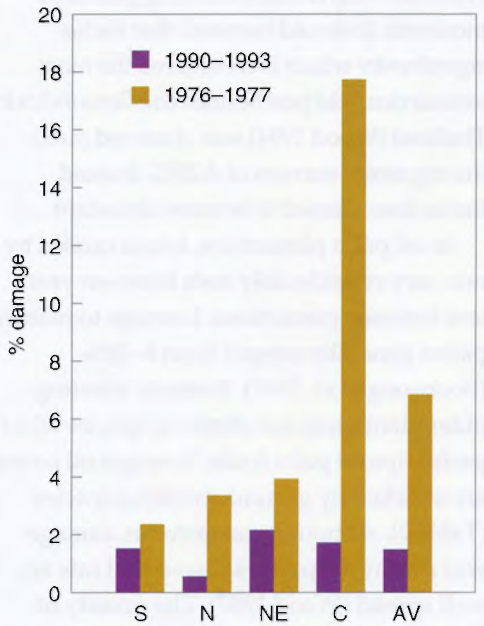

Figure 1.
Average pre-harvest damage (%) in rice in southern (S), northern (N), north-eastern (NE), and central (C) Thailand, and the average (AV) of the four regions from 1990–1993 compared with 1997–1977 (Hongnark et al. 1993).

Damage in upland

Upland is defined as those areas that are 600 m above sea level. In Thailand, most upland is in the north, with some in the north-eastern and southern regions. In these areas, rice, wheat, barley, temperate fruits (apple, pear, strawberry, macadamia etc.), vegetables (cabbage, carrot, onion, broccoli etc.) and coffee are cultivated. In upland, rice damaged by rodents appears to be generally low. Birds such as spotted munia (*Lonchura punctulata*), sharp-tailed munia (*Lonchura striata*) and Pegu sparrow (*Passer flaveolus*) are more problematic (Hongnark et al. 1984). In the north-east, four species of rodents (*B. indica*, *R. losea*, *Mus cervicolor*, *Mus caroli*) are a problem in wheat (damage 6.4%, Hongnark et al. 1994). In the north, these species—and additionally *Rattus rattus* — occur in barley plantations which mainly serve the brewing industry. Various plots in a field of 800 ha were damaged by 0.4–17% during harvest (Artchawakom et al. 1986).

Rodents as Carriers of Disease

A recent outbreak of leptospirosis in a rural area in north-eastern Thailand killed 107 people between October–December 1997 while a total of 2,236 had to be treated for leptospirosis during that year (Chokvivat 1998). The incident was broadly covered in the media and it drew fresh attention to the rodent problem. Although it is not clear which rodent species actually transmitted the disease, this incident emphasises the need for a better knowledge of the epidemiology of rodent-borne diseases in this region. During 1986–1988, only 466 cases of leptospirosis were reported. This record is believed to underestimate the real incidence of the disease because laboratory facilities were not appropriate for screening of large numbers of blood samples from all parts of Thailand. Frequently, leptospirosis is incorrectly diagnosed as influenza or a virus infection (Silapapochakul 1992). As a consequence of the recent outbreak of leptospirosis, the Environmental Health Bureau (Department of Health) started an extension program (three years, 1998–2000) to monitor and control leptospirosis in north-eastern Thailand. The activities include (i) training of officials of the Department of Health working in regional health centres in appropriate protection against leptospirosis, (ii) training of local technicians to work on rodent population estimation in urban areas, and (iii) training in correct and efficient use of rodenticides. Also, universities in Thailand (i.e. Mahidol) started to focus on diseases transmitted by rodents.

B. indica in Thailand and *R. norvegicus* were found to be infected with species of the hantavirus family (Schmaljohn and Hjelle 1997), members of which are responsible for an increasing global health problem. The Seoul virus carried by Norway rats is known to induce haemorrhagic fever with renal syndrome in humans, a condition which can be potentially fatal (Schmaljohn and Hjelle 1997). Sera collected from wild rodents (*B. indica*, *M. cervicolor*, *R. losea* and *R. rattus*) caught in rural areas of Chiang Rai Province, northern Thailand, were positive using an immunofluorescent antibody test (Lietmeyer 1988).

These two examples of rodent-borne diseases are especially relevant to Thailand and form only a part of the long list of pathogens in rodents that can affect humans. This subject has been dealt with in detail previously (Gratz 1994; Singleton and Petch 1994; Schrag and Wiener 1995). It must be noted that humans in Thailand do not only have close contact with rodents (be it in the rice field or inside houses), but additionally, rodents form a part of the diet of the rural population (see also below). Of 142 and 123 farmers who were surveyed for their rodent control practice in two different regions in northern Thailand, 79% and 55%, respectively, reported consuming rodents regularly (Boonsong et al. 1994). In particular, *B. indica* is highly regarded as a meat source.

Current Control Methods and Extent of Adoption by Farmers

Since the Thai–German Rodent Control Project was set up in 1975, systematic, preventative rodent control methods have been recommended for use in rice and field crops (Weis 1981). After the project ceased in 1979, the Department of Agricultural Extension continued promoting the methods in all regions by establishing the Rodent Control Campaign Project (1988–1993). The objective of the project was to decrease rodent populations in agricultural areas and to maintain low populations by training 2,500 extension officers at the subdistrict level to have a good knowledge of rodent control which they could transfer to 250,000 farmers. The operating area included rice fields in 40 provinces, field crops in 12 provinces, and oil palm and cacao in 12 provinces. The total area was 0.864 million hectares with extension plots (where rodenticides were provided through governmental funds) of 16,000 hectares in 40 provinces. After the first year, the Division of Project and Programme Evaluation, Office of Agricultural Economics, undertook an evaluation of practical adoption by farmers (Anonymous 1989). It revealed that most farmers accepted systematic and preventative rodent control. The survey evaluation showed that all farmers in extension plots were highly accepting of mechanical or physical control techniques, but 33% did not accept use of chronic rodenticides. In extension plots, 67% of farmers accepted use of both acute and chronic rodenticides. Acceptance of these poisons in service areas (those areas that had to buy rodenticides on the private market) was less than 10%. After this initial evaluation was completed, the Department of Agricultural Extension continued the Rodent Control Campaign Project for five years until 1993.

In rice and field crops, the control method consists of two steps (Weis 1981); knock down of the rat population and subsequent maintenance at low density.

▶ Knockdown step

Chemical control with zinc phosphide or trapping, digging, blanketing or drives. Blanketing or drives are conducted by groups of people who circle an area (about 0.24 ha), cut the vegetation and herd the rats into a small area (2–4 square metres) before they are caught or clubbed.

▶ Maintenance of population at low density

Mechanical or physical methods as mentioned above and chemical control using chronic rodenticides (anticoagulants) such as coumatetralyl, brodifacoum, flocoumafen etc.

