cerebral veins. Although there is no known treatment, angiostrongyliasis is rarely fatal.

Up until 1992 some 2500 cases of this disease had been reported although the number of actual cases must be many times this number (Kliks and Palumbo 1992). The disease is widespread throughout Southeast Asia and has been recorded in at least ten species of *Rattus* as well as from *Bandicota indica* (Gratz 1988). Margonos and Ilahude (1974) found *A. cantonensis* infections in *R. diardii, R. argentiventer* and *R. norvegicus* in areas around Jakarta whereas Lim et al. (1965) reported the nematode occurring in *R. annandalei* and *R. jalorensis.*

Capillariasis

Capillaria hepatica infections are extremely common among rodents and other mammals throughout the world (Baylis 1931; Read 1949) and although this nematode infects humans there is very little evidence that it is at all pathogenic (Kumar et al. 1985). In Indonesia, a survey of 147 *Rattus argentiventer* revealed that 74 had livers infected with *C. hepatica*, an infection rate of 50.3% (Tjahaya Haerani S.A. Saenong 1984).

Trichinosis

Rats are part of the commensal animal cycle of trichinosis, the disease caused by the nematode *Trichinella spiralis.* Trichinosis passes to humans through the eating of infected meat, and the disease ranges in severity of symptoms from relatively mild discomfort to death. The rats become infected in the same way that pigs do, via the eating of infected porcine muscle. Particularly susceptible are rats living in garbage dumps or areas where they have access to raw household wastes. Pigs feeding on the carcasses of dead rats are a frequent source of infection in villages in which pigs are allowed to feed around the streets and houses (Gratz 1988). However, studies in Thailand have shown very few rats to be infected with *T. spiralis* even during serious outbreaks of the disease amongst the human population. Dissamarn and Indrakamhang (1985) examined 1125 rats and found none with evidence of infection with *T. spiralis*. Kettivuti (1983) however, reported that rats do play a role in the spread of the disease in Thailand.

CHAPTER 7

The Potential of Non-Chemical Methods of Rodent Control

'The only general rule about the influence of natural enemies on vertebrate host/prey populations that emerges...is that there are no general rules. Every case would appear to deserve specific consideration and opportunities may exist that are not immediately obvious.' — Brian J. Wood (1985)

In Chapter 3 we provided an overview of the literature on rodenticides as it related to rodent pest management in Southeast Asia. In this chapter we will consider the prospects of non-rodenticide techniques.

The chapter is divided into three main sections: biological control, physical or mechanical control and manipulation of farming practices. Sterility control through the use of chemical analogues or hormone treatment will not be considered because the prospects of using them to control rodent pest populations are remote. Some sterility agents work well under laboratory conditions but not in the field because they are either too expensive to use on a broad scale or fail because field populations of rodents are able to compensate moderate levels of sterility (see Marsh 1988; Bomford 1990 for review).

Occasionally, mechanical control, sterility control and habitat manipulation are combined under the one banner of biological control. We prefer to consider them separately and confine 'biological control' to only those methods that use true biological agents such as micro- or macroparasites and predators.

One special case of sterility control, immunosterility, will be considered in the biological control section because infertility is conferred by an immunological response to a protein delivered by a virus.

7.1 Biological Control (Diseases)

Background and potential

Biological control has been defined as the action of biological organisms to maintain another organism at a lower average density than it would attain in their absence (Waterhouse and Norris 1987). Operatively this is a sufficient definition, however, from a wildlife management viewpoint a biological control agent would only be successful if the effect on the pest organism is maintained below a defined density. This density is generally related to the 'economic injury level' of a rice farmer, forester, grazier, etc. If the damage by a pest species is below this level then the species is tolerated and further control is not required.

There have been numerous successful biological control programs instigated against plants and insects. In vertebrate populations, the only successful control program has been the use of the myxomatosis virus against rabbits (see Fenner 1983 for details). This dearth of successful biological control programs for vertebrate pests is largely because of insufficient effort by researchers and not because the problems are insurmountable. This lack of effort is due partly to disease not being regarded as an important limiting factor for vertebrate populations during the 1950s 1960s and 1970s — and partly to the number of failed introductions of vertebrate predators to control pests, introductions, which in many cases, led to additional biological problems (see Spratt 1990 for details).

