Impacts of Rodents on Rice Production in Asia

Grant Singleton

Summary

This paper provides an up-to-date review of the preharvest impact of rodent pests on rice-based agricultural systems in 11 Asian countries: Bangladesh, Cambodia, People's Republic of China, India, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Philippines, Thailand, and Vietnam. Under traditional rice farming systems, rodents generally cause chronic losses to production in the order of 5–10% per annum. In many areas, this figure has risen dramatically over the last few decades, most noticeably in places where cropping frequency has increased from one to two or three crops per year. Today, it is not unusual for smallholder rice farmers to report chronic yield losses of 20–30% per annum, rising to 50% or even total crop loss in certain seasons. In many areas, farmers actually abstain from planting a second or third rice crop because of the expectation of severe rodent damage. This 'forgone' loss in productivity is rarely taken into account. In Asia, a loss of 5% of rice production amounts to approximately 30 million t; enough rice to feed 180 million people for 12 months. Postharvest losses are probably of a similar magnitude to preharvest losses. However, the data are patchy and there have been few studies of the impacts of rodents on postharvest storage of rice in the past decade.

From the assessment of impacts of rodents on pre- and postharvest operations, it is clear that rodents play a significant role in influencing food security and poverty alleviation programs for the rural poor in Asia. Another important impact is the influence of rodent-borne diseases on the health, and hence, productivity output of humans (both rural and urban). The prevalence of rodent zoonoses is increasing and is likely to be an important impetus for rodent management in rice agricultural communities in the future.

This report highlights the relatively few published studies on the ecology, biology, and management of rodent pests compared with some major insect and disease pests of rice. There is much basic research still required to underpin the strategies being developed to manage rodent pests. Moreover, much of the current rodent control activities by farmers are reactive rather than palliative. Few farmers follow the recommendations of their government agencies. This is a major issue (either the recommendations are ineffective or they are inappropriate for farmers (i.e., too expensive or too labor intensive).

General research needs are identified in this report as well as specific priorities for research and extension for national agricultural research and extension systems (NARES) determined from consultations with collaborators in specific countries. The Rodent Ecology Work Group of IRRI provides one important avenue to promote research on rodent pests in the region. However, stronger expert input is required. IRRI is well placed to play an important role in providing access to this expertise, in providing leadership in research, and in building the capacity of extension staff and farmers in Asia to translate research outputs into management outcomes for the rural poor.

In summary, IRRI has the unique comparative advantage to provide the foci and regional linkages for research and training and the continuity for tackling the important problem of rodent impacts on rice production. The major outcomes from this research and extension effort would be significant improvements in agricultural production, in food security, and in both human and environmental health.

Recommendations

1. IRRI develops the expertise that enables it to provide scientific leadership and/or direction in projects on rodent management in rice-based agroecosystems in Asia. IRRI has the institutional linkages (NARES and advanced

research institutes [ARIs]), the high profile, and the continuity that have it well placed to play an important leadership role.

2. IRRI provides a catalyst for developing research in rice-based agroecosystems that aims to develop ecologically based rodent management that is environmentally benign and is consistent with sustainable agricultural practices. This is currently being addressed through the Rodent Ecology Work Group (REWG), although the rodent expertise is being accessed via informal linkages with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Sustainable Ecosystems because of a collaborative Australian Agency for International Development (AusAID)-funded project (ceases June 2002).
3. IRRI takes a lead in addressing the critical shortfall in research expertise on vertebrate pests, particularly rodents, in Asia. The new 4-week Integrated Pest Management (IPM) course developed by the IRRI Training Center now includes a 2-day module on rodent biology and management. This is an encouraging development; however, participants in the course will not have a primary interest in rodent management. I strongly recommend the development of a 1-month training course directed specifically at principles and practices of rodent biology and management with an emphasis on ecologically based rodent management.
4. IRRI considers in the immediate future an annual appointment of 2-3 months of a rodent specialist who is active in research in the region (shuttle scientist). This person would play a lead role in the REWG as part of the Lowland Irrigated Rice Research Consortium; concentrate in developing multilateral linkages and promoting and supporting key research priorities; assist with developing and instigating training programs (face-to-face) and training modules (web-based); promote multidisciplinary linkages (e.g., ecology, sociology, and agronomy; upland and lowland cropping systems; crop and forage systems); and promote capacity-building of farmers through facilitating the translation of research outputs into management outcomes for farmers.
5. IRRI considers in its next long-term plan a full-time position to provide leadership in research and extension of rodent biology and management. This position could be supported through either core funds or external funds. Some possible donor agencies based on current interest are listed in a subsequent section .
6. IRRI considers developing or facilitating research that links rodent management in rice cropping systems with improvements in health of rural farming communities. There are many rodent-borne zoonoses and it is recommended to concentrate on one or two, such as leptospirosis and rat typhus. A linkage between IRRI and the World Health Organization (WHO) would be beneficial in this circumstance.
7. The REWG is serving an important role in fostering bilateral projects with NARES on rodent management in Asia. However, a low funding base limits its current activities. A brief description of research and implementation needs for Asia is presented on pages 19–22. These are priority areas to develop if further funds become available.

Linkages between IRRI, CSIRO, and NARES

Rodent Ecology Work Group (1998-2001)

In 1998, the IRRI IPM Network and the CSIRO Rodent Research Group established the REWG that promotes

- communication between scientists and extension personnel who are involved or interested in the biology and management of rodent pests;
- collaborative research on decisions of rodent management by farmers, population ecology of rodents, and assessment of the association between yield loss of crops and rodent density in the region;
- strengthening of capacity through facilitating exchange and collaboration between scientists from NARES and advanced agricultural research centers; and
- an important focus for the exchange of information on rodent issues between institutions within the CGIAR network (none of the CGIARs currently have expertise on rodent biology and management).

The specific objectives were as follows:

- To enhance ecological research in rodent management;
- To utilize the ecological framework in developing management strategies;

- To provide a forum for rodent experts for reviewing, developing, and conducting collaborative research on rodent management and sharing of research methods and results;
- To develop a shared set of objectives and research agenda and evaluations of control options; and
- To share experiences, methodologies, and results, and promote exchange of expertise between countries.

Current activities of the IRRI REWG (linked with CSIRO Rodent Research Group)

(i) Rodent Pest Network e-mail bulletin board (established in June 1998, it currently has 115 members from 66 institutions in 29 countries.

(ii) Rodent Newsletter "War Against Rats"(published twice a year, the newsletter has 240 subscribers from 165 institutions in 49 countries.

(iii) Collaborative studies

- CSIRO, IRRI, Institute of Agricultural Sciences (IAS) and Plant Protection Department (PPD), Vietnam: "Enhancing capacity in rodent management in the Mekong delta region using nonchemical methods." This is funded by AusAID under its Capacity-building for Agriculture and Rural Development (CARD) scheme (2000-2002).
- IRRI, IAS, PPD Vietnam, Danish Pest Infestation Laboratory, CSIRO: Seed funds to promote the establishment of the REWG. This was funded by IRRI-Danish International Development Agency (DANIDA) (1998-99).

(iv) Annual meetings of rodent scientists from Asia and elsewhere (1998-2001) under the umbrella of the project "Management of rodent pests in rice-based farming systems in Southeast Asia" funded by the Australian Centre for International Agricultural Research (ACIAR).

The REWG (2001-2004) – as part of the IRRI Irrigated Lowland Rice Research Consortium

New funding from the Swiss Agency for Development and Cooperation (SDC) came on stream in 2001 to fund a 4-year consortium on lowland irrigated rice. The REWG is one of five work groups funded under this consortium.

The objectives of the REWG are as follows:

1. To enhance ecological research on rodent pest species.
2. To develop further the concept of "ecologically based rodent management (EBRM)."
3. To provide a forum for rodent experts to develop and conduct research, to share research methodologies, and to share results.

The budget is approximately US$123,000 with US$20,000-25,000 distributed each year to NARES.

In an operational sense, the REWG will

1. serve as a platform for research and extension partnerships,
2. optimize expertise in the region from scientists belonging to advanced research centers,
3. assist through leveraging support from national agencies and funding bodies to support bilateral programs, and
4. provide an opportunity for joint planning of research priorities and methodologies, and then implementation.

An inaugural meeting of staff from IRRI and NARES was held in Hanoi on 27 Sep 2001. Sixteen people attended the meeting, drawn from Australia, Indonesia, Lao PDR, Philippines, Thailand, United Kingdom, and Vietnam. Two Cambodians were present as observers. (Cambodia does not grow sufficient irrigated lowland rice to be part of this consortium.)

A key discussion point was on how to raise awareness of the REWG. Physical actions were identified (e.g., create a web page), and there was discussion on the main focus of rodent management and how to sell the high need for research and extension in the region. Four selling points were identified: poverty alleviation, food security, public health, and environmental issues (sustainable production). In countries such as Thailand and Vietnam where rice is exported, it was decided that public perception on health and environmental issues would be of higher importance in lowland irrigated rice regions.

Training

(a) Some researchers from developing countries may be supported by REWG funds to attend the 2nd International Conference on Rodent Biology and Management.

(b) Training courses on IPM/EBRM at IRRI (it is possible to use leverage of the REWG to get bilateral funding to support in-country people to attend international training courses.

REWG activities, October 2001 to March 2003

Each country identified key research and extension activities to be funded during the 18-month period from October 2001 to March 2003 (see table below).

These activities were given interim approval. Each institution provided details on the methods, budget, and timelines in November 2001. Dr. Singleton, Prof. Escalada, and Dr. K.L. Heong reviewed the proposed methodologies of each project prior to final approval of their respective budgets in early 2002.

Preharvest losses in rice production in Asia caused by rodents

Economic importance of rice to the region

More than 90% of the world's rice is produced and eaten in Asia, with rice producing 35–60% of the total food energy for the three billion people living in the region (Khush 1993).

Rice is the single most important food crop in Southeast Asia. In countries such as Indonesia, where rice is the staple food, self-sufficiency in rice production is an important influence on social stability. In recent years, Indonesia has needed to import rice to meet her domestic demand. The rat is now the number one preharvest pest for rice crops in Indonesia (Geddes 1992, Singleton and Petch 1994) and its economic impact is of major concern to the Government of Indonesia.

In Asia, claims of annual preharvest losses in rice production by rodents range from 5% in Malaysia to 17% in Indonesia (Table 1). In countries where losses are low on a national scale, the patchy distribution of rat damage can still result in devastating losses on a local scale. This is often the case in Malaysia. Therefore, in Malaysia, rodents are still considered an important preharvest pest.

> Under traditional rice farming systems, rodents probably caused chronic losses to production in the order of 5-10% per annum. However, in many areas, this figure has risen dramatically over the last few decades, most noticeably in places where cropping frequency has increased from one to two or three crops per year. Today, it is not unusual for smallholder rice farmers to report chronic yield losses of 20-30% per annum, rising to 50% or even total crop loss in certain seasons. In many areas, farmers actually abstain from planting a second or third rice crop because of the expectation of severe rodent damage. This 'forgone' loss in productivity is rarely taken into account.

In this section, I review the data available on preharvest losses caused by rodents in Asian rice fields. There are few detailed studies of rodent damage to rice tillers at the field scale. The error estimates from these intensive studies are usually ±2%. However, when one scales up to the village, district, provincial, or national level, the damage estimates become less robust. It is extraordinarily difficult to provide accurate assessments of rodent damage above the field level because of the typical patchy pattern of rodent damage. Table 1 summarizes the impacts of rodent pests at the national level. Details of the origins of these data are provided for each country in subsequent sections. A second table converts these impacts for selected countries and for Asia into forgone consumption of rice for humans because of what has been consumed by rats (Table 2).