After the Rodent Control Campaign Project had ended in 1993, further campaigns were organised from 1995 to 1997 in an area of 864,000 ha near the Kong River in the north-eastern region to control rodent invasions from Lao People's Democratic Republic. Governmental service continued also for every province in that free rodenticides were provided if extension officers had spotted a rodent problem. The AZRG further monitored the control practices of farmers to obtain a realistic view of the degree of adoption of the publicised methods. They interviewed farmers growing soybeans (after the rice crop was harvested) in the north, north-eastern and central regions. This revealed that about 90% of farmers used zinc phosphide to control rodents when damage was conspicuous (Boonsong et al. 1994, 1995, 1996). Farmers used germinated rice (paddy soaked in water for three nights) or broken rice as bait. The proportion of zinc phosphide mixed with the bait was generally 2–3 times higher than the recommended dose indicating an overuse of acute poison. When farmers observed bait-shyness of rats, they switched to a more attractive bait type such as fresh fish, field crabs (*Somanniathelphusa* spp.) or golden apple snails (*Pomacea canaliculata*) caught in rice fields. In the dry season, when crabs and snails are not abundant, they used mechanical control techniques such as shooting, digging or trapping. As mentioned earlier, many farmers consume rats; in such areas mechanical control over chemical methods were preferred. Farmers also learned that during the booting stage to harvest of rice, most rodents do not take poisoned bait due to the presence of the more attractive rice crop. At that time, farmers usually dug out rat holes instead of applying poison. The surveys further showed that farmers growing rice and field crops did not like to use anticoagulant rodenticides for various reasons. First, the price of anticoagulants was higher than that of zinc phosphide. Second, anticoagulants were sold only in big towns and were not as readily available as zinc phosphide, and third, the effect of chronic anticoagulants was considered too slow.

In conclusion, in the long term, the rodent control scheme has been only partially adopted by farmers in rice fields and field crops. There is a reliance on the use of acute rodenticides despite their limitations

(Prakash 1988), with the only alternative being traditional, mechanical control. Control is usually only considered when the problem is obvious. Preventative measures during periods when rodent numbers are low are the exception rather than the rule, and this situation prevails today.

Rats cause extensive damage to oil palm estates in southern Thailand. In large oil palm estates (>30 hectares) the farm managers generally follow Malaysian plant protection technology from the Palm Oil Research Institution of Malaysia (PORIM). PORIM recommends that control with anticoagulant rodenticides should commence when 5% of the oil palm fruits show fresh damage, and control should be repeated over large areas every six months. During field visits by AZRG to oil palm plantations, it was observed that second-generation anticoagulants like flocoumafen occasionally led to extensive secondary poisoning of predators like barn owls (*Tyto alba*) (AZRG, unpublished observation). In small holdings, most farmers are not interested in rodent control. When the price of fresh fruit is low (less than 2 baht per kilogram), oil palms grow in natural conditions without the use of fertiliser or rodent pest control.

Other control approaches like habitat manipulation and protection of known predators of rodents are regularly proposed to farmers by the Department of Agricultural Extension during extension activities. For instance, farmers employ the former by regularly clearing excessive vegetation on dykes. Measures such as reduction of dyke size are also considered when new fields are designed. Individual farmers reported that they especially take care of predators like birds of prey or snakes, however, this does not appear to be a common view. Thus to date, an integrated rodent control approach, though pursued by individuals, is not occurring on a broad scale.

Rodent Research by the AZRG

Rodent research in agriculture is primarily the responsibility of the Department of Agriculture, especially the Agricultural Zoology Research Group (AZRG) of the Division of Entomology and Zoology. Research activities focus on various species, such as rodents, bats, birds, crabs,various snails and slugs which are injurious to plants. During the last 20 years, research has been conducted on the following topics:

- Species identification and density estimation of rodents in economic crops such as rice, maize, soybean, mungbean, oil palm and longan.
- Life history of key pest species.
- Ecology: seasonal variations in rodent density in economic crops.
- Crop damage and loss assessment in rice, oil palm, soybean, maize etc.
- Chemical control: efficacy of rodenticides in the laboratory and in the field.
- Integrated pest management: combined application of rodenticides, mechanical control and cultural practices.

Following are some examples of research on the population ecology of pest rodents in Thailand.

The home range length (or maximum diameter of the home range) of rodents in rice fields has been studied at the Rice Research Station of Pathum Thani using eosin stain (Khoprasert et al. 1977) and mark–release captures in Prachin Buri Province (Somsook et al. 1983). It was found that the maximum radius moved within a week was 90 m and 100 m for *B. indica* and *Bandicota savilei*, respectively. *R. argentiventer* moved a maximum radius of 50 m and *R. losea* 46 m.

The long-distance movement of rodents in rice fields has been studied in an area located in Bang Plama District, Suphan Buri Province (about 100 km north-west of Bangkok) (Boonsong et al. 1984b). Two crops of rice per year were grown with the major crop planted in July and harvested in October and the second crop planted in February and harvested in May. A total of 1,253 rodents were caught in monthly field trips during January to October 1984. They were ear-tagged and released in an area of 8 km^2. The catch consisted of four species, *R. argentiventer* (51.3%), *R. losea* (18%), *B. indica* (20.4%) and *B. savilei* (10.3%). Only six marked rats were recaptured in the release area; three *B. indica*, two *B. savilei* and one *R. losea*. This low number was in part explained by the extreme trap-shyness of tagged rice-field rats; additionally, farmers conducted intensive rodent control campaigns during the study period. Two great bandicoot rats (*B. indica*) were re-trapped 63 and 95 days after release. They had moved about 1 km from the area where rice had already been harvested to the area where rice would be harvested in the next 2 weeks. Two lesser bandicoot rats (*B. savilei*) were recaptured after 70 days when they had moved about 2 km from a rice crop at tillering stage to a harvesting area. The single recaptured *R. losea* had moved about 1 km within 40 days from rice at the seedling stage to a harvesting area. In conclusion, it appeared that rodents moved towards areas where rice was being harvested.

In the Central plain, Somsook et al. (1983) studied the population dynamics of the lesser rice-field rat, *R. losea*, from March 1982 to March 1984 in rice fields in Prachin Buri Province (about 300 km east of Bangkok). In this area, floating rice is grown once a year. Rice is planted in June and harvested in December. The rice stubble is left in the field until the following February. During the rainy season, the study area was flooded up to 1.5–2 m from August to October 1983. In 1984, the water level in the rainy season was lower with a maximum of 0.50 m. Rodents were trapped for four nights of each month (800 trap nights). When the water level was high, live-traps were placed on polystyrene sheets. Trapping revealed that *B. indica*, *R. argentiventer* and *R. losea* were present with *R. losea* being the dominant species (90%). The population of *R. losea* showed a clear cyclic pattern with numbers increasing towards the harvest period of rice (Figure 2). Quality and availability of food are certainly major factors influencing the breeding of rodents (Singleton and Petch 1994). It appears that the water level in the rice fields also influenced the population as the numbers of rats were considerably higher in the second wet season (Figure 2) when the water level was lower. Interestingly, *R. argentiventer* could not be trapped in the area when the water was high (1982), but was present during a low water level (1983) indicating that the rats had probably moved out of the area during flooding. Breeding of *R. losea* commenced in September, and most pregnant females were caught in November and December.