Interest in the potential of biological agents to regulate or limit vertebrate populations was sparked in the late 1970s when theoretical models indicated that micro- (viruses, bacteria, protozoans) and macro- (helminths, arthropods) parasites could regulate host populations (see Anderson 1980 for review). This increased interest was accompanied by a more positive attitude to the potential of biological agents to control vertebrate pest species, as attested in a series of reviews on the potential of parasites (Scott and Dobson 1989; Spratt 1990; Singleton and Redhead 1990; Singleton 1994), predators (Sinclair 1989; Pech et al. 1992) and both parasites and predators (Wood 1985) to regulate vertebrate (generally pest) populations.

A recent series of laboratory experiments on the dynamics of a mouse–nematode interaction have vindicated the conclusions drawn from the mathematical models (Scott 1987, 1990). Unfortunately, the modelling and laboratory studies are a long way ahead of field studies. Some small-scale enclosure experiments have been conducted on small mammal populations (Barker et al. 1991; Gregory 1992) and a large-scale replicated and manipulative field trial is in progress to examine the effect of a liver nematode, *Capillaria hepatica*, on field populations of house mice, *Mus domesticus*, in Australia (see Singleton et al. 1995).

Current research on biological control in Southeast Asia

There is little research in progress in Southeast Asia on biological control of rats. To put it simply, the expertise is lacking. One notable exception is research on the use of predators to control rodents. We will consider predators in a later section.

Interest in the potential of using biological agents to control vertebrate populations is gaining momentum. There is strong interest in Thailand and Vietnam of the prospect for biological control of rodent pests. Both countries have some research in progress but it is at a very early stage.

In Vietnam, the candidate is a zoonotic bacterium, *Salmonella enteriditis*. It is proposed that a strain toxic to rodents but less so to domestic animals and humans be formulated. One strain has been identified (D-I7-F4) and has been formulated for delivery in baits (Pham Van Toan pers. comm. 1993). The potential for widespread use of this organism for controlling rodent pests in agricultural crops is limited because of risks to other small vertebrates. It must be stressed that only a few species of small mammals in Southeast Asia and Indo-China are pests of agriculture. The remainder are an integral part of the natural ecosystem and should be protected from non-target poisoning.

In Thailand, the project is about to begin. There they will be examining the effectiveness of a protozoan, *Sarcocystis singaporensis*, for controlling *Rattus argentiventer* (T. Jäkel pers. comm.). This research is at a very early stage. Because rats are an intermediate host of the protozoan, there will be time delays in transmission to other rats; also the rate of transmission will be dependent on the density of the definitive hosts. The definitive hosts are mainly snakes, which are generally at low densities in intensive agricultural regions of Southeast Asia. Thus, the rate of transmission is likely to be low. Therefore the protozoan only offers hope as a biocide (a biological agent that is presented in a bait to kill animals rather than relying on natural transmission).

For *Sarcocystis* to be used successfully it needs to satisfy two main conditions. First, it needs to be highly pathogenic to rats under field situations. Second, its cost of production and distribution will need to be competitive compared with existing chemical rodenticides. If the first condition is met and not the second, then the adoption rate by farmers who generally have very little disposable income, is likely to be low.

Immuno-sterility — a new prospect and possible generic approach

Generally, people equate biological control with an agent that causes high host mortality. Certainly this was the case in the successful use of myxoma virus to control European rabbits in Australia. The successful epizootic of myxoma in 1950 led to a greater than 99% mortality rate of rabbits (Fenner and Ratcliffe 1965). Increased mortality of the host is not the only avenue to successful biological control of mammalian pests. A feature of the life history of mammalian pests is their high potential reproductive rate. This is particularly so with rodent pests which typically reach maturity in 5 to 7 weeks and produce a litter every 3 to 4 weeks. Rodents are also typically opportunistic breeders and are able to rapidly take advantage of an extension in suitable conditions for breeding (e.g. the change in production from one to two rice crops per year resulted in a change from one to two breeding seasons per year, Lam 1980). Therefore, a biological method that can reduce their breeding performance may enable the effective management of mammalian pests such as rodents (e.g. Caughley et al. 1992).

Fertility methods that use steroids or other agents to block gonadal regulation hormone (GnRH), affect the normal hormonal function of reproductive organs and treated animals become socially subordinate (see Bomford 1990 and Tyndale-Biscoe 1994 for discussion). In pest species with a high reproductive potential the loss of these animals would rapidly be compensated.

Another approach is to induce sterility from an immunological reaction to proteins of sperm (e.g. structural proteins) or ova (e.g. zona pellucida). Sterility is produced through blocking fertilisation or implantation of the ova. In either case, there would be no interference with the steroidal functions of the animal's gonads. Thus a sterilised animal should be able to maintain its social status.