A word of caution may be given to those who rely on the generic participatory rural assessment (PRA) for gauging whether rodents are important pests of rice systems. In most cases, the questions on

Activity	Country and institution	Budget (US$)
Economics of rat meat business, Mekong Delta, Vietnam	Vietnam, PPD	4,000
Campaign for CTBS in Bac Lieu Province	Vietnam, PPD	7,000
Movement on rats and their use of habitat	Vietnam, IAS	4,000
Develop better methodology for damage assessment	Vietnam, IAS	4,000
KAP survey (post-test) in Vinh Phuc, Vietnam	Vietnam, NIPP	1,500
Assessment of impact of CTBS technology in Indonesia - Central Java and Sulawesi	Indonesia, RIR	3,000
KAP survey (post-test) in Cilimaya, West Java, Indonesia	Indonesia, RIR	2,000
Anthropological effects of rodent management, Indonesia	Indonesia, RIR/IRRI (Morin)	1,000
Problem definition and extent of rodent damage in lowland irrigated rice	Lao PDR	4,000
Baseline survey of KAP, Thailand	Thailand, DAE	2,000
Baseline survey of KAP, Philippines	Philippines, Leyte State University	5,500

Table 1. Overview of the preharvest impact of rodents on rice in Asia.

Country	Preharvest loss (%)	Comments
Bangladesh	>50% in districts	No national data
Cambodia	Patchy; no national data	High rank as pest by farmers
China PDR	5–10%	Few data over past decade
India	5–15%	Few data over past decade
Indonesia	15–17%	
Lao PDR	Upland 10–15%; higher in outbreak years	Upland rice; <5% in lowland rice
Malaysia	5%	Few data over past decade
Myanmar	5-40%; with outbreaks	No national data
Philippines	Variable; >20% in districts	Require revision of national data
Thailand	6% lowland; 7% upland	Few data over past decade
Vietnam	>500,000 ha with high damage	No estimate of percentage losses at national level

Table 2. Forgone human consumption because of grain lost to rodent pests before harvest, based on 1999 estimates.[a]

Country and population (million)	Production of "rough rice" ('000 t)	Estimated rodent damage (%)	Production without rodents ('000 t)	Estimated production loss ('000 t)	Annual consumption[b] (rough rice) (kg person^{-1} yr^{-1})	Rice daily calorie intake (%)	People fed/year if no rat loss (million)
ASIA	540,621	5	567,652	27,031	150	32	181
(3,585.4)		10	594683	54,062			362
(206.3)	(1895 import)	10	54,487	4,953			19.9
Indonesia	49,534	17	57,955	8,421	249	52	33.8
Vietnam[c] (77.6)	31394 (3800 export)	30%–615,000 ha 5%–7 million ha	33585	2,191	280	67	7.8
		20%–615,000 ha 5%(3.5 million ha	32619	1,225			4.4

[a]The production and consumption figures are drawn from IRRI rice facts. [b]Annual consumption is generally given as kg person^{-1} yr^{-1} of milled rice and production relates to "rough rice." Therefore, we need to convert by dividing production figures, adjusted for exported and imported grain, by total population. For Vietnam, the high export indicates more grain in storage so we a used 1.7 multiplier based on figures from Asia and Indonesia. [c]Vietnam has an average yield of 4.1 t ha^{-1}; national figures in 1999 indicated that rats caused high damage (10–75%) to 245,000 ha in the Mekong Delta and 370,000 ha in the Red River Delta. Low damage of 5–10% was recorded in 610,000 ha in the Red River Delta. Nationally, we have developed two scenarios: the first assumes an average of 30% loss in areas where damage is high (a reasonable assumption, given some crops are not harvested at all) and 5% loss on average elsewhere; and the second, a conservative estimate, assumes an average loss of 20% of production for 615,000 ha and an average loss of 5% for half of the remaining area of production (i.e., 3,500,000 ha).

pest impact posed to the farmers will provide responses that focus on insects because most farmers equate the word pest to mean insects, not rodents.

Two recent books provide a good resource for those interested in rodent biology and management. The first book addressed the theme of ecologically based management of rodent pests (Singleton et al 1999a). The second book has a broader theme of rats, mice, and people (Singleton et al 2003). Both books have contributions that specifically address the problem of rodent pests in rice agroecosystems in Asia.

BANGLADESH

There are two main rice agricultural systems in Bangladesh: irrigated and lowland rainfed. The principal pest species are *Bandicota indica* and *B. bengalensis*. There is limited economic assessment of the effect of rats on rainfed deepwater rice. The results of the evaluation, however, were impressive: yield losses were 68% in 1987 and 32% in 1988 (Islam et al 1993). An important caveat to these results is that the studies were conducted on a research farm at sites that had a history of high rat damage.

Another study in 1982-83 reported rat damage to both the winter irrigated ("boro" rice crop) and the deepwater crops (Karim et al 1987). The rat damage was quantified for the deepwater crop by counting the number of stems cut. On average, 3.5 and 2.1 stems m^{-2} were damaged at the flooding stage and at harvest, respectively. A mean of 56.7 undamaged stems m^{-2} were present at harvest, indicating that mean loss of tillers m^{-2} to rats was 0.9% (5.6/62.3; assuming additive effects of the damage). However, estimates of minimum yield loss obtained by excavating burrows of *Bandicota* spp. indicated that crop losses were much higher. These rats hoard rice in their burrows. A mean of 57.8 kg rice ha^{-1} was stored in burrows, which reflected a 5.7% loss in production based on the average national yield for deepwater rice in 1982-83.

There are few data available on the ranking of the impact of rodents on rice production in Bangladesh. The most recent reports are at least 15 years old. One was a 4-year survey in Bangladesh from the early 1980s that listed rodents as the fifth most important pest of deepwater rice (Catling 1980). Up to 52% of fields had significant rat damage at harvest of the wet-season rice. A later survey ranked rodents as the third most important pest (Catling et al 1988).

An impact survey of rodents to assess effects on sustainable livelihood of subsistence farmers is urgently needed and is proposed as part of a Poverty Elimination Through Rice Research Assistance (PETRRA) study on IPM involving rodents (Belmain, pers. commun.).

CAMBODIA

In Cambodia, there are no reliable estimates of the impact of rodents at the national level. Rodent pests cause the greatest restraint to production, especially in times of population outbreaks. The history of these outbreaks is not documented. In non-outbreak years, the impact of rats is greatest on individual families (Jahn et al 1999). The best available data have been collected from farmer surveys and are summarized in Table 3. Annually, it is estimated that 0.1% of the total rice production area suffers from 100% damage by rats (DA 1998). At a finer scale, a PRA on factors that reduce rice production found that 80–100% of farmers generally considered rats to be their main preharvest pest (Table 4). In a village where irrigated rice was the main production system, a majority of farmers estimated that losses caused by rats were greater than 20% (L. Leung and M. Solieng, 2001, pers. commun.).

The principal pest species appear to be *Rattus argentiventer*, *B. indica*, and *R. exulans*. However, few data are available. Based on farmers' descriptions, *R. rattus*, *R. koratensis* (= *R. sikkimensis*), and *R. losea* are probably present in villages as well (Leung 1998).

The following quotes drawn directly from Jahn et al (1999) summarize what is known about the impact of rodents in Cambodia:

"....rice production is 86% rainfed lowland rice, 8% irrigated lowland, and 6% deepwater and upland rice. Among lowland rice farmers (n = 1265), 27% reported wet-season rat problems, and 46% reported dry-season rat problems."

"Due to the small-scale, subsistence nature of Cambodian rice farming, and due to poor distribution of food, rat outbreaks destroy savings and create food shortages. An outbreak in 1996 destroyed rice (>12,600 t) sufficient to feed over 50,000 people for a year."

"...in 1996, yield losses from rats represented 0.3% of national production and only 4% of Svay Rieng's total paddy production. National statistics do not convey the fact that, during an outbreak, hundreds of farmers lose their entire crop, sending them into a cycle of poverty from which few escape."

Table 3. Lowland rice areas that suffered high losses due to rats (>70%), Cambodia 1990–96 (Jahn et al 1999).

Province	Area damaged (ha)							Total	Mean
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*		
Kampong Thom	-	161	118	76	68	456	1965	2844	474
Siem Reap	-	-	181	-	-	103	-	284	142
Battambang	592	98	-	193	-	-	-	883	294
Kandal	452	-	-	72	-	-	-	524	262
Prey Veng	-	64	-	-	86	511	125	786	197
Svay Rieng	93	164	236	472	230	786	4902	6883	983
Takeo	-	56	-	183	-	-	580	1011	337
Total	1512	543	535	1052	384	1856	7695	13577	1940
Av yield (t ha^{-1})	1.30	1.35	1.40	1.45	1.50	1.60	1.64		
Estimated production loss (t)	1965	733	749	1525	576	2969	12619	21136	3019
Value of production loss (US$)	285,818	106,618	108,945	221,818	83,782	431,855	1,835,490	3,074,327	439,190

[a] Price of rice = 400 riel kg^{-1}; exchange rate US$1 = 2,750 riel (1997); - = no information.

Table 4. Response to a question from a participatory rural assessment[a]: "Which pests caused the highest damage to your rice crop?".

Farming community	Farmer respondents (no.)	Pests causing highest damage to rice crops			
		Rats	Insects	Crabs	Birds
Svay Rieng (1)	35	100	0	0	0
Svay Rieng (2)	33	100	0	0	0
Bantey Mean Chay (2)	23	100	0	0	0
Bantey Mean Chay (2)	21	81	0	19	0
Siem Reap (1)	27	96	4	0	0
Seam Reap (2)	22	18	82	0	0
Pursat	12	92	8	0	0
Kamphong Cham	43	81	19	0	0
Battambang	18	61	0	39	0

[a]PRA conducted by Dr.Leung, Dr. Solieng, and others in Cambodia in 2000 (unpubl. data).

As for Lao PDR, the rice production systems are changing toward greater irrigation and use of varieties that allow two crops per year. This greater intensification may lead to an increase in rodent problems in rice crops in the future.

A new project funded by ACIAR focusing on lowland irrigated rice cropping systems began in September 2001. The project involves scientists from the University of Queensland and is aimed at incorporating strong farmer participation through an adaptive management framework. The principal aim of the project is to develop better rodent pest management strategies that are consistent with the ecological, technical, and socioeconomic constraints faced by local communities. To achieve this goal, Cambodian personnel have been drawn from the principal research (Cambodian Agricultural Research and Development Institute) and extension (Provincial Office of Agricultural Extension) agencies.

CHINA

There are no published figures on the impact of rodents on rice production in the 1990s. Before 1990, the rodent problems were serious, especially from 1982 to 1986 (Table 5). In China, in the period immediately prior to 1985, the official estimated loss of rice to rodents was approximately 10% (Zhao 1996). The main species that cause damage to rice are *R. norvegicus, R. losea, R. flavipectus (=R. tanezumi), Mus musculus, Apodemus agrarius, R. nitidus,* and *B. indica*. In the Dongting Lake area, Hunan Province, *Microtus fortis* occasionally causes very serious preharvest damage to rice (Zhang et al

Table 5. Relationship between yield loss caused by rodents and index of rodent abundance in late rice crops in Linxian, Guangxi Province (Zhao 1996).

Year	Area (ha)	Index of rodent abundance (%)	Yield loss (x 10^3 t)	Average loss, (kg ha^{-1})
1984	4,266.67	17.7	2.50	589.5
1985	5,000.00	7.7	1.44	289.5
1986	7,573.33	6.9	1.96	259.5

1999).

Report on rodent impacts from Sichuan Plant Protection Agency (2001)

Because of the lack of an integrated approach, systematic monitoring, proper baiting technique, hazards of poisoning, as well as changes in the ecological and sociopolitical environment, the damage caused by rodent pests is becoming serious not only in the poorer mountainous areas but also in the highly productive plains in Sichuan Province. The mean food grain loss is estimated at about 320 kg ha^{-1}, with loss of rice yield for particular farmers ranging from 0.5 to 15%. A significant amount of grain (1 million t) is also lost in storage to rodent pests.