The population dynamics of mice in corn fields were studied in the northern region in Tak Fa District, Nakhon Sawan (240 km north of Bangkok) from May 1986 to September 1991 (Boonsong et al. 1991). In this area, corn was the principal crop which suffered extensive damage from rodents. Mark–release trapping was used to study the movements and to estimate population density of rodents. A total of 2,200 rodents were caught on 37 occasions. Most of the rodents were mice (96.6%) with 71.8% *M. cervicolor* and 24.8% *M. caroli*. Figure 3 shows the population dynamics of *M. cervicolor*. Similar to the situation in rats, fluctuations in mouse populations reflected the changes in agricultural and climatic conditions. During the dry season (November–May)

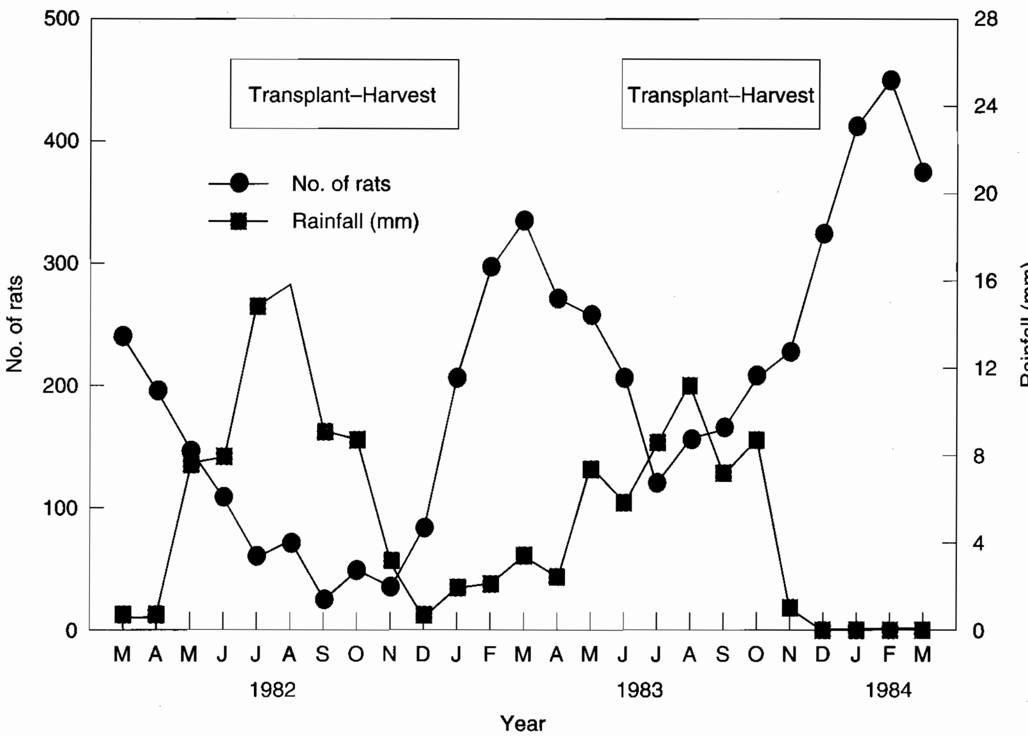

Figure 2.
Population dynamics of the lesser rice-field rat, *Rattus losea*, in floating rice in the central plains of Thailand from March 1982 to March 1984 (Somsook et al. 1983), showing the numbers of rats trapped in 800 trap nights per month and the monthly average rainfall.

populations increased to 40–90 mice/ha, while in the rainy season (May–October) only 12–19 mice/ha were found. Pregnant females were recorded in the dry as well as in the wet season (Figure 3) indicating that *M. cervicolor* reproduced most of the year except February to May. The survival period of this species in the field was about five months. A home range of 300–400 m^2 was recorded for *M. cervicolor*.

Some recommendations for control campaigns in Thailand have been derived from the population studies outlined above. Usually, knockdown of rodent populations starts in the dry season after harvest when less food is available and rats readly accept rodenticide bait containing zinc phosphide. This is also the time when drives and blanketing are conducted. Once the population has decreased in the wet season, chronic poisons and mechanical control are used until the booting stage of the various crops.

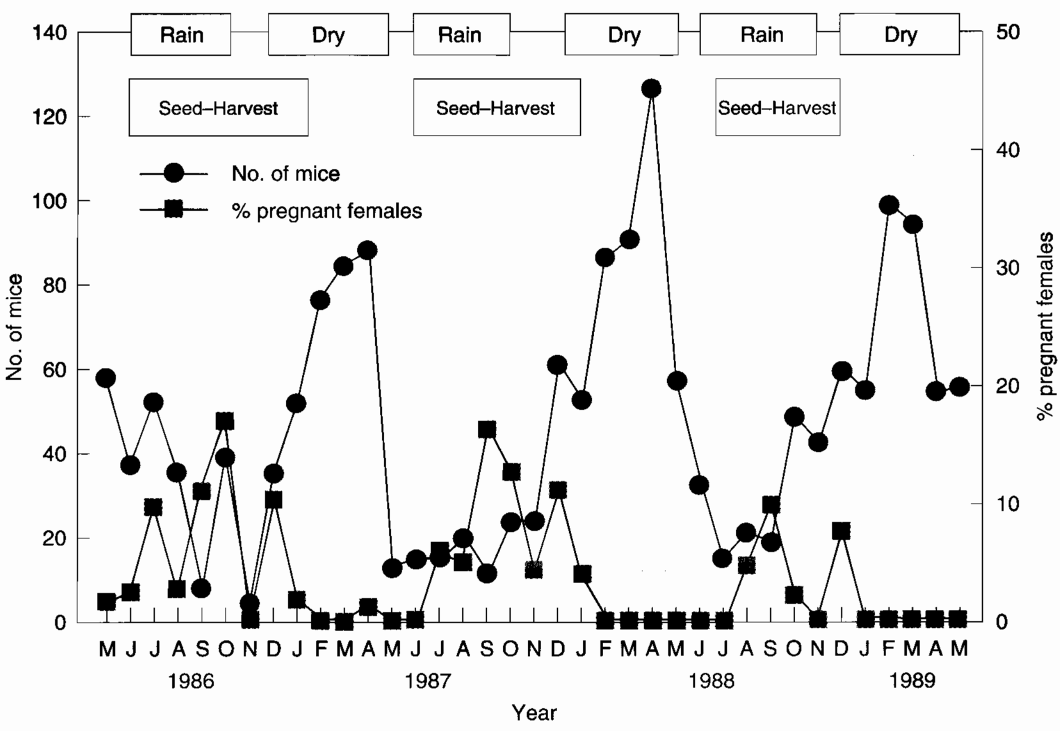

Figure 3.
Population fluctuations of the fawn-coloured mouse, *Mus cervicolor*, in corn fields in northern Thailand from May 1986 to May 1989 (Boonsong et al. 1991), showing numbers of mice trapped during 800 trap nights per month and the percentage of pregnant females.