Once an immuno-sterilising agent is developed, the next challenge is to sterilise a sufficient proportion of a population to enable effective management. Delivery of the agent may be by baits or by a species-specific disseminating recombinant virus.

A Cooperative Research Centre (CRC) for Biological Control of Vertebrate Pest Populations, with its headquarters at CSIRO Division of Wildlife and Ecology, Canberra, Australia, is at the forefront of research on immuno-sterility and methods for the delivery of a sterilising agent. The concept and progress of the research is reviewed by Tyndale-Biscoe (1994).

The current focus of the CRC is on the biological control of rabbits and foxes. However, much of the basic research supporting the potential of this approach was on laboratory rodents. For example, sperm antigen (Shagli et al. 1990) and zona pellucida peptide (Millar et al. 1989) have been shown to cause contraception in rats and in mice. This work on rodents has been restricted to the laboratory but has great potential for use in controlling rodent pests (see Singleton and Redhead 1990, for discussion).

A survey of murine viruses in mice, *M. domesticus*, in southern and eastern Australia (Smith et al. 1993) and a study of the dynamics of the seroprevalence of six of these viruses in a wild mouse population (Singleton et al. 1993), provided essential information on which of these viruses could be a candidate vector for an immuno-sterilising agent of mice. Other criteria in the selection process include the ease of genetic manipulation of the virus, its species-specificity and features of the life history of the virus (see Shellam 1994 for details). A herpes virus has been chosen as the most promising vector of a mouse immuno-sterility antigen. If successful, this system could provide a generic model for controlling pest species of Asian rodents.

It has taken 5 years to get to this stage with the mouse system and it could be another 5 years before field trials can be conducted. However, if successful, the spillover effects will be substantial and the time required to do similar research on Asian rats should be considerably shorter. An important first step in Asia is to conduct the ground work on the basic population biology of both host and pathogens and the associated epidemiology of the interaction between host and pathogen. This information is lacking for Southeast Asia. Surveys of potential pathogens of key rodent pests need to be conducted along the lines of that done on house mice in Australia so that candidate viral vectors can be identified.

Infrastructure and expertise to conduct disease-based biocontrol research in Southeast Asia

Expertise in molecular biology and genetic engineering are developing at a rapid pace in most Asian countries. These skills are only part of the equation for an effective research program on the biological control of rodents. An effectual infrastructure is required to enable a multidisciplinary approach which incorporates molecular biology, virology, epidemiology, reproductive physiology and population ecology. Of the countries we visited, Malaysia, and possibly Thailand, have the requisite infrastructure.

In Malaysia, MARDI and the Faculty of Veterinary Medicine and Science, University Pertanian Malaysia, have the infrastructure and much of the expertise to conduct research into biological control of rodents. What is lacking is an overview of how the research elements interlock, and expertise in aspects of the epidemiology, population ecology and reproductive physiology of rodents. A collaborative link with Australian scientists at CSIRO Division of Wildlife and Ecology would cover these gaps in expertise and provide the best opportunity in Southeast Asia for examining potential biological control candidates, particularly for immuno-sterility, of the rice field rat, *R. argentiventer*. Because *R. argentiventer* is one of the major preharvest pests to rice crops in most Southeast Asian and Indo-China countries, there would be substantial spillover benefits from research conducted in Malaysia.

Restrictions in time and resources meant that we were unable to follow up the situation in Thailand.

7.2 Biological Control (Predators)

At any international meeting that has a session on the management of small mammals, the potential of predators as biological control agents will be discussed. Claims of successful control of rodent pests by avian predators come from countries as diverse as China, Israel and Malaysia. Without exception, these claims lack clear scientific support. Unfortunately, the lack of good replicated and manipulative field studies to support such statements are not unusual in the field of wildlife management (see Sinclair 1991).

Some data do suggest that avian predators are a major cause of density dependent mortality in field voles, *Microtus agrestis*, in Sweden (Erlinge 1987; Erlinge et al. 1988), in wood rats, *Rattus tiomanicus*, in oil palm plantations in Malaysia, and in house mice, *M. domesticus*, in cereal farms in Australia (Sinclair et al. 1990).

In the case of the mouse–raptor system, predators appear only to be able to regulate mouse numbers up to a threshold prey density. Above this value, if environmental conditions favour high reproduction by mice, the mouse population will increase faster than the predation rate and mouse populations will escape regulation (Sinclair et al. 1990). A model of the interaction between barn owls, *Tyto alba*, and wood rats in Malaysia, led Smal et al. (1990) to arrive at a similar conclusion. In oil palm plantations, the effect of barn owls is likely to be minimal if rat populations rise above 60 to 70 rats/ha.

