The Australian Centre for International Agricultural Research (ACIAR) was established in June 1982 by an Act of the Australian Parliament. Its mandate is to help identify agricultural problems in developing countries and to commission collaborative research between Australian and developing country researchers in fields where Australia has a special research competence.

Where trade names are used this does not constitute endorsement of nor discrimination against any product by the Centre.

ACIAR TECHNICAL REPORTS SERIES

This series of publications contains technical information resulting from ACIAR-supported programs, projects, and workshops (for which proceedings are not being published), reports on Centre-supported fact-finding studies, or reports on other useful topics resulting from ACIAR activities. Publications in the series are distributed internationally to a selected audience. Recent numbers in the series are listed inside the back cover.

Singleton, G.R. and Petch, D.A. 1994. A Review of the Biology and Management of Rodent Pests in Southeast Asia. ACIAR Technical Reports No. 30, 65p.

ISBN 1 86320 124 6

Typesetting and layout: K & B Publications, Canberra, Australia.

Printed by: CPN Publications, Canberra, Australia.

A Review of the Biology and Management of Rodent Pests in Southeast Asia

Grant R. Singleton and David A. Petch

Australian Centre for International Agricultural Research
Canberra 1994

The Authors

Dr Grant R. Singleton, Principal Research Scientist, CSIRO, Division of Wildlife and Ecology, PO Box 84, Lyneham, ACT, Australia 2602

David A. Petch, Biosis Australia Pty Ltd, PO Box 489, Port Melbourne, Australia 3207

Contents

Acronyms and Abbreviations

ABS	Active Barrier System
ACIAR	Australian Centre for International Agricultural Research
AARD	Agency for Agricultural Research and Development , Ministry of Agriculture, Indonesia
BIOTROP	Regional Center for Tropical Biology
BORIF	Bogor Research Institute for Food Crops, Indonesia
CRC	Cooperative Research Centre for Biological Control of Vertebrate Pests, Canberra, Australia
CRIFC	Central Research Institute for Food Crops, Indonesia
CSIRO	Commonwealth Scientific and Industrial Research Organisation, Australia
DFCP	Directorate of Food Crop Protection, Ministry of Agriculture, Indonesia
EFS	Environmentally Friendly System
FAO	Food and Agriculture Organization
HFRS	Haemorrhagic Fever with Renal Syndrome
IPC	Integrated Pest Control
IPM	Integrated Pest Management
IRRI	International Rice Research Institute, Philippines
M-99	MASAGANA 99 (national rice production program of the Philippines)
MARDI	Malaysian Agricultural Research and Development Institute
MORIF	Maros Research Institute for Food Crops, Indonesia
NCPC	National Crop Protection Center,
PCO	Pest Control Officer
PICA	Predict, Inform, Control, Assess (management strategy for rodents)
BPI	Bureau of Plant Industry, the Philippines
PPS	Plant Protection Service
SEWS	Surveillance and Early Warning System
SURIF	Sukamandi Research Institute for Food Crops
UPLB	University of the Philippines, Los Baños
USDA	United States Department of Agriculture
WHO	World Health Organization

CHAPTER 1

Introduction

'World-wide, 3.5 million rats are born everyday. In India, where the human population exceeds 600 million, rats outnumber man ten-fold.' — R.L. Semple (1982)

Rodents are arguably the most important mammalian pest at the global level. This technical report will focus on the impact of rodents in Southeast Asia where rats have been identified as either the most important (Geddes 1992) or one of the major constraints to agricultural production (Grist and Lever 1969; Hopf et al. 1976; Hoque et al. 1988).

Hoque et al. (1988) identified 29 species of rodents of economic importance in Southeast Asia. Most cause economic losses to crops pre- or postharvest. Some however, are of importance simply because they transmit disease to humans or to domestic stock. Diseases of livestock will be discussed in Chapter 6. The primary emphasis of the other chapters will be on the economic impact and management of rodents in agricultural areas in Southeast Asia, particularly in rice cropping systems.

The focus on the association between rodents and rice is simply because the staple food of rodents is generally grain, and rice is the single most important food crop in Southeast Asia. The importance of rice to the people in the region is underlined by two facts:

(i) Rice provides 35 to 60% of the total food energy for the three billion people living in Asia.

(ii) More than 90% of the world's rice is produced **and eaten** in Asia (Kush 1993).

The current conservative estimate is that rodents in rice growing regions typically cause annual losses preharvest of between 5 and 15%. The highest reported impact by rodents in Southeast Asia is in Indonesia where around 17% of rice production is lost (Geddes 1992). In countries such as India, rodents cause even higher losses postharvest.

The preharvest losses caused by rodents is a problem dating back hundreds, and probably thousands, of years. The chronic and prolonged nature of rodent depredation has led to a level of acceptance by growers. Many farmers have taken the view that for every 10 rows of grain sown, two are planted for the rats.

This situation cannot be tolerated under current population pressures. Asia's population was 3.1 billion in 1990 and is likely to increase to 4 billion by 2025 (Lampe 1993). This is in a region where poverty is prevalent. To meet the food requirements of Asia's population in 2025 the production of rice will need to increase by 70% (Kush 1993). There is little scope for increasing the area of land devoted to rice production. Indeed, there is likely to be a loss of arable land because of urban encroachment and loss of soil fertility. Given the effect of rats on rice production in Southeast Asia, there is a pressing need to improve the management of rodent pests in the region.

Concern about the damage caused by rats in Southeast Asia, led to a meeting of an expert panel on rodent control in rice crops in September 1990 at IRRI, Philippines (Quick 1990). Two of the recommendations from this meeting were:

(i) More research was required to reduce the use of rodenticides, and incorporate Integrated Pest Management (IPM) principles.

(ii) More research was required on the potential of biological control. Such research requires a multi-disciplinary team of researchers; only one was identified — CSIRO, Division of Wildlife and Ecology, Canberra.

Both recommendations are fundamental to the strategy of rodent management that underpins the research imperative of the Rodent Research Group at CSIRO, Australia (see Redhead and Singleton 1988a; Singleton and Redhead 1989)

Also highlighted at the meeting was the general demise of the infrastructure for training and research on rodent management in countries such as the Philippines which previously had good programs in place. Coupled to this was the fact that approximately two-thirds of the 'rodent experts' at the meeting were either retired, about to retire or no longer active in rodent research. The prospects for progress in methods of rodent management, or in implementing existing management technologies, in Southeast Asia did not look promising.

ACIAR recognised the need for a review of the rodent problem in Southeast Asia and commissioned the authors of this technical report to:

(i) review the national strategies for the control of rats;

(ii) review the ecological data available on the principal pest species and identify the main gaps in knowledge;

(iii) determine the emphasis being placed on ecologically sustainable control of rodents through a reduced use of chemicals;

(iv) review the data available on economic losses caused by rodents; and

(v) identify zoonotic diseases that present risks to humans and commercial livestock.

We were interested also in determining which countries possessed the best infrastructure to accommodate research on biological control — in particular, development of research into sterility caused by immuno-contraception.

This report provides details of our findings. We will be concentrating on the five countries that we visited; Indonesia, Laos, Malaysia, the Philippines and Thailand. In the case of Malaysia, we will be restricting our considerations to Peninsular Malaysia because there is very little published information on rodent pests in Sabah and Sarawak. Some information is given for Vietnam. Although we did not visit that country, we have been able to obtain information on a recent rodent problem and have included this information where appropriate.

The report is not meant to be exhaustive. Rather, the aim is to provide a focus for future research directions on rodent management in Southeast Asia, and to provide a resource for scientists and managers involved in rodent management in the region.

CHAPTER 2

Pest Species of Rodents and Their Impact

'Although damage of 10% (at the district level) may not sound alarming it becomes disastrous if all the rice in one village is completely damaged. I have personally been in such villages during the initial phase of the survey in the Viengkham district. Some farmers visited have not had a rice harvest for two successive years.'
— Walter Roder (pers. comm. 1993 — Lao/IRRI project)

In this chapter, the major rodent pest species, their economic impact, and the crops they effect in Indonesia, Laos, Malaysia, the Philippines and Thailand are reviewed and brief mention made of a recent rodent problem in Vietnam. Less detailed information on rat problems in other Southeast Asian countries is provided in Hoque at al. (1988).

The main pest species of rats in Southeast Asia are the rice field rat, *Rattus argentiventer*, the black rat, *Rattus rattus diardii*, the wood rat, *Rattus tiomanicus*, the Norway rat, *Rattus norvegicus* and the little Malay rat (or the Polynesian rat), *Rattus exulans*. Descriptions of these rats are provided by Sody (1941) and Marshall (1977).

As an introduction to the magnitude of losses caused by rats in rice crops, an overview of economic losses is provided for each of the five countries (Table 2.1). The importance of these losses, and their impact on the economy of each country, are even greater when the size of rice holdings, the percentage of holdings sown to rice and the amount of land devoted to each method of rice production (dryland, irrigated, rainfed, deep-water) are taken into account (Table 2.2). As an interesting comparison, figures for Vietnam have been included in Table 2.2. The rice production of Vietnam increased markedly between 1989 and 1992 (Lam 1993; see Table 2.12). It is now one of the most productive rice growing countries in Southeast Asia.

The average size of rice holdings in each country is of particular interest because rat damage is typically patchy in its distribution. This magnifies the potential losses of individual families. It is not unusual for rural families to experience losses of greater than 50%. Indeed, in some areas losses of up

Table 2.1 Estimates of damage caused by rats to rice crops in five countries in Southeast Asia.

Country	Year	Estimate of annual losses	References
Java Indonesia	1980	US$40 million (regional estimate) (248 000 ha damaged and 160 000 t of rice lost; 17% of rice production)	Indrarto (1984)
Indonesia	1987	US$1 billion (figures were from the Food Crops Statistic Division of Central Bureau of Statistics (1988); estimated loss, assuming 17% damage, was 8.21 million t)	Geddes (1992)
South Sulawesi, Indonesia	1983–1992	US$5 million (figures from the Plant Protection Center, Maros — regional estimate; 16 900 t of rice lost, 16.9% of production)	Ir Shagir (1994 pers. comm.)
Laos	1991	Kip 6.2 million (US$44 000) (cost of bounty) (Luang Prabang Province only)	Onchaum (pers. comm.)
Malaysia	1982	RM 43 million (US$17.3 million) (based on losses of 5% and production loss in 1982 of 87 332 t)	Lam (1982)
Philippines	1975	US$67.3 million (based on losses of 5% in 1975; losses of <0.52% were claimed to be achieved between 1976 and 1980)	Hoque et al. (1988)
Thailand	1989	Bht 6 billion (US$2.3 million) preharvest loss; Bht 5 billion (US$2.0 million) postharvest loss (survey from Thai Office of Agriculture Economics — lowland rice only)	Tongtavee et al. (1990)

Table 2.2 Summary of size of rice holdings (ha), the percentage of holdings sown to rice and the amount of land ('000 ha) devoted to each culture method (after Huke and Huke 1990).

Country	Ave Farm Size	% Sown	Dryland	Irrigated Wet	Irrigated Dry	Rainfed	Deepwater
Indonesia	0.96	37	1486	1295	2895	2112	467
Laos	2.20	86	279	38	6	363	0
Malaysia							
Peninsula	2.10	20	1	218	183	29	0
Sabah	3.40	19	11	6	1	58	0
Sarawak	3.50	30	84	12	1	172	0
Philippines	2.78	39	165	999	839	1393	8
Thailand	4.20	59	241	1251	638	7731	340
Vietnam	0.70	75	407	1565	1616	1201	410

to 100% have been reported. Moreover, losses of these magnitudes may occur over consecutive years as has been observed in Laos (Walter Roder — Lao/IRRI project, pers. comm.), Malaysia (Tuan Haji Embi Yusof, Deputy Director MARDI, pers. comm.), and Indonesia (Achmed Mohammed bin Fagi, Director SURIF, pers. comm.). Therefore average annual losses in production from rats of just 5% for a particular country still present a substantial problem. Our conclusions concur with those of Fall (1990) who reasoned that average losses by rodents have little meaning for individual producers of rice. When farming families in Southeast Asia are so dependent on rice for their annual diet and income, losses of greater than 30% are often devastating. High losses two years in a row can be catastrophic.

The data on economic losses caused by rodents generally lack rigour. The vegetative recovery of rice plants that have had tillers cut by rats, and the changes in the capacity of plants to regenerate as they mature, further complicates estimates of losses (see Buckle et al. 1985; Wood 1994). It is not surprising therefore that estimates of losses caused by rats may vary considerably within a country and sometimes within a local region. For example, a survey in 1982 in Indonesia of 48 randomly selected fields covering 1141 ha indicated that losses were around 17%. This represented a loss of production of 760 t. Official figures from the same area in the same year, but covering 100 000 ha, was 790 t. Official losses were underestimated by 100 times (Buckle 1990). This may explain why the estimate for Indonesia in 1980, which was based on the number of hectares damaged, was so much lower than the estimate in 1987, which was based on the value of the national rice crop and assumed 17% damage by rats. However, it was not clear from the report of the 1980 estimate of losses whether it was confined to specific regions of rice production, or whether it was for the entire country. Therefore in Table 2.1 we have supplied notes on how the estimates of losses were determined.

2.1 Indonesia

2.1.1 Magnitude of the rodent problem

Rats cause substantial economic losses to rice, as well as to most other crops including oil palm, sugar cane, maize, cassava, soybean, groundnut, coconut, mung bean and sweet potato. The damage by rats to rice is by far the greatest agricultural problem in Indonesia (Geddes 1992).

The major rodent problems occur in irrigated lowland rice. Van der Laan (1981) observed that during 1961 to 1970, rats were the major pest of rice production in the districts of Subang and Cirebon (West Java). Rats also are significant pests of other crops such as tidal rice and deepwater rice in Sumatra and Kalimantan. Rodents appear to be seriously affecting crops in the newly settled transmigration areas in Sumatra. The principal rodent pest of rice crops in Indonesia is *Rattus argentiventer*. In Sumatra, where there is greater diversity of crops, *Rattus exulans* is just as great a problem as *R. argentiventer* (Ir Rochman, pers. comm.). There are also minor problems caused by *R. rattus diardii* and *R. norvegicus* inhabiting houses throughout Indonesia. Other rodent species are pests of rice and other crops in Irian Jaya. Because of the small area of rice grown in Irian Jaya, and the different methods of cultivation compared to the rest of Indonesia, we will not consider rodent problems in that region.

South Sulawesi — a case study

In South Sulawesi there are 700 000 ha planted to rice per year of which 600 000 is rainfed, lowland rice. Around Pinrang and Sidrap (the rice-bowl of Sulawesi) there are 100 000 ha of irrigated land which produce two crops per year. Some rainfed areas also produce two crops but this is usually a low percentage of available cropping land.

A network of 154 'IPM observers' have been reporting crop losses from the Pinrang and Sidrap region to the Plant Protection Center at Maros every 2 weeks since 1983/84. These observers record the amount of crop damage and apportion the likely cause of damage to insects, diseases or rodents. Four categories of infestation by rats are reported:

1. Very light damage — losses <5%
2. Light to medium damage — losses 5–24%
3. Heavy damage — losses 25–75%
4. Crop failure — losses >75%

Based on an average yield of 5.2 t/ha, an economic estimate of yield loss was calculated at harvest. From 1983/84 to 1991/92, an average of 16900 ha were infested per year by rat damage, with an estimated average annual economic loss of 10.1 billion rupiah (US$4.7 million) (Data courtesy of Ir Shagir, Plant Protection Center, Maros) (Table 2.3).

Annual average loss to rice production caused by rats in the 'rice bowl' of South Sulawesi is approximately 16.9%. The number of hectares damaged by rats varies markedly between years (range: 1985 — 6000 ha; 1988 — 38 000 ha). This is a measure of rat incidence which provides a qualitative indication of rat density. These data indicate that although rats cause a chronic economic problem, there are episodic outbreaks of rat populations that cause acute economic losses. A sequence of only nine years is insufficient to determine whether these outbreaks follow a cycle. Interestingly, in the two periods of high rat densities, rat damage was high for two consecutive years. A sequence of two years of high rodent numbers also occurs during major mouse plagues in Australia (Redhead 1988; Singleton 1989; Singleton and Redhead 1989).

In summary, rodents are currently the number one preharvest problem to rice production in South Sulawesi. Previously tungro virus was the greatest problem, but changes in crop rotations and time of transplanting have greatly reduced the impact of tungro virus. Synchrony of planting and improved hygiene around crops also have reduced losses caused by rats but the problem is still substantial.

Indonesia in general

Data collected by the forecasting centres of the Directorate of Food Crop Protection in Indonesia indicate that rats cause losses of around 17% per annum to rice crops in Indonesia (Geddes 1992). The value of the Indonesian rice crop taken from 1987 figures is 9819 billion rupiah (approx US$4.64 billion) (Geddes 1992). The potential harvest if losses to rats were excluded would be worth approximately US$5.6 billion. Annual losses to rats therefore amount to about US$1 billion.

A recent publication by the Natural Resources Institute (the scientific unit of the U.K. Overseas Development Administration) examined the 'Relative importance of preharvest crop pests in Indonesia' (Geddes 1992). Estimates of pest importance were

Table 2.3 Incidence of rat damage and estimates of yield losses and economic losses caused by rats to irrigated rice (100 000 ha) in the rice-bowl of South Sulawesi. Data courtesy of Ir Shagir, Plant Protection Center, Maros.