The plains of Sichuan Province is a "rich" area compared with the mountainous areas. Rice yield in Sichuan is about 6,500 kg ha^{-1}, and the area devoted to rice is about 2,250,000 ha. No data from other provinces exist, but Dr. Guo Cong (pers. commun.) suggests that the rat problem may be easing elsewhere in China.

In the 1980s, great effort was focused on

Table 6. Comparison of effects of three different control methods on rodent damage to preharvest rice in Dongting Plain, Huanshou County, Hunan Province (Chen 1996).

Treatment		Year	Mean yield (kg ha^{-1})	Rate of loss (%)	Loss (kg ha^{-1})
Early-season rice	Integrated	1988	6226.5	0.29	18.0
	control	1989	5737.5	0.10	5.7
	Control by	1988	6190.5	0.76	46.9
	rodenticide	1989	5796.0	0.56	32.4
	Traditional	1988	5887.5	9.13	537.3
	control	1989	5643.0	7.49	422.7
Late-season rice	Integrated	1988	6019.5	0.52	1.92
	control	1989	6094.5	0.11	6.75
	Control by	1988	6130.5	1.17	71.7
	rodenticide	1989	5772.0	0.84	48.45
	Traditional	1988	5763.0	8.59	495.0
	control	1989	5875.5	8.60	505.35

organized campaigns (Table 6). The scale of these campaigns was very large. In recent years, however, local governments are not as influential and these campaigns are no longer being organized or financed. Instead, the current method adopted by farmers is to buy rodenticide or bait from local markets, with management implemented at the individual farmer level.

In China, the legal rodenticides are anticoagulants. However, farmers do not like the "slow" action and they do not see dead animals for their efforts. Therefore, most of the rodenticides in the market are illegal (Guo Cong, pers. commun.).

INDIA

In India, rodents have long been reported as having a substantial impact on rice crops (Rao and Joshi 1986) and are now the main constraint to rice production, irrespective of production system (Parshad 1999, Rao 2003). The principal pest species are *B. bengalensis*, *Millardia meltada*, and *Mus booduga*. Some 25 years ago, rodents were reported to consume between 10% and 15% of the national production of all grains in India (Barnett and Prakash 1975). Recently, Hart (2001) claimed that the overall losses of grain to rodents in India were approximately 25% in the field before harvest and 25-30% postharvest. She further suggested that losses to rodents alone cost at least US$5 billion annually in stored food and seed grain in India. Rice crops are a vital food for India and both chronic and catastrophic losses to rodents have been reported. The chronic losses are economically more important and often these losses go unrecognized (Sridhara 1992).

Although Hart's claims appear rather high, there is compelling evidence that rodents have a major impact on rice production in India. Parshad (1999) has recently produced an excellent review of the impact of rodents on rice production. The results of his review, together with reviews by Sridhara (1992) and Chopra et al (1996), are summarized in Table 7. This analysis indicates that preharvest losses to rice are generally in the range of 5–15%.

Added to the chronic annual losses caused by rodents are episodic outbreaks that cause famine-like conditions (Chauhan and Saxena 1983, Prakash and Mathur 1987). A summary of rodent outbreaks in rice production areas from 1990 to 2000 is provided in Table 8.

Two regions particularly hard hit by these outbreaks are Mizoram and Arunachal Pradesh. The cause of these outbreaks is not clear, although in these regions, the flowering of bamboo is often given as a causal factor.

Periodic outbreaks also occur in Andhra Pradesh following flash floods or cyclones in this deltaic region. For example, the 1996 cyclone was followed by an outbreak of rodent populations in 1997, leading to damage of up to 29% of the standing rice crop at early tillering. This prompted the government to provide free rodenticides at a cost of US$3.8 million. In one district alone (West Godavari), 4.3 million farmers were affected by the rodent outbreak (Rao 1998).

In India, major changes in agricultural systems have increased the rodent problem in recent decades. For example, the Indira Gandhi Canal brought more cultivable land under irrigation, but there was a concomitant increase in rodent impacts on crops because the irrigation canals provided access routes for the lesser bandicoot rat to move into areas where it had never been previously recorded. This species then replaced desert rodents as the dominant rodent species (Mohan Rao, pers. commun.).

Dr. Rao is working in India in the development wing of the Federal Ministry of Agriculture. His role is to try to link the research of the All-India

Table 7. Preharvest losses to rice crops in India attributed to rodents.

Location	Rice crop	Rodent impact	Reference
Punjab	Irrigated	5% (range 1.1–17.5) (46–528 kg ha^{-1})	Anonymous 1991 (Indian Council of Agricultural Research)
Uttar Pradesh	Irrigated	98–213 kg ha^{-1})	Rana et al 1994
Madhya Pradesh	Rainfed	1.3–6.7% 60.8 kg ha^{-1}	Patel et al 1992
West Bengal	Irrigated	261 kg ha^{-1}	Chakroborty 1975
Meghalaya	Lowland and upland rainfed	12.5% 10%	Singh et al 1994
Mizoram	Upland rainfed	4.3%	Singh et al 1994
Andhra Pradesh	?Delta rice	2.7–100% 60–2,345 kg ha^{-1}	Rangareddy 1994
	Rainfed	9.6–60.6%	Rajasekhraran and Dharmaraju 1975
	Delta rice	15% (range 10–60%)	Anonymous 1977
Karnataka	Various	1.1–44.5%	Chakravarthy et al 1992
	Various	62–79.7%	Prakash et al 1986
??	Irrigated	13.3%	Chaudhry and Badaya 1985
Haryana	Irrigated	3.7% (range 0.5–16.4%)	Chopra et al 1996

[a]Modified from Sridhara (1992), Chopra et al (1996), Parshad (1999), and Rao (2003).

Table 8. Rodent outbreaks in India, 1990-2000 (Rao 2003).

Year	State or territory	Area affected	Estimated loss
1990/91	Gujarat	Saurashtra region	Not available
1994	Pondicherry	Karaikal region	Not available
1994	Tamil Nadu	Cauvery Delta	Not available
1997/98	Andhra Pradesh	210,000 ha in Godavari Delta	3,301.85 t of rice
1999	Manipur	1,000 ha of jhum rice	Not available
1999/2000	Mizoram	53,945 ha of rice, maize and vegetable crops	Not available
1999/2000	Arunachal Pradesh	7,000 ha of rice and maize	Not available
1999/2000	Nagaland	1,000 ha of rice	Not available
2000	Manipur	1,264 ha of jhum rice	Not available

Coordinated Research Project (consisting of 10 cooperating centers spread through India) with extension staff working from within a different institute (Institute of Central Agricultural Research [ICAR]). ICAR extension staff have no training in rodent management and have few linkages with rodent researchers. Therefore, the national seminars or workshops organized by ICAR institutes do not cover topics on rodent problems. The result is that research and extension departments are working in isolation to address rodent pest problems; research personnel are unaware of what is going on in extension and vice versa. Dr. Rao has an unenviable task. He took the lead in the following activities that he is trying to instigate at different levels in India (see also Rao 2003):

State sector

- Popularizing the nonchemical approach
- Popularizing the community approach among farming communities
- Inclusion of rodents in pest/disease surveillance activities
- Creating awareness through various communication media
- Making available safer rodenticides at vulnerable places
- Creating more trained manpower in rodent pest management
- Liaising with public health authorities
- Ensuring quality control, especially in the use of zinc phosphide

Central sector

- Enhancing research activities at ICAR on rodent surveillance and nonlethal rodent management strategies
- Extending timely guidance to states/UTs on proper control operations
- Ensuring the availability of chemical inputs from the pesticide industry

Private industry sector

- Timely supply of rodenticides by the industry
- R & D for developing safer formulations
- Ensuring availability of rodenticides at vulnerable places

Dr. Rao provides the following quote, which is true of much of Asia, with the possible exception of China.

"In South Asia, there is a dwindling number of competent scientists working on rodent pest management. Scientists with entomology background are normally recruited for rodent projects and naturally they are not much interested in rodent research since the subject is totally different and their performance is often assessed in an entomological framework for personal promotions." (Mohan Rao 2001, pers. commun.)

INDONESIA

The most common rodent pest in rice fields is the rice field rat, *R. argentiventer*, which in Indonesia is the single most important preharvest pest to rice crops, causing annual losses of around 17% (Geddes 1992, Singleton and Petch 1994). This figure of 17% has been used repeatedly for Indonesia. We will now consider whether there is support for this estimate. Discussion will focus on lowland irrigated rice because this is the most important crop in Indonesia and the information on rodent impacts is primarily confined to this crop.

Detailed damage assessment

Buckle (1988) conducted detailed measures of crop depredations by rodents in Java. His studies included detailed damage assessment in farmers' fields. Buckle also used small fenced plots to estimate potential yield where there was no rodent damage. He concluded that 17% was a conservative estimate of preharvest losses caused by rodents in rice.

An ACIAR-funded project on rodent biology and management began in West Java in 1995. This study included damage assessment across 6–8 sites with rodent damage quantified at 10 transects per site (see Singleton et al [1998] for details). In the 1995 dry season and 1995-96 wet season, the combined mean yield was approximately 10.1 t ha^{-1} on sites with rodent management (using a trap-barrier system with a lure crop) and 8.1 t ha^{-1} on untreated sites. Rodent management did not eliminate rodent damage–for the dry-season crop, 8% of tillers were damaged during the ripening stage of the crop (Singleton et al 1998). Therefore, in 1995-96, rats caused annual losses of 25–30% to rice production. Preharvest yield losses of 15–25% were similarly reported from a study conducted in West Java in 1997 (Singleton et al 2003) and these were similar to those reported by the Indonesian Bureau of Statistics for West Java in 1997 (15–18%). However, in some years, losses were not as severe. For example, in the 1996 dry-season crop at the same study site, losses were estimated to be less than 5%.

The ACIAR study indicated that annual losses in rice production ranged from 5% to 30%, with most years >15%. Again, this is consistent with an estimate of annual losses of around 17%.

Broad-scale provincial damage assessment

Figures on rodent damage are collected at the national level by the Forecasting Center for Pest and Diseases. The provincial staff who collect these data generally have training in entomology or plant pathology. None would have been trained in rodent biology and, consequently, they would only notice rodent damage when it is at a high level. The reporting consists of estimates of areas with moderate (>10%), high (>30%), or severe (70–100%) rodent damage (Tables 9, 11a & b). Given that 5% damage to tillers is usually not noticeable, and 10% damage is only detectable by a trained eye, then damage estimates of 10(30% would typically be underestimates of damage intensity. Nevertheless, estimates of mean damage intensity were generally higher than 15%. Of particular note were the high losses in Java and Sulawesi—the two principal rice bowls of Indonesia.

Of interest is the fact that 5,225 ha were 100% destroyed by rodents in 1995. Given an average farm size of 0.75 ha (range of 0.5–1.0 ha) in Indonesia, then approximately 7,000 families would have had no crop to harvest. This alone highlights the important impact of rodent pests on rice agricultural systems in Indonesia.

Forgone rice cropping

In 1998, Indonesia faced a critical rice shortage because of the effect of drought. A national IP-Padi 300 program was developed with the aim of identifying areas where a third rice crop could be produced (based on water availability) during August-November. Rodents were identified as one of the most important factors likely to severely limit the yield of this third crop. Consequently, much manpower and resources went into managing rodents during this growing season. Although a reasonable crop was produced, the threat of rodent impacts is one of the main reasons that a third crop has not been grown in these areas subsequently.