Biological Control of Rodents Using *Sarcocystis singaporensis*

Since 1993, the AZRG and the Department of Parasitology, Hohenheim University, Germany, have cooperated in the framework of a GTZ (Deutsche Gesellschaft für Technische Zusammenarbeit—German Technical Cooperation) project to develop a biological method for rodent control using the apicomplexan protozoan *Sarcocystis singaporensis* which naturally occurs in rats in Southeast Asia. This section provides some background information on the biology of this parasite and considers its possible application against rodent pest species.

Biology and host range of *Sarcocystis singaporensis*

S. singaporensis was discovered by Zaman and Colley (1975) at a time when the obligate two-host life cycle of the sarcosporidia had been recognised (Rommel and Heydorn 1972) and research on this group of parasites was intensive. The original material (sporocysts) was obtained from faeces of a reticulated python (*Python reticulatus*) sold at a butcher's shop in Singapore (Zaman and Colley 1975). Shortly after discovery, Zaman (1976) investigated the intermediate host range of this species and found the parasite to be highly host-specific. Only laboratory rats (*R. norvegicus*) were susceptible to infection through the oral route using sporocysts containing sporozoites, the stage infective for the intermediate host. Other animals, like mice (*Mus musculus*), dogs, cats, chickens, and a rhesus monkey were not susceptible to infection and showed no clinical signs of disease (Zaman 1976; Beaver and Maleckar 1981). Infection of rats by sporozoites is usually followed by two rounds of asexual multiplication inside endothelial cells of various organs, a process by which merozoites are formed (Brehm and Frank 1980). About one month after infection, merozoites eventually invade the muscles to form characteristic cysts (so-called 'sarcocysts') in the striated muscles which contain a third stage, the bradyzoite. Bradyzoites are infective for pythons once the snake preys on rodents.

Subsequently, the definitive and intermediate host range of *S.singaporensis* was studied in more detail using numerous snake and rodent species from various parts of the world (Häfner and Frank 1984; Häfner 1987; Jäkel et al. 1996, 1997b). These studies confirmed the reticulated python in Southeast Asia as the natural definitive host and most suitable to infection with respect to the quantity and quality of sporocysts that developed in the snake's intestine. It appears that *S. singaporensis* also occurs in Australia. Morphologically similar sarcocysts were found in *Rattus fuscipes* (Rzepczyk and Scholtyseck 1976). *Aspidites melanochephalus*, the Australian black-headed python, was found experimentally to be a suitable definitive host (Häfner 1987). The natural definitive host in Australia still remains to be determined. Among boid snakes outside the Australasian region, only *Python sebae*, the African rock python, could be experimentally infected. However, numbers of sporocysts shed with faeces were low and morphological anomalies of sporocysts occurred indicating that these snakes do not provide optimum conditions for the parasite's development (Häfner 1987). Therefore, it seems unlikely that *S. singaporensis* can survive elsewhere, even if other python species and rats were present.

Among rodents, *Rattus* spp. and *Bandicota* spp. were suitable intermediate hosts (Häfner and Frank 1984). Additionally, *Nesokia indica*, the short-tailed bandicoot rat, was highly susceptible to infection (Jäkel et al. 1996).

Pathogenic effects of *S. singaporensis* in rodents

Zaman (1976) was the first to recognise the pathogenic potential of *S. singaporensis*. He observed that infection of laboratory rats resulted in acute disease, and death, beyond a particular inoculation dose. Wood (1985) made similar observations on infected Malayan wood rats (*R. tiomanicus*) in the laboratory. This was important because it indicated that there existed a parasite with a potential to control wild rats. Up-to-date data on the pathogenicity of parasites in wild rodents are scarce.

The stage responsible for disease in rodents is the merozoite which develops inside endothelial cells. Subclinical infections (which probably prevail in the wild) are characterised by two distinct peaks of merozoite development in the rat—one occurs around day 6 post infection (p.i.), the other around day 16 p.i. (Brehm and Frank 1980). After inoculation of a lethal quantity of sporocysts, numbers of merozoites increase enormously around day 11 p.i., especially in the lungs. This induces a fatal pneumonia (Jäkel et al. 1996). The factors responsible for the pathology are not fully understood. Mechanical destruction of endothelial cells due to massive development of merozoites seems one likely cause. Furthermore, it has been demonstrated that tumour necrosis factor released by macrophages upon encounter with parasite-antigen is able to kill cultivated cells (Fayer et al. 1988).

The project has determined the degree of pathogenicity of *S. singaporensis* in wild Norway rats (*R. norvegicus*) from Southeast Asia (Thailand), North Africa (Egypt) and Europe (Germany). The parasite appears to be more virulent in hosts occurring outside its natural distribution range. Rats outside Southeast Asia can be killed with about one tenth of the inoculation dose (Table 3).

Table 3.
Dose-dependent mortality of wild Norway rats (*Rattus norvegicus*) of different geographic origin after infection with *Sarcocystis singaporensis*[a] (original data).

Origin of rats	Inoculation dose (Number of sporocysts)				
	1×10^4	2×10^4	5×10^4	1×10^5	2×10^5
Thailand	n.d.[b]	0/10 (0)[c]	2 (1)/10 (2)	7 (0)/10 (1)	10 (7)/10 (7)
Egypt	0/6	10/10	4/4	n.d.	n.d.
Germany	0/6	14/18	3/3	n.d.	n.d.

[a] a parasite isolate from Thailand was used

[b] n.d. = not determined

[c] numbers of rats that died within 16 days/numbers of rats inoculated. Numbers in parenthesis indicate those rats which were naturally infected.

R. norvegicus is the most resistant species in Thailand. Other species like *Rattus exulans, R. argentiventer* and *R. tiomanicus* become moribund at much lower sporocyst doses. Bandicoot rats (*Bandicota* spp.) appear to be particularly susceptible to infection as indicated by massive development of sarcocysts. Adult bandicoot rats usually do not survive an inoculation with 8×10^4 to 1×10^5 sporocysts (AZRG, unpublished observation).

Whether the bradyzoite (the chronic stage inside muscles of the rat) can cause considerable pathologic effects is equivocal. Intriguingly, the number of parasites which develop in striated muscles can be extremely high (up to a billion per gram muscle), especially in wild rats (Figure 4), often without causing any apparent signs of disease. On the other hand, we have observed considerable numbers of laboratory rats as well as wild Norway rats (*R. norvegicus*) that become anorexic, and show rough fur and slow movements during chronic infection. It has been demonstrated that *Sarcocystis* infection renders rodents prone to predation (Hoogenboom and Dijkstra 1987). Impaired mobility due to high sarcocyst numbers in muscle tissue may be an important contributing factor.

There are controversial observations concerning the impact of *S. singaporensis* infection on rodent fecundity. During experiments performed in the last 10 years at the Department of Parasitology, Hohenheim University, Germany, it was observed that sub-lethally infected female laboratory rats (Wistar and F-344 strains) either did not become pregnant or aborted litters. However, in a recent experiment with laboratory-bred wild Norway rats (*R. norvegicus*) from Germany, infection had no effect on fertility as the number of progeny of infected females was similar to non-infected controls (T. Jäkel, unpublished observation).