Year	Incidence of rat damage ('000 ha lost to damage[a])	Yield loss ('000 tonne)	Economic loss (billion rupiah)
1983/84	25.8	51.7	15.5
1984/85	21.6	43.1	12.9
1985/86	6.1	12.2	3.7
1986/87	9.1	18.2	5.5
1987/88	11.0	22.0	6.6
1988/89	38.1	76.2	22.9
1989/90	19.5	39.0	11.7
1990/91	10.0	20.0	6.0
1991/92	10.8	21.7	6.5
Mean	16.9	33.8	10.1

[a] In South Sulawesi, 700 000 ha of rice are sown annually, of which 600 000 are lowland rice.

determined over four agro-climatic zones: SUB-MONTANE (altitude 1000 to 2000 m), WETLAND (dry season less than 4 months), DRY (dry season >4 months) UNIRRIGATED and DRY IRRIGATED. The ranking of preharvest pests was based on their relative economic importance. The two main factors considered were the actual losses to crops with existing control measures and the cost of control measures (Geddes 1992). Rankings were obtained from 72 scientists and bureaucrats drawn from 27 institutions within Indonesia, 13 scientists from IRRI and 7 agricultural scientists from the United Kingdom. Only two of these people were identified as rodent biologists (Ir Rochman, Bogor RIFC and Dr A. Toerngadi, Agricultural University, Bogor).

Rats were ranked as the most important non-weed pests in three of the four agro-climatic zones; they ranked fourth in the sub-montane zone. The number one ranking was both for all crops and for rice alone. The report concluded: 'Rats are the most important preharvest pest in Indonesia as a whole'. The ranking for pests of rice crops in Indonesia found through a survey of experts working in agriculture in Indonesia by Geddes (1992) are shown in Table 2.4.

The report by Geddes also had a compilation of the responses from IRRI scientists on preharvest pests of rice crops for other Southeast Asian countries (Myanmar, Thailand, Vietnam, Cambodia, Laos, Malaysia, Indonesia, the Philippines) over all ecosystems. Again rats were ranked as the most important pest (Table 2.4).

In Indonesia, rats are particularly a problem for the small land holder. The patchy nature of rat depredation means that, if affected, a land holder is likely to lose most of his crop. The small farmer is also constrained in the ways in which he can combat rats. Most single farmers in Indonesia (and elsewhere in Southeast Asia for that matter) have less than two hectares in which to grow all their crops. They also have very limited labour with which to undertake all the activities required of their farms. This means that they generally cannot plant all the farm at once and the resulting asynchronous planting substantially extends the availability of food to rodent pests.

A similar situation exists on a larger scale for much of the lowland irrigated rice. For example, in West Java the large irrigation area (250 000 ha) serviced by the Jatiluhur reservoir is divided into five areas (approx. 50 000 ha each). Because of the need to ration the water from the reservoir there is a staggered planting of rice throughout the irrigation district. There is a two week break between the planting of rice in each of the areas and this happens twice a year. Thus, there is almost a continuous food supply throughout the year for rodent pests of these crops.

2.1.2 Structure of rodent research

Rodent research comes under the umbrella of the Ministry of Agriculture. The Ministry is split into the Agency for Agricultural Research and Development (AARD) and the Directorate of Food Crop Protection (DFCP). AARD has a number of institutes including the Central Research Institute for Food Crops (CRIFC). Rodent research is conducted within CRIFC at the Bogor, Sukamandi and Maros Research Institutes for Food Crops (BORIF, SURIF and MORIF).

One rodent specialist is located at BORIF and apart from his work at Bogor on the efficacy of various rodenticides, he oversees research on rodent problems in tidal rice at a transmigration region in Sumatra. The rodent research effort is not high. As is often the case in Asia, the rodent group is under the direct supervision of an entomology research group.

Rodent research at SURIF is supervised by entomologists and the rodent field work is conducted by the farm manager of the research farm. A project assessing the effectiveness of using early maturing rice varieties and aromatic rice varieties as 'trap crops' (see Lam 1988, for details of the concept) was planned for 1993.

Rodent research at MORIF only began in 1994 and is again supervised by entomologists. The research emphasis is similar to SURIF. The effect of 'trap crops' on rat numbers is being assessed using fenced areas which have rice at the tillering and emergent stages (rows of rice are resown weekly). The study site is 20 ha with a 5 × 5 m fence plus two multiple capture traps located per hectare.

DFCP staff also have some involvement in rodent control through the Jatisari Forecasting Center. Their main role is extension and conducting training courses for staff involved in integrated pest management at 10 crop protection centres located in Indonesia. The scientist in charge of rodent control, Dr Joko Priyono, was involved in a collaborative research study with Japanese scientists on the population ecology of *R. argentiventer* from 1985 to 1992. The aims and scope of this study are outlined in Murakami et al. (1990).

2.1.3 Are rodent pests viewed as a priority by the Indonesian Government?

Dr Fagi, Director of CRIFC since March 1994 and prior to that Director of SURIF, considers rats to be the number one pest of rice crops in Java. To quote him, he recognises that at present the research on

Table 2.4 Ranking of the various pests of preharvest rice crops in Indonesia and through Southeast Asia as a whole, modified from Geddes (1992).

Rank	Indonesia	Southeast Asia
1	Rats (*Rattus* spp.)	Rats (*Rattus* spp.)
2	Stemborer (various species)	Tungro virus (vector-*Nephotettix virescens, N. nigropictus*) Brown Planthopper Stemborer (various species) Rice blast (*Pyricularia oryzae*)
3	Bacterial leaf blight (*Xanthomonas* pv. *oryzae*	Gall midge (*Orseolia oryzae*) Sheath blight Brown spot (*Drechslera oryzae*)
4	Brown planthopper (*Nilaparvata lugens*)	Rice Bug Birds (various species)
5	Tungro virus	Hispa (*Dicladispa armigera*) Bacterial leaf blight Leaf folder (*Cnaphalocris medinalis*)
6	Rice Bug (*Leptocorisa oratius*)	Golden apple snail (*Pomacea canaliculata*) — Philippines Ufra disease (*Dityenchus angustus* nematode)
7	Rice blast (*Pyricularia oryzae*)	
8	Narrow brown leaf spot (*Cercospora oryzae*)	
9	Sheath blight (*Rhizocotonia solani*)	
10	Narrow brown leaf spot (*Cercospora oryzae*)	

rats at SURIF is 'based on instinct rather than on a good scientific background'. Dr Ibrahim Manwan (Director of CRIFC until February 1994 and current Member of the Board of Management of IRRI) strongly believes rats are a major problem for rice growers in Indonesia. He also emphasises that rats are an important problem in Indonesia in other crops. He is concerned, not only by the current lack of expertise in rodent pest management in Indonesia, but also by the lack of training in rodent biology and in vertebrate pest management.

Dr Hasnuddin, Director of MORIF, considers rats to be the major preharvest pest to rice crops in South Sulawesi. He is keen for an increase in research effort in rodent control especially directed toward reducing chemical use in management operations. He stressed that community interest in tackling the rodent problem is high, with the provincial governor requesting an increase in research effort.

2.2 Laos

2.2.1 Magnitude of the rodent problem

About one quarter of the four million people who live in Laos are dependent upon shifting cultivation in upland areas of the country. This type of rice cultivation accounts for about 40% of the rice growing area in Laos but only for about 20% of rice production. The major rodent problems for rice in the Lao PDR occur in the areas where upland rainfed rice is grown. A survey of rice farmers in Luang Prabang and Oudomxay Provinces conducted by Roder et al. (1992) (Table 2.5) revealed that most respondents nominated weeds as the principal contraint on rice production with rodent pests coming second. There are some rodent problems in rainfed lowland and irrigated lowland rice but they are minor compared to those experienced in the uplands (J. Schiller — Lao/IRRI Project. pers. comm.).

The slash-and-burn agriculture associated with upland agriculture in Laos results in a very different crop management system to the other agro-geographic regions in Southeast Asia. In the uplands, there has historically been an eight year fallow between crops. Villagers therefore generally have to move house every couple of years (every year in some cases). However, in recent years there has been an emphasis on reducing the relocation of villages. Official policy is to eliminate shifting cultivation by the year 2000 (Fujisaka 1991). This has

Table 2.5 Major constraints to upland rice production as indicated by survey of farmers in Luang Prabang and Oudomxay Provinces Lao PDR (from Roder et al. 1992).

	Percentage of respondents				
		Luang Prabang			
Constraint	**Oudomxay** (32)[a]	**Vienkham** (53)[a]	**Pakseng** (20)[a]	**Xieng Ngeun** (24)[a]	**Average** (129)[b]
Weeds	81	83	95	83	85
Rodents	12	85	80	38	54
Insufficient rainfall	47	49	10	83	47
Land availability	47	11	45	62	41
Insects	69	34	20	29	34
Labour	31	25	25	17	24
Soil fertility	31	26	0	29	21
Erosion	9	9	15	25	15
Domestic animals	16	21	15	8	15
Wild animals	6	22	10	4	11
Disease	6	19	5	0	8
Suitable varieties	0	0	0	0	0

[a] Number of farmers from each province.
[b] Total number of farmers surveyed.

led to a fallow of only 3 or 4 years between crops for the same patch of land. The immediate effects on rodent population dynamics of this more intensive farming and more frequent clearing are not yet evident. One would suspect that the community composition of rodent species will change. Those best adapted to a commensal life and to high levels of disturbance will thrive. These are likely to be the species that have high reproductive potential and cause the most damage to rice crops. Changes in community dynamics of rodent species following dramatic changes in farming practices warrant close scrutiny.

The magnitude of rodent damage to rice crops in the upland regions varies markedly between years. For example, rats caused heavy losses in 1991 after several years with only minor losses. In 1991, it was common for growers to report losses of greater than 50% of their rice crops. The Luang Prabang Provincial Government responded to these losses by providing an incentive for farmers to kill rats. A bounty of 10 kip (700 kip = US$1) was paid for each rat tail deposited with the authorities. Over 600 000 tails were collected by growers (see Table 2.6).

An assessment of rat damage at the village level was conducted also in 1991 (see Table 2.5). These assessments can be misleading because of the patchy nature of damage. Some villages suffered losses of up to 100% of their rice cops (Walter Roder, pers. comm.) and for these people the losses were catastrophic.

We spent two days visiting and interviewing villagers in the upland region of Luang Prabang province. A detailed set of questions was asked to farmers from each village. We have included a summary of their responses because of the dearth of published information on rat problems in Laos, especially those in upland Laos (Tables (2.7–2.10). These interviews provide a valuable catalogue of an important problem that has not been previously assessed by wildlife biologists.

Table 2.6. The area of upland rice damaged by rats and the number of rat tails collected in Luang Prabang Province, Laos 1991 (Data courtesy of Dr Walter Roder).

District	**Area damaged (ha)**	**Percentage of total crop**	**Rat tails '000**
Luang Prabang	24	<1	0
Xieng Nguen	21	<1	8
Pak Ou	8	<1	0
Nambak	589	9	22
Ngoi	1009	15	42
Pakseng	623	14	25
Phone Say	556	10	4
Viengkham	1131	16	230
Phonkhoun	218	15	0
Other tails (direct to Agricultural Service)			215

All farmers expressed strong concern for the losses they suffered from rodents, especially during 1991. A common theme in the answers was that the 1991 outbreak of rodents was associated with the flowering of one or more bamboo species. Indeed the local name for mouse is 'norkey' which literally translates as mouse of bamboo flower.

The following quote probably summarises the general opinion: 'If there is no bamboo flowering, there is 5 to 10% damage to upland rice crops. If bamboo is flowering, then there is 60 to 70% damage of the crop. After bamboo flowering, rats eat the fruit of the bamboo and the rats breed quickly. The pattern of the plague is the appearance of big rats and then small mice.'

After visiting the areas affected by the 1991 plague and talking to government officials and villagers, we were not convinced of this link between the bamboo flowering and rodent outbreaks. The story appears to have developed only over the last ten years or so and may have come across from northern Thailand (Walter Roder, pers. comm.) One would expect that if there were a well established relationship between bamboo flowering and the appearance of rodent plagues, then the story would be enshrined within the folklore of the local people. They are very careful observers of the environment and it is extremely unlikely that such an important relationship would have gone unnoticed prior to the past decade. It may be that the bamboo/rodent story

Table 2.7 Responses by Lao Government officials and villagers from Luang Prabang, Laos, to questions on rodents in agricultural systems.

Question	Mr Thongsavanh Taipagnavong, Salakham Research Farm, Vientiane	Mr Onchanh; Mr Honmpheng, Agricultural Services and Lao/IRRI Project, Luang Prabang
Size of rats and local name	Not asked; he provided the 1980 FAO report and was involved in organising the visit of Dr Chaturvedi (India)	Norkey (small and mouse like), Norway (rat) and American Norway (the BIG one). The villagers think Norkey comes from the flower of bamboo (literal translation is mouse from bamboo flower)
Which have been the problem years for rats and mice?	1990/91; other notable years were 1979 (?), 1983, 1986/87 Problem every year in wet season; some years sow seed 2 or 3 times	1990/91; another notable year was 1987. Only some damage at sowing; main damage at booting stage (Sept/Oct)
Level of losses caused by rodents	Severe in uplands	1991 — 4237ha damaged (10 448 families surveyed); bounty cost 6 220 760 kip
What is the reason for eruption of rodent populations?	Bamboo flowering	(i) weather — after a dry year (ii) flowering of bamboo (iii) rats invade from neighbouring countries (e.g. Vietnam)
Which bamboo species is responsible for rodent increases?	Not asked	Highlighted those that flower in Feb/Mar and flower for 1.5 months
Are there losses to stored grain?	Major problem in uplands; minor problem in lowlands	Yes; no details
How are the rodents controlled?	(i) Bounty system — 10 kip/tail (ii) Recommend warfarin or zinc phosphide — not used widely as too expensive and farmers need training	Answer same as for Mr Thongsavanh Future management recommendations: (i) Same bounty system as in 1991 (ii) Native traps, especially pitfalls (iii) Traditional traps + pitfalls 'Only work on first day then rats too clever'

Table 2.8 Responses by Lao Government officials and villagers from Luang Prabang, Laos, to questions on rodents in agricultural systems (cont.).

Question	Mr Boonghame, Deputy Director, Agricultural Services, Luang Prabang	Head of Agricultural Staff Pak Seng Province
Size of rats and local name	Small and large rats; he would not estimate the ratio of small to large tails collected	'Thumb' (Norkey) rat and 'wrist' (no local name) rat; more of the smaller animals
Which have been the problem years for rats and mice?	1990/91; outbreaks have occurred on average every 5 or 6 years. Outbreak in western part of Luang Prabang Province in 1992	1991; problem with 'wrist' rat every 6 or 7 years in Pak Seng Province according to the older farmers in the district
Level of losses caused by rodents	Quoted same figures as Mr Onchanh	1991: 45% damage; rice increased in price from 100 kip/kg to 250 kip/kg; 60 kg of zinc phosphide distributed at 1200 kip/kg
What is the reason for eruption of rodent populations?	(i) Forest destroyed so rats have nowhere else to live and eat (ii) Very few predators have not been killed off by the farmers (iii) Old people claim that rats are a problem when bamboo flowers (but it didn't flower in 1991!)	No reason given, but bamboo and dry weather were intimated as possible causes
Which bamboo species is responsible for rodent increases?	There was no widespread flowering of bamboo in 1991	May 'bong' and May 'sot' which flower in April/May (sow rice in mid May/June)
Are there losses to stored grain?	Yes; no details	Not asked
Do rats show signs of disease? Do people get diseases during rodent outbreak?	No increase in disease in people during an outbreak	No obvious signs of disease in rats
Do the people use rats as a food source?	Not applicable	Eat medium sized rat
How are the rodents controlled?	Did not recommend zinc phosphide (too expensive and a 'bad' poison) Recommended driving rats into nets around each padi and using pitfall and bamboo traps. Also highlighted the need to: reduce harbourage by weeding rice fields; use local traps; not kill predators	Did not recommend zinc phosphide as it is too expensive and there are problems with secondary poisoning.
How do you rank rodents as an agricultural pest?	Number 1 problem in upland rice is weeds. Number 2 problem is white grub and rats	Important problem; no ranking given

Table 2.9 Responses by Lao Government officials and villagers from Luang Prabang, Laos, to questions on rodents in agricultural systems (cont).

Question	Bakor Villagers Luang Prabang Province (30 families)	Kamu Villagers Luang Prabang Province (51 families)
Size of rats and local name	'Thumb' rat and 'wrist' rat; small rat is more common	'Calf' rat and 'wrist' rat; also smaller rat
Which have been the problem years for rats and mice?	From 1970 to 1993, only one outbreak in 1989; expect moderate damage every 3 years	1991; problem at sowing in 1993
Level of losses caused by rodents	In non-rat years yield is 1.5 t/ha; in problem years yield is between 200 and 500 kg/ha	In non-rat years there is enough rice for 7 months — in 1991 there was only enough for 5 months; in other years there is commonly a loss of 20%
What is the reason for eruption of rodent populations?	Not known; likely to have a problem when May 'bung' bamboo flowers	Not asked
Which bamboo species is responsible for rodent increases?	May 'song' May 'hok' and May 'bung'	Not asked
Are there losses to stored grain?	Not asked	Wrist rat causes losses to stored grain
Losses to other crops?	Also damage to maize and opium crops	Also to maize
Do rats show signs of disease? Do people get diseases during rodent outbreak?	No indication of disease caused by rats	No problem with disease
Do the people use rats as a food source?	Hunted rats are used for food	Rats are eaten
How are the rodents controlled?	After 1980, district agronomists recommended zinc phosphide mixed with chicken meat and placed in the ricefield. Rats are also hunted with a crossbow	Mixture of maize and zinc phosphide which is considered effective; local traps are also used for control
How do you rank rodents as an agricultural pest?	Main pests are white grub, army worm and grasshopper. Rat is the most important pest after panicle stage	Rats are the primary pest

is an argument of convenience, deflecting the blame to an act of nature rather than to the farm management of the hill tribes. However it is difficult to be definitive when reviewing the cause of an outbreak that occurred two years earlier and when so little is known about the animals involved.