In both eastern and southern Kalimantan, large tracts of land have been cleared and irrigated for the express reason of growing rice. Rodent pests have had a major influence on the success of these transmigration regions. In southern Kalimantan, the aim was to develop 900,000 ha. Rodent depredations to the rice crops grown in these new lowland irrigated ricecrops were a major factor that led to the program stopping at 450,000 ha. In eastern Kalimantan, the impact of rats was so severe that some farmers stopped growing rice and converted to livestock (R. Roothaert, CIAT, pers. commun.).

The above are clear examples of how rats can limit when and where rice can be grown in some instances. This forgone cost of not growing rice rarely enters into economic estimates of the impact of rodents on rice cropping systems.

Summary of impacts of rodents

The above analysis reaffirms that rodent pests are economically the number one preharvest pest in rice-growing agricultural systems in Indonesia. This fact is clearly recognized by the Government of Indonesia (Table 10). Moreover, approximately 17% losses in preharvest production of rice nationally would be a reasonable, and probably conservative, estimate.

If preharvest losses in Indonesia were reduced from 17% to 8% (an achievable target), then it is estimated that savings would amount to more than US$0.6 billion per year. Put another way, rats consume or damage enough rice to feed an extra 30 million Indonesians for a year—with rice on average providing 70% of the daily energy requirements of Indonesians . If these losses were halved, then there would be sufficient rice to feed an extra 10–15 million Indonesians for a year.

Table 9. Preharvested rice areas damaged annually by rats in Indonesia, 1997–2000.[a]

Year	Area damaged[b] (ha)				
	L	M	H	NH	Total
1997	67,763	7,852	1,510	1,203	78, 328
1998	127,591	21,722	13,087	11,150	173,550
1999	153,349	49,254	19,497	15,602	237,702
2000	90,885	15,441	5,386	4,812	116,524

[a]Source: Directorate of Food Crop Protection.[b] L = light damage (<25%); M = medium damage (25-50%); H = high damage (50-90%); NH = no harvest (>90% damage).

Table 10. Ranking of economically important nonweed pests of rice in Indonesia.

Pest	Ranking in decreasing order of economic significance			
	1983-85	1986-90	1991-94	1995-97
Rice field rat	1	1	1	1
Brown planthopper	2	4	2	3
Rice stem borer	4	2	3	2
Rice leaffolder	3	3	Not ranked	Not ranked

[a]Source: Forecasting Center for Pest and Diseases, Jatisari, West Java.

Table 11a. Rodent damage and crop loss to rats for lowland rice in 1995.

Province	Damaged area (ha)	Mean damage intensity (%)	Area of total crop loss (ha)
DKI Jakarta	35	10.37	0
Jawa Barat	29,006	16.08	241
Jawa Tengah	11,282	14.32	662
D.I. Yogyakarta	2,138	11.28	0
Jawa Timur	4,493	22.18	485
D.I. Aceh	5,755	17.90	0
Sumatera Utara	878	16.00	10
Sumatera Barat	1,073	20.20	25
Riau	700	20.50	12
Jambi	597	24.10	105
Sumatera Selatan	2,380	22.50	217
Bengkulu	949	12.70	0
Lampung	1,473	18.60	70
Bali	212	25.40	0
NTB	550	15.90	0
NTT	45	5.30	0
Kalimantan Barat	1,476	32.40	337
Kalimantan Tengah	2,781	23.70	446
Kalimantan Selatan	140	20.20	0
Kalimantan Timur	1,385	23.10	19
Sulawesi Utara	612	28.80	110
Sulawesi Tengah	9,815	14.60	158
Sulawesi Selatan	23,362	32.40	2,179
Sulawesi Tenggara	1,972	24.80	149

[a]Source: Bureau of Statistics, Government of Indonesia.

Table 11b. Intensity of rodent damage and area damaged by rodents in lowland irrigated rice in 1995.[a]

Province	Intensity of rat damage and area damaged (ha)				
	Low (<25%)	Medium (25-50%)	High (50-90%)	No harvest	Total area
D.I Aceh	7,760	729	45	113	8,647
Sumatera Utara	2,204	180	42	35	2,461
Sumatera Barat	537	193	94	34	858
Riau	593	179	56	40	868
Jambi	434	88	16	9	547
Sumatera Selatan	3,295	383	47	225	3,950
Bengkulu	1,108	541	23	174	1,846
Lampung	5,248	764	213	779	7,004
DKI Jakarta	151	61	8	0	220
Jawa Barat	42,794	6,579	5,077	3,258	57,708
Jawa Tengah	14,341	2,298	3,321	925	20,885
D.I. Yogyakarta	757	310	3	54	1,124
Jawa Timur	4,020	444	585	235	5,284
Bali	364	21	0	0	385
Nusa Tenggara Barat	298	107	0	0	405
Nusa Tenggara Timur	212	2	0	0	214
Timor Timur	19	0	0	0	19
Kalimantan Barat	3,170	914	208	442	4,734
Kalimantan Tengah	4,248	417	189	121	4,975
Kalimantan Selatan	1,513	1,152	563	439	3,667
Kalimantan Timur	875	130	0	56	1,061
Sulawesi Utara	294	16	1	0	311
Sulawesi Tengah	1,231	220	72	2	1,525
Sulawesi Selatan	20,579	3,996	1937	3,671	30,183
Sulawesi Tenggara	8,013	1,581	563	685	10,842
Maluku	1,840	110	0	8	1,958
Irian Jaya	103	102	5	0	210
Total	126,001	2,1517	13,068	11,305	15,9057

[a] Source: Bureau of Statistics, Government of Indonesia.

LAO PDR

In Lao PDR, the greatest problem with rodents in agricultural systems appears to be in the rainfed upland habitats (Singleton and Pech 1984, Schiller et al 1999), where the principal pest species are *Rattus exulans*, *R. losea*, *R. rattus*, *Bandicota* spp. and *Mus* spp. (mainly *Mus caroli* and *M. cervicolor*) (Khamphoukeo et al 2003). Farmers rank rodents as the second most important constraint to upland rice production. (Weeds are number one.) However, upland farmers consider rodents as the problem they have least control over (Schiller et al 1999).

Lowland rainfed and irrigated rice

Most of the rice (>70%) is grown in the lowlands, with irrigated rice making up only 12% of the crops. Information on the impact of rodent pests on rice production in this cropping system was restricted to questionnaires conducted on farmers' perceptions of production constraints. Schiller et al (1999) reviewed the data obtained from these questionnaires. Although many farmers mentioned rodents, they generally ranked them in the lowest three of 11-12 major constraints identified.

An emerging issue, however, is that the amount of land under irrigation is increasing by approximately 10% yr^{-1}. This will result in greater intensification of cropping, with more crops grown per year. Based on the experiences of neighboring countries in the Mekong Delta, rodent problems would be expected to escalate, unless cropping systems are developed with the biology of key rodent pests taken into consideration.

Upland rainfed rice

A survey conducted in 1992 identified rats as the second most important constraint to upland rice production (Lao-IRRI 1992).

Acute losses. A major concern often expressed was the episodic outbreaks of rodents in the upland cropping systems. These massive outbreaks can lead to crop losses of >50% and indeed some farmers reported losses of 100% (Singleton and Petch 1994). The causes of these outbreaks were not clear. Farmers linked these outbreaks to the flowering of bamboo, but there was no strong evidence supporting or denying this explanation. During the current ACIAR-funded project (1999-2002) on rodent biology and management in upland agroecosystems in Laos, historical data have been collected on the occurrence of outbreaks from a minimum of four districts in each of four provinces. Some records date back to the early 1950s and it was evident that outbreaks of rodent populations were not a recent phenomenon. The earliest recorded outbreaks were in 1953 in Houaphanh and in 1957 in Luang Prabang. The most recent outbreaks were in two districts of Houaphanh Province in July and August 2001 (Bounneuang Duang Boupha et al 2003). This outbreak was in upland rice and maize. Specimens were collected and this outbreak may have been associated with bamboo flowering.

Chronic losses. During 1998-2001, site visits to villages in the uplands of Luang Prabang, Oudomxay, Houaphanh, and Sekong have provided consistent information from farmers that annual preharvest losses to rats were generally around 15%. Observations of damage to rice crops and recent formal assessment of rodent damage both support what farmers are telling us (Bounneuang Duang Boupha et al 2003).

MALAYSIA

The main rodent pest species in Malaysian rice crops is the rice field rat *R. argentiventer*. Annual losses to rice caused by rodents are 4–5% (MARDI, unpubl. data, 1994). The yield loss at the national level is generally patchy, with individual farmers losing large proportions of their crop. Therefore, for the individual farmer, rats can have catastrophic effects on his livelihood.

There have been no published reports on the impacts of rodents in Malaysia since the review by Singleton and Petch (1994). (Refer to this publication for further details.)

MYANMAR

Agriculture is a major component of the Myanmar economy, contributing 42% to its GDP with 65% of the labor force involved in agriculture (http://www.cia.gov/cia/publications/factbook/geos/bm.html). The main crops are rice, maize, oilseed, sugarcane, and pulses. Rodents cause significant damage to each of these commodities, particularly to rice. Rice is the national staple crop of Myanmar, accounting for 97% of total food grain production. There has been a national initiative since 1992 to increase the area double-cropped with rice. It is estimated that about 1.5 million ha are currently double-cropped, although only 18% of rice is grown under irrigation. A majority of cropping consists of one rice crop (4 million ha) and other crops in the spring and winter. Indeed, 53% of rice is grown under rainfed conditions (http://www.irri.org/vis/facts/myanmar.pdf).

Chronic rat problems have accompanied double-cropping elsewhere in Southeast Asia, whereas acute, sporadic rodent problems are generally associated with rainfed single rice crops. The farming communities are generally poorer in the single rice crop regions, with livelihood security therefore of major concern when occasional high losses in income are accrued from rodent depredations. The Myanmar Agricultural Service has identified the rainfed crops as the priority for reducing rodent impacts on production. Moreover, the greatest impacts of rodents tend to occur among the poorer communities, because they do not have the economic capital to absorb chronic losses or sporadic acute losses and do not have the knowledge base or living conditions to minimize losses postharvest or to reduce rodent contamination of food and drinking water. Therefore, the main potential beneficiaries of rodent management would be the rainfed farming communities that have low annual average family incomes (often less than US$200).

Rodent problems preharvest have a major impact in Myanmar, where 75% of the population reside in rural areas and depend on agriculture for their livelihood. The rodent problem is not well defined, but in the rice-dominated agricultural system, which is largely rainfed, the rodent impacts appear to be patchy and acute, with losses for affected individual farmers typically in the range of 5-40%.

Little is known in Myanmar about the identity and geographic distribution of the major rodent pest species, let alone the biology of the main pest species. Attaining such knowledge and developing a simple rodent taxonomic key is a high priority. Nothing is known about the causes of localized rodent outbreaks, which occur every year but usually in different localities each year. An analysis of the spatial patterns and history of outbreaks against patterns of rainfall, soil type, water levels, timing of monsoon rains, etc. would be an essential step in better defining the problem.

PHILIPPINES

The major rodent pest species in the Philippines are *R. tanezumi* (synonym: *Rattus rattus mindanensis*) in Luzon and the Visayas, and R. argentiventer in the islands of Mindanao and Mindoro. *Rattus norvegicus* and *R. exulans* generally are of minor concern, except in the islands of Cebu and Palawan (Fall 1977).

Although there were claims that rodents caused damage to crops (<1% of annual production) (Hoque et al 1988, Sumangil 1990), the official figure has been increased to 3–5% in recent years (Plant Protection Section, Bureau of Plant Industry) and reports in 2001 from farmer groups in Iloilo (Panay), Isabela (northern Luzon); Nueva Ecija (Central Luzon), and Pangasinan (central west of Luzon) indicated that actual impact was higher than 10%. Damage was patchy, with farmers from these regions reporting annual losses of 30–50% in some years (Singleton unpubl. data; E. Benigno and D. Sanchez, NCPC, UPLB, pers. commun.; Appendix 1).