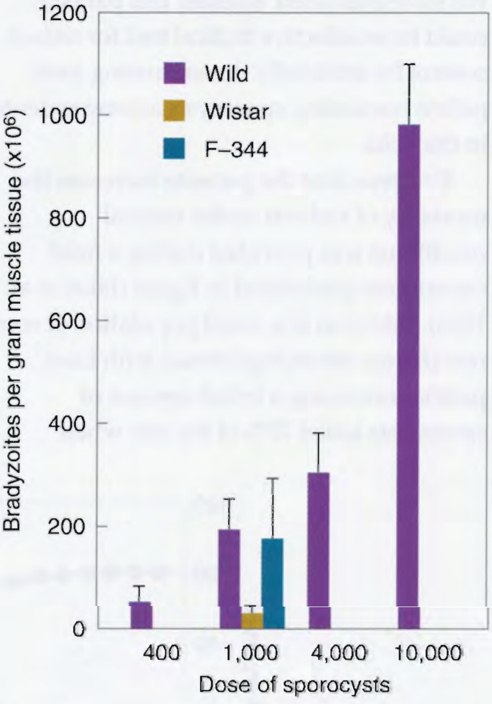

Figure 4.
Density of bradyzoites of *Sarcocystis singaporensis* in the muscles of wild and laboratory strains of *Rattus norvegicus* (F-344, Wistar) eight weeks after inoculation with various sporocyst doses (400–10,000). Bradyzoites were obtained by tryptic digestion of muscles; values are the mean ± standard deviation of 6–8 rats per treatment.

In conclusion, *S. singaporensis* infection in rodents induces almost 100% mortality once above a threshold level of infection (Table 3). The effect of *S. singaporensis* infection on the fertility of rodents is less well founded. When there is a reduction in fertility, the effect may be influenced by the sex and age of the host, its genetic background, or status of the immune system.

S. singaporensis as a potential biological control agent

We have examined whether this parasite could be an effective tactical tool for rodent control by artificially disseminating food pellets containing sporocysts among rodents in the field.

Evidence that the parasite increases the mortality of rodents under natural conditions was provided during a field experiment performed in Egypt (Jäkel et al. 1996). Infection of a small population of roof rats (*Rattus rattus frugivorous*) with food-pellets containing a lethal amount of sporocysts killed 73% of the rats when compared to the effect of a placebo. A characteristic time-course of activity of rodents artificially infected in the field is presented in Figure 5.

Recent field experiments in Thailand (plots up to 4 ha) showed that *S. singaporensis* is highly effective against *R. norvegicus* and *B. indica*. Parasite-induced mortality ranged between 60% and 80% (Jäkel et al. 1997a; Jäkel et al., 1999). Importantly, the latter results indicate that *S. singaporensis* can be used as a biocontrol agent inside its natural distribution range in Southeast Asia despite the fact that the parasite frequently occurs in rodents in this region (O'Donoghue et al. 1987; Jäkel et al. 1997b). This conforms with the prospects previously outlined by Wood (1985).

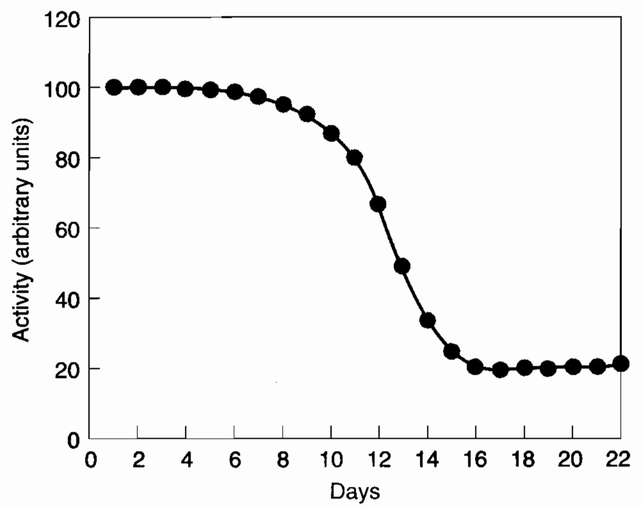

Figure 5.
Representative measurement of the activity of wild rats (*Rattus norvegicus*) after infection with *Sarcocystis singaporensis* (day 0 = day of infection) (modified from Jäkel et al. 1996, 1997a). The activity of rats (10–100 animals) is expressed as the consumption of plain bait or the number of footprints on tracking plates. Note that activity declines around day 10, indicating the onset of parasite-induced mortality among rats. Usually, dead rats can be seen in the field 10–16 days post infection. At that time, merozoites of *S. singaporensis* synchronously leave their host cells in the lungs inducing a fatal pneumonia in their hosts.

Laboratory experiments showed that natural infections usually do not provide protection against lethal sporocyst doses (Table 3). The reasons behind this remain to be fully determined, however, analysis of the T-cell response after infection revealed that low numbers of sporocysts do not induce the formation of memory CD4 T-cells (Jäkel et al. 1998) which are usually responsible for the persistence of immunological memory in the rat (Bell et al. 1998). Assuming that the high numbers of bradyzoites developing in the muscles (Figure 4) are proportional to those of the preceding stage (the merozoite which can cause extensive pathology), these data indicate that rats can tolerate substantial numbers of multiplying parasites before they show signs of disease. A certain degree of infection is tolerated, and may even suppress immune function (Gill et al. 1988). However, rats can become resistant to acute infection if they ingest a sublethal but high number of sporocysts (Jäkel et al. 1996); accordingly, in this case numbers of memory CD4 T-cells were significantly increased (Jäkel et al. 1998). With regard to rodent control, these observations indicate that low numbers of parasites in the environment are no obstacles to control measures using the parasite. However, a proper bait formulation is needed which prevents unintended immunisations during field application.

From research into practice

Current research activities of the project focus on three major topics: (i) development of a parasite-bait which is highly palatable and preserves viability of sporocysts, (ii) developing conditions for mass-production of the parasite, and (iii) defining an application scheme which could complement or become integrated with other practices of rodent control.

Developing a suitable parasite-bait is the most difficult part and will be the key factor in a possible commercial exploitation of the method. During our field experiments, a bait was used which had been developed by the Bayer AG, Monheim, Germany. It consisted of a wheat paste with a high oil content and was sweetened with sugar. The parasite-inoculated mixture was superior to other food items and especially attractive to *Rattus* spp.and *B. indica* from Thailand. Unfortunately, a high oil content seems to have negative effects on the viability of sporocysts, and therefore other parasite-bait formulations are currently under investigation. The project aims to achieve a storage stability period of at least three months under local conditions (high ambient temperature, high humidity).

Sporocysts can be mass-produced in reticulated pythons (Jäkel et al. 1996), therefore the project is constructing a pilot production unit in cooperation with Thai private industry to rear and keep pythons. In Thailand, snake farms are found all over the country, serving as tourist attractions or providing products for the leather industry. We have observed experimentally that pythons (2–3 m length) shed up to 4×10^9 sporocysts in the faeces after a single infection without showing any signs of disease. The animals can be reinfected six to eight times per year. In the snake's intestine, immune reactions against the parasite are not apparent. A lethal dose for a single rat ranges between 2×10^5 sporocysts (inside the natural distribution range of the parasite; Table 3) to 2×10^4 sporocysts (outside the natural distribution range; Jäkel et al. 1996).