There is much work to be done to ascertain whether any of these stories about the relationship between rodent plagues and bamboo flowering are true. There is so little known about the biology of the rodents that even the identity of the main pest species is uncertain. From talking to farmers and officers of the Agricultural Services and Extension Agency, it appears that there are three sizes of pest rodents. The largest one is assumed to be a bandicoot, probably the great bandicoot, *Bandicota indica*, the middle sized one the ricefield rat, *Rattus argentiventer*, and the smallest probably a species of *Mus* (*M. caroli* or *M. cervicolor*).

2.2.2 Structure of rodent research

The magnitude of the rodent problem in the Lao PDR is recognised at both the provincial (particularly upland provinces) and national levels of government. Research effort is weak and there is no indication that this will change in the short term. This is despite the widespread recognition of the rodent problem. The best resource of information on the biology of rodent pests was Mr Thongsavanh Taipagnavong, Deputy Director of the Agricultural Extension Agency, Salakham Research Farm, Vientiane.

2.2.3 Are rodent pests viewed as a priority by the Laotian Government?

We met with Mr Kou Chansina, the Director General of Agriculture and Extension. He was well informed on the rodent problems in Laos and asked whether we could recommend management strategies following

Table 2.10 Responses by Lao Government officials and villagers from Luang Prabang, Laos, to questions on rodents in agricultural systems.

Question	Pon Tong Villagers Luang Prabang Province
Size of rats and local name	Problem with 'wrist' rat in upland regions; problem with 'calf' rat in lowland regions; also smaller rats
Which have been the problem years for rats and mice?	1990/91; also some damage at sowing in 1993
Level of losses caused by rodents	Chronic problem in lowlands (two crops/year) with little damage to dry season crop (yield – 2t/ha) and high damage to wet season crop (yield – 0.7t/ha)
What is the reason for eruption of rodent populations?	Not known but farmers think that bamboo flowers provide enough food for the rats
Which bamboo species is responsible for rodent increases?	*Bambusa tulba* and *Oxythenetera parvifolia;* flower from April to May
Are there losses to stored grain?	Yes, but species unknown
Do rats show signs of disease? Do people get diseases during rodent outbreak?	Not known
Do the people use rats as a food source?	Yes, larger rats are eaten
How are the rodents controlled?	Zinc phosphide was used for 1990/91 outbreak (yield loss about 2/3 without chemical and 1/3 with chemical); crossbows and local traps also used

our visit to Laos. We stressed that a basic understanding of the biology and population ecology of the key rodent pests would be required before worthwhile management strategies could be developed. Mr Chansina was well briefed on the 1991 outbreak of rodents in the upland provinces.

2.2.4 If rats are a high priority why is the research effort so poor?

In Laos the answer is simply lack of resources. The country not only lacks money to put into rodent research but also lacks well-trained vertebrate ecologists.

2.3 Malaysia

In Malaysia there are 400 000 families growing 500 000 ha of rice. The three principle rice growing regions are MUDA, in Kedah State, Penang State and the east coast region. MUDA contains a large irrigation scheme and is regarded as the 'rice bowl' of Malaysia. MUDA consists of 90 000 ha, 25% of the land under cultivation for rice in Malaysia, and produces 50% of Malaysia's rice.

2.3.1 Magnitude of the rodent problem

The main pest species in Malaysia are *Rattus argentiventer* in rice, *Rattus rattus tiomanicus* in oil palm, *Rattus rattus diardii* in stored grain and recently in oil palm, and *Rattus exulans* in houses. We will focus on rat problems in rice crops. Annual losses to rice caused by rodents is generally around 4 to 5% (Tuan Haji Embi Yusof, Deputy Director MARDI, pers. comm.), however, as with other countries in Southeast Asia, the patchy nature of the damage means that individual farmers may lose large proportions, if not all, of their crop. Thus rats can have catastrophic effects on the livelihood of individual farmers.

To get an indication of the densities of rats that can occur in some regions in Malaysia, a study was conducted of two areas that have planting times for rice out of phase by 2.5 months. An 8.3 km fence, plus traps, was constructed between the two areas. As many as 6872 rats were caught on one night and 44 101 rats during a nine week period (Lam et al. 1990a). Rice yields in areas where there was no protection to the crops were 0.8 and 1.1 t/ha, whereas crops that were fenced had yields of 4.2 and 4.3 t/ha (Lam et al. 1990a). This is an extreme case but indicates the effect rats can have when agricultural conditions suit them.

In a study where fields of rice were selected at random, the impact of rats on yields revealed losses ranging from 2% to 10% (Buckle et al. 1985). Another study in Malaysia indicated losses of around 40%; average yields were 4.2 t/ha in nine areas where rats were controlled and 2.5 t/ha where there was no control (Wood 1984a). In larger trials the difference was not as pronounced in some areas, thus reflecting the heterogeneity of habitat use by rats. Overall, however, the average difference in yields was 33% (Wood 1984a).

2.3.2 Structure of research

Scientists at the Malaysian Agricultural Research and Development Institute (MARDI) are responsible for research and a limited amount of development of technologies for the management of rodent pests. In 1992, there were two scientists undertaking research on rodents within MARDI. One working on rice (at the Rice Research Institute, Kepala Batas) and the other on cocoa (at the Cocoa and Coconut Research Center, Perak).

The small team at the Rice Research Institute of MARDI is led by Mr Lam Yuet Ming. Because of the structure of MARDI, Mr Lam must focus on rat problems in rice crops. This focus is restrictive given the mosaic of rice, coconut, cocoa, banana and oil palm in many of the rice growing areas. A study of the way rats use these different crops in time and space would be an essential prerequisite to an understanding of the factors that influence the dynamics of rat populations in rice crops.

In rice, the emphasis of the research is on toxicology and the use of a physical barrier with multiple capture traps located at openings in the barrier (see section in chapter 7 on Active Barrier Fence/ Environmentally Friendly System). In cocoa and oil palm, the emphasis of the research is on avian predators as a mechanism of control. For example, researchers from the Palm Oil Research Institute of Malaysia, Ministry of Primary Industries, have developed predictive modelling of the potential of barn owls, *Tyto alba,* to control wood rats, *R. tiomanicus*, either by themselves or with rodenticides (Smal et al. 1990).

Other research on rodents is conducted in Malaysia by private industry. For example, oil palm estates have in the past funded research of rodent pests (e.g. Wood and Liau 1977; Wood 1984b; Wood and Liau 1984a,b), and are responsible for their own rodent management programs.

2.3.3 Are rodent pests viewed as a priority by the Malaysian Government?

Tuan Haji Embi Yusof — Deputy Director General of MARDI (Research Support and Development), confirmed that rodents cause an average annual loss of about 5% to rice crops, that these losses were extremely patchy, and that often individual farmers suffered substantial (>50%) losses. These foci of damage, which varied in location between years, meant that rats were viewed as an important agricultural pest by the Malaysian Government. However, he did not foresee a likely increase in research personnel working on the problem in the near future.

2.4 The Philippines

2.4.1 Magnitude of the rodent problem

The major rodent problems in the Philippines occur in rice crops where the principle rodent pest species are *Rattus rattus mindanensis* in Luzon and the Visayas and *Rattus argentiventer* in the islands of Mindanao and Mindoro. *Rattus norvegicus* and *Rattus exulans* generally are of minor concern except on the islands of Cebu and Palawan (Fall 1977).

Rodents also cause significant problems around houses and grain stores and to other crops such as coconuts. On the main island of Luzon, *R. r. mindanensis* is also the principle pest species in these situations.

The history of major rat problems in the Philippines is linked to major changes in agricultural practices. For example, in the 1950s, widespread irruptions of rat populations in Mindanao and Mindoro followed a rapid expansion in the amount of land cultivated to rice. Crop losses of 8% of rice production were attributed to rats in 1953/54 valued at US$55.3 million (Sumangil 1990). During the early 1950s rat depredations led to widespread food shortages on Mindanao island (Crucillo et al. 1954). The introduction of two crops a year in the 1960s to regions of the Philippines further exacerbated rat problems because rats responded by having two breeding seasons rather than one.

National losses to rice crops by rats were estimated by the Bureau of Plant Industry in the 1970s. Losses in the early 1970s ranged from 3.2% to 4.5% for wet season crops and 1.65% to 2.47% for dry season crops. Losses were reported in 90% of fields surveyed and losses were greater than 10% in 7% of the crops (Hoque et al. 1988). Average losses of just less than 5% were estimated in 1975 to be worth approximately US$67.3 million. A National Rodent Control Program, based on integrated pest management protocol, was implemented in 1976 and losses fell immediately to less than 1% (see Sumangil 1990). Average annual losses were 0.52% between 1976 and 1980 (Hoque et al. 1988).

The rat problem in the Philippines was still claimed to be under control in the 1990s with annual losses of less than 1%. Success was attributed to the implementation of the National Rodent Control Program in 1976 (Sumangil 1990). The success of the program in the late 1970s was at a time when there was a strong infrastructure of training in rodent pest management through close involvement of researchers from the Denver Wildlife Research Center, USDA. This was combined with an active field program emanating from the Rodent Research Center at UPLB, Los Baños (see section 2.4.2 for details). In the 1990s there is little of this infrastructure remaining, yet the Bureau of Plant Industry claims that national losses caused by rats are being maintained below 1%.

Ms Hoque still regards rodents as a significant problem in rice crops in the Philippines with damage up to 35% in some areas. Scientists at IRRI confirm that rats are still a substantial problem to rice farmers in the Philippines based on regular reports of rat damage that they receive from the main rice-growing regions (G.R. Quick, pers. comm. 1994).

We provide the following case study to illustrate the current rodent problem in the Philippines. During a visit to IRRI in April 1993, we met with a farmer leader from Mindoro. The rice grown in Mindoro is mainly lowland and irrigated. The farmer reported that substantial rat damage occurred to his rice crop in the previous year — in late September 1992 he estimated a harvest of 3.75 t/ha; in December his harvest was 1.03 t/ha. He had a 4.0 hectare farm and he indicated that these rat losses were typical for his village. In general, on Mindoro Island rat damage is highest in the wet season. Damage is variable from year to year, with bad years resulting in losses around 30%. Some farmers had lost virtually their whole crop in some years.

Of interest is that this 'Barangay' (=village) had not seen a government Pest Control Officer (PCO) for years. The PCOs showed very little interest in the rat problem and the farmers were not following the recommended 'sustained baiting strategy'.

2.4.2 Structure of rodent research

Past

In 1968, the National Center for Crop Protection (NCPC) was built as an annex of the University of the Philippines at Los Baños. Initially, the NCPC was in effect the Philippines Rodent Research Center. The role of the center was to conduct research and to train field officers. In the 1970s the NCPC had strong input from staff of the Denver Wildlife Research Center, U.S. Department of Agriculture, through funding from the U.S. Agency for International Development.

In the mid 1970s, the Philippines Bureau of Plant Industry employed rodent pest control officers (PCOs). These officers were trained at the NCPC and were then sent out to the provinces to provide a surveillance and early warning system (SEWS) and an avenue for distribution of rodent baits. The field officers were trained to implement a 'sustained baiting strategy' developed by the Rodent Research Center of the NCPC in consultation with the U.S. Department of Agriculture.

Current

In 1992, the 'sustained baiting strategy' is still the basis for rodent control in the Philippines. This is despite the fact that:

(i) The strategy is poorly adopted by farmers (Ocampo 1980)

(ii) Mr Jesus Sumangil (Plant Protection Section, Bureau of Plant Industry), who coordinated the national rodent control program from its inception, retired in 1991. His retirement coincided with the lapse of the SEWS. Instead, it is left to field technicians to report back to the central agency of the Plant Protection Section in Manila, on an ad hoc basis.

(iii) If a problem is reported the farmers then have to go through a 4-tier system of information flow (village (Barangay) — municipality — province — national) before rodenticides will be issued to them. This causes a time delay in the distribution of anticoagulant rodenticides which leads farmers to take other actions such as rat drives, flame throwing and alternative chemicals.

(iv) Farmers, who prefer to see tangible results for their actions (i.e. dead rats near the site of poisoning), would rather use zinc phosphide than the recommended anti-coagulant rodenticides (anti-coagulants take a minimum of 5 days to kill a rat and the bodies are rarely visible).

In 1994, there is only one person (Maranda Hoque) in the NCPC who maintains an input into control of rodent pests. Unfortunately her input is only via training; there are no funds for research on rodents so her research is on insect pests of vegetable crops.

When there are reports of high numbers, 'sustainable baiting' is rarely implemented. Instead, the traditional method of rat drives is generally used. This is a decision based on political expediency. Provincial or Municipal governments can provide labour (which is cheap) and the farmers can also participate in the exercise. An exercise that produces a tangible (if not effective) result in the form of dead rats. This then appeases the farmers!

2.4.3 Are rodent pests viewed as a priority by the Philippine Government?

Mr Agito de la Pas (Officer-in-Charge of Documentation and Information, Plant Protection Service, BPI) whose current position includes responsibility for rodents and other vertebrate pests of agricultural crops, summed up the view of the Philippine Government with the following statement:

> *'Rats are not a problem in the Philippines. They were a significant problem in the 1950s and 1960s but not now. The problem has been overcome since the introduction of rodent control pest officers.'*

The BPI is responsible for extension and provision of chemicals for implementation of control. Their extension program is based on the 'sustainable poison program'.

2.4.4 Rodent research at the International Rice Research Institute

IRRI scientists have contact with many rice farmers, especially in Luzon. Rat problems are constantly being raised. Although the official average level of rat damage in the Philippines is approximately 1%, there are instances where local rat damage is high. Given the average farm size is 1 ha, it is not unusual for a farmer to lose their only crop to the depredations of rats.

Another concern for IRRI scientists is the high value of their experimental crops. In 1987 a survey of 51 scientists at IRRI suggested that rat damage occurred in 86% of 171 field experiments causing complete loss of data in 6.4% of experiments and partial loss of data in 59.1% (Ahmed et al. 1987). These losses were quantified at US$370 000 per annum. In the past, rice crops at IRRI have been surrounded by steel fences fitted with a single electrified wire . The electric current is sufficient to deter rather then kill rats. Neighbouring farmers, however, in their desperation to control rats have redirected mains-power into their paddy fields. This has led to at least 11 human fatalities (Quick and Manaligod 1990). Interestingly, the survey undertaken by Ahmed et al. (1987) on rat damage to crops at IRRI revealed that complete loss of field data was highest in plots protected by the electric fences.

Currently, Dr Graeme Quick (Leader of Agricultural Engineering) is experimenting with the use of a temporary fence of plastic with multiple-capture live-traps placed every 20 m along the fence. This method has been termed the 'Active Barrier System' (ABS) and is based on a method developed in Malaysia (Lam 1988; Lam et al. 1990a). This approach is considered in more detail in Chapter 7.

2.5 Thailand

2.5.1 Major rodent problems

Rodents cause significant damage to a range of crops in Thailand (e.g. rice, oil palm, barley, soybean, mungbean, coconut, macadamia nut). Of major economic importance are losses in rice and oil palm crops. Fifteen species of rodents have been identified as important pests to agricultural crops. The principal pest in rice crops is *Rattus argentiventer*.

In rice crops, losses are on average 6% in lowland and 7% in upland rice. Damage occurs every year in upland rice whereas damage is more variable in lowland crops. The most recent loss figures were from 1985. There has been no research in upland rice for 5 years. In lowland rice they now expect losses to be <6% because of advances in control methods.

In oil palm plantations, losses caused by rats vary considerably both between years and between plantations. The losses generally range from 6 to 36%. The main pest species are *Bandicota indica* and *Rattus losea* to young (<4 years) palms and *R. tiomanicus* and *R. diardii* to older palms.

2.5.2 Structure of research and control of rodents

Research on rodent pests is conducted by staff of the Agricultural Zoology research group, Division of Entomology and Zoology, Department of Agriculture. The research group is located at Bangken near Bangkok. The unit is directed by Mr Sermsakdi Hongnark and consisted of about 5 research staff plus support staff. The physical infrastructure support was equal to the best we had seen in Southeast Asia (MARDI, Malaysia had similar facilities). This included animal houses and associated laboratories. However, the range of animals studied was diverse, including not only mice and rats but also snails, slugs, crabs, bats and birds.

The emphasis of the research is mainly on use of chemicals (Table 2.11) although there has been one population study of *R. argentiventer*. Current research on rodents is in oil palm, barley and soybean crops. There is no current research in rice because they felt that a satisfactory warning system is in place, backed up by adequate control methods.

2.5.3 Are rodent pests viewed as a priority by the Thai Government?

We did not get the opportunity to visit any Government officials other than those at Bangken. We would require further information to clearly assess the priority of the Thai Government for the control of rats in agricultural crops.

2.6 Vietnam

2.6.1 Vietnam — a brief look at a recent rodent problem

Rats have caused damage to rice crops and other agricultural crops in Vietnam for many decades. Recent changes in economic structure to agricultural production has led to a 38% increase in rice production in Vietnam. This increase has occurred mainly in the Mekong and Red River deltas (Table 2.12). Yields have increased also (Table 2.12). Factors leading to these increases include more intensive farming and a general increase from two to three crops per year (L V. Thuyet, Director, National Institute of Plant Protection, pers. comm.). Both of these practices would benefit rodents through increasing food supply and extending the availability of high quality food. The latter would extend the period of breeding of female rats because their breeding season is linked to the stage of crop development (see Lam 1980; Fiedler 1986). It is not surprising therefore, that serious rat problems began to be reported in the Mekong River delta in early 1992.

Rat problems in the Mekong River delta — 1992/93

In the winter-spring season in 1992, the area of damaged rice in the Long-An, Tien-Giang and Dong-Thap provinces was 10 125 ha. At the same time of year, but across 10 provinces, the area damaged by rats was 44 000 ha in 1993 and 31 500 ha in 1994. For the whole of the Mekong delta an estimated 100 000 to 300 000 t of rice was lost to rats in 1993. In Long-An province alone, 10 000 ha suffered 10 to 30% damage and 40 000 ha suffered greater than 50% damage. In Ha-Tien and Kien-Giang provinces, 822 ha suffered greater than 80% losses in yield.