In Central and northern Luzon, the advent of direct seeding has escalated the rat problem, especially if there is a mixture between transplanted and direct-seeded rice (R. Joshi, PhilRice, pers. commun.). In 1998, 150 rice farmers surveyed from three municipalities of the Ifugao rice terraces in northern Luzon identified rats as a major pest. The farmers also reported that they had little knowledge on how to manage the impacts of rats (Joshi et al. 2000). PhilRice also has reported high rat damage to hybrid rice nurseries.

A priority for the Philippines is to quantify the impacts of rodents. Farmers living in the rice bowls of the Philippines and staff from both PhilRice and the National Crop Protection Center (NCPC) provide a clear message that rodent pests are a major restraint to rice production. However, the extent of the impact has not been quantified.

An indirect measure of the importance of rodent pests is the wide range of management actions undertaken by farmers (Appendix 1) and the requests for me to conduct mini farmer field schools (with NCPC colleagues) on the biology of rats and on the trap-barrier system. The outputs from the decision analysis conducted with farmers on factors influencing management actions for rodents are summarized in Appendix 1.

THAILAND

The principal rodent pests of rice are *R. argentiventer* and *B. indica*, although recent surveys showed *R. losea* to be more abundant (Boonsong et al 1999).

In rice crops, losses average 6% in lowland and 7% in upland rice. Damage occurs every year in upland rice, whereas damage is more variable in lowland crops. Very few data have been collected in the 1990s. Therefore, the reviews by Singleton and Petch (1994) and Boonsong et al (1999) are still current.

There is a heavy use of rodenticides in Thailand. From 1993 to 1997, the annual government subsidy for rodenticides for farmers was approximately 20 million baht (US$450,000) (A. Payakaphanta, Department of Agriculture Extension, pers. commun.).

VIETNAM

In Vietnam, recent changes in economic structure affecting agricultural production have led to a doubling in rice production. This increase has occurred mainly in the Mekong and Red river deltas. Factors contributing to this increase in yield include more land under production and a general increase from two to three crops per year. Both these practices benefit rodents by way of increasing their food supply and extending the periods in a year when high-quality food is available. The latter would extend the period of breeding of female rats because their breeding season is linked with the stage of the rice crop (from 1-2 wk before maximum tillering through harvest). It is not surprising, therefore, that serious rat problems have been reported nationally since the adoption of the market economy in 1989.

Lowland irrigated rice

In Vietnam, the most common rodent pests in lowland irrigated rice fields are the rice field rat, *R. argentiventer*, and the lesser rice field rat, *R. losea*. The rodent problem has escalated in the past 5–10 years. For example, the area of crop severely damaged by rats increased to more than 600,000 ha in 1998 (Singleton et al 1999b). In June 1997, the Vietnamese Ministry for Agriculture and Rural Development classified rodents as one of the three most important problems faced by the agricultural sector.

The rodent problem in Vietnam is thought by many to be predominantly in the Mekong Delta. In the early 1990s, this appeared to be the case. However, in 1999 and 2000, severe rat damage was reported in a greater rice area in the Red River Delta than in the Mekong Delta (Ministry of Agriculture and Rural Development).

In 1997, 22 provinces applied a rat bounty scheme for specific times of the year and 55 million rats were collected. The cost of the bounty scheme was approximately 62 billion dong (approximately US$4.5 million). In 1998, an estimated 82 million rats were killed using bounties and other techniques. In the province of Vinh Phuc alone, more than 5 million rat tails were returned from January to September 1998. In this province of only 1.1 million people, the authorities estimated that there were well more than 10 million rats; 10 rats for every person.

In the Mekong Delta, in provinces such as Tien Giang, Dong Thap, and Soc Trang, marked changes in farming systems have led to increased reports of rodent impact (Lan et al 2003). These changes include both the expansion in area of planted rice and the growing of two or three crops per year where previously there were only one or two crops per year. An overview of the increase in impact of rodent pests in rice fields of the Mekong Delta is presented in Table 12.

Lowland rainfed rice

There are some provinces in the Mekong Delta that have significant areas of rainfed rice (e.g., Bac Lieu and Bac Binh). Again, reports of rodent impacts have been common in recent years, particularly in Bac Lieu where there has been a marked expansion in rice cropping.

CSIRO staff visited Bac Binh Province in March 2001. A survey of rodent impact on rice farmers in the province had been conducted by World Vision Vietnam (Le Anh Tuan, unpubl. data). The survey indicates a current loss of productivity ranging from 10% to 35 %, with the highest losses concentrated in the mid-land zone. Similar estimates of overall loss were obtained during our own interviews, with extreme losses of 50–100 % observed for some marginal, rainfed cropping areas of the mid-land and upland regions. Several fields were seen in which 100% loss of the "winter" crop had occurred.

Case study: Bin Thuan District, Bac Binh Province (K. Aplin and G. Singleton, unpubl. observations)

The Binh Thuan Pistrict of Bac Binh Province is made up of a series of distinct landforms that largely determine the distribution and nature of farming systems. This natural system is being modified through the construction of a series of dams and irrigation canals that will greatly increase the agricultural area with access to reliable, year-round

Table 12. Rodent situation in south Vietnam, 1991-2000 (see also Lan et al 2003).[a]

Year	Area infected by rats (ha)	Total area cultivated year $^{-1}$ (x 10^3 ha)	Distribution (Heavily infected provinces)
1991	6,200	3,162.7	Dong Thap, Long An, Kien Giang, Tien Giang
1992	18,640	3,213.4	Long An, Dong Thap, Kien Giang, Tien Giang, An Giang
1993	107,481	3,257.0	Dong Thap, An Giang, Tay Ninh, Tien Giang, Long An , Can Tho, Soc Trang
1994	134,616	3,337.0	Long An, Tay Ninh, Soc Trang, Can Tho, Kien Giang, Dong Thap.
1995	82,706	3,758.3	Long An, Kien Giang, An Giang, Can Tho, Dong Thap, Minh Hai, Tay Ninh.
1996	133,600	3,883.2	Long An, Dong Thap, Kien Giang, Can Tho, Bac Lieu, Soc Trang, Tay Ninh, Vinh Long, An Giang.
1997	138,881	3,976.7	Can Tho, Tay Ninh, Soc Trang , An Giang, Vinh Long, Ho Chi Minh city,
1998	189,468	4,053.6	Can Tho, Kien Giang, Soc Trang, Vinh Long, Long An, An Giang, Dong Thap, Bac Lieu,
1999	245,003	4,108.1	Vinh Long, Kien Giang, Soc Trang, Tra Vinh, Dong Thap,An Giang, Long An, Can Tho, Bac Lieu.
2000	111,865	4,049.7	Vinh Long, Ca Mau, Tay Ninh, An Giang, Soc Trang, Can Tho , Dong Thap, Bac Lieu.

[a] Based on regular reports from field extension officers to the Southern Region Plant Protection Center at Tien Giang (data provided by Mr. Ho Van Chien).

water resources. The major rodent species, based on frequency of capture, were *R. argentiventer, B. savilei*, and *B. indica*.

1. Coastal dune complexes ('coastal area'): there are at least two coastal dune complexes in the area, a younger (Holocene?) complex that consists of white sand with minimal soil development, and an older (late Pleistocene?) complex with orange sand and a more mature soil profile. Both complexes preserve their original undulating dune morphology and hence provide a variety of slopes and aspects for agricultural use. These areas are used primarily for horticultural activity, with only very small areas of rainfed rice grown in low-lying areas. Apparently, there are no plans to bring irrigation water to these areas.

The communes located in this landform are Hong Phong and Hoa Thang. Survey data for Hoa Thang indicate a total of 11 ha of rice; with an estimated yield loss of 30%. Our own interviews suggested that 10 ha of rice are grown, with low levels of rodent damage. Three rice crops are produced per year using water available year-round from a natural seepage and with synchronized planting. The major crops for the commune are watermelon (2,200 ha) and cashew.

2. Major rivers and associated alluvial fans and terraces (mid-land area): the greater part of this region consists of a complex of elevated alluvial fans with predominantly sandy to gravel-rich soil. These fans are clearly inactive and relate to periods of much higher river flow and sediment transport than what occur today. They have a poorly developed soil profile and are used primarily for grazing or timber reserves, with some horticultural crops including tree crops.

The current river courses are inset within this relict landscape. The channels are typically confined and have narrow, active alluvial terraces that support linear complexes of rice fields, presumably making use of seasonal floodwaters. In several areas, such as along the southern edge of the Luy River and north along the lower reaches of its major tributaries, the channels are bordered by broad, inactive (i.e., nonflooding) alluvial terraces with loamy, organic soil. These terraces stand 3 m or more above the active channels and constitute the major rice-cropping areas in Bac Binh District.

Among the communes visited, Luong Son, Phan Thanh, Phan Ri Thanh, Hai Ninh, and Phan Hiep have significant areas of rice fields situated on these alluvial terraces, with smaller and less contiguous areas in Binh An, Phan Dien, and Phan Hoa. In the majority of areas, these rice fields are exclusively rainfed and typically support a dual cropping regime (summer [He Thu] and autumn [Mua] crops), with occasional third crops (winter-spring [Dong Xuan]) if conditions permit. Growing seasons are typically 90–100 d, each separated from the next by a 20–30-d fallow. All crops are direct-seeded, with the time of seeding usually determined by individual farmers on the basis of water availability.

3. Mountains and foothills (upland area): high mountains enclose Bac Binh District to the north and northeast, and form the border with Lam Dong and Ninh Thuan provinces, respectively. The ranges rise steeply from the alluvial landscape and are penetrated by narrow valleys with streamside terraces and lower slopes that provide arable land.

Phan Son Commune was visited where rice fields are located along several distinct valley systems, with fields located both in the active stream channel (flow controlled by small-scale terrace works) and on raised alluvial terraces (rainfed systems). Areas immediately upslope of the rice fields support hamlets and gardens, interspersed with areas of open scrub. In many places, the stream valley supports dense thickets of bamboo and shrubs, often running between areas of rice fields.

The total area of cultivated rice at Phan Son is close to 340 ha, divided into around 10–12 distinct field complexes, with the largest areas situated on the raised terraces. Three rice crops are usually grown, with fallows of 20–30 d between each crop. However, some fields were said to produce four crops without fallow; these may be the fields located in the valley floor where water is presumably available year-round and where stream flow may provide constant nutrient enrichment. All rice fields are direct-seeded with the timing determined by the Farmers' Committee. The intensive cropping regime was said to have begun in 1990 with the instigation of a market economy; prior to that date, most fields were cropped once a year. The farmers in these habitats identified rodents as an important pest of their rice crop.

At Phan Son in the uplands, it was claimed that damage had increased about 10 yr ago, at the time that they had increased cropping from a single to two or three crops a year in response to the change to a market economy.

At Binh An, rodent damage was said to be low at present. However, the chairman of the People's

Committee expressed the view that rodent damage would increase as more areas are brought under reliable irrigation.

These reports suggest a general link between levels of rodent damage and increased frequency of rice cropping. A similar link between agricultural intensification and rodent damage has been suggested for other regions of Southeast Asia, including the Mekong Delta.

In comparison with the preharvest loss, postharvest damage appears to be fairly minimal. This was irrespective of whether grain was stored inside residences or in separate rice stores.

Upland rainfed rice

Apart from the report at Phan Son in Bac Binh Province, no other information was found on the impact of rodent pests on upland crops in Vietnam.

Summing up

The statistics tell the story. Nationally, the area of crop with high rat damage has increased from approximately 50,000 ha in 1993 to 245,000 ha in 1995 and 600,000 ha in 1998. The impact appeared to plateau in 1999 with “only” 500,000 ha. This is for a country that has about 8.1 million ha under cultivation.