Therefore a single infection of a snake can yield material to kill about 2×10^4 to 2×10^5 rats.

S. singaporensis could be a new tactical tool in rodent control, with its application being similar to chemical rodenticides, and complementing other non-chemical approaches (McCallum 1996; Chambers et al. 1997; Singleton et al. 1998). Field studies are planned to determine the effectiveness and acceptance of the method at the farmers' level. As well as an easy-to-use design of a parasite-bait, a low price will be crucial for its success on the rodenticide market.

Synopsis and Future Concepts

As outlined previously, rodent management in Thailand mainly relies on the use of chemical rodenticides and mechanical methods, an approach which was developed in the mid-seventies. This approach has also contributed to a substantial reduction in the rodent problem, especially in rice, because extension programs were continuously conducted to reach the farmer. However, rodent damage to agriculture continues, notably that by mice to various field crops or climbing rat species to oil palm. Effective control against rats is lacking in crop stores of small landholders or in urban areas. Recent outbreaks of leptospirosis among humans in Thailand indicate that research and practical control measures are necessary to restrict the spreading of rodent-borne diseases.

According to the 8th National Economic and Social Development Plan (1997–2001), it is the policy of the Ministry of Agriculture and Cooperatives that the use of pesticides should be reduced as much as possible. Therefore, efforts are underway to implement an integrated pest management (IPM) strategy in selected pilot areas in the country. In 1997, the Department of Agricultural Extension started an IPM program against plant diseases and insect pests including 100 demonstration plots (80 ha each) in various parts of the country. Currently, strategies for rodent control management included in the curricula of the education program mainly focus on chemical approaches, with environmentally friendly techniques only playing a minor role at present. The AZRG is testing new methods in biological control using the parasitic protozoan *Sarcocystis singaporensis* and mechanical approaches like the trap –barrier system. It is planned to regularly apply these techniques in demonstration plots of the above mentioned IPM program. The future will show if these methods are accepted by farmers in Thailand and can be promoted at a larger scale.

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17. Farmer Participatory Research on Rat Management in Cambodia

Gary C. Jahn, Mak Solieng, Peter G. Cox, and Chhorn Nel

Abstract

In Cambodia, rats destroy an estimated average 0.1% of the total rice production area annually. The impact of rat damage can be great on individual farmers and their families. Due to the small-scale, subsistence nature of Cambodian rice farming, and because of poor food distribution, rat outbreaks destroy savings and create food shortages. An outbreak in 1996 destroyed rice sufficient to feed over 50,000 people for a year. Typically, farmers' rat management efforts have poor success. To improve rat management at a village level, we initiated farmer participatory research (FPR) in April 1998 and began meeting with farmers in nine villages in the Svay Teap district of Svay Rieng Province in south-eastern Cambodia, bordering Vietnam. The objectives of the FPR were to identify weaknesses in current farmer practices to manage rats, compare community-based to individual farmer-based rat management, and test the effectiveness of early wet season trap crops as a means of reducing rat populations in the wet season.

Keywords:

Rats, rice, farmer participatory research, Cambodia, crop loss

Overview of Rodent Damage in Lowland Rice

FARMERS REPORT two to six kinds of rats or bandicoots in their villages. Their descriptions coincide with accepted rodent taxonomy. Collection of rats by hunting and trapping confirm the presence of three species in or near rice fields: *Rattus argentiventer*, *Bandicota indica* and *Rattus exulans*. Based on farmers' descriptions, *Rattus rattus*, *Rattus koratensis* and *Rattus losea* are probably present in villages as well (Leung 1998).

In Cambodia, rats are the only pests that attack all stages of the rice crop in each of the major rice ecosystems: rainfed lowland, irrigated lowland, upland and deepwater rice (Jahn et al. 1997a). The area of rice production is 86% rainfed lowland, 8% irrigated lowland and 6% deepwater and upland rice (Javier 1997). Among lowland rice farmers (n = 1265), 27% reported wet season rat problems and 46% reported dry season rat problems. However, only 13% of farmers actively attempted to manage rats. Farmers often regard rat infestations, like the weather, as a force that cannot be controlled. In both seasons, rodenticides are the most common form of rat management (Jahn et al. 1997b).

Annual pre-harvest rice losses due to rat damage average US$439,000 (Table 1), a substantial figure in a country where the average annual per capita income is US$200 (Anon. 1996). These crop loss figures are from only 8 of 20 provinces. They represent significant under-estimates because rat damage in fields can easily go undetected or unreported and estimates of post-harvest damage are not included. Nevertheless, some observations can be made:

- the total rice area damaged by rodents in Cambodia is estimated to average approximately 2,000 ha/year —this is about 0.1% of the total rice area (2.3 million ha in 1996);
- the level of rat damage varies greatly from year to year; and
- some provinces are more affected than others e.g. Svay Rieng compared with Siem Reap (Table 1).

Estimated average losses suggest that rats may not be a particularly important constraint to national rice production. For example, in 1996, yield losses from rats represented 0.3% of national production and only 4% of Svay Rieng's total paddy production. However, national statistics do not convey the fact that, during an outbreak, hundreds of farmers lose their entire crop, sending them into a cycle of poverty from which few escape. To recover losses, a farmer must borrow money at very high interest rates. This means that the farmer cannot afford essential inputs, such as fertiliser or additional labour, in the following season. This leads to weaker crops, greater susceptibility to pests and ultimately lower yields, necessitating further borrowings.

Another aspect of crop loss is the poor distribution of food in Cambodia. From 1995 to 1997 Cambodia produced a rice surplus for the first time since 1969, but hundreds of villages suffered food shortages. The rat outbreaks of 1996 destroyed at least 12,600 t of paddy (Table 1)—equivalent to enough rice to feed more than 50,000 people for a year. Many of Cambodia's rice farmers are self-sufficient, producing just enough food for their own families. When these families lose their crops to rats, they generally do not have the resources to purchase rice, and food shortages result. While rats appear to have a relatively minor impact on national rice production, they can have a major impact on individual fields (CIAP 1998). Occasionally the total loss of some rice crops is reported in most Cambodian districts. In certain provinces, e.g. in Svay Rieng (Figure 1), entire crops are destroyed by rats every year.