The potential faster numeric response by prey species of rodents than their predator species is just one problem that besets efforts to use predators as biological control agents. Another problem is the ability of prey species to maintain their densities when prey densities are low (e.g. near the end of the non-breeding season). This can be offset somewhat if the predator is highly mobile. For example, avian predators can aggregate or disperse in response to changes in prey densities in space and time.

Returning to the barn owl–wood rat system, shortage of nesting sites appears to be an important limit to the growth of barn owl populations (Duckett 1991, in Smith 1994). Smal et al. (1990) estimated that one breeding pair per 6 to 8 ha was required for owls to effectively control rat populations. The introduction of nest boxes (one per 5 ha) increased the owl density to the requisite level and it was the aggregation and dispersal of non-breeding juvenile owls that enabled the predator to respond to fluctuations in rat densities. A key point to come from this study is that compensatory migration by predators would work only if a few plantation owners use nest boxes (Smith 1994).

Further research is required to test the generality of the impact of owls on rats in oil palm plantations and to examine the mechanics of this interaction. For example, is there differential predation of rats based on their size and sex class and their habitat use? If so, how does this affect the productivity of the prey population? In house mice, one study reported that barn owls took a greater proportion of juvenile females than other age or sex classes of mice (Dickman et al. 1991). The differential predation rate was correlated with the greater use of open vegetation by juvenile females compared to adults. In this situation, the impact of owls on the breeding population of the mice was minimal. This type of information would assist in assessing whether barn owls would be as effective in controlling rats in rice fields as they are in oil palm plantations. The open spaces and comparative paucity of nesting and perching sites in rice fields would suggest not.

The potential of vertebrate predators to control vertebrate pests is gaining acceptance (see Newsome 1990) and the above examples lend credence to this potential. So, rather than dismiss poorly documented claims that predators can control rodent pests, we should be encouraging well designed studies to assess the impact of predators on their prey species. Whatever the role predators may play in controlling rodent populations, it is clear that reduction in predators, particularly avian predators, should be avoided.

As an interesting aside, there have been no studies of the impact of human 'predation' on rat populations in regions where rats are used as an important protein supplement to the human diet. Rats are a common source of human protein in Laos, the Philippines and Vietnam. The greatest impact humans would have on rat populations would occur when rat densities are low. Hunting rats at low densities may regulate rat numbers through maintaining their densities at low levels ('predator pit'). Increased development and better transport links to isolated regions, will increase availability of other sources of food which require less energy and time to obtain. Rat problems may escalate as a consequence.

7.3 Physical Methods of Control

Physical methods to exclude rats from high value crops (e.g. seed nurseries for rice crops; research plots) or crops faced with a high risk of rodent damage (e.g. early or late sown crops) are in use in a number of countries in Southeast Asia. The major shortcoming of these methods are the cost of the materials, the high person-power requirements to maintain barriers, and the ability of rats to climb most surfaces and to penetrate small gaps.

Rice as a 'trap crop' for rats

Researchers in Malaysia have capitalised on the ability of rats to find weaknesses in a barrier system. They inserted multiple capture live-traps in the corners of rectangular fences, providing the rats with an entry point to the crop being protected. The fence is about 500 mm into the irrigated crop with traps placed on mounds of soil. Rats appear to take the line of least resistance when they come to the fence, following it until they come to a dry mound and then climb up and enter the trap. Instead of entering the crop the rats are caught in the trap (Lam 1988, Lam et al. 1990a).

This combination of a fence plus multi-catch traps is referred to by the Malaysians as an 'Environmentally Friendly System' (EFS). The fence is 1 m high with the bottom buried 50 to

100 mm into the ground. The opening of the funnel trap is flush with a hole in the fence and traps are placed on raised mounds just above the water level. The number of traps in a fence depends on the length of the fence and the size of the rat problem. Generally, there is one trap in each corner of a rectangle. The fences used by MARDI tend to be of plastic supported by bamboo stakes, but local farmers often use recycled metal.