In 1999, the Vietnamese Government developed a special program on rodent control. Rat committees were set up in provinces and although there was a noticeable reduction in rodent impact, there were still 236,500 ha with high rodent damage (consisting of 221,800 ha of rice).

In summary, there is compelling evidence that rats cause average annual yield losses preharvest to rice of 10–15%.

Postharvest losses in rice production in Asia caused by rodents

Rodent and insect pests have an enormous economic impact on stored grain in developing countries. Many Asian agricultural institutions regard the magnitude of postharvest losses as a widespread problem, but usually no common effort is made to control post-harvest damage (Hopf et al 1976). Moreover, few studies have quantified the impact. Damage estimates strongly depend on assessment methods and reports of up to 20% postharvest losses of rice are not unusual. Estimates worldwide put the annual loss of food caused by rodents at about 11 kg per person; this value is equivalent to the combined gross national product of 25 of the poorest countries in the world (Gwinner et al 1996). Postharvest damage by rodents includes direct consumption of stored grain and contamination by rodent excrements, parasites, and corpses and damage to containers (e.g., bags). Also, in Indonesia, Suharno (1987) reported that rodent gnawing was the cause of treatment failures for insect pests, and increased treatment costs in bag stacks sealed under plastic enclosures after disinfestation with carbon dioxide.

In India, losses of grain to rodents are estimated to be 25-30% postharvest at a cost of at least US$5 billion annually in stored food and seed grain (FAO 1999). Another author claims that this could be a conservative figure, based on estimates that there are in excess of 2.5 billion rats in India and each one potentially could cause US$10–15 billion in damages each year (Hart 2001). The basis for these figures is that rodents eat an amount of food equivalent to 7% (rats) to 20% (mice) of their body weight daily. Therefore, the potential annual consumption of grain per rat is about 6.5 kg and per mouse, about 1.5 kg. These figures consider the potential damage one rat or mouse could do over a year, but the turnover of rodent populations is such that the average survival of rodents would be 3-5 mo. Nevertheless, the estimates of loss are impressive.

One of the best estimates of rodent impact postharvest is from a detailed study of rodent pests in central Punjab in Pakistan, where for every person living in a village, there were 1.1 house rats. Extrapolating the results from this regional study to the national level, it was estimated that 0.33 billion metric t (rice, maize, and wheat) worth US$30 million were consumed by house rats in the villages of Pakistan every year (Mustaq-Ul-Hassan 1992). The study did not consider the impact of rats in and around major cities.

Control measures are most likely to be efforts by individual farmers (rodenticides, trapping) often with little effect (Hopf et al 1976). In many Asian countries, farmers simply accept postharvest damage partly due to the lack of simple and effective methods of rodent control.

In some Asian countries, the species involved in postharvest damage of several storage facilities are known from the survey of Hopf et al (1976). Depending on type of storage, season, and country, a diverse suite of small rodents such as *Rattus* spp. (usually *R. norvegicus* and *R. rattus*), *Mus* spp., and *Bandicota* spp. can be important for postharvest losses. Often, for a particular region, the rodent species causing damage in the fields are different from those causing problems postharvest.

Although there is general consensus that rodents cause substantial postharvest losses, surprisingly little information is available in the scientific literature on the actual damage and subsequent financial losses. Rodent damage to stored grain is thought to be high in tropical and subtropical countries; however, estimates vary considerably (Table 13).

Within the ASEAN region, few estimates of damage to grain in storage are available. In the Philippines, Rubio (1972) estimated rodent damage at 40-206 kg per rice mill warehouse in Laguna. Sayaboc et al (1984) observed an average daily loss of 3.6 kg in commercial grain storage. Considering that there were 100,223 grain storage structures in the country, national daily loss was estimated to be 38,800-312,824 kg.

With reference to spillage, these authors report that rodents spill 7.5 times as much grain as they consume. The model developed by Benigno (1985) indicated that rat control is more critical in ‘closed’ warehouses that provide optimum reproductive and survival rates to a resident population. He recommends long-term studies on reproduction, survival, and movement, by age classes and by species, as well as research on the effects of interspecific competition on reproduction and survival.

An ‘expert consultation’ among staff of OECD, FAO, and WHO has classified rodent damage to stored products as one of the top seven global rodent pest problems. In 1979, it was estimated that 33 million t of stored cereal were lost to rodents each year (WHO 1979). The main rodent species implicated in eating stored grain are commensal rodents such as the black rat (*R. rattus*), the Norway rat (*R. norvegicus*), the house mouse (*M. domesticus*), and the bandicoot rat (*B. indica*) (Prakash 1988, Meyer 1994). All four of these species occur in Indonesia, where the government’s main grain handling authority (BULOG) has expressed a strong interest in reducing rodent losses to stored grain (Singleton and Petch 1994).

A literature search of several databases showed that only one article on postharvest damage by rodents has been published in the journals listed since 1994 (plant science) and 1989 (biological sciences). In this article, the effectiveness of brodifacoum in

Table 13. Rodent damage in storage facilities, rearranged after Buckle and Smith (1994) and Hopf et al (1976).

Country	Species	Damage	Source
Laos	*Rattus* spp. *Mus* sp.	Up to 10% widespread	Direction de’l Agriculture, Vientiane, Laos
Malaysia	*R. exulans*	Common	Crop Protection, Department of Agriculture, Kuala Lumpur, Malaysia
	R. rattus diardii *R. exulans* *R. norvegicus* *Mus musculus*		Muda (1986)
Thailand	*R. norvegicus* *R. rattus* *R. exulans* *Bandicota* sp. *Mus* spp.	5% widespread	Plant Pest Control Research Centre, Plant Industry Division, Department of Agriculture, Bangkhen, Thailand
Philippines	*R. norvegicus* *M. musculus*	5%	Bureau of Plant Industry, Region VI, Iloilo City, Philippines
	R. norvegicus *R. tanezumi*		Caliboso et al (1986)
Korea	*R. norvegicus* *R. rattus* *Mus molissimus*	20% widespread in rural areas	Pest Control Section, Plant in Protection Division, Agricultural Production Bureau, Ministry of Agriculture and Forestry, Seoul, Korea
Indonesia	*R. rattus diardii* Mus musculus (+ *Suncus murinus*; an insectivore)		Sidik et al (1986)

storage rooms and other structures on active burrows is reported (Sarker and Jaeger 1997).

In theory, postharvest management to control rodents should be relatively straightforward to implement through focusing on making storage facilities rodent-proof. However, mice can penetrate gaps less than 8 mm in size and most rodents are good climbers and/or can use drains to enter premises. Moreover, rodent proofing is costly to construct and also to maintain. Many novel methods have been used to try to prevent rodents from entering grain stores in villages in developing countries, but, at best, these reduce rather than eliminate infestation. Often, the rodents do not nest in small village grain stores. This again shifts the focus on the basic ecology of the rodents that cause postharvest losses–which species are these, where do they breed, where do they come from, and when do they move into grain stores? The answers will depend on the region, storage facility, and country.

Health impacts of rodents on rice agroecosystems in Asia

The effect of rodents on human health will be an emerging issue in the next 5–10 yr. There are more than 60 rodent-borne zoonoses (diseases that affect humans) (Gratz 1996). The main diseases for concern within the rice-growing agricultural zones are leptospirosis (6,000 cases in Thailand in year 2000 with 320 deaths; A. Payakaphanta, pers. commun.); the arena- and hantaviruses that cause haemorrhagic diseases (Mills 1999); the plague (*Yersinia pestis*); rat typhus (*Rickettsia* sp.); and neuro-angiastrongyliasis (from lungworm of rodents-see Prociv et al 2000).

Many research challenges exist because little is known about

(i) the status of these zoonoses in Asia;
(ii) which are key reservoir species;
(iii) the persistence of the infective parts of the disease life cycle in rice agroecosystems; and
(iv) the basic human epidemiology of these diseases (incidence of infection, morbidity rates; transmission rates, age- and sex-related effects, effects of socioeconomic status, etc.).

There have been increasing concerns about rodent-borne diseases over the past 5–10 yr (see box). However, much of the work on rodent-disease interactions has been conducted in developed countries (e.g., hantaviruses and lyme disease in USA), in Africa, or in South America (Mills 1999). There is a general lack of data on rodent-borne diseases and their impacts in Asia, especially in Southeast Asia.

> There is a rise in concern of rodents as a health risk in rice agroecosystems because of increase in travel of people between rural and urban areas and between countries, increased population density that amplifies the ability of a disease to spread through a population, and increased clearance of natural habitats that promotes rodent-human contact.
>
> *In poorer communities, if a rodent zoonotic causes disability for a poor farmer for a month at a key time, then it may lead to no crop, a late crop, or reduced crop yield. Each can lead to a debt treadmill.*

Future research and implementation needs for Asia

An overview of the current management methods adopted by farmers in the various Asian countries to control rodents is presented in Table 14. This table also summarizes the recommended national rodent management strategies and the lead government agencies for rodent research and extension. There is a striking difference between countries in their approaches to rodent management. Also, in only a few instances are farmers adopting the management strategies recommended by government. This serves to highlight the lack of an integrated management program for rodent pests that is both effective and relevant to the needs of farmers with smallholdings. Historically, farmers have had little direct involvement in the formulation and testing of rodent management strategies. A high priority, therefore, is to develop management programs that consider what farmers are prepared to implement and to have strong farmer involvement in demonstration projects and experiments aimed at testing the efficacy of rodent management.

In Vietnam, farmer participation through community groups has been an integral part of rodent management projects in the Mekong and Red River delta regions during the past 3 yr. The results have been encouraging. More needs to be done elsewhere in Asia to encourage strong farmer participatory research on rodent pests in rice agroecosystems (see points 7 and 8 in the next section). Linked with this is the need to develop collaborative projects involving biologists, social anthropologists, sociologists, and

Table 14. Review of current national government priority for managing rodent pests, the lead government agencies for research and extension, and the principal control actions currently conducted by farmers against rodent pests in rice production systems.

Country	National government priority	Farmer priority	Lead government agency		Current control by farmers (government recommendation in parenthesis)
			Research	Extension	
Bangladesh	High	High	BRRI and BARI	BARI (and NGOs)	Reactive use of rodenticides; fumigation of burrows; traps (rodenticides-no clear operational national policy)
Cambodia	Moderate	High in regions	CARDI	AEC	Community rat hunts; digging; reactive use of poison (ZnPh of variable quality) (reactive provision of bounties and ZnPh)
China PR	Moderate	??	Various		Reactive use of acute and chronic rodenticides (chronic rodenticides)
India	Very high in regions	??	AICRRP Funded by IRC	ICAR	Bunds–low growth; trapping; reactive use of rodenticides in mass-scale control programs (rodenticides: surveillance then pulse application; fumigation);
Indonesia	Very high	Very high	CRIFC: RIR	DFCP; RIR	Reactive use of poisons; fumigation (sulfur); hunting; bunds – low growth (except main channels); CTBS; bounty (EBRM: CTBS; bunds–low growth; synchronous crops; etc.)
Lao PDR	High in uplands	High in uplands	NAFRI: Provincial Dept Agric	Provincial Dept Agric	Bounties; hunting; digging; reactive use of poison (ZnPh; unknown Chinese) (no government recommendations formulated)
Malaysia	Low	Patchy	MARDI	Dept Agric	Reactive use of acute poison (ZnPh); anticoagulants (use anticoagulant weekly for 8 wk after planting crop; barn owls as predator)
Myanmar	High	High	MAS	MAS	Reactive use of poisons; hunting; digging
Philippines	Low	High[a]	?Not clear PhilRice	BPI, RCPC, NCPC	Reactive use of acute poison (ZnPh); seasonal rat drives (postharvest); digging; bunds–low growth (sustainable baiting using anticoagulant after planting crop)
Thailand	Moderate (high for health)	??	DOA-AZRG	DOAE-PPS	Reactive use of acute poison (ZnPh); digging; hunting (strategic use of chronic [or acute] poisons; pit traps)
Vietnam	Very high	Very high	MARD: IAS-south NIPP-north	MARD: PPD and sub-PPDs	Bounties; reactive use of poisons (ZnPh; unknown Chinese; BioRat; anticoagulant); plastic fences; CTBS (BioRat; cat as predator (developing CTBS/EBRM principles))

[a] Based on personal visits to the main rice bowls of the Philippines (Iloilo, Isabela, Pangasinan) and on reports directed to me from other provinces (Laguna, Marinduque, Nueva Ecija).

agronomists. IRRI is well positioned to play a key role in these multidisciplinary projects because of its strength and leadership in Asia in socioeconomics and social anthropology in agricultural systems.