Three different species of rat were observed but their generic status was uncertain. We have focussed on changes in agricultural practices, outlined above, as the principal contributing factor to these increases in rat densities. Possible explanations provided by our Vietnamese colleagues were:

(i) The water level of irrigated crops was 0.5 to 0.6 m lower than in previous years. This was

Table 2.11 Summary of recent and current laboratory and field studies presently being conducted on vertebrate pests by the Thailand Agricultural Zoology Research Group.

	Research	Year	Project Leader
1.	Damage appraisal of rice due to rodent pests in the north	1991–92	Sermsakdi Hongnark
2.	The use of difethialone (wax block) for rat control in the rice field	1991–92	Sermsakdi Hongnark
3.	Field trial for the use of bromadiolone for rat control in barley	1991–92	Sermsakdi Hongnark
4.	Study on squirrel control methods in cocoa-coconut plantation	1992–93	Yuvaluk Khoprasert
5.	Field trial on palatability of different zinc phosphide poisoned baits on rodents in soybean	1991–93	Puangtong Boonsong
6.	Efficacy of flocoumafen (wax block) in pomelo plantation	1991–92	Taksin Artchawakom
7.	Field trial on palatability of different zinc phosphide poisoned baits on rodents in oil palm plantations	1991–93	Puangtong Boonsong
8.	Anti-fertility effect of *Pueraria mirifica* against lesser field rat *Rattus losea*	1991–94	Korndaew Suasa-ard
9.	Efficacy test of anticoagulant rodenticide against *Mus* spp. in the laboratory	1991–93	Korndaew Suasa-ard

thought to benefit rat production and their rate of development.

(ii) There was a migration of rats from the Cambodian side of the border because of food and water shortages in Cambodia.

(iii) An increase in the killing of predators (e.g. snakes and birds of prey) had unbalanced the ecosystem.

The control measures that were adopted included the use of zinc phosphide; catching of rats by hand; digging ditches around crops, filling these with water and then pouring oil onto the surface; use of barrier fences; and the use of electric traps. To encourage cooperation by farmers, many local authorities applied a bounty system for rat tails (T. Q. Hung, Director General, Plant Protection Department, Ministry of Agriculture and Food Industry, pers. comm.).

Table 2.12. Yield and production of rice in Vietnam 1985–1993 (from data provided by the National Plant Protection Department, Ministry of Agriculture and Food Production, Hanoi).

	1985	1990	1991	1992	1993
Yield (t/ha)					
Winter/spring rice	3.50	3.78	3.15	4.01	3.88
Early summer rice	3.33	3.38	3.48	3.39	3.57
Summer rice	2.22	2.65	2.85	2.73	2.94
Average	2.78	3.19	3.09	3.33	3.43
Production (million tonnes)					
Throughout Vietnam	15.875	19.225	19.427	21.540	21.900
Red River delta	3.092	3.618	3.118	4.000	4.513
Mekong delta	6.860	9.480	10.351	11.000	10.742

2.7 If Rodents are a High Priority Why is the Research Effort so Poor in Southeast Asia?

The research effort on rodent pest management in Southeast Asia does not match the apparent magnitude of the problem. Countries such as Malaysia and Thailand have good scientific teams working on rodents but in both cases the teams are small and under-resourced.

In Laos the answer is simply lack of resources. The country not only lacks money to put into rodent research but also lacks well trained vertebrate ecologists.

In contrast, the Philippines had a good, reasonably well resourced research effort back in the 1970s and early 1980s. However, this research effort has virtually come to a standstill and the intellectual capital is rapidly being lost.

In Indonesia where the rodent problem is greater than for most other Asian countries, the situation is best summed up Dr Ibrahim Manwan, Director of CRIFC, Indonesia. When asked why so few resources (people and equipment) were allocated to research on rats if they were such an important problem in rice (and other) crops, he made the following points:

(i) Pest management courses in universities are dominated by entomologists and plant pathologists. People trained as entomologists find it too difficult to work on rats. In many young scientists there is also a psychological barrier to working on rats.

(ii) The research on rats over the past 20 years has focused on poisons. The output has been routine testing for national registration, some research on how to use the chemicals and comparisons of their relative efficacies. He saw a definite need in Indonesia for further research on rodent pest management that went beyond 'traditional techniques' of rodent control (e.g. fumigants and poisons).

(iii) Dr Manwan was concerned at the dearth of young and enthusiastic graduate students involved in rodent research. He clearly stated that the greatest challenge facing fresh initiatives in rodent pest management in Indonesia was recruiting young scientist(s) who had the right credentials (academic and general aptitude) for undertaking a collaborative project with rodent population specialists from overseas.

Unfortunately, the lack of trained rodent scientists is not restricted to developing countries. In a preface to a book on 'Rodent Pest Management' that he edited, Professor Ishwar Prakash (1988) wrote,

> *'It is felt this work on rodent pest management will trigger more research effort for the benefit of mankind and help .... in revitalising serious work in this field which, it appears, has dampened during the last few years.'*

It is five years since this book was published and Professor Prakash has since retired along with other eminent workers in the field of rodent biology and control. The replacements have been few. The situation led him to repeat his plea at the 'Rodents and Rice' expert panel meeting held at IRRI in 1990 (Prakash 1990). His main point was that rodents are a global pest and we cannot afford to lose the expertise which will be needed to assist in the fight to control them. A fight that we fear will gain more and more recognition through necessity as years pass by, not only in developing countries but also in developed countries.

CHAPTER 3

Current Control Strategies

' The principal of the cultural control of rats is the purposeful manipulation of the environment to make it less favourable to rats, thus exerting economic control of the rats by reducing their numbers and crop damage.' — Lam Yuet-Ming (1990)

The strategies adopted for managing rodent pests in agricultural systems vary from country to country in Southeast Asia. Differences are related to which species are the main pests, the type of crops, the method of cropping in the case of rice (e.g. dryland, irrigated, upland, deepwater), the availability and affordability of rodenticides, the infrastructure of pest management (including extension), the level of knowledge on the basic biology of the main pest species, and the social and political structures within a country.

In this chapter we will consider the national and local strategies adopted to control rodents in rice crops in Indonesia, Laos, Malaysia, the Philippines and Thailand.

Rodenticides provide the basis for the current management strategies in most countries. Much has been written about the use of rodenticides and their efficacy under field conditions in Southeast Asia (e.g. Wood and Liau 1977; Buckle et al. 1979; Benigno and Sanchez 1984; Fiedler et al. 1990; Meehan 1984; Wood 1984a; Lam 1985; Sanchez and Benigno 1985a; Lam et al. 1990b; Sumagil 1990; Buckle 1994) and integrated management schemes based on the use of rodenticides have been trialed in Peninsula Malaysia and Central Java (see Buckle et al. 1985 and Buckle 1990 for reviews).

High cost/benefit returns have been demonstrated in a number of studies aimed at evaluating chemical control of rodents in Southeast Asia (e.g. Wood 1971; Buckle and Rowe 1981; Lam et al. 1986; Lam et al. 1990b). However, the success of these management operations generally require a series of bait applications. The challenge facing wildlife managers is to convince growers to continue bait applications after growers begin to perceive a drop in rodent activity (see Lam et al. 1990b).

In the immediate future, rodenticides are likely to play an important role in any integrated management strategy directed at reducing the impact of rodent pests. Because of the extensive literature that exists on rodenticides and their use, we will not be considering chemical control in any depth, instead we refer interested readers to the above papers.

3.1 National Strategies for the Control of Rodents

3.1.1 Indonesia

National rodent training courses are conducted infrequently (last one was in 1988) by the Jatasari laboratory of the Directorate of Food Crop Protection. There is not a well structured national rodent control program. Basically, the extension of rodent management focuses on advising farmers on which poisons to use and how to use them. As in the Philippines and Malaysia, the second generation anticoagulants are recommended to the farmers. The farmers however, prefer to use zinc phosphide because of the higher cost of anticoagulants and the tangible results provided by zinc phosphide (dead rats near the bait).

A community based program of rat control is incorporated in the FAO inter-country program for the development and application of integrated management in rice growing in South and Southeast Asia (van Elsen and van de Fliert 1990). This program has only recently been implemented but has had little input from vertebrate population biologists. The program was implemented in areas with chronic rat damage and appears to have been successful in reducing losses (van Elsen and van de Fliert 1990).

3.1.2 Laos

At the national level, control of rodents is the responsibility of the Department of Agriculture and Extension. At the provincial level, control of rodents is the responsibility of staff from Agricultural Services. There is no coordinated national rodent control program.

3.1.3 Malaysia

National management and extension program

The main method for rat control is the use of chemicals. As in the Philippines, farmers prefer to use zinc phosphide (cheap; dead rats are visible) even though MARDI and the Department of Agriculture recommend the use of wax blocks of brodifacoum (a second generation, one feed, anticoagulant). Regardless of which chemical is used, the strategy is the same. Baits are placed every 10 paces in the open (about 60 bait stations per ha). If a rat problem was evident during the harvest of the previous season's crop, then baiting is recommended once a week for eight weeks after planting of the next rice crop.

Rodenticides are subsidised by the Malaysian Government. The farmers obtain the rodenticide on credit at a subsidised cost from a co-operative. The farmer pays for the poison after he has harvested and sold his crop.

A physical barrier interspersed with multiple-capture traps, is another recommended method of rat control. This method is generally used in regions where rat damage has been typically high. The use of these barriers is based on reports from field officers from the Department of Agriculture who monitor the level of crop damage by rodents. Control operations are recommended when greater than 15% of hills of a standing rice crop are damaged by rats.

The MARDI researchers we spoke to identified farmer apathy as the main impediment to effective control of rats. Apart from there being many farmers who do not follow the recommended baiting schedule (they tend to stop baiting after 2 to 4 weeks), others show a lack of basic farm hygiene practice (e.g. no synchrony in planting crops; surrounds of crops are weed infested) or do not even plant crops because they are more interested in biding their time until the urban sprawl reaches them so that they can sell their land.

3.1.4 The Philippines

A Rodent Research Center was established at the University of the Philippines at Los Baños in 1968. This Center became part of the National Crop Protection Center (NCPC) when it was established in 1976. Benigno (1985) provides a brief history of the establishment of these centers and of the support provided by international bodies.

The main function of these centers was to provide training of field officers, and undertake extension and research. There are four tiers of information flow on pest management in the Philippines. The base level is the Barangay (village level), followed by the municipality, province and then the Bureau of Plant Industry (BPI) in Manila. Field officers are employed by the BPI and are referred to as Pest Control Officers (PCOs). The PCOs are attached to municipalities.

National management and extension program

A national rice production program, MASAGANA 99 (M-99), was instigated in 1975. This program included a national rodent management program. If farmers had a rodent problem they had access to free technical help and to a non-collateral credit program which provided bank loans for purchase of rodenticides. The latter was only available if they followed the M-99 program. This recommended management program, which was based on sustained use of anticoagulants placed strategically in bait stations, is detailed in Appendix 1.

The BPI also developed, in parallel, a surveillance and early warning system (SEWS). Information was channelled annually to the BPI at Manila. This information was used to assess rat problems on a national scale. The SEWS system was not operational in 1992. The onus is now on PCOs to report any significant rodent problems.

The adoption of the M-99 rat control program in Laguna the year after it was proclaimed was low. Only 12.5% of farmers adopted the recommended control, and then only in part, and only 18.5% were aware of it (Dizon 1978). Two reasons were suggested for this low adoption rate: one was that farmers considered 5 to 20% damage by rats to rice tillers was not sufficient for control action; the other that there was a poor information flow despite PCOs being trained to extend the M-99 program (Dizon 1978). In Bulacan, initial adoption rates of M-99 by farmers were high but fell rapidly over the next 5 years (Ocampo 1980).

In the 1990s, the M-99 program is still current yet it appears that the rate of adoption is very low. Another cause for non-compliance in recent times was the 4-tier system of information flow. If a farmer reported significant rat damage, access to rodenticides under the M-99 program required approval from the BPI. By the time this approval was given, the rodenticides provided were too late for effective and economic control.

In summary, the M-99 program has been in operation for over 15 years yet does not have a high adoption rate by farmers. The crucial information that is required is whether this is a result of poor extension and implementation, or whether the control methods are perceived as inappropriate by the farmers.

Rodent research personnel

Research on rodents at the NCPC was linked closely with the Denver Wildlife Research Center (USDA, Colorado, USA) from 1968 to 1983. The main result of this collaboration between USDA and NCPC was the development of the national 'sustained baiting strategy' which was adopted as part of M-99. During this period four Masters theses and two PhD theses were produced. Unfortunately, once qualified, most of these people moved away from rodent research. Since 1983 the level of research has declined. At the NCPC in 1992, there was one scientist with extensive rodent research experience and, at the time, this scientist was working primarily on insect pests.

Training of Pest Control Officers

The training program of Pest Control Officers (PCO) was based at the NCPC. The program concentrates mainly on insect and weed problems. In 1992, the training program of a PCO covered 3 weeks of which 3 hours were devoted to rodent management.

3.1.5 Thailand

Control is implemented by officers of the Animal Pest Section of the Plant Protection Service of the Department of Agriculture. There are 30 Plant Protection Service Units and each unit is responsible for usually 2 of the 73 Provinces in Thailand. Each province has 10 districts and there is one agricultural officer in each district. Therefore there are 730 district officers that report back to the PPS units.

If a severe rodent problem is reported, the relevant PPS unit will recommend to the Department of Agriculture that rodenticides be distributed to farmers. The rodenticide is free to farmers, but not to private oil palm plantations. For single applications, zinc phosphide is recommended to farmers. When continuous chemical use is required, pulse baiting using anticoagulants is recommended.

Training of Plant Protection Service staff

Rodent control courses lasting 3 to 4 days are held for PPS staff. These courses are presented by the Agricultural Zoology Research Group at Bangken. This research group also provides an input into training courses provided for international programs on integrated pest management. However, the emphasis on vertebrate pests in these programs is usually low.

3.2 Concluding Remarks

Both Malaysia and the Philippines have national rodent control programs in place that have low adoption rates by farmers. We have provided possible reasons why this may be the case. The suggestion of farmer apathy may be a convenient explanation for pest control officers and researchers who have in place a management strategy. However, the problem of farmer perception in relation to rodent management has been given scant, if any, attention.

Inadequately considering farmer practices, and overestimating their skills are thought to account for the lack of success of IPM programs against insects and weeds in developing countries (Brader 1979; Heong et al. 1992). Perhaps a similar argument can be applied to rodent management programs. An interesting template for tailoring management programs for the end user, the farmer, is presented by Norton and Heong (1988).

CHAPTER 4

Ecology of the Major Pest Species

'Considering that rodent research and rodent control are continuous processes, we cannot afford to allow the extinction of rodent research centres. If national governments are unable to support rodent research, International Organisations should find funds to maintain research on these global pests.' — Ishwar Prakash (1990)

4.1 Previous Research in Indonesia

Early studies of the biology of the rice field rat, *Rattus argentiventer*, and the problems they cause in Indonesian rice fields, were conducted by van der Meer Mohr in the 1920s and van der Goot in the 1930s and 1940s (cited in van der Laan 1981). They reported that these rats require food rich in starch and that breeding is influenced by the quality and availability of food. The favoured nesting sites are the banks of rice fields. The first young (10 to 12 in a litter) are born approximately 10 days before the rice crop is ready for harvest. Occasionally, rats suddenly migrate in masses to other crops and cause high levels of damage. The reason for this sudden migration was not stated.

Van der Laan (1981) provides a diagrammatic cross section of a typical burrow and nest of the rice field rat in a bank of a rice field. The burrows are shallow and consist of two entrances, a nest site and a blind-ending gallery for an emergency exit. Despite the nest sites being located on the edge of the rice field, rat damage is typically concentrated in the centre of a rice bay (or sawah) (van der Laan 1981).

From these early studies of rat damage, shortening of the harvest period was recommended as an important cultural control measure (van der Goot 1937, in van der Laan 1981) and planting two or more crops annually was identified as exacerbating the problem (Grist and Lever 1969). This was at a time when growing two crops per year was an exception rather than the rule.

From our talks with various scientists and examining literature in two libraries (BIOTROP & BORIF), we are aware of only one reasonably detailed ecological study of rats in rice crops in Indonesia. This was a study on *R. argentiventer* near Jatisari on Java during 1985 to 1992. The study was by Japanese scientists and was supported by JIKA. Some of these findings appear in a training manual for rodent management (used at Jatisari Forecasting Center), and some information on the breeding and population dynamics of rats is presented in Murakami et al. (1990).

Further information has been gathered by scientists at SURIF during their studies on rodent control methods. Data on the number of rats captured during trapping programs at SURIF are presented in Figure 4.1. This shows that, over a six-year period, rodents were generally more common in the latter part of the dry season than during the wet season. No information was available on trapping effort, which may have been greater during the dry season. Nevertheless, these data give some indication of the prevalence of rodents over the year.

There is currently also an ecological study of rats in south Sumatra conducted by Ir Rochman from BORIF. The study is in a trans-migration area where there is a diversity of crops with rice being the main crop. The emphasis is on the degree of damage to various crops and the efficacy of poisons. The close proximity of 'other crops' (especially vegetable crops) has resulted in *Rattus exulans* causing just as much damage to rice crops as *R. argentiventer*.

4.2 Previous Research in Laos

Virtually no research on rodents has been conducted in Laos. The emphasis is on extension of management techniques developed in other countries. Staff from Agricultural Services in Vientiane occasionally hold training courses for people from the Districts. However, they are only trained in methods to control lowland rats.

Some information is available on the farmers' perception of rodents as pests of rice crops. This information has been gathered as part of general surveys on farmer perceptions of constraints to growing rice (see Table 2.3).