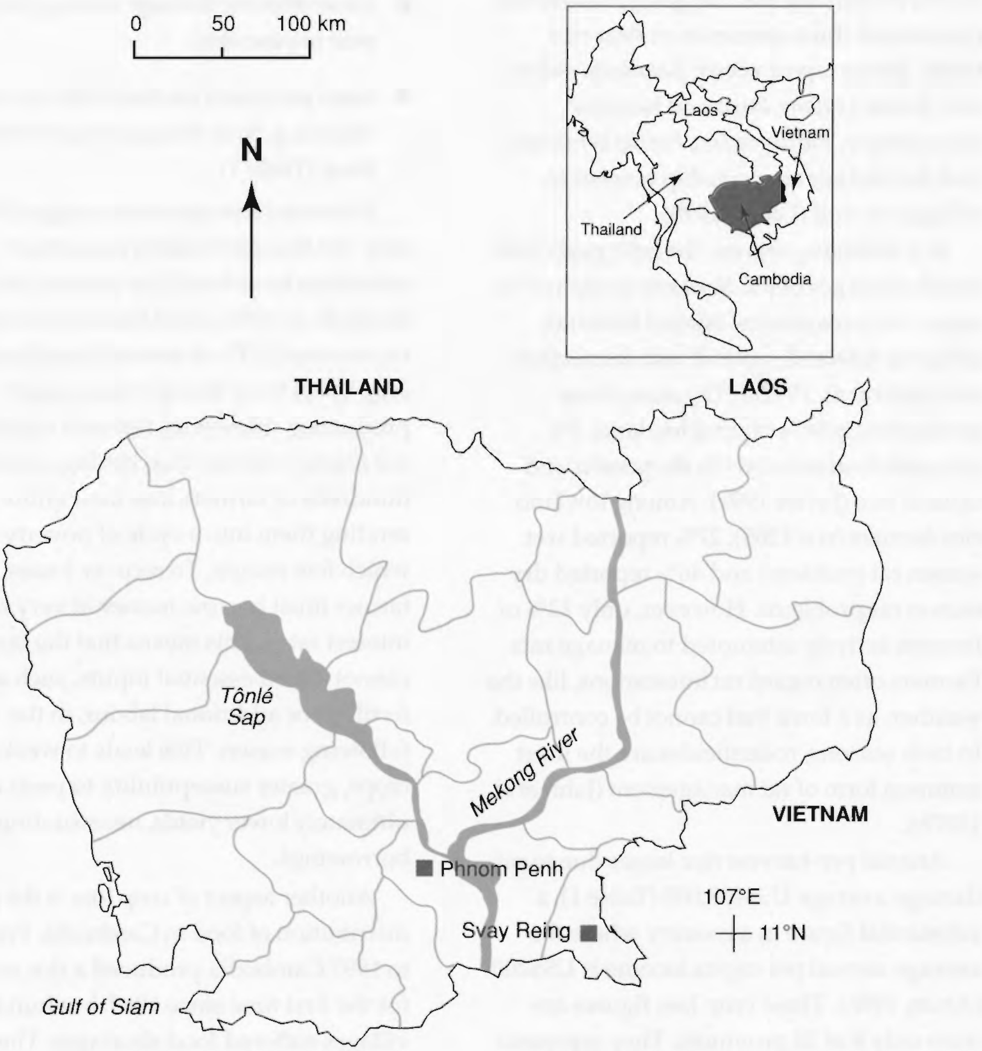

Figure 1.
Map of Cambodia.

Because more dry season rice is now produced, rice is available all year round in more places. This provides a source of food to sustain and increase rat populations, potentially promoting rat problems in the future. The trend in the yield loss data (Table 1) is consistent with this projection. The different timing of rice crops in Cambodia and Vietnam may also contribute to increasing rat numbers and population migrations following the next available crop, or fleeing flood waters (G.R. Singleton, pers. comm.).

Farmers in Svay Rieng near the Vietnam border reported that rat populations were very high just after the end of the Khmer Rouge period in 1979. This may have been associated with poor maintenance of fields and loss of control of rat populations during that time. Alternatively, when the war ended and rice cultivation was extremely low, rats from the vast, weedy, uncultivated areas may have congregated in the cultivated fields.

Farmers (n = 50) in Svay Rieng reported high rat activity during 1995–97, which is consistent with data in Table 1. These farmers saw rats as a significant pest problem and made traps or bought poisons to control them. The poison commonly available is zinc phosphide imported from Thailand or Vietnam. Chemical analysis by the Division of Agricultural Toxic Substances of the Department of Agriculture of Thailand revealed that 'purple powder', said by vendors to come from Vietnam, contained no zinc phosphide. A product from Thailand, labelled "80% zinc phosphide" was found to contain 12% zinc phosphide. The instructions on the label, however, were appropriate for 12% zinc phosphide. Rodenticides are sold in Cambodia without any labels, or with labels in Thai, Vietnamese or Chinese, but not in Khmer (the language of Cambodia). Chronic rodenticides, used in Thailand and Vietnam, are not commonly available. This may be due to their high price.

We have seen examples of active rat fences with traps, known as trap–barrier systems (TBSs), in Prey Veng (Figure 1) around early wet season (EWS) crops in high risk situations. The Cambodia–IRRI – Australia Project (CIAP), a collaborative research project between the Cambodian Department of Agronomy and the International Rice Research Institute (IRRI) with funding from the Australian government, has used TBSs in farming systems demonstrations throughout Cambodia and on research stations since 1990. CIAP produced an instructional video in Khmer about the TBS in 1993. The video tape has been broadcast nationally several times every year since then. Copies of the video were distributed to provincial agriculture offices free of charge and it is occasionally seen being played in rural restaurants around the country. Information about TBSs is also coming from Vietnam. In addition, some farmers learn about the TBS through integrated pest management (IPM) farmer field schools or from non-governmental organisations (NGO).

Although they are eaten in Cambodia (and are quite tasty), rats do not appear to form an appreciable part of the diet in rural areas of Cambodia, where rats are sometimes considered a snack for men, but inappropriate food for women. Naturally, during famines and food shortages, rats (and just about any other animals) are eaten. Some Cambodians have made a business of catching rats and selling them to Vietnam.

Table 1.
Lowland rice production losses due to rat damage in Cambodia from 1990 to 1996 (– = no information available).

Province	1990	1991	1992	1993	1994	1995	1996	Total	Average
Area Damaged (ha)									
Kampong Thom	–	161	118	76	68	456	1 965	2 844	474
Siem Reap	–	–	181	–	–	103	–	284	142
Battambang	592	98	–	193	–	–	–	883	294
Kandal	452	–	–	72	–	–	–	524	262
Prey Veng	–	64	–	–	86	511	125	786	197
Svay Rieng	93	164	236	472	230	786	4 902	6 883	983
Takeo	–	56	–	183	–	–	123	362	121
Kampong Cham	375	–	–	56	–	–	580	1011	337
Total	**1 512**	**543**	**535**	**1 052**	**384**	**1 856**	**7 695**	**13 577**	**1 940**
Average yield (t/ha)	1.30	1.35	1.40	1.45	1.50	1.60	1.64		
Est. production loss (t)	1 965	733	749	1 525	576	2 969	12 619	21 136	3 019
Value of production loss (US$)	285 818	106 618	108 945	221 818	83 782	431 855	1 835 490	3 074 327	439 190

Note: (a) price of rice is 400 riel/kg; (b) exchange rate US$1 = 2750 riel (1997).
Source: Department of Agronomy, Ministry of Agriculture, Forestry and Fisheries, Royal Government of Cambodia.