The remainder of this section contains brief descriptions of research and implementation needs for Asia in general. Some specific requirements for each country are provided in an abridged form in Table 15.

Research and extension emphasis for NARES (see also Table 15)

1. Basic taxonomy and ecology: Research in rice-based agroecosystems that aims to develop ecologically based rodent management that is environmentally benign and is consistent with sustainable agricultural practices through
   (i) development of a clear understanding of which rodent species are major pests for

Table 15. Review of level of resources, available knowledge from participatory rural assessment (PRA) and some major opportunities for research and implementation needs.

Country	Standard of resources			PRA available -region(s)	Major opportunities (needs) In the next 5 yr
	Infra-structure	Rodent scientists	Extension		
Bangladesh	?	Limited	??	Limited information	Clear specification of problem; ecology; farmer participatory research; capacity building of researchers and extension staff
Cambodia	Poor	Poor	Poor	Yes	Taxonomy; ecology; build expertise in biology and extension (participatory research); national laboratory
China PR	Good	Good	??	Limited information	??
India	Poor	Good	Medium	??	Consolidation of biological data; coordinated national program; capacity building and implementation
Indonesia	Good in Java	Good	Medium to poor	Yes – Java	Capacity building of extension staff and farmers; biology of rats in rainfed systems; biocontrol (sterility); zoonoses
Lao PDR	Poor	Poor	Poor	Yes – uplands and lowlands	Ecology; spatial use; build expertise in biology and extension; national laboratory
Malaysia	Medium	Too few	??	Limited information	Good experimental study of effect of barn owls on rat populations; lure crops for CTBS
Myanmar	Poor	None	Medium	None	Clear specification of problem; ecology; farmer participatory research; capacity building of researchers and extension staff
Philippines	Poor	Poor	Poor	Only Iloilo	Definition of needs (PRA); build expertise in biology and extension; EBRM + CTBS
Thailand	Good	Aging	Good	Medium	Build new expertise in biology; capacity building of farmers; zoonoses
Vietnam	Medium	Medium	Very good	Yes – Red River & Mekong Delta	Build expertise in biology; capacity building of farmers; crop system and impact (GIS)

specific regions and to develop up-to-date and “user-friendly” taxonomic keys. These regions include Laos and Cambodia; the uplands of Vietnam and regions of rainfed rice such as Bac Binh Province; Kalimantan and eastern islands of Indonesia.

(ii) understanding the association between population density and yield loss for the major pest species in each rice-based agricultural system (apart from Java, Indonesia, little is known about this association). This will set the density thresholds for action and establish what proportion of a population would need to be controlled to reduce yield loss to acceptable levels.

(iii) a better understanding of the population ecology of the pest species: breeding ecology (why is breeding triggered just prior to maximum tillering), habitat use, diet (what do rats eat during fallow period and vegetative stage of rice) and population dynamics associated with the cropping systems.

2. Effect of farming systems on rodent dynamics: Better definition of the impact of different farming systems on the dynamics and behavior of rodent pest species; working with farmers to determine whether farming systems can be slightly modified (e.g., greater synchrony of growing of rice crops) to make it less attractive to rodents.
3. Spatial use: Knowledge of seasonal and interannual dynamics of how rodent species use their habitat is fundamental to developing effective management plans. This information is lacking in Lao PDR and Cambodia, in rainfed rice-growing areas of most countries, and is rudimentary in Bangladesh, Thailand, and Vietnam.

4. Changes in farming systems and rodent impacts: Escalations in the impact of rodents on rice-growing systems in Vietnam indicate that changes in farming systems (one rice crop to two or three crops per year; two crops to three crops per year) may have been responsible. The collection by IRRI staff of GIS information on farming systems in Bac Lieu and Soc Trang since 1995, coupled with regular records of rodent impact since 1993 for this region (at the district level), provides an opportunity to examine this association at a relatively fine scale. Historical accounts of years of high rat impact could provide an indication of the association at a broad scale. Clarification of this association would
   (i) provide a basis for examining modifications in farming systems for managing the rodent problem;
   (ii) clarify the impact of changing systems from one rice crop to two crops; two crops to three crops; rainfed to irrigated; etc, and hence would assist in forecasting the consequences of such changes.
5. Balance conservation of beneficial species with control of pest species: Exploring the impact of management actions on community ecology (including nonpest species of rodents) and alerting governments to the unwanted and unintended effects of large-scale "culling" operations. A corollary to this is identifying and promoting the "ecological services" provided by nontarget species at risk during these operations.
6. Biological control: Facilitating research on the potential of biological control of rodent pests, including the impact of predators, of biocides such as Sarcocystis, and of fertility control agents (e.g., immunocontraception).
7. Participatory problem assessment: Through links with IRRI colleagues with a strong sociological background, interacting with NARES personnel and farmers to develop a decision analysis process that focuses on "best practice management based on current knowledge." This would also help identify key gaps in our knowledge of the biology, ecology, and management of particular rodent pests.
8. Sociocultural attitudes toward/economic constraints to rodent control: It is important to know why management actions for rodent pests work in some rice agroecosystems, for some socioeconomic groups, but not others. Comparative studies across different cultural groups and agricultural systems will provide an important insight in the robustness of various management techniques. Likewise essential are collaboration with staff from national extension agencies to assist in developing strong farmer participation, and sociological studies to identify which management actions are or are not adopted and what factors will likely affect these decisions.
9. Tools to assist researchers from NARES:
   (i) Synopsis of the biology of key pest species: Often researchers and extension personnel in developing countries do not have easy access to the literature on rodents. The CSIRO Rodent Research Group maintains a catalogue of publications for Southeast Asia. Of immediate value would be a synopsis of the biology of each species. This information could be delivered together with a taxonomic key using the package Lucid ("Rodent Lucid").
   (ii) Techniques manuals: The CSIRO Rodent Research Group has developed a manual on research techniques for studying rats living in lowland irrigated rice agroecosystems. This manual needs to be extended to include (a) tools for measuring sociological and agronomical parameters, and (b) biological techniques for South Asia and rainfed agroecosystems.
10. Epidemiology of rodent-borne zoonoses: The effect of rodents on human health will be an emerging issue in the next 5–10 yr. Of the 60 or so rodent-borne zoonoses (diseases that affect humans), the most important are leptospirosis, the arena and hantaviruses that cause haemorrhagic diseases, the plague, rat typhus, and lung worm that causes neuro-angiastrongyliasis. Research is needed to look into
    (i) the status of these zoonoses in Asia,
    (ii) the identity of key reservoir species, and
    (iii) the persistence of the infective parts of the disease life cycle in rice agroecosystems.

In summary, there is still much research required on the general biology of the 8-10 most important rodent pests in Asia. Our knowledge base falls well behind that for some of the major insect pests and disease agents of rice. To highlight this point, I have summarized the differences in research effort on these species compared with the principal rodent pest in Asia, the rice field rat, *R. argentiventer* (Fig. 1, 2).

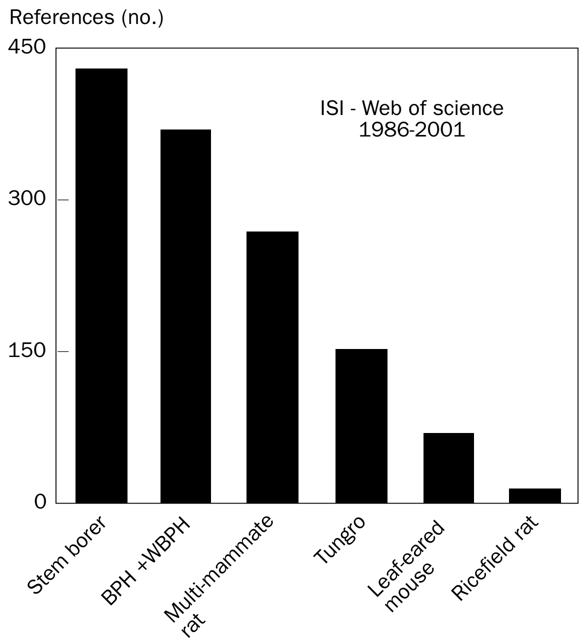

Fig. 1. Number of publications from 1986 to 2001 in the ISI web of science on a subset of rice pests. (Note:The multi-mammate rat is an African species.)

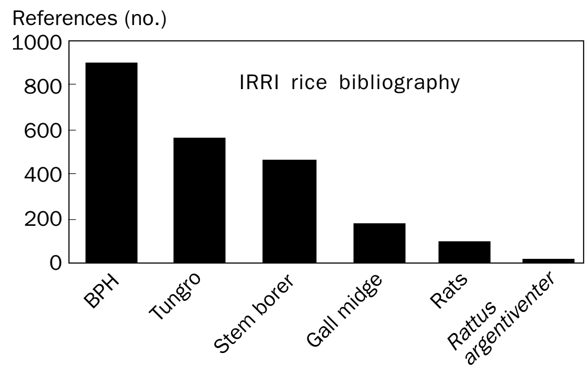

Fig. 2. Number of publications from 1986 to 2001 listed in the IRRI rice bibliography on a subset of rice pests.

Value-adding to existing research at IRRI

The following existing IRRI projects could be enhanced through the addition of a specific rodent component:

1. Integrated Upland Agricultural Research Program (Luang Prabang, Lao PDR)
2. Accelerating Poverty Elimination Through Sustainable Resource Management in Coastal Lands Protected from Salinity Intrusion: A Case Study in Vietnam (Bac Lieu, Mekong Delta, Vietnam)
3. Natural Resource Management-International Rice Parks

Role of IRRI in advancing research and extension activities on rodents

- IRRI, through the REWG, has identified key NARES staff. Many of these people, the extension staff in particular, have other calls on their time but recognize that rodents are an important issue. They require leadership on rodent biology and management and collaborative linkages with experts from ARCs in developed countries and with colleagues from other countries in Asia. IRRI can assist through identifying the right people (from NARES and ARCs) for the specific high-priority tasks in each country and then in establishing and nurturing these linkages (both bilateral and multilateral). Therefore, the REWG could provide an important platform to facilitate fruitful interactions between scientists from a variety of disciplines, nationalities, and agencies.
- IRRI will be able to provide leadership in "broadly based IPM" projects in rice agroecosystems through linking research on IPM of insects and weeds with that of rodents. This is a most exciting development.
- Monitor developments in contemporary international rodent projects in agricultural systems (e.g., EU Staplerat Project in eastern Africa) to know progress in management of rodent pests in rice systems.
- Develop an active international network from developed countries of small mammal specialists (e.g., ecologists, modelers, epidemiologists, biotechnologists), wildlife managers, and extension specialists. IRRI can act as a catalyst to encourage and facilitate the inputs of these scientists into practical rodent management in developing countries. There is a vast pool of rodent expertise in developed countries, especially in basic research, but there is not a focal point for assembling and redirecting this knowledge and research energy toward food security and poverty alleviation. IRRI can provide a high-profile rallying point for this expertise.
- Through focused training programs, IRRI can help foster interest and the development of the next generation of young rodent biologists and wildlife managers. This is an express need in Asia where there are too few tertiary institutions offering appropriate undergraduate courses.