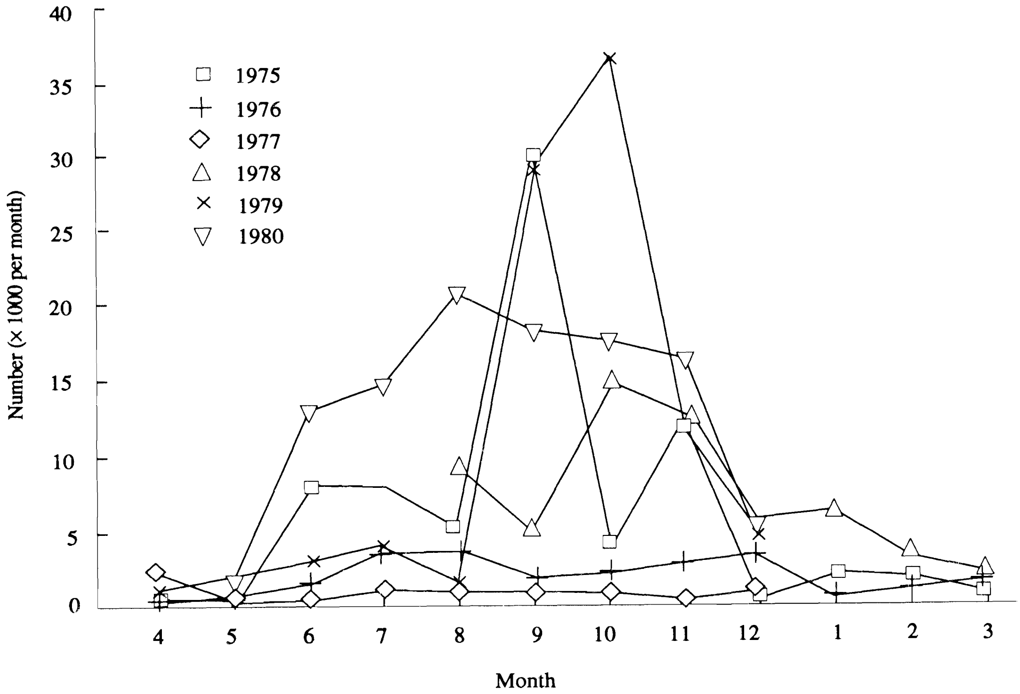

Figure 4.1 Number of rats caught per month at Sukamandi between 1975 and 1980.

4.3 Previous Research in Malaysia

Most of the research effort on understanding the population biology of rats in Malaysia has been on the rice field rat *R. argentiventer*, and the wood rat, *Rattus tiomanicus*. The extent of published information on various ecological parameters on these and other rodent pest species in Malaysia is summarised in Table 4.1.

The studies by Wood and Liau on the wood rat provide the best coverage of the biology and population dynamics of a rodent species in Southeast Asia (Wood 1984b, Wood and Liau 1984a, b). However, many gaps in our knowledge of the population ecology of the wood rat remain.

Detailed and extensive studies of the breeding biology of the rice field rat have been made (e.g. Lam 1980, 1983). The most important finding for the management of this species is that breeding corresponds to the milky and ripening stages of the rice crop (Lam 1983). On single-cropped farms, female rats only breed once per year. In areas where two crops are produced per year there are two main breeding seasons, each of approximately three months. Also, there is an indication that male rats are sexually mature at an earlier age in double cropped areas (Lam 1983). Together, these findings indicate that rat populations are well adapted to take advantage of changes in the timing of the availability of a high quality food resource. Double or even triple cropping (as is becoming common in areas such as the Mekong River delta in Vietnam, see Chapter 2) will substantially increase the annual productivity of a population of rats and hence increase their depredation of rice crops. Similarly, depredations by rats are higher in a district where there is asynchronous planting of crops because this will increase the period during which ripe crops are available as a food source, which in turn will extend the breeding season of rats.

Little is known about the habitat use, dispersal patterns or home range of *R. argentiventer*. This information is essential for knowing where and how far apart poisons should be placed, for developing better farm management practices and for assessing the likely transmission rates of potential biological control agents.

Table 4.1 Summary of the extent of published information on various ecological parameters of the major rodent pests in rice crops in Malaysia. Information was assigned to one of five categories (see footnote).

	Rattus argentiventer	***Rattus tiomanicus***
Abundance	+++[1,2]	++++[3]
Habitat use	–	+[3]
Breeding	+++++[4,1]	++[3]
Survival	–	++++[5]
Age structure	+++[6,1]	++++[5]
Diet	–	+++[5]
Predator/prey	–	++++[7,10]
Disease	–	–
Taxonomic status	–	–
Species interaction	–	–
Damage 'in-crop'	+++[1,8,9]	–
Damage 'postharvest'	–	–

Note: – = no information; + = anecdotal reports; ++ = restricted to a single sample/survey; +++ = restricted to one or two growing seasons or a long-term data set not calibrated against other measures; ++++ = extensive data collection of calibrated measures over at least one year; +++++ = extensive study with replicated high quality data collected over at least one year.

[1] Wood (1971), [2] Lam et al. (1990a), [3] Wood (1984a), [4] Lam (1983), [5] Wood and Liau (1984a), [6] Lam (1988), [7] Lenton (1980), [8] Buckle and Rowe (1981), [9] Buckle et al. (1985), [10] Smith (1994).

Nor do we know whether interactions with other species of rodents influence the habitat use and population dynamics of the rice field rat or vice-versa. The latter knowledge is important because management strategies developed specifically for the rice field rat may help another rodent species to develop pest status.

The effect of barn owls on populations of *R. tiomanicus* in oil palm plantations has been the subject of an interesting series of studies. These will be considered further in Chapter 7.

4.4 Previous Research in The Philippines

During the 1970s and early 1980s the National Crop Protection Center undertook a number of studies investigating certain aspects of the ecology of the main rodent pests. These studies were often conducted as part of postgraduate studies undertaken at the University of the Philippines, Los Baños. Investigations were made into crop preferences of various rodent species, reproductive measures, habitat and dietary preferences, and movement into and out of crops. The results of much of this work are summarised in Sanchez and Benigno (1985a). However most of the work undertaken at the NCPC concentrated on the interaction between rodents and rodenticides. Virtually all the research effort on understanding the population biology of rats in the Philippines has been on *R. r. mindanensis.* The extent of published information on various ecological parameters on these and other rodent pest species in the Philippines is summarised in Table 4.2.

In common with *R. argentiventer* in Malaysia, the best information available on *R. r. mindanensis* is on factors that influence its breeding. Again, breeding is linked with the ripening stages of the crop and, in areas where two crops are produced per year, there are two breeding seasons (see Fall 1977).

There is some information on the habitat use of *R. r. mindanensis* (Sumangil 1990; Libay and Fall 1976) but there is much we do not know. Of most interest is the report by Libay and Fall (1976) of high densities of rats in marshland adjacent to rice fields in Luzon. Rat drives along the fringes of the marshland indicated densities in the vicinity of 10 000/ha . The authors contrasted the chronic crop losses experienced in most rice-growing regions in the Philippines with the rat 'outbreaks' that historically have occurred in areas adjacent to wide marshlands. This study emphasises the variation that can occur in the population dynamics of rat populations in different habitats, and the potential influence of non-rice habitats on the densities of rat populations in adjacent rice fields.

A recently completed radio-telemetry study of movements by R. *r. mindanensis* on rice farms near Calauan in southern Luzon, indicated that 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 postharvest 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 postharvest 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 postharvest (Singleton et al. 1993; unpublished data).

Table 4.2 Summary of the extent of published information on various ecological parameters of the major rodent pests in rice crops in the Philippines. Information was assigned to one of five categories (see footnote).

	Rattus rattus mindanensis	*Rattus argentiventer*	*Rattus exulans*	*Rattus norvegicus*	*Rattus* spp.
Abundance	+++[1]	–	–	–	–
Habitat use	++[2]	–	–	–	–
Dispersal	++[3,4]	–	–	–	–
Breeding	+++[5]	+++[6]	–	–	–
Survival	–	–	–	–	–
Age structure	–	–	–	–	–
Diet	++++[7]	–	–	–	–
Predator/prey	–	–	–	–	–
Disease	–	–	–	–	–
Taxonomic status	+++[8]	–	–	–	–
Species interaction	+[9]	–	–	–	–
Crop damage					
— at IRRI	++[10]	–	–	–	–
— elsewhere	+++[11,12]	–	–	–	–
Postharvest damage	–	–	–	–	++[13]

Note: – = no information, + = anecdotal reports ; ++ = restricted to a single sample/survey; +++ = restricted to one or two growing season or a long-term data set not calibrated against other measures; ++++ = extensive data collection of calibrated measures over at least one year; +++++ = extensive study with replicated high quality data collected over at least one year.

[1] Kumer (1985), [2] Libay and Fall, (1976), [3] Lavoie et al. (1971), [4] Sanchez (1971), [5] Marges (1972), [6] Sumangil et al. (1980), [7] Tigner (1972), [8] Sanchez and Benigno (1985b), [9] Uhler (1967), [10] Ahmed et al. (1987), [11] Fulk and Aktar (1981), [12] Benigno (1979), [13] Aganon (1981).

4.5 Previous Research in Thailand

There is little published information available in the scientific literature on rat research in Thailand. There is, however, an active research group on vertebrate pests in the Thailand Agricultural Zoology Research Group. Research on rodent pests of agriculture is conducted by this group but in recent years much of the focus has been on field trials of the efficacy of various rodenticides (Table 2.11). We are aware of one population study conducted on *R. argentiventer* in rice crops, however we have seen no details of this research.

4.6 Concluding Remarks

Research on the population ecology of pest species of rodents provides the essential framework for developing management strategies (see Redhead and Singleton 1988b; Singleton and Redhead 1990). Unfortunately, most of the population research on rodent pests in tropical countries simply consists of studies that examine the effectiveness of a particular poison. These studies contribute little to our understanding of the factors that regulate or limit field populations, or the mechanisms that generate a population outbreak. If we had this knowledge, we would most likely be able to improve substantially the efficiency of chemical use. This would achieve the double goal of making rat control cheaper and reducing the amount of chemicals in the environment.

Malaysia and the Philippines have the best published information on the biology of rodent pests of agriculture in Southeast Asia. Even in these countries however, there are large gaps in our knowledge of the population ecology and general biology of the rat species that cause the major losses to agriculture.

Unfortunately, the gaps in our knowledge are far greater in the other countries in Southeast Asia. This is particularly so in Laos where one cannot proceed beyond the identities of the major pest species of rodent. Although more is known about the basic biology of rodents in Indonesia than in countries like Laos, we could find only two proceedings from conferences (Rochman 1987; Murakami et al. 1990) and one training manual (Anon. 1992) with published information on the population ecology and habitat use of rats in agricultural lands.

Until more basic research on the population biology and habitat use of rodent pests is conducted in countries such as Indonesia and Laos, an improvement in the efficiency and cost effectiveness of rodent control will continue to be a dream rather than reality.

Plate 1. Sowing rice crops asynchronously prolongs the breeding season of rats — since rats breed from when the rice is milky ripe to when it is harvested.

Plate 2. Rats typically cause foci of damage which often occur away from the edge of the crop (stadium effect). The yellow areas in this crop in Malaysia indicate damage caused by rats.

Plate 3. Wire live-capture traps with conical entrances are used in Malaysia, Philippines and Indonesia.

Plate 4. Processing of rats for information on their demography and breeding condition, Luzon, Philippines.

Plate 5. Rats are fitted with radio-collars to enable their movements to be tracked.

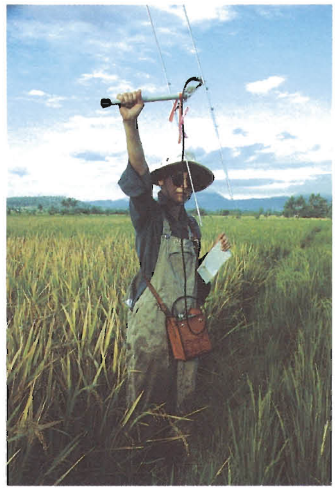

Plate 6. Aerials are attached to portable receivers to locate rats fitted with a radio. Apart from one daily check on nest sites, the tracking of rats is done at night when fixes are done each hour.

Plate 7. A physical barrier with a trap in position. This method was developed in Malaysia.

Plate 8. A linear barrier with traps on trial in the Philippines. The barrier is located between a likely rat harbourage and the developing rice crop. (Photograph courtesy of Julian Seddon.)

Plate 9. Milky ripe and freshly transplanted rice are used as a 'trap crop' at Pinrang, South Sulawesi. Multiple capture traps can be seen in each corner of the fence.

Plate 10. A diverse landscape in tropical Southeast Asia provides a haven for more than one species of rat.

Plate 11. Various bamboo devices which garrotte or shoot (using a crossbow) rats have been developed by Laotians living in the uplands near Luang Prabang.

Plate 12. Most of the rice in Southeast Asia is hand threshed. This protracts the harvest and extends the availability of high quality food for the rats.

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 macro-parasites and predators.

One special case of sterility control, immuno-sterility, 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.

CHAPTER 8

Synthesis and Conclusions

'In order to achieve long term control (of rodents), the dynamics of the pest population must be taken into account. Methods that affect population dynamic processes (birth, death, immigration, emigration) need to take account of density dependence, which regulates many animal populations. The spatial dynamics of the species concerned must also be considered.' — R.H. Smith (1994)

In this chapter we return to the objectives of this Technical Report and synthesise the key points that have emerged from our review of the literature on rodents in Southeast Asia and visits to research institutes in Indonesia, Laos, Malaysia, the Philippines and Thailand.

8.1 National Strategies for Rodent Control

The Philippines in the late 1970s and early 1980s developed a commendable national strategy for rodent control which was part of the national rice program, MASAGANA 99. The infrastructure was in place to support this national program through the instigation of a National Crop Protection Center, the provision of training and research supervision from staff of the Denver Wildlife Center, and the development of a field network of pest control officers coordinated through the Bureau of Plant Industry. Unfortunately less than 15% of rice farmers adopted the recommended control practices. Better adoption rates may have followed if there had been a more concerted extension program and more consideration of what growers would adopt. The fact that growers were unlikely to act if rat damage was less than 20% (Dizon 1978) is an important lesson. Of further concern are the developments over the past 5 to 10 years. There has been a general demise of the infrastructure supporting the control program, the loss of trained personnel and cessation of research on rodent pests.

Although the Malaysian national program is not as well defined as the Filipino program, the problem of farmer apathy and preference to use inefficient chemicals which kill rats at the site of poisoning rather than use recommended anti-coagulants which do not (highlighting the importance of visual cues) evokes a similar theme. Both situations highlight the imperative to consider the cultural and social background of the end-users of a management program.

Cultural and sociological influences are important aspects of any pest control program whether it be directed at invertebrates (Norton and Heong 1988) or vertebrates (Norton and Pech 1988; Posamentier 1990). Rodent control in Asian countries is no exception. In an integrated rodent management program implemented in Indonesia as part of the FAO inter-country program of integrated pest management, two key factors were identified. One was the support and active involvement of a village leader or another prominent person. The other was the active participation of a large group of villagers in the coordination of management operations (van Elsen and van de Fliert 1990). Unfortunately, this program lacked another key element — the involvement of a vertebrate biologist experienced in rodent management.

In Table 8.1 we present comparisons of the relative magnitude of the rodent problem and the current infrastructure for managing these problems in the five countries we visited. Apart from the FAO program, which was not evident in our visits to West Java and South Sulawesi, Indonesia has no semblance of a national or regional program to control rats. The situation is the same in Laos. The Philippines still has a national rodent control program but its adoption rate is low. Malaysia and Thailand have loosely structured programs. In the case of Malaysia there is no economic imperative to reduce rodent losses at the national level. The Malaysians appear to be primarily concerned with dampening the high variation in losses caused by rodents.

Curiously, the future development of an effective national rodent control program is probably brighter for Indonesia than the other countries we visited because high and middle ranking officials plus

Table 8.1 Comparison of degree of rodent problem, current infrastructure for control of rodents and gaps in knowledge in the five countries in Southeast Asia.

Country	Problem	Infrastructure	Knowledge of rodents
Indonesia	high (17% per year)	limited	low to medium
Malaysia	low (<5% per year), high in places	good	medium to high
Laos	high — upland low — lowland	minimal	minimal
Phillipines	moderate, high in places	once very good, now limited	medium
Thailand	moderate, patchy	good	medium

village leaders recognise the magnitude of the problem caused by rats, and their will to address the problem is growing (see Table 8.2).

8.2 Ecology of Rodent Pests — the Gaps

An understanding of the population dynamics, habitat use and factors that influence breeding, survival and movements of rats is essential for the development of an effective, economic and sustainable management program. Compared to the temperate regions of the world where changes of season have a marked influence on the population dynamics of rodents, seasonal effects are less pronounced in the tropics. It is not surprising therefore that pest species of rodents tend to cause chronic problems in the tropics. However, changes in agricultural practices, such as increasing the number of rice crops produced per year or increasing the amount of arable land in a region, can rapidly lead to marked increases in the magnitude of rodent problems. There have been well documented cases of this occurring in the Philippines and Malaysia. Also, the recent rat plagues in Laos and Vietnam could be related to changes in the management of rice crops.

Individual variation and spacing behaviour

Whatever the direct cause, we know that some species of rats respond well to broadscale cultivation of rice crops. We also know that the onset of breeding of rats is linked to specific stages of development of the rice crop. These are population responses. Little attention has been paid to why individuals respond differently. In studies of small mammals in non-tropical regions it is often these individual differences that provide the essence of understanding how populations are regulated or limited (e.g. Lidicker 1975; Krebs 1985; Cockburn 1988). Factors that influence spacing behaviour and mating systems have been of particular interest (e.g. Lambin and Krebs 1991).