Farmer Participatory Research on Rat Management

In April 1998, CIAP joined with the Catholic Relief Service (CRS)—an international NGO, to improve rat management in Svay Rieng through education and research. CRS was already using action research to work with farmers on issues that they saw as important. We refer to this approach as 'farmer participatory research' (FPR). By involving farmers directly in the research process, we aimed to develop more appropriate strategies more quickly (Cox et al. 1997). We assessed current rodent management techniques, identified obvious weaknesses that could be improved immediately, and identified areas that required investigation to see if improvements could be made.

Farmers' practices

The farmers were familiar with TBSs, but did not use them because they were too expensive. Some farmers in neighbouring provinces were using the TBS on EWS crops, which are more valuable and more susceptible to rat damage than traditional wet season crops. In these cases, the value of the crop may have been high enough to justify the cost (Table 2). In the wet season, farmers usually grow traditional Cambodian rice varieties that take five to seven months to mature. These varieties will be at the booting stage, a stage particularly vulnerable to rat damage, in October or November. EWS crops are usually modern IR varieties (i.e. varieties developed by IRRI), which take only 110 to 130 days to mature. Planted at the beginning of the wet season, the EWS crops are at booting stage in June or July, when other fields have not been transplanted or are still tillering. The wet season farmers in Svay Teap (a district of Svay Rieng Province) were trying to control rats, but with limited success. Some farmers in the area were already experimenting with EWS crops. None of the farmers had ever heard of using an EWS crop with a TBS as a trap crop for rats.

The last rat control campaign was a government-sponsored rat hunt about 15 years ago, when villagers were paid for rat tails. Some farmers dug out the rat burrows in their own fields and a few set home-made traps. A number of farmers used rat bait but complained that it was not very effective. Zinc phosphide was the only rodenticide used and no pre-baiting occurred. Baits were only left out overnight and collected in the morning to prevent poisoning of domestic animals. Farmers had no clear idea of when to apply poison baits or the dosage of poison to use. Only a few farmers built traps, but these were not very effective (G.C. Jahn, personal observation).

Most of the farmers in Svay Teap thought that rats were indigenous populations that lived in the forest, sisal, bunds and weedy areas during the dry season. They thought that rats did not migrate very far. In contrast, farmers in Kampong Ro (another district of Svay Rieng) and Takeo thought that rats migrated from Vietnam. If the rat populations in Svay Teap were indigenous, we reasoned that hunting rats before the wet season, and using trap crops in the EWS would help reduce the rat population in the wet season. CIAP and CRS paid for TBSs on EWS trap crops in three villages: Bot Slok, Veal and Chrok Metes (Figure 2).

Table 2.
Cost of trap–barrier system (TBS) materials relative to the value of different rice crops.

Crop	Variety	Field size (ha)	Yield (kg)	Value of rice (riel/kg)	Value of harvest (riel)	Cost of TBS (riel)
Wet season	Traditional	0.7	500	290	145000	113 500
Early wet season	Modern	0.7	990	500	495000	113 500

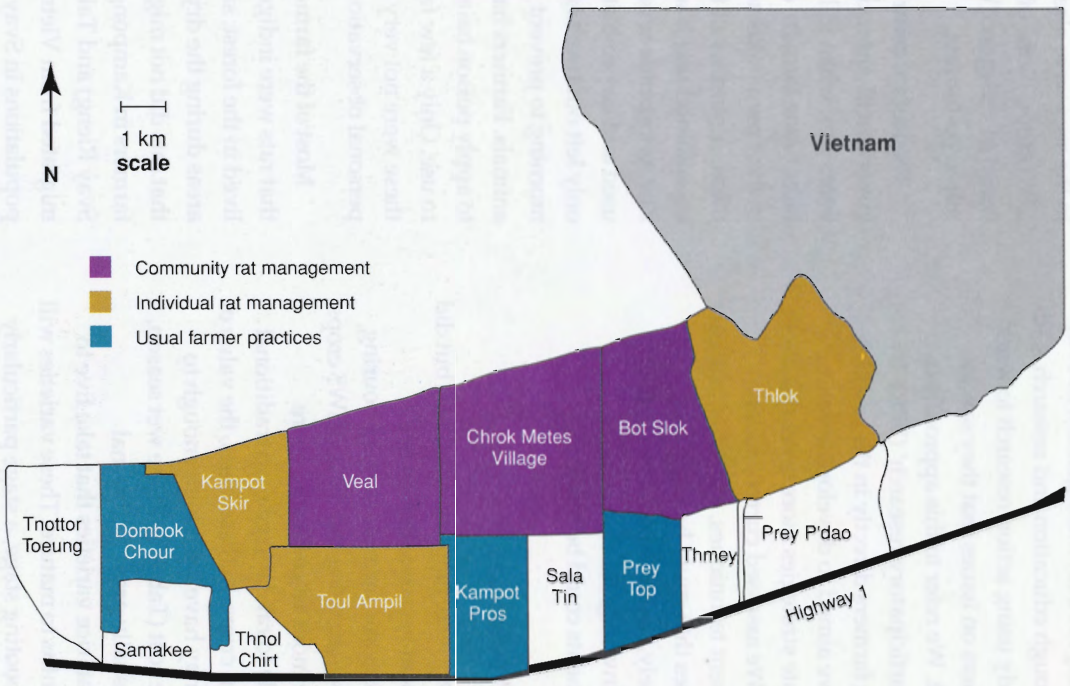

Figure 2.
Map of Chrok Metes Commune (Svay Teap District, Svay Rieng Province, Cambodia). Trap crops and other communal practices were tested in the vilages of Veal, Chrok Metes and Bot Slok. Individual farmers were trained in rat management in Kampot Skir, Toul Ampil and Thlok. Usual rat management practices were monitored in Dombok Chour, Kampot Pros and Prey Top.

Rat hunts were conducted in each of these villages before the TBS was erected (Figure 3). The villagers constructed the traps and put up the fences after receiving instructions (Figures 4 and 5). Later in the season, improved baiting and trapping methods were taught to these villagers as a group, encouraging synchronous, community-based rat control. Farmers in all of these villages monitored rat populations and damage to crops. EWS yields were weighed, adjusted to 14% moisture and converted to t/ha. Technicians from CRS assessed grain damage.

RESULTS AND DISCUSSION

Rat hunts were very popular with the villagers, although the number of rats (unidentified species) captured on these hunts varied from none to 48, depending on the village. The differences in the number of rats captured may have been due to the number of rats living in the village, as indicated by the rat counts from the rice bunds later in the season (Table 3). The trap crops caught few rats (Table 3). The higher number of rats caught in bunds throughout Bot Slok suggests that the plastic barrier may have kept rats out of the field, although rats did not enter the traps. If so, then the TBS protects the EWS crop from rats, but does not actually serve as a means of reducing rat populations in the wet season. Besides rats, the traps caught other animals (Table 3). The villagers ate all these animals.

Photo: Peter Cox.

Figure 3.
Rice farmers prepare for a night rat hunt in Svay Rieng Province, Cambodia

Photo: Mak Solieng.

Figure 4.
Villagers in Svay Rieng Province, Cambodia, building a rat fence with traps around an early wet season crop.

Photo: Mak Solieng.

Figure 5.
Khmer villagers building rat traps.