A permanent or part-time rodent biologist at IRRI can play a major role in developing links with universities in the region to

(i) assist with the development of syllabus for tertiary courses in wildlife management in Southeast Asia where there is a dearth of such courses, and
(ii) assist with the supervision of post-graduate students.

> Other groups in the world may provide some of these services from time to time but these groups come and go, depending on the commitment of specific donor agencies and/or on the energies of individual scientists. IRRI has the unique comparative advantage to provide the foci and regional linkages for research, training, and continuity, for tackling the important problem of rodent impacts on rice production.
>
> Short-term "band aid" approaches have not provided sustainable management in the past, partly because of the complexity of the problem, but often because of the lack of continuity of research and extension leadership for staff from NARES. A concerted long-term coordinated approach facilitated by IRRI is required to promote, mentor, and encourage the current and future generations of rodent research and extension staff in developing countries.

Opportunities at country level and possible donor agencies

Specific opportunities or needs for research and implementation of rodent management on a country basis are presented in Table 15. This section addresses a subset of these needs and recommends possible donor agencies. Most of these agencies have provided funds in Asia sometime over the past 5 yr for research on rodent pests or for capacity building for rodent management.

There are five broad areas:

1. Build on the basic skills that have been developed in countries such as Lao PDR to provide progress on rodent management in rainfed, upland systems (Lao PDR, Thailand, Vietnam) (ACIAR, SDC)
2. Provide a resource base to support rodent researchers and extension staff in developing countries in Asia (IRRI REWG, SDC, ACIAR, NGOs)
3. Provide assistance in countries that are sadly lacking in "modern" rodent management expertise (or simply have little expertise)—e.g., Bangladesh (PETTRA funds), Philippines (AusAID, CIDA, NGOs) and Lao PDR (ACIAR, AusAID, NGOs)
4. Capacity building and implementation in countries where the infrastructure (rodent expertise in biology and management and institutional [government] support) is in place—Vietnam (and, hopefully, Indonesia, although as a nation, it has much more diversity in its agroecosystems, cultural groups, etc.) (AusAID, IRRI REWG, ACIAR, NGOs)
5. New emphasis (epidemiology of rodent-borne diseases (leptospirosis, rat typhus, viral-borne haemorrhagic diseases, plague, lung worm, etc.). We see rodent impacts on human health as an important driver for specialist expertise on rodents in the next 5-10 yr (WHO, Rockefeller Foundation, pharmaceutical private sector, USAID, NGOs, Chinese government [for work in China]).

Possible linkages with other CG centers

Possible links with the International Livestock Research Institute (ILRI)

1. Rodents as reservoirs for disease of livestock and farmers (e.g., leptospirosis; rat typhus; salmonella; angiostrongylus; fasciola; cryptosporidium).
2. Benefits and risks of using rodents caught in trap-barrier systems as a source of high-protein supplement for pigs, ducks, and aquaculture (and humans in some regions). What are the risks of transferring disease? Can the rats be treated appropriately (e.g., barbecued) to minimize this risk?
3. Crop-Animal Systems Research Network (CASREN)—an ADB-funded initiative in the Philippines, Indonesia, Vietnam, China, and Thailand that is concentrating on small landholders (0.3-3.5 ha). Most are rainfed areas (lowland and upland) and the emphasis is on complementing livestock production with crop production. One initiative being proposed for the Philippines and Indonesia (West Java) is planting of forage along the borders of crops and on the banks of main irrigation channels. A conflict may arise through providing "improved" habitat harborage (source habitats?) for rats. However, such conflicts may be resolved if they are approached from an integrated perspective. For example, there are key times to keep growth low along these crop margin habitats for rodent management, but, at other times of the year, the focus should be on forage biomass and quality. Indeed, there are already reports of conflict:

farmers in the Cirebon area of West Java are reluctant to grow forage for stock along the margins of crops because of their concerns about providing good rat habitat (Dr. Beriajaya [BALITVET], pers. commun.).

Possible links with Centro Internacional de Agricultura Tropical (CIAT)

There is nobody working on rodent biology or management at CIAT but Dr. Anthony Bellotti indicated that it was a definite gap in their expertise.

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Decision analysis for Luna, Isabela Province, of current actions plus proposed use of CTBS.

Action (what)	Timing (when)	Feasible	Socially OK (neighbor)	Economic (benefit-cost)	Environment-friendly	Politicallly acceptable (gov't)	Priority
1. Zinc phosphide	Before maximum tillering	Yes	Yes	Yes	No	Yes	High
2. Racumin	Before maximum tillering or as needed	Yes	Yes	Yes	No	Yes	Medium
3. Cleanliness (banks, villages, etc.)	Always (every 2 mo - banks)	Yes	Yes	Yes	Yes	Yes	High
4. Clever bounty (limited season)	After land preparation	Yes	Yes	Yes	Yes	Yes	Medium
5. Digging/flooding burrows	When active hole (maximum tillering to 1 wk postharvest)	Yes	Yes	Yes	Yes	Yes	Medium
6. Battery operated electric current (with flooding burrow)	Anytime	Yes	No[a]	Yes	No	No	Low
7. Banks <30 cm	Land preparation	Yes	Yes	Yes	Yes	Yes	High
8. Two-month fallow		Yes?	Yes?	Yes	Yes	Yes	Medium
9. Alternate crops (to promote fallow)	e.g., soybean	Yes	Yes	Yes	Yes	Yes	Medium
10. CTBS	2-3 wk prior to main crops	Yes (availability of water?)[b]	Yes	Yes	Yes	Yes	Pilot study

[a]Thought to affect the libido of male operators–this was a concern raised by a female farmer. [b]If availability of water is a problem, then perhaps use direct seeding (matures 10 d earlier than transplanted rice). Other concern was anticipating when the irrigation water is to be released. Many plant 3 wk in advance but find the water is delayed for 2 wk so in effect have a 5-wk early trap crop. Direct seeding would reduce this risk by about 10 d. Other action to consider–control of rats along the main irrigation canals. Apparently, this is the responsibility of a specific authority. They keep the growth of grass in check but that is all. Perhaps they should be encouraged to control rats using fumigation, flame throwers, or rodenticides.

Decision analysis for San Jacinto/San Jose, Pangasinan Province, of current actions plus proposed use of CTBS. Note that scale of action is currently at the individual farmer level for most actions.

Action (what)	Timing (when)	Scale (where)	Feasible	Socially OK (neighbor)	Economic (benefit-cost)	Environment-friendly	Politically acceptable (gov't)	Priority
1. Cleanliness (banks, villages, etc.)	Year-round	Farmer	Yes	Yes	Yes	Yes	Yes	High
2. Rat hunt (dig/ flooding burrows)	Oct/Nov	Farmer	Yes	Yes	Yes	Yes	Yes	Medium
3. Rat drive	Oct/Nov and Mar/Apr	Community	Yes	Yes	Yes	Yes	Yes	Medium
4. Small dikes	Land preparation	Farmer	Yes	Yes	Yes	Yes	Yes	High
5. Zinc phosphide	Before harvest	Farmer	?	?	If >5% loss	No	Yes	Medium
6. Racumin	Before harvest	Farmer	?	?	If >5% loss	No	Yes	Low
7. Biological control	Year-round	Farmer	Yes	Yes	Yes	Yes	Yes	High
8. Rat traps	Year-round	Farmer	Yes	Yes	Yes	Yes	Yes	Medium
9. Fumigation	Dry season after harvest	Farmer	Yes	No	Yes	Yes	Yes	Low
10. Crop timing	Planting	Community	Yes	Yes?	Yes	Yes	Yes	High
11. CTBS	2-3 wk prior to main crops	Community[a] (availability of water?)	Yes	Yes	Yes	Yes	Yes	High

[a]Price of rice could drop if everyone harvests at the same time.

Fig. 1. Cropping schedule at Luna municipality, Isabela.[a]

May		
June	Plant crop (takes 2-4 wk to plant crop within barangay)	
July		*Low problem with rats*
August		
September		
	Harvest crop (Sept/Oct) WET SEASON (100 cavans ha^{-1})	
October		
	———————1.5-mo fallow	
November		
December	Plant crop (takes 2-4 wk to plant crop)	*Greatest problem with rats*
January		
February		
March		*Moderate problem with rats*
	Harvest crop (March/Apr) DRY SEASON (120 cavans ha^{-1})	
April		
	————————2-mo fallow	
May		

[a]**Most rat control work is conducted during December. Maize can be planted at any time of the year.**

Current practices (farmers' comments):
*If funds are available, the municipality provides zinc phosphide.
*There is no guarantee that the government will respond when the farmers have a rodent problem; occasionally, the response via production of poison is too late.
*Zinc phosphide works the first time and a few rats are killed, but it does not work as well on subsequent attempts (bait shyness).
*Hazards are present; nontarget deaths-kills dogs and chickens; they thought dogs were eating poisoned rats; it is possible that dogs were licking or eating bait directly because zinc phosphide usually breaks down quickly once ingested by a rat.
*One participant noted that zinc phosphide kills only males and does little to harm the potential for breeding females.

Fig. 2. Cropping schedule at San Jacinto, Pangasinan.[a]

May		
June	Sow or transplant crops	*Most rat problems occur here*
July		
August	**WET SEASON**	
September		
October		
	Harvest crop (Oct/Nov)	
November		
	————————————1-mo fallow	
December	Sow or transplant crops	
January		
	DRY SEASON	
February		
March		*Moderate problem with rats*
April		
	Harvest crop (March/Apr)	
	————————Mungbean, vegetable, or maize often grown (April to June)	
May		

[a]10% of the farmers grow a third rice crop other than the alternative crops listed. Maize can be grown throughout the year. Main rat problems occur during July and August. Rat problems are less severe during October. Rat damage sometimes occurs during the dry season. Rat damage frequently happens to maize. Average farm size is less than 1 ha. Current rat control methods mentioned by farmers include rat drives, prayer, use of Racumin, zinc phosphide, and maintaining cleanliness.

APPENDIX 2

Table 17. Decision analysis for rodent management on the IRRI Farm–12 Oct 2001.

Action (what)	Timing (when)	Scale (where)	Feasible	Economic (benefit-cost)	Environment-friendly	Socially OK (public)	Politically accepted (IRRI)	Priority
1. Sustained baiting	Whole year	Perimeter and field	√	√**?**	**X**	√**?**	√**?**	M review
2. Need-based baiting (pulse)	Relate to signs of rats (monitoring)	Perimeter and field	√	√**?**	**X?**	√**?**	√	M review
3. Flame thrower	(a) On request (b)Strategic	Perimeter of crops/fallow	√	√	√	√	√	(a) Medium (b) High
4. Linear TBS–selected areas	(a) Whole year (b) Short season	Whole farm	√Traps stolen?	?	√√	√	√**?**	High (pilot program)
5. Fallow management (sanitation)	Whole year	Whole farm	√	√	√	√	√	High
6. CTBS		Whole farm (end plots?)	√Traps stolen?	√**?**	√√	√	√	High (pilot program)
7. ABS	On request	Whole farm	√	√**?**	√√	√	√	Low user pays
8. Synchrony of cropping		Whole farm	√	na	√√	√	**??**	High
9. Blanketing		At harvest and mowing	√Labor-intensive?	??	√√	√	√	High
10. Covered canal: baits or fumigation		Canals	√	√	√	√	√	Bait–high Fum-low

Comments: Research is required on (i) habitat use and movements by rats; (ii) efficacy of Racumin (first-generation anticoagulant–sustainable baiting) and bromadiolone (second-generation anticoagulant–pulse baiting); (iii) effectiveness of CTBS on IRRI farm; (iv) efficacy of linear TBS; and (v) breeding ecology of rats.