Landscape ecology

Knowing what influences spacing behaviour is important also for understanding how and why rats use different habitat patches. In the tropics, where land holdings of less than 1 to 2 ha are the norm, land use patterns of humans generally result in a patchy landscape. We therefore need to know how these population patches are interconnected by the migration of rats, the relative demographic importance of each habitat patch and how these patches in combination influence the overall population dynamics of the species we are trying to control. This metapopulation approach to rodent control is occasionally discussed (see Smith 1994) but good field studies of tropical rat populations are lacking.

Community dynamics

At the next level up, we need to know what other species of rodents are living in the various habitat patches that occur in, and adjacent to, rice crops. If control operations effectively manage a particular rat species are there other species that may attain pest status? For example, in the Philippines, *R. argentiventer* is the major pest species on some islands. *R. r. mindanensis* is present on these islands

Table 8.2 Comparison of each country's interest and ability to collaborate in an ACIAR project on rodents focused on habitat use, population processes and disease.

Country	Interest[a]	Standard of Resource		Commitment
		Physical	Human	
Indonesia	high	limited to moderate	limited to moderate	3 scientists (entomologists) 2 technicians
Malaysia	high	moderate	high	1 scientist (mammalogist) 1 technician
Laos	high	poor	poor	unskilled
Phillipines	low	limited	limited	none
Thailand	high	moderate	moderate	uncertain

[a]Interest expressed by high ranking government officials — not just scientists.

but is not considered a pest. On islands such as Luzon where *R. argentiventer* does not occur, *R. r. mindanensis* is an important pest to rice growers. A similar story is emerging with *R. r. diardii* which is now considered a pest in some oil palm plantations in Malaysia where *R. tiomanicus* has been controlled. Apparently, *R. tiomanicus* usually excludes *R. r. diardii* from oil palm plantations (Y. M. Lam, pers. comm.; Wood 1994).

Effect of disease on rodent population dynamics

Diseases of rodents are covered in detail in Chapter 6. There have been virtually no field studies in Asia to systematically survey the diseases present in rat populations, let alone consider the effect of specific diseases on the population dynamics of rats.

Effect of predators on population dynamics

The potential of vertebrate predators to control populations of rodents is reviewed in Chapter 8. Predators are likely to have a sustained effect only in combination with other control measures that maintain rodent populations below certain densities. Promising results have been reported through the combined use of predator nest boxes and rodenticides in oil palm plantation in Malaysia (Smal et al. 1990). Whether similar results can be obtained for controlling rat populations in rice fields is open for investigation.

8.3 Ecology of Rodent Pests — Research Priorities

There is still much to be learned about the population ecology of the major rodent pest species in Southeast Asia. The relative knowledge available in each country on the biology of these species is summarised in Table 8.1. Malaysia has made the best progress through detailed studies of the ecology of the wood rat *R. tiomanicus* in oil palm plantations and good studies on aspects of the population ecology of the rice field rat *R. argentiventer*. Even in Malaysia, however, there are major gaps in our knowledge of the population dynamics and habitat use of the rice field rat. A better understanding of processes that influence increases in rat populations and that limit the growth of these populations, will provide a strong basis for cost effective and sustainable strategies for managing rodent pests. Therefore a first priority is to develop high quality, replicated, descriptive studies of the population dynamics of rat populations. Of particular interest are factors that limit breeding, reduce survival and influence dispersal. This would require monthly live-trapping studies of rats at designated trapping sites and regular kill samples at adjacent sites to assess breeding status and litter sizes.

The study of habitat use through mark-release-recapture studies and radio-telemetry is a high priority for the reasons outlined in section 8.2. Eventually, attention needs to be directed at rodent species of secondary importance, to anticipate which, if any, may become a greater problem after the main pest species has been effectively managed.

Also of interest are the interactions between diseases (micro- and macro-parasites) and rodent populations. Such studies would require an enormous input of personnel and time. As a first step, the focus should be on identifying which murine diseases are endemic to particular regions. Where possible these surveys should include samples taken at different stages of the seasonal dynamics of rat populations. These studies would also provide essential information on potential biological control agents.

Predator studies are not to be discouraged but we do not see them as a high priority given the resources required to do well designed predator–prey studies and the low likelihood of predators being a major regulating factor of rats in rice fields

Once the descriptive phase has been completed, it is then essential to develop replicated field experiments to evaluate critically the key factors postulated to influence population processes. Ideally, these should consist of experiments that compare different manipulations of a factor. This replicated experimental approach is basic to our development of effective wildlife management but has been rarely used in previous studies of rodent pests in Southeast Asia.

Social and cultural factors have been identified as important for the development of management strategies of rodents. During the descriptive stage of population studies these factors need to be noted. Whereas during the final development and implementation of control strategies, social and cultural factors become an integral part of the research program.

8.4 Rats as Vectors of Disease

In addition to the economic benefits that can be derived from the control of rodent pests there are also important public health considerations for rodent pest management. As vectors of disease, rodents are second to no other mammalian group, and carry a wide variety of viral, bacterial and parasitic diseases (Chapter 6). As humans and livestock are in regular contact with rodents — through rodent control activities, (unintentionally) shared housing arrangements and the use of rodents as food by both humans and their domestic animals — the potential for transmission of zoonotic disease in high. There is however, only a small body of literature examining the importance of rodents as carriers of zoonotic disease in Southeast Asia and much of this work is restricted to determining whether or not rodents are infected with certain diseases. There is little real investigative work into the exact role that rats play in the epidemiology and transmission of human and animal disease. It must be assumed, however, that rodents are an important link in the transmission of many diseases and that they also act as important reservoirs for disease thus frustrating many attempts of disease control. The imperative for rodent control on the basis of the control of zoonotic disease must rank very high.

8.5 Concluding Comments

A clear message that came through from our visits to research groups in Southeast Asia and from reading the literature, is that there is little exchange of ideas, of research progress or of the challenges that respective countries or even regions within countries, face in their efforts to reduce the depredation of rodents in agricultural areas. We hope that this report will begin to break down the barriers to information flow. An important role for an ACIAR funded project on rats in the region would be to promote communication between those involved in efforts to manage rodent pests in Southeast Asian countries.

Throughout this report we have highlighted the generally poor infrastructure and scarcity of good quality educational courses for both scientists and technicians in rodent management. The one area that has been covered reasonably by most countries is the technical detail associated with the application of chemicals, although the knowledge of how to use these chemicals effectively under field conditions varied considerably between countries. We have not addressed chemicals and their use in any detail because there are sufficient publications and texts on rodenticides and their use (see Meehan 1984; Prakash 1988; Buckle and Smith 1994), and better qualified people than us in this area of rodent control. However, the general interest of scientists and government officials that we spoke to was not in the prospects for rodenticides, but the prospects for non-chemical methods. There was a general acceptance of the need for a better understanding of the population ecology of rodent pests and the processes that influence the population dynamics of these animals. It was in this area that we received the most requests for assistance in training because of inadequate levels of education available in the affected countries.

Training of scientists from Southeast Asian countries in the areas of rodent ecology, epidemiology and approaches to biological control would be another key responsibility for Australian scientists involved in an ACIAR-funded project. It is the development of expertise in these areas that hold the key to achieving:

(i) less reliance by farmers from developing countries on chemicals for controlling rats;

(ii) management strategies that are sustainable and environmentally benign.

Our research for this report has provided the clear message that rats are the number one preharvest pest of rice crops in Southeast Asia. At the moment the major concern is the loss of income from the depredation caused by rats, the exceptions being the localised heavy losses which result in severe hardship for rural people. With the likely addition of another billion mouths to feed in Southeast Asia by the year 2025, a loss of 10% of the crop to rodents will add considerably to the anticipated shortages of food for humans and will inevitably lead to loss of life. Add to this the diseases that rodents transfer to humans and their livestock, and the challenge to control the depredation of rodents becomes an even greater imperative. An imperative that can be embraced only through the advent of a greater will by Asian governments to tackle the problem through the development of better trained specialists in rodent research and management, and the promotion of research beyond the routine assessment of the efficacies of rodenticides.

8.6 Acknowledgements

We extend our thanks to Robyn Singleton and Karen Molloy for their support, encouragement and tolerance during the preparation of this report. We received excellent cooperation and hospitality from many people during our visits to Indonesia, Laos, Malaysia, Philippines and Thailand. We thank them all. Particular mention is made of the encouragement and assistance we obtained from Dr Brian Walker, Dr John Copland, Dr Graeme Quick, Dr John Schiller, Dr Water Roder and Dr Ibrahim Manwan. We thank Lisa Chambers and Peter Brown for their comments on a draft of this manuscript. Finally we thank Dr Denis Hoffmann who suggested that we embark on this project and then facilitated its progress by assisting GRS to obtain an ACIAR small purpose grant which funded our visits to Southeast Asia.

References

Aganon, T.M. 1981. Survey of rat damage in Nueva Ecija ricemill warehouses. Los Baños, University of the Philippines, unpublished M.Sc. dissertation.

Ahmed, M.S., Fieldler, L.A. and Heinrichs, E.A. 1987. Economic losses by rats on experimental rice farms in the Philippines. Crop Protection, 6, 272–6.

Anderson, R.M. 1980. Depression of host population abundance by direct life cycle macroparasites. Journal of Theoretical Biology, 82, 283–311.

Anon 1992. International training course on pest surveillance and forecasting January–February 1992. Subject: Rat. Directorate of Food Crop Protection, Directorate General of Food Crop Agriculture, Ministry of Agriculture, Indonesia 26 p.

Barker, S.C., Singleton, G.R. and Spratt, D.M. 1991. Can the nematode *Capillaria hepatica* regulate abundance in wild house mice? Results of enclosure experiments in southeastern Australia. Parasitology, 103, 439–449.

Basaca-Sevilla, V., Cross, J.H. and Pastrana, E. 1986. Leptospirosis in the Philippines. Southeast Asian Journal of Tropical Medicine and Public Health, 17, 71–74.

Baylis, H.A. 1931. On the structure and relationship of the nematode *Capillaria (Hepaticola) hepatica* (Bancroft). Parasitology, 23, 533–543.

Beaver, P.C. and Rosen, L. 1964. Memorandum on the first report of *Angiostrongylus* in man, by Nomura and Lin, 1945. American Journal of Tropical Medicine and Hygiene, 13, 589–590.

Benigno, E. A. 1979. The assessment of infield damage to crops caused by rats. Los Baños, University of the Philippines, Unpublished PhD Thesis, 124 p.

——1985. Rodent pests current status and needs. In: Sanchez, F.F. and Benigno, E.A., ed., Rodent biology and control, Los Baños, Laguna, Philippines, University of the Philippines, 125–139.

Benigno, E. A. and Sanchez, F. F. 1984. Rodent problems in the Association of Southeast Asian Nations. In: Dubock, A.C., ed., Proceedings of a Conference on the Organisation and Practice of Vertebrate Pests. Surrey, England, ICI, 37–47.

Bomford, M. 1990. A role for fertility control in wildlife management. Bureau of Rural Resources Bulletin No.7, Canberra, AGPS Press, 50 p.

Brader, L. 1979. Integrated pest control in the developing world. Annual Review of Entomology, 24, 225–254.

Braysher, M. 1993. Managing vertebrate pests: principles and strategies. Canberra, Australian Government Printing Service, 58 p.

Brooks, J.E., Naing, H., Walton, D.W., Myint, D.S., Tun, M.M., Thaung, U. and Kyi, D.O. 1977. Plague in small mammals and humans in Rangoon, Burma. Southeast Asian Journal of Tropical. Medicine and Public Health, 8, 335.

Buckle, A. P. 1990. Recent developments in rice rat control. In: Quick, G.R., ed., Rodents and rice, report and proceedings of an expert panel meeting on rice rodent control. Manila, Philippines, International Rice Research Institute, 87–96.

—— 1994. Rodent control methods: chemical. In: Buckle, A.P. and Smith, R.H., Rodent pests and their control. Oxon, U.K., CAB International, 127–160.

Buckle, A. and Rowe, F.P. 1981. Ricefield rat project Malaysia. Technical Report 1977–1980. London, Centre for Overseas Pest Research, 99 p.

Buckle, A. P., Rowe, F. P. and Yong, Y. C. 1979. Field trails of two warfarin baiting methods against the rice field rat (*Rattus argentiventer*) in Peninsular Malaysia. Malaysian Agricultural Journal, 52, 78–95.

Buckle, A.P. and Smith, R.H. 1994. Rodent Pests and their Control. Wallingfod, U.K., CAB International, 405 p.

Buckle, A. P. Yong, Y. C. and Abdul Raman, H, 1985. Damage by rats to rice in South east Asia with special reference to an integrated management scheme proposed for Peninsular Malaysia. Acta Zoologica Fennica 173, 139–144.

Cabrera, B.D. 1976. *Schistosomiasis japonica* in field rats in Leyte, Philippines. Southeast Asian Journal of Tropical. Medicine and Public Health, 7, 50.

—— 1977. Studies on *Paragonimus* and paragonimiasis in the Philippines. II Prevalence of pulmonary paragonimiasis in wild rats *Rattus norvegicus* in Jaro, Leyte, Phillipines. International. Journal of Zoonoses, 4, 49–55.

Carlos, R., Kundin, W.D., Tsai, C.C., Inving, G.S. and Batungbakal, C. 1970. Leptospirosis in the Philippines: isolation studies. Acta Medicine Philippina, 6, 149–153.

Carney, W.P., S. Masri, Salludin, P.F.D. and Putrali, J. 1974. The Napu Valley, a new schistosomiasis area in Sulawesi, Indonesia. Southeast Asian Journal of Tropical Medicine and Public Health, 5, 246–251.

Caughley, G., Pech, R. and Grice, D. 1992. Effect of fertility control on a population's productivity. Wildlife Research, 19, 623–627.

Childs, J.E., Glass, G.E., Korch, G.W. and LeDuc, J.W. 1988. The ecology and epizootiology of hantaviral infections in small mammal communities of Baltimore: a review and synthesis. Bulletin of the Society for Vector Ecology, 13, 113–122.

Chiu, J.K. 1962. Two species of *Paragonimus* occurring at Alilo village of Tainpei county, Taiwan (Formosa). Kyushu Journal of Medical Science 13, 51.

Cockburn, A. 1988. Social Organization in Fluctuating Populations. London, Croon Helm.

Crucillo, V., Otanes, F. and Morales, J.L. 1954. What we're doing to control field rats in Cotabato, Philippines Islands. Pest Control, 22, 9–12.

Dickman, C.R., Predavec, M. and Lynam, A.J. 1991. Differential predation of size and sex class of mice by the barn owl, *Tyto alba*. Oikos, 62, 67–76.

Dissamarn, R. and Indrakamhang, P. 1985. Trichinosis in Thailand during 1962–1983. International. Journal of Zoonoses, 12, 257–266.

Dizon, R. C. 1978. Diffusion of a rat control innovation among Masagana 99 farmers in Laguna, Philippines. Los Baños, University of the Philippines, unpublished M.Sc. dissertation.

Erlinge, S. 1987. Predation and noncyclicity in a microtine population in southern Sweden. Oikos, 50, 347–352.

Erlinge, S., G. Göransson, G. Högstedt, G. Jansson, O. Liberg, J. Loman, I.N. Nilsson, von Schantz, T. and Sylvén, M. 1988. More thoughts on vertebrate predator regulation of prey. American Naturalist, 132, 148–154.

FAO 1987. A summary of the process and evaluation results of the strategic extension campaign on rat control in Malaysia. Evaluation Report SEC/No. 2, August 1987, 25 p.

Fall, M. W. 1977. Rodents in Tropical Rice. Technical Bulletin No. 36. College of Agriculture., University of the Philippines, Los Baños.

—— 1990. Controlling rice losses to rodents in rural communities. In: Quick, G.R., ed., Rodents and rice, report and proceedings of an expert panel meeting on rice rodent control. Manila, Philippines, International Rice Research Institute, 7–16.

Farhang-Azad, A. and Traub, R. 1985. Transmission of murine typhus rickettsiae by *Xenopsylla cheopis*, with notes on experimental infection and effects of temperature. American Journal of Tropical Medicine and Hygiene, 34, 555–563.

Fenner, F. 1983. Biological control, as exemplified by smallpox eradication and myxomatosis. Proceedings of the Royal Society of London (B), 218, 259–285.

Fenner, F. and Ratcliffe, F.N. 1965. Myxomatosis. Cambridge, Cambridge University Press.

Fiedler, L. A. 1986. Biology and management of riceland rats in Southeast Asia. In: Reissig, W.H. et al. ed., Illustrated guide to integrated pest management in rice in tropical Asia. Los Baños, Philippines, International Rice Research Institute, 319–332.

Fiedler, L. A., Ahmed, M.S. and Ze Ya 1990. Efficacy of burrow fumigation in reducing rodent activity in Philippine rice fields. Malaysian Agriculture Plant Protection Society Proceedings.

Fujisaka, S. 1991. A diagnostic survey of shifting cultivation in northern Laos: targeting research to improve sustainability and productivity. Agroforestry Systems, 13, 95–109.

Fulk, G.W. and Aktar, M.T. 1981. An investigation of rodent damage and yield reduction in rice. Tropical Pest Management, 27, 116–20.

Geddes, A. M. W. 1992. The Relative Importance of Pre-harvest Crop Pests in Indonesia. Chatham, U.K., Natural Resources Institute Bulletin, 47, 70 p.

Gratz, N.G. 1988. Rodents and human disease: a global appreciation. In: Prakash, I., ed., Rodent pest management, Baton Rouge, CRC Press, Baton Rouge, 101–171.

—— 1990. Societal impact of rodents in rice agriculture. In: Quick, G.R., ed., Rodents and rice, report and proceedings of an expert panel meeting on rice rodent control. Manila, Philippines, International Rice Research Institute, 17–26,

—— 1994. Rodents as carriers of disease. In: Buckle, A.P. and Smith R.H., ed., Rodent pests and their control, Oxon, U.K., CAB International, 85–108.