Up to 129 rats have been caught in one trap (26 × 28 × 62 cm) in one night (Lam et al. 1990a). In one region, 56 320 rats were caught during eight trapping periods (trapping periods ranged from 33 to 116 days). Trapping commenced around 46 days after planting and generally 60% of the total catch was obtained within the first 3 weeks of trapping. Benefit-cost assessment of the EFS in this area in Malaysia which had a severe rat problem (56% of farmers had complete yield losses the year previous) provided ratios of 19:1 to 28:1 using plastic fences and 7:1 using metal fences (Lam et al. 1990a). These estimates did not take into account the cost of person-power to build or maintain the fences.

The effectiveness of the EFS in Malaysia is summed up by the following quote: 'The use of physical barriers and traps is recommended in areas with high endemic rat infestations, in areas adjacent to large tracts of abandoned rice land and in asynchronously planted areas.' (Lam 1990).

Engineers at IRRI modified the design of the Malaysian fence and developed a cheaper fence which had traps every 15 m rather than only in corners. The Active Barrier System (ABS) has proven so successful at the IRRI research farm that, of the previous control methods, electrified fences have been virtually phased out and the use of chemical baits has been reduced. Before the ABS was introduced, there were 160 people employed over two shifts to control rats. The implementation of the ABS plus the replacement of open drains and irrigation channels, and the synchronisation of cropping schedules, has seen the removal of the night shift and a major reduction in the rat patrol team from 160 down to 40 persons (Quick pers. comm.).

The studies in Malaysia and the Philippines have clearly indicated the potential of the barrier plus trap systems. Both groups have recorded substantial reductions in crop losses when the EFS or ABS is used (Lam et al 1990a; Quick pers. comm.). Unfortunately, the surrounding rat population was not monitored in either case. It is not known whether the breeding condition, sex ratio and age structure of the rats that enter the traps are representative of the source population or whether the rat population in the vicinity of the traps is able to compensate for the loss rate.

Why should one be interested in the population structure, breeding behaviour and dispersal of the rat populations?

In the developed world, attempts to control vertebrate pests by physical barriers ('passive' barriers) have met with success only if done on a large scale (e.g. the dingo fence in Australia which is >10 000 km long), with a large initial outlay of funds, and with a high maintenance budget (e.g. Queensland paid $A3.5 million in 1982 to upgrade part of its dingo fence). Attempts to control vertebrate pests through trapping and shooting (e.g. bounty system on dingoes, foxes and rabbits in Australia) have met with little success.

There are two main reasons for the ineffectiveness of 'passive' barriers and bounty systems. One is that pest species generally have a rapid turnover of their population and are well adapted to compensate for moderate increases in the rate of loss of animals from their population. The other is that generally most of the animals removed are social subordinates or weanlings; the breeding nucleus of the population remains intact.

If the rats are compensating for the rate of loss of animals being trapped, then a farmer using an ABS will be literally harvesting rats without having a marked effect on the population density. Moreover, if there is a density effect on breeding performance of rats, then the continual removal of animals from the population could extend the breeding season and also increase the rate of maturation of young rats. This in turn could lead to a greater population density than would otherwise be obtained and an extension of the time that rats are at densities greater than the tolerable 'economic injury level' of farmers.

The ABS could therefore potentially lead to an increase in rat problems to neighbouring growers that do not use the fence. Also, the artificial maintenance of densities outside the fence could increase the risk of rapid invasion of the crop by rats if the fence is not adequately maintained — information on this is needed so that future users can be informed whether there is a need for continual vigilance right up to harvest.

Finally, there is known to be intra- and inter-species differences in the trappability of rodents (e.g. Krebs and Boonstra 1984; Singleton 1987). This could present two problems. First, if there are two species of rodents and one is more trappable than the other, then the less trappable species may become a greater pest. This would occur if there is a concomitant decrease in competition for resources following a decrease in density of the trappable species. Second, if there are intra-species differences in trappability then we do not know whether a decrease in capture success reflects a representative decrease in the density of rats in the neighbouring crops or just a decrease in the trappable population.

There is circumstantial evidence at the IRRI farm that the level of rat damage to rice is less in the areas outside of, but in the immediate vicinity of, the ABS (G.R. Quick, pers. comm.). If such a 'halo effect' exists then differential trappability of *Rattus rattus mindanensis* would not appear to be a problem. This needs to be verified by live-trapping studies.

The possible 'halo effect' of an ABS is being promoted as providing protection to adjoining unfenced rice. There are no data to support these claims outside that collected at the research farm at IRRI.

Effect of barrier systems on rat population dynamics

A collaborative 15 month project between scientists of CSIRO Division of Wildlife and Ecology, Australia and of the Agricultural Engineering Division of IRRI, Philippines, was conducted in Calauan, southern Luzon, Philippines, to assess many of the questions raised about the impact of barrier systems on rat population dynamics. The collaborative project was funded by an ACIAR special purpose grant.

The project began in June 1993 and had the following objectives:

(1) To undertake a study of the population dynamics and dispersal patterns of rats in and around rice crops which have an ABS and those which do not.

(2) To determine whether the rats that enter the traps of the ABS are representative of the surrounding population of rats.

(3) To assess whether an ABS produces a 'halo effect' by reducing rat numbers in neighbouring crops that are not fenced.

(4) To assess the relative benefits of strip (Active Linear Barrier) versus enclosed fences (ABS).

This population study assessed the behaviour of the rats towards the fence (through mark-release-recapture and radio-tracking individual rats) and whether this harvesting approach led to compensatory increases in survival, breeding and rates of maturity of neighbouring populations.

The replicated ecological study was of a relatively low density population of rats; at the beginning of the study there were approximately 120 rats per hectare but thereafter densities were generally less than 20 per hectare. The principal findings were:

- More adult (particularly male) and less juvenile rats were caught in traps associated with the barriers to those caught in traps located in the immediate vicinity or on farms where no barriers were present.
- The barriers had no significant effect on the density of the surrounding population of rats.
- The barriers provided no greater protection of crops in the immediate vicinity of the barriers (i.e. no 'halo effect').
- Movements and home ranges of rats were no different on sites with or without barriers. Home range size depended on the synchrony of crop development within a local region: rats 'tracked' crops once they became milky ripe. The average home range for male rats was approximately 0.6 ha just prior to or post harvest and 1.8 ha during the milky-ripe stage. The average home range for female rats was approximately 0.3 ha just prior to or post harvest and 0.8 ha during the milky-ripe stage. Home range size also increased with age of the rat. Linear movements of >275 m by 7 of 12 rats occurred on 17 occasions when the crop was milky-ripe. Only one of 30 rats covered such a distance just prior to or post harvest.
- More rats were captured in barriers placed in early maturing than later maturing crops.

Overall, physical barriers with traps had no effect on rat populations or on the level of damage to rice crops during a 14 month period when rat densities were generally 20/ha or less. The radio-tracking indicated that rice crops beginning at the milky-ripe stage are attractive to rats, supporting the contention by Lam (1988) that crops at this stage could be used as a lure to rats if they are fenced with traps (trap crop concept).

The consistently low densities of rats during the study restricted the generality of the findings. Low rat densities led to low sample sizes and to low levels of rat damage to both the 1993 wet season and the 1994 dry season crops. In particular, the low levels of damage severely restricted assessment of whether an ABS produces a 'halo effect'.

The findings from the collaborative CSIRO/IRRI project indicated three promising areas for further research.

Examine critically whether physical barriers plus traps are of greater benefit if earlier maturing and more aromatic rice is grown within their borders ('trap crop') compared to that grown outside. A 'trap crop' may then generate a 'halo effect'.

Determine the range of densities over which an ABS would be cost effective. Lam (1992) has shown benefit–cost ratios of greater than 19:1 when rat densities are very high, we have shown negative returns for densities of 20 rats per hectare or less.

Determine the optimal configuration (size of barrier and spacing of traps) and number (per hectare) of barriers for particular crop management systems.

Extending the 'trap crop' concept

The concept of using rice itself as a 'trap crop' (Lam 1988) is being extended to include aromatic early-maturing varieties of rice. Small plots of this aromatic early-maturing rice are planted within the normal rice crop. The expectation is that rats will be attracted to the 'trap crop', thus protecting the surrounding rice crop.

Preliminary studies of this concept are in progress in Indonesia. If the concept shows promise, research will be needed on the optimal ratio between 'trap crop' and normal crop, the best location of the 'trap crop' in the agricultural landscape and the general applicability of the concept in different rice growing systems. The last point covers the broad range of rice systems (e.g. lowland, upland, tidal rice; irrigated, non-irrigated; etc) as well as the heterogeneity of the local landscape (e.g. large tracts of rice in a major irrigation district; rice grown in areas adjacent to large tracts of abandoned land) and local farming practices (e.g. synchronous versus asynchronous planting).

Current use of barrier systems

The EFS/ABS and variants (usually without traps) are in use in the Philippines, Malaysia, Indonesia and Vietnam. The simple 'technology' is still too costly for most farmers (US$1 per metre), however, there is much interest in the concept. These fences are most popular with farmers for use around seed beds in which rice seedlings are grown for transplanting.