Gregory, R.D. 1992. On the interpretation of host-parasite ecology: *Heligmosomoides polygyrus* (Nematoda) in wild wood mouse (*Apodemus sylvaticus*) populations. London, Journal of Zoology, 226, 109–121.

Grist, D.H. and Lever, R.J.A.W. 1969. Pests of Rice. London, Longmans, Green and Co. Ltd., 520 p.

Harinasuta, C., Sornmani, S., Migasena, P., Vivatanasesth, P., Pongpaew, P., Intarakao, C. and Vudhivai, N. 1976. Socio-economic, health and nutritional status of the villagers in the Nong Wai Irrigation Area, Khon Kaen, Northeast Thailand. Southeast Asian Journal of Tropical Medicine and Public Health, 7, 601–621.

Heong, K.L., Escalada, M.M. and Lazaro, A.A. 1992. Pest Management Practices of Rice Farmers in Leyte, Philippines. Los Baños, Philippines, International Rice Research Institute, 57 p.

Hopf, H. S., Morley, G. E. J. and Humphries, J. R. O. ed., 1976. Rodent Damage to Growing Crops and to Farm and Village Storage in Tropical and Subtropical Regions. London, Centre for Overseas Pest Research, 115 p.

Hoque, M. M., Sanchez, F. F. and Benigno, E. A. 1988. Rodent problems in selected countries in Southeast Asia and islands in the Pacific. In: Prakash, I., ed., Rodent pest management. Baton Rouge, CRC Press, 85–99.

Huke, R.E. and Huke, E.H. 1990. Human Geography of Rice in Southeast Asia. Manila, Philippines, International Rice Research Institute.

Indrarto, N. 1984. Five year rat control program in Indonesia. In: Ducock, A.C., ed., The organisation and practice of vertebrate pest control. Fernhurst, U.K., ICI, 475–485.

Jackson, M.H. and Huchison, W.M. 1989 The prevalence and source of toxoplasma infection in the environment. Advances in Parasitology, 28, 55–105.

Jackson, M. H., Huchison, W.M. and Siim, J. 1986. Toxoplasmosis in a wild rodent population in central Scotland and a possible explanation of the mode of transmission. London, Journal of Zoology, (A), 209, 549–557.

Kettivuti, A. 1983. Current status of trichinosis in Thailand. Journal of the Thailand Veterinary Medicine Association, 34, 355–372.

Kliks M. M. and Palumbo, N. E. 1992. Eosinophilic meningitis beyond the Pacific Basin: The global dispersal of a periodomestic zoonosis caused by *Angiostrongylus cantonensis,* the nematode lungworm of rats. Social Science and Medicine, 34 199–212.

Krebs, C.J. 1985. Do changes in spacing behaviour drive population cycles in small mammals? In: Behavioural ecology: ecological consequences of adaptive behaviour, Sibly, R.M. and Smit, R.H., ed., Symposium of the British Ecological Society, 25, 295–312.

Krebs, C.J. and Boonstra, R. 1984. Trappability estimates for mark-recapture data. Canadian Journal of Zoology, 62, 2440–2444.

Kumar, V., Brandt, J. and Mortelmans, J. 1985. Hepatic capillariasis may stimulate the syndrome of visceral larva migrans, an analysis. Annales de la Societe Belge de Médecine Tropicale, 65, 101–104.

Kumer, S.S. 1985. Influences of some weather factors on the activity of rats and efficiency of IRRI electric fences. Unpublished report, Manila, Philippines, International Rice Research Institute.

Kush, G. S. 1993. More food and a safe environment. In: Food comes first for Asia. Parkville, Australia, Crawford Fund for International Agricultural Research, 31–33.

Lam, My-Yen,. 1993. A review of food research in Vietnam, with emphasis on postharvest losses. Canberra, Australian Centre for International Agricultural Research. ACIAR Technical Report, 26, 109 p.

Lam, Y. M. 1980. Reproductive behaviour of the rice field rat, *Rattus argentiventer* and implications for its control. Proceedings National Rice Conference. Malaysia, 243–57.

—— 1982. Rats as rice field pests — their importance and control. In: Khoo, K.C., Lam, Y.M., Teoh, C.H., Lim, W.M. and Mohamad, B.M., ed., Rodent pests in agricultural crops in Malaysia, Kuala Lumpur. Malaysian Plant Protection Society: 9–17.

—— 1983. Reproduction in the field rat *Rattus argentiventer*. Malayan Nature Journal, 36, 249–282.

—— 1985. Performance of Bromadiolone as a rodenticide against *Rattus argentiventer.* MARDI Research Bulletin, 13, 303–308.

—— 1988. Rice as a trap crop for the rice field rat in Malaysia. In: Crabb, A.C. and Marsh, R.E., ed., Proceedings 13th Vertebrate Pest Conference, 13, 123–128.

—— 1990. Cultural control of rice field rats. In: Quick, G.R., ed., Rodents and rice, report and proceedings of an expert panel meeting on rice rodent control. Manila, Philippines, International Rice Research Institute, 65–72.

Lam, Y.M., Yeoh, G.H., Ho, N.K. and Siti Zubaidah, M.R. 1986. Evaluation of some rice field rat chemical control methods. Teknologi-Padi (MARDI), 2, 27–33.

Lam, Y. M., Ho, N. K. Fouzi, A. Abdul Jamil, R. Zarullail, S. Abd Halim, I. Lim, S.S. and Heng, W.L. 1990. Field performance of chlorophacinone against rice field rats in the MUDA irrigation scheme, Peninsular Malaysia. Journal of Bioscience, 1, 77–86.

Lam, Y. M., Supaad, M. A., Chang, P. M., Mohamed, M. S., Goh, C. S. and Radzi, H. 1990. An innovative approach for protecting rice against severe rat depredation. Proceedings of the 3rd International Conference. on Plant Protein in the Tropics, 20–23 March, Genting Highlands, Malaysia.

Lambin, X. and Krebs, C.J. 1991. Spatial organization and mating systems of *Microtus townsendii.* Behavioural Ecology and Sociobiology, 28, 353–363.

Lampe, K. 1993. Will Asia starve? In: Food comes first for Asia. Parkville, Australia, Crawford Fund for International Agricultural Research, 59–71.

Lavoie, G. K., Atwell, G. C., Swink, F. N., Sumangil, J.P. and Libay, J.L. 1971. Movement of the ricefield rats *Rattus rattus mindanensis* in response to flooding and ploughing as shown by fluorescent bone labelling. Philippine Agriculture, 55, 325–30.

Lenton, G.M. 1980. Biological control of rats by owls in oil palm and other plantations. Biotrop Special Publication No. 12, 87–94.

Libay, J.L. and Fall, M. W. 1976. Observations on an exceptionally dense population of wild rats in marshland. Philippines Journal of Biology, 5, 207–212.

Lidicker, W.Z. Jr. 1975. The role of dispersal in the demography of small mammals. In: Golley, F.B., Petrusewicz, K and Ryskowski, L., ed., Small mammals their productivity and population dynamics. Cambridge, Cambridge University Press, 103–34.

Lim, B.L., Ow-Yang, C.K. and Lie, K.J. 1965. Natural infection of *Angiostrongylus cantonensis* in Malaysian rodents and intermediate hosts and preliminary observations on acquired resistance. American Journal of Tropical Medicine and Hygiene 14, 610–21.

Marchette, N. 1966. Rickettsiosis (Tick Typhus, Q Fever, Urban Typhus) in Malaysia. Journal of Medical Entomology, 2, 339.

Marges, B.E. 1972. The reproduction and seasonal abundance of the common ricefield rat, *Rattus rattus mindanensis* Mearns, at Siniloan, Laguna. Los Baños, University of the Philippines, unpublished M.Sc. dissertation.

Margonos, E.A. and Ilahude, H.D. 1974. *Angiostrongylus cantonensis* in rats and intermediate hosts in Jakarta and its vicinity. Southeast Asian Journal of Tropical Medicine and Public Health, 5, 236–245.

Marsh, R.E. 1988. Chemosterilants for rodent control. In: Prakash, I., ed., Rodent pest management, Baton Rouge, CRC Press, 353–367.

Marshall, J.T. 1977. Family Muridae. In:. Boonsong, L. and McNeely, J.A., ed., Mammals of Thailand, Kuruspha, Thailand, 397–487.

Meehan, A.P. 1984. Rats and Mice: Their Biology and Control. East Grinstead, U.K., Rentokill Ltd.

Millar, S.E., Chamow, S.M. Baur, A.W. Oliver, C. Robey, F. and Dean, J. 1989. Vaccination with a synthetic zona pellucida peptide produces long-term contraception in female mice. Science, 246, 935–938.

Mitchell, G.F., Tiu, W.V. and Garcia, V. 1991. Infection characteristics of *Schistosoma japonicum* in mice and the relevance to the assessment of schistosome vaccines. Advances in Parasitology, 30, 168–200.

Murakami, O., Priyono, J. and Triastiani, H. 1990. Population management of the ricefield rat in Indonesia.In: Quick, G.R., ed., Rodents and rice, report and proceedings of an expert panel meeting on rice rodent control. Manila, Philippines, International Rice Research Institute, 49–54.

Nalim, S. 1980. Zoonotic diseases transmissible from Indonesian rodents. Biotrop Special Publication, 12, 101–107.

Newsome, A.E. 1990. The control of vertebrate pests by vertebrate predators. Trends in Ecology and Evolution, 5, 187–191.

Ngyen, V.A., Ngyen, D.H, Le, T.V., Ngyen, V.L., Ngyen T.L. and Pham, V.D. 1974. Les salmonelles isolées des rats et des musaraignes dans le Région de Saigon-Gaidanh. Bulletin de la Societe de Pathologie Exotique, 67, 579.

Niphadkar, S.M. and Rao, S.R. 1969, On the occurrence of *Raillietina celebensis* (Jericki 1902) in rats of Bombay with special reference to its zoonotic importance. Indian Veterinary Journal, 46, 816.

Norton, G.A. and Heong, K.L. 1988. An approach to improving pest management: rice in Malaysia. Crop Protection, 7, 84–90.

Norton, G.A. and Pech, R.P. 1988. Vertebrate Pest Management In: Australia: decision analysis/systems analysis approach. CSIRO Division of Wildlife and Ecology, Project Report No. 5, Melbourne, CSIRO Publications, 67 p.

Ocampo, B. 1980. Adoption of recommended crop protection technology among rice farmers in Balucan, Philippines. Los Baños, University of the Philippines, unpublished M.Sc. dissertation.

Pech, R.P., Sinclair, A.R.E., Newsome, A.E. and Catling, P.C. 1992. Limits to predator regulation of rabbits in Australia: evidence from predator-removal experiments. Oecologia, 89, 102–112.

Pesigan, T.B., Farouq, M., Hairstor, N.B. Garcia, E.G., Santos B.D. and Besa, A.B. 1958. Studies of *Schistosoma japonicum* infections in the Philippines. Bulletin of the World Health Organisation, 18, 345.

Posamentier, H. 1990. Economic and community aspects of national rodent control programs. In: Quick, G.R., ed., Rodents and rice, report and proceedings of an expert panel meeting on rice

rodent control. Manila, Philippines, International Rice Research Institute, 97–101.
—— 1994. Multimedia campaigns in rodent management programmes for smallholders. In: Bucke, A.P and Smith, R.H., ed., Rodent pests and their control, Oxon, U.K., CAB International, 339–362.
Prakash, I., ed. 1988. Rodent Pest Management, Baton Rouge, CRC Press.
Prakash, I. 1990. Rodent control: the need for research. In: Quick, G.R., ed., Rodents and rice, report and proceedings of an expert panel meeting on rice rodent control. Manila, Philippines, International Rice Research Institute, 1–6.
Quick, G. R., ed. 1990. Rodents and Rice. Report and proceedings of an expert panel meeting on rice rodent control. Manila, Philippines, International Rice Research Institute, 132 p.
Quick, G.R. and Manaligod, H.T. 1990. Some aspects of physical control of rice rodents. In: Quick, G.R., ed., Rodents and rice, report and proceedings of an expert panel meeting on rice rodent control. Manila, Philippines, International Rice Research Institute, 31–34.
Read, C.P. 1949. Studies on the north American helminths of the genus *Capillaria* Zeder, 1800 (Nematoda). I. Capillarids from mammals. Journal of Parasitology, 35, 223–230.
Redhead, T. D. 1988. Prevention of plagues of house mice in rural Australia. In: Prakash, I., ed., Rodent pest management, Baton Rouge, CRC Press, 191–205.
Redhead, T.D. and Singleton, G.R. 1988a. The PICA Strategy for the prevention of losses caused by plagues of *Mus domesticus* in rural Australia. EPPO Bulletin, 18, 237–248.
—— 1988b. An examination of the "PICA" strategy for the prevention of losses caused by plagues of the house mouse (*Mus domesticus*) in rural Australia. In: Norton, G.A. and Pech, R.P., ed., Vertebrate pest management in Australia: decision analysis/systems analysis approach. CSIRO, Division of Wildlife and Ecology, Project Report No. 5. Melbourne, CSIRO Publications, 18–37.
Roder, W., Phengchanh, S. and Keobualapha, B. 1992. Weeds in rice slash-and-burn fields in northern Laos. LAO-IRRI Project, Luang Prabang, LAO PDR.
Rochman, Ir. 1987. Problems and management of rodent. Bogor, June 1987, Rice Production Training Course, CRIFC.
Shagli, R., Matityahu, A., Gaunt, S. J. and Jones, R. 1990. Antigens on rat spermatozoa with a potential role in fertilization. Molecular Reproduction and Development, 25, 286–96.
Sanchez, F.F. 1971. Rodent Research Center Annual Report 1971, 80 p.
Sanchez, F. F. and Benigno, E. A. 1985a. Rodent Biology and Control. The National Crop Protection Center, Philippines. Laguna. Los Baños, University of the Philippines, 152 p.
—— 1985b. Methods of rodent control. In: Sanchez, F.F. and Benigno, E.A., ed., Rodent biology and control. Laguna, College of Agriculture, Los Baños, University of Philippines, 55–79.
Scott, M.E. 1987. Regulation of mouse colony abundance by *Heligmosomoides polygyrus*. Parasitology, 95, 111–124.
—— 1990. An experimental and theoretical study of the dynamics of a mouse-nematode (*Heligmosomoides polygyrus*) interaction. Parasitology, 101, 75–92.
Scott, M.E. and Dobson, A. 1989. The role of parasites in regulating host abundance. Parasitology Today, 5, 176–83.
Semple, R. L. 1982. Biology of Rodents and their Control. The Asean Crop Post Harvest programme. Technical Paper Series No. 2, 21–49.
Shagli, R., Matityahu, A., Gaunt, S.J. and Jones, R. 1990. Antigens on rat spermatozoa with a potential role in fertilization. Molecular Reproduction and Development, 25, 286–296.
Shellam, G.R. 1994. The potential of murine cytomegalovirus as a viral vector for immunocontraception. Journal of Reproduction, Fertility and Development, 6, 401–409.
Silpapojakul, K., Chayakul, P., Krisanapan, S, and Silpapojakul, K. 1993. Murine typhus in Thailand: clinical features, diagnosis and treatment. Quarterly Journal of Medicine, 86, 43–47.
Sinclair, A.R.E. 1989. Population regulation in animals. In: Cherett, J.M., ed., Ecological concepts, Oxford, Blackwell Science Publications 197–241.
—— 1991. Science and the practice of wildlife management. Journal of Wildlife Management, 55, 767–773.
Sinclair, A.R.E., Olsen, P.D. and Redhead, T.D. 1990. Can predators regulate small mammal populations?: evidence form house mouse outbreaks in Australia. Oikos, 59, 382–392.
Singh, K.I., Krishnasamy, M. and Ming H.T. 1987. Collection of small vertebrates and their endoparasites from Ulu Endau, Johor, Malaysia. Malayan Nature Journal, 41, 349–356.
Singleton, G.R. 1987. A comparison of the effectiveness of pitfall and Longworth live-trapping techniques in population studies of house mice. Acta Theriologica, 32, 245–259.
—— 1989. Population dynamics of an outbreak of house mice (*Mus domesticus*) in the mallee wheatlands of Australia — hypothesis of plague

formation. London, Journal of Zoology, 219, 495–515.

—— 1994. The prospects and associated challenges for the biological control of rodents. Proceedings 16th Vertebrate Pest Conference, Santa Clara, USA (In press).

Singleton, G.R. and Redhead, T.D. 1989. House mouse plagues in the Victorian Mallee region. In: Nobel, J.C. and Bradstock, R.A., ed., Mallee ecosystems and their management. Melbourne, CSIRO Publications, 418–433.

—— 1990. Future prospects for biological control of rodents using micro- and macro-parasites. In: Quick, G.R., ed., Rodents and rice, report and proceedings of an expert panel meeting on rice rodent control. Manila, Philippines, International Rice Research Institute, 75–82.

Singleton, G.R., Chambers, L.K. and Aguilera, E.G. 1993. Assessment of the IRRI active barrier system for rodent control. Unpublished ACIAR Mid-term project report, Special Purpose Grant. Manila, Philippines, International Rice Research Institute.

Singleton, G. R., Chambers, L. K. and Spratt, D. M. 1995. An experimental field study to examine whether *Capillaria hepatica* (Nematoda) can limit house mouse populations below plague densities in eastern Australia. Wildlife Research (In press).

Singleton, G. R., Smith, A. L., Shellam, G. R., Fitzgerald, N. and Müller, W. J. 1993. Prevalence of viral antibodies and helminths in field populations of house mice (*Mus domesticus*) in southeastern Australia. Epidemiology and Infection, 110, 399–417.

Smal, C.M., Halim, A.H. and Amiruddin, M.D. 1990. Predictive modelling of rat populations in relation to use of rodenticides or predators for control. Palm Oil Research Institute of Malaysia, Occasional Paper No. 25, 55 p.

Smith, R.H. 1994. Rodent control methods: Non-chemical and non-lethal chemical. In: Bucke, A.P and Smith, R.H., ed., Rodent pests and their control, Oxon, U.K., CAB International, 109–125.

Smith, A. L., Singleton, G. R., Hansen, G. M. and Shellam, G. R. 1993. A serosurvey of virus and *Mycoplasma* among populations of wild house mice (*Mus domesticus*) in southeastern Australia. Journal of Wildlife Diseases, 29, 219–29.

Smith, C.E.G, Turner, L.H. Harrison, J.L. and Broom, J.C. 1961. Animal Leptospires in Malaysia., 3. Incidence in rats by sex, weight, and age. Bulletin of the World Health Organisation, 24, 807.

Sody, H.J.V. 1941. On a collection of rats from the Indo-Malayan and Indo-Australian regions. Treubia, 18, 255–325.

Spratt, D. M. 1990. The role of helminths in the biological control of mammals. International Journal of Parasitology, 20, 543-50.

Sudomo, M. 1984. Ecology of schistosomiasis in Indonesia with certain aspects of control. Southeast Asian Journal of Tropical Medicine and Public Health, 15, 471-474.

Sumangil, J. P. 1990. The control of ricefield rats in the Philippines. In: Quick, G.R., ed., Rodents and rice, report and proceedings of an expert panel meeting on rice rodent control. Manila, Philippines, International Rice Research Institute, 35–47.

Sumangil,J.P., Macanas, A.M. and Ferrer, L.S. 1980. Reproductivity of ricefield rats in poisoned habitat. Proceedings. Symposium. on Small Mammals: Problems and Control. Biotrop Special Publications No.12, 95–100.

T-W-Fiennes, R. 1978. Zoonoses and the Origins of Human Disease. London, Academic Press.

Tan, D.S.K. 1973. Occupational distribution of leptospiral antibodies in West Malaysia. Medical Journal of Malaysia, 27, 253–257.

Thanongsak, B., Potha, U., Thirachandra, S. and Impand, P. 1983. Leptospirosis in man and rodents in north and northeast Thailand. Southeast Asian Journal of Tropical Medicine and Public Health, 14, 481–487.

Tigner, J.R. 1972. Seasonal food habits of *Rattus rattus mindanensis* (the Philippine ricefield rat) in Central Luzon. Boulder, University of Colorado, unpublished PhD dissertation.

Tjahaya Haerani S.A. Saenong 1984. Penelitan *Capillaria hepatica* pada *Rattus argentiventer* di daerah Cakung, Jakarta, University of Jakarta, unpublished M.Sc. Thesis.

Tongtavee, K., Boonsong, P. and Hongnark, S. 1990. A review of rodents and control methods in Thailand. Training Manual: rice cultivation technique and extension, Thai Government (DTEC & DOA), and Japanese Government (JICA), Oct 1991.

Traub, R. and Wisseman, C.L. 1973. Current concepts of the ecology of Chigger-borne rickettsiosis (Scrub Typhus). Japanese Journal of Medical Science and Biology, 27, 1–19.

Traub, R., Wisseman, C.L. and Farhang-Azad, A. 1978. The ecology of murine typhus — a critical review. Tropical Diseases Bulletin, 75, 237–317.

Turner, R.W., Martoprawiro, S. and Padmowirjono, S.A. 1974. Dynamics of the plague transmission cycle in Central Java (Ecology of potential flea vectors). Health Studies in Indonesia, 2, 15–37.

Tyndale-Biscoe, C.H. 1994. Use of vectors for immunosterilisation of feral pest mammals. In: Wood, P.R., Willadsen, P., Vercoe, J.E., Hoskinson, R.M. and Demeyer, D., ed., Vaccines in agriculture: immunological applications to animal health and production. Melbourne, CSIRO Publications, 137–143.

Uhler, L.D. 1967. The seasonal abundance of *Rattus rattus mindanensis* at the International Rice Research Institute, College, Laguna. Philippines Agriculture, 51, 581–86.

van der Laan, P.E. 1981. The Pests of Crops in Indonesia, English translation and revision of De Plagen van de Cultuurgewassen in Indonesia, by Kalshovenvan, L.G.E. (Vol. 1 1950; Vol. 2 1951). Jakarta, Ichitiar Baru, Van Hoeve.

van Elsen, K. and van de Fliert, E. 1990. Development of a community-based program on integrated rodent management in rice in Indonesia. In: Quick, G.R., ed., Rodents and rice, report and proceedings of an expert panel meeting on rice rodent control. Manila, Philippines, International Rice Research Institute, 109–104.

van Peenen, P.F.D., Light, R.H. and Sulanti Saroso, J. 1971. Leptospirosis in wild mammals in Indonesia — recent surveys. Southeast Asian Journal of Tropical Medicine and Public Health, 2, 496–502.

Vajrasthira, S. 1969. Paragonimiasis in Thailand. In: Harinauta, C., ed., Schistosomiasis and other snail transmitted helminthiasis. Proceedings 4th Southeast Asian Seminar on Parasitology and Tropical Medicine, Manila, Philippines.

Velimirovic, B. 1972. Plague in South-east Asia. Transactions of the Royal Society for Tropical Medicine and Hygiene, 66, 479.

Waterhouse, D.F. and Norris, K.R. 1987. Biological control: Pacific Prospects. Melbourne, Inkata Press.

WHO. 1982. Working group on rickettsial diseases 1982. Rickettsioses: A continuing disease problem. Bulletin of the World Health Organization, 60, 157–164.

—— 1983. Haemorrhagic fever with renal syndrome: memorandum from a W.H.O. meeting. Bulletin of the World Health Organization, 61, 269–275.

Wood, B.J. 1971 . Investigations of rats in ricefields demonstrating an effective control method giving substantial yield increase. PANS 17, 180–193.

—— 1984a. Rat pests of tropical crops. In: Dubock, A.C., ed., Proceedings of a conference on the organisation and practice of vertebrate pests, Surrey, England, ICI, 265–287.

—— 1984b. A long-term study of *Rattus tiomanicus* populations in an oil palm plantation in Johore, Malaysia. I. Study methods and population size without control. Journal of Applied Ecology, 21, 445–464.

—— 1985. Biological control of vertebrates — a review, and an assessment of prospects for Malaysia. Journal of Plant Protection in the Tropics, 2, 67–79.

—— 1994. Rodents in agriculture and forestry. In: Bucke, A.P and Smith, R.H., ed., Rodent pests and their control, Oxon, U.K., CAB International, 45–83.

Wood, B. J. and Liau, S. S. 1977. Preliminary studies of the toxicology of anticoagulants to rats of oil palms, with special reference to the prospects of resistance. In: Wastie, R.L and Earp, D.A., ed., International development in oil palm. Kuala Lumpur, Incorporated Society of Planters, 380–395.

—— 1984a. A long-term study of *Rattus tiomanicus* populations in an oil palm plantation in Johore, Malaysia. II. Recovery from control and economic aspects. Journal of Applied Ecology, 21, 465–472.

—— 1984b. A long-term study of *Rattus tiomanicus* populations in an oil palm plantation in Johore, Malaysia. III. Bionomics and natural regulation Journal of Applied Ecology, 21, 473–495.

Appendix

Rat Control in Rice Fields

Adapted from 'The Philippine Recommends for Rice — 1976' and specially reproduced for the MASAGANA 99 rice Program.

JOINT RECOMMENDATIONS OF THE BUREAU OF PLANT INDUSTRY; THE COLLEGE OF AGRICULTURE, UNIVERSITY OF THE PHILIPPINES AT LOPS BAÑOS; THE RODENT RESEARCH CENTRE1; AND THE PHILLIPINE-GERMAN CROP PROTECTION PROGRAMME[2]

For many years, rats have been a persistent problem of rice growers throughout the Philippines. Field damage by rats costs the nation millions of pesos every year (Figure 1).

Nearly all rice farmers suffer some rat damage, although extent of losses vary. Based on cut tillers at harvest, average losses are approximately four per cent. Each year some farmers suffer very heavy damage, even total losses at times. Fortunately, such occurrences are rare. A typical hectare of rice land may have an average of 20 to 200 rats, but some areas adjacent to swamps, marshes or waste area may have as many as 10000 rats per hectare.

Your chances of having heavy damage (over 10 per cent) on your farm are less than 1 in 10. If you plant near areas where rats can live between crops (for example, coconut groves, wasteland, or irrigation canals), your chances of having heavy damage are usually greater. Even under these conditions, the baiting method outlined in the following pages has been consistently successful.

Rat control is an essential investment, which requires money, time, and effort. Under most circumstances, only the equivalent cost of approximately one cavan of palay per hectare (40 to 60 pesos) is enough to protect your crop.

Kinds of Rats

Approximately 30 kinds of rats occur in the Philippines. Only two, *Rattus rattus mindanensis* and *Rattus argentiventer*, are serious pests in major rice growing areas. These two types are difficult to recognise separately. In some regions, *Rattus exulans* and *Rattus norvegicus* attack rice crops. It is not possible, at present, to recommend different control measures for the different species. Most rat control methods affect whatever species is living in your field.

General Measures

Several general agricultural practices may be helpful in reducing potential rat problems. Cutting weeds along dikes and canal banks and adjacent waste areas, particularly several weeks before transplanting and during the early stages of rice growth, removes cover which rats need to survive. Transplanting at about the same time as your neighbours may reduce your chances of heavy damage. Fields maturing much earlier or much later than the surrounding ones often have very heavy rat damage and emergency measures at this stage are usually not successful. Killing rats at any time by any method may be helpful, but for the farmer who wants to protect his crop, there is no substitute for continuous rat control throughout the crop period! In areas with extremely high rat populations, baiting with acute poisons before seedbedding or transplanting, is also desirable.

Sustained Baiting

Chronic poisons provide a means of carrying on continuous rat control with very little cost and

[1] The Rodent Research Center is a cooperative research and training center supported by the bureau of Plant Industry, the University of the Philippines at Los Baños, the National Economic and Development Authority, the National Science Development Board, the national Food andAgriculture Council, and the U.S. Agency for International Development.

[2] The Philippine-German Crop Protection Programme is an integrated crop protection program of the bureau of Plant Industry.

labour compared to some of the other methods. These bait materials are used at low concentration, so the amount of chemical is small. Rats must eat poisoned bait every day for several days, usually less than a week before they are killed.

Because the symptoms develop slowly over a period of days, rats usually die in their burrows or in other protected areas. Many people like to count dead rats after poison baiting. This usually is not possible with chronic poisons. If bait is being consumed and you replace it regularly, you are killing rats! Your efforts will be rewarded by reduced damage. After 10 to 12 weeks of baiting you can expect to have reduced the rat population in and around your rice farms so that you can be assured of a good crop.

Costs are Low

The major costs of sustained baiting with chronic toxicants are for the bait carrier and for the time required to visit the bait stations regularly. Approximately 10 kilos of bait material is the most that is required under usual conditions to protect one hectare of rice for the entire crop. The labour required is approximately 1 man-hour each week throughout the crop. Many suitable chemicals are available. The costs of chronic toxicant, enough to treat 10 kilos of bait, range from 1.50 to 15.00 pesos depending on the material used, the source of supply, and the area of the country.

Materials to Use

Chronic toxicants require bait material, a chemical concentrate and bait containers. Most grains can be used for bait material: choose one which is avail able or can be obtained at low cost in your region. Many farmers have obtained good results using low quality milled rice or rice shorts. Do not use rough rice (palay), because rats remove the hulls and do not ingest much of the toxicant.

Many chronic toxicants are available in the Philippines as concentrates. Ratoxin, Racumin, Tomorin, Diphacinone, and Liphadione are examples of commercial chemicals which are available at agricultural stores. Prices and package sizes vary considerably, but all of the materials have similar action. When comparing prices, note that some concentrates can be used to prepare more bait material than others. To determine the actual cost of chemical in a finished bait, divide the retail cost of the concentrate by the number of kilos of bait to be treated. Read the label carefully so you can follow the manufacturer's instructions.

Local materials can usually be obtained at little or no cost for making bait stations. Sections of bamboo with nodes at middle or ends, one litre cans, or discarded one quart oil cans, opened at both ends, make good containers. Under very wet conditions, it is sometimes desirable to use larger bait stations which afford maximum protection from the weather. In areas with many rats, it is important to use enough stations to allow all animals easy access to bait.

Procedures

It is important to have bait material available to all rats occupying your field from planting until rice grains mature: Because only a limited number of rats can feed at a single bait container, the number of containers must be provided in relation to the number of rats damaging your fields.

The following methods, tested under Philippine conditions, will help you relate the intensity of your control efforts to the potential damage to your crop. These procedures are recommended as a guide for your operations.

1. Mix the recommended concentrate with the bait material. Using more chemical than recommended does not improve control and will only increase your expense.
2. Select five baiting locations for one hectare of riceland to be protected. The locations should be at least 50 metres apart for good coverage. Containers can be placed on or along dikes, or supported above water level in the paddy. Other good locations to place bait containers are dike intersections, canal banks or old threshing mounds.
3. Begin baiting as soon as your fields have been transplanted. Place one container at each location and put six tablespoons of bait inside. After three days, check the bait containers. If all of the bait has been eaten at one location, place two additional containers and place six tablespoons of bait in all three, check again in three to four days. If the bait is gone, place three additional containers at the locations where this happened and maintain approximately six tablespoons of bait in each.
4. Continue to check the bait containers twice a week. If rats continue to consume most of the bait at some of the locations, place increasing amounts of bait in each container. A one litre can will hold up to 18 tablespoons. Try to anticipate increases in consumption so that bait will be left in the containers each time you check; add additional full containers if necessary. This is important. If bait is not available

after rats have learned to come to the stations, there may be heavy feeding on nearby plants.

5. Remove and replace bait that becomes mouldy or excessively wet.
6. Because the few remaining rats, less than ten per cent of the original population, will prefer the developing grains to the bait, baiting may be stopped at least two weeks before harvest unless bait consumption remains high. When bait consumption begins to decline, some of the stations at each point may be removed.

What to Expect

Usually, bait consumption will increase rapidly sometime during the period three to eight weeks after transplanting. This is the period when rats are moving into your paddies. Do not be alarmed by this rapid increase. Continue to replenish the bait and consumption will generally level-off or decline. If your neighbours are also practicing rat control, the increases will not be as great. When rice heads mature, bait consumption usually drops off sharply because there are only a few rats remaining. Although the remaining rats concentrate their feeding on grain heads, pre-harvest damage should be minimal. Remember that chronic toxicants work differently from other materials. Don't become discouraged if you don't find dead rats; they die in their burrows.

Safety

All agricultural pesticides are poisons and should be used carefully. Store pesticides in clearly labelled containers out of reach of children and pets. Do not use mixing cans or spoons used for measuring pesticides for any other purpose. Do not breathe the dust or vapours. Do not eat, drink, or smoke while handling chemicals. Wash your hands thoroughly each time you finish your work.

Chronic toxicants are relatively safe compared to other pesticides. They cause breakdown of the blood clotting process and animals usually die from internal bleeding. If treated bait or concentrate is accidentally eaten, take the person to a doctor or clinic immediately. Treatment for poisoning with chronic toxicants consists of oral doses of Vitamin K, and in some cases, blood transfusion.

Cooperative Rat Control

When a farmer uses chronic poisons, the protective effects of baiting usually extend outside his farm for as much as 200 metres in each direction. Particularly during the first eight weeks after transplanting, rats from peripheral areas will be attracted to bait containers. If your neighbours also practice sustained baiting, your results will be improved and everyone's costs will be reduced.

Technical Help

These recommendations have been approved for implementation beginning in mid-1975 under the national rice production program — MASAGANA 99. Farmers qualifying for MASAGANA 99 loans or supervision may contact MASAGANA 99 rice extension technologists or participating banks for additional details. For additional advice on rat control or for help in securing rat control materials, consult a Bureau of Plant Industry pest control officer or MASAGANA 99 rice extension technologist.

Recent ACIAR Technical Reports

No. 15 Marketing perspectives on a potential Pacific spice industry, Grant Vinning, 59p., 1990.

No. 16 Mineral nutrition of food legumes in Thailand with particular reference to micronutrients, R.W. Bell et al., 52p., 1990.

No. 17 Rice production in Sri Lanka, K.M. Menz (ed.) 51p., 1990.

No. 18 Post-flask management of tissue-cultured bananas, Jeff Daniells and Mike Smith, 8p., 1990.

No. 19 The utilisation of remote sensing in the South Pacific, D. van R. Claasen, 59p., 1992.

No. 20 Hybridisation techniques for acacias, Margaret Sedgley, Jane Harbard and Rose-Marie Smith, 11p., 1992.

No. 21 Production of pathogen-tested sweet potato, Peter Beetham and Angela Mason, 47p., 1992.

No. 22 Plants fed to village ruminants in Indonesia, J.B. Lowry, R.J. Petheram and B. Tangendjaja (ed.), 60p., 1992.

No. 23 Allozyme electrophoretic methods for analysing genetic variation in giant clams (Tridacnidae), J.A.H. Benzie, S.T. Williams and J.M. Macaranas (ed.), 48p., 1993.

No. 24 Tuna baitfish and the pole-and-line industry in Kiribati, N.J.F. Rawlinson, D.A. Milton and S.J.M. Blaber, 92p., 1993.

No. 25 Economic aspects of raw wool production and marketing in China, J.W. Longworth (ed.), 62p., 1993.

No. 26 A review of food research in Vietnam, with emphasis on postharvest losses, My-Yen Lam, 111p., 1993.

No. 27 Selection for water-use efficiency in grain legumes, G.C. Wright and R.C. Nageswara Rao, 70p., 1994.

No. 28 Afforestation and rehabilitation of *Imperata* grasslands in Southeast Asia: identification of priorities for research and training, Nigel D. Turvey, 52p., 1994.

No. 29 Research and development prospects for faba bean, Colin Piggin and Steven Lack (ed.), 44p., 1994.