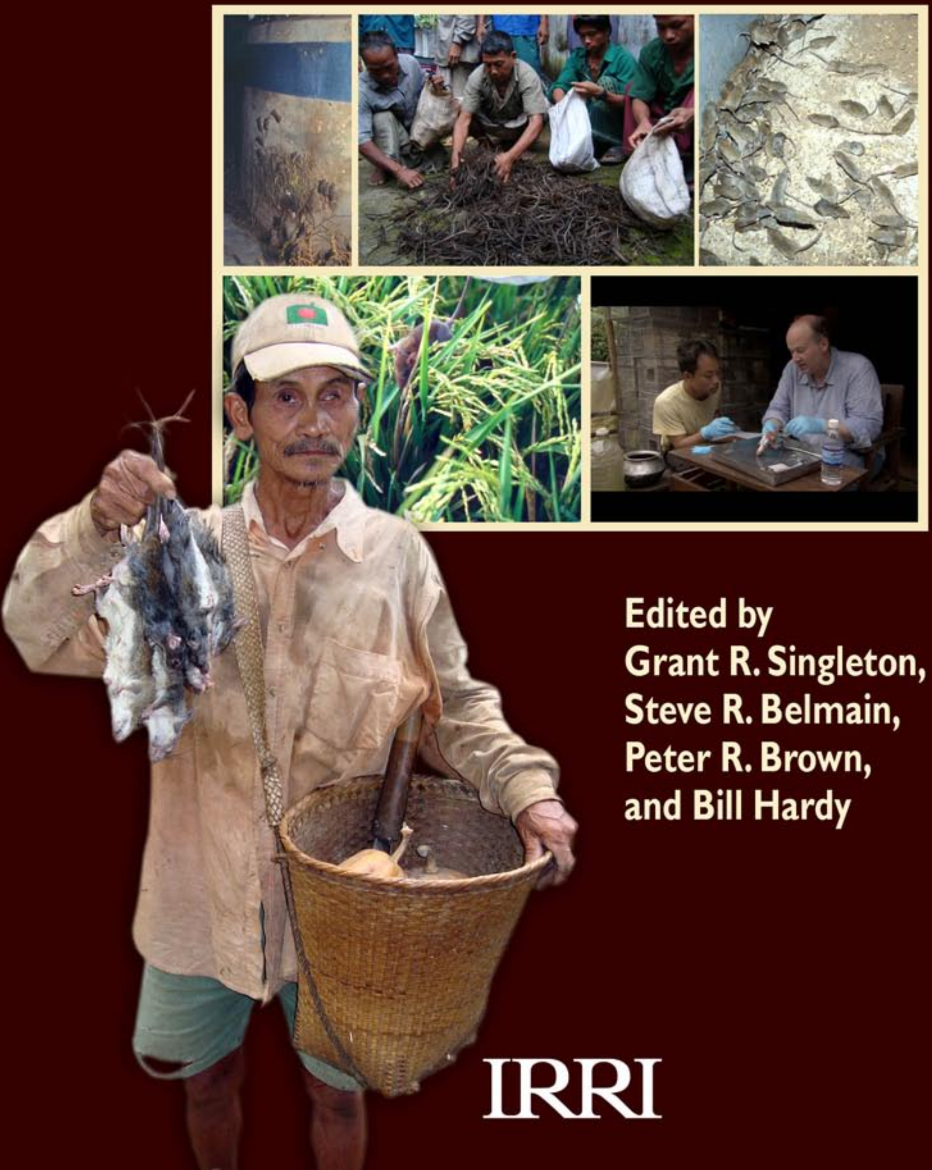
Rodent Outbreaks:

Ecology and Impacts



Edited by
Grant R. Singleton,
Steve R. Belmain,
Peter R. Brown,
and Bill Hardy

IRRI

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IRRI
INTERNATIONAL RICE RESEARCH INSTITUTE

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Foreword 1

Rats have long been the scourge of smallholder farmers in many rice-growing regions in Asia and throughout the world. In 1990, the International Rice Research Institute held an international workshop simply called “Rats in Rice,” which assembled rodent experts from around the globe. Unfortunately, at that time, most of the experts were retired or about to retire. The senior editor of this book, Grant Singleton, attended that workshop for his first rat meeting and it must have had an impact on him because, within 4 years, he was back in the Philippines, and over the next decade he ventured into Indonesia, Laos, Vietnam, and Myanmar, researching the ecology and management of rodent pests. I am pleased that some 20 years later he organized a second international rodent conference hosted by IRRI, “Impacts of Rodent Outbreaks on Food Security in Asia,” held on 26-28 October 2009. The conference generated much international interest, including an article in *Science* in February 2010 as part of a special issue on “food security.” I am particularly pleased that the deliberations of the conference have now been captured in this book.

This book is timely because, in recent years, population outbreaks of rodents in the rice-cropping systems of Asia have escalated. There has been precious little formal documentation of the factors that lead to rodent population outbreaks, their impacts, and the successes and failures of management actions, particularly in developing countries. The authors bring together in this publication a more complete picture of rodent outbreaks and their implications. The book examines case studies of the recent rodent outbreaks in Asia with a view to drawing generalities. However, an added strength of the book is that it goes beyond the rice ecosystems of Asia and ventures into other ecosystems in Australia, New Zealand, East Africa, Europe, and North America, to allow readers to compare the factors that generate outbreaks of rodent populations on five continents.

I am pleased that our Institute in recent years has been able to take a lead role in Asia for research on rodent biology and management, with a focus on smallholder rice farmers. A book of this stature on rodent outbreaks is long overdue. I also note that there are some recipes for rodent culinary delights in the Appendix. I can honestly say that I have partaken of such a gastronomic experience, and, yes, it tastes like chicken! I strongly endorse this timely book, which literally provides food for thought. Enjoy!

Dr. Robert S. Zeigler
Director General
International Rice Research Institute

Foreword 2

In 1934, Hans Zinsser published *Rats, Lice, and History,* detailing in a rambling but iconic manner the history of typhus fever and its impact on civilization. This was the first of several books to deal with how rats and the diseases they spread have affected the course of history. The elephant missing from the room was of course the role of rats as agricultural pests, a problem that has been less visible to agricultural scientists and too often treated as an insoluble problem designed by the gods to test human resilience. The elephant is now firmly in the room, as this book attests. In particular, concerns about food security dominate the early 21st century, and this has focused attention on agricultural pests that take food from hungry mouths as well as spread disease.

Rodents have been the favorite study animal for graduate students in developed countries because of their rapid life cycle and convenient size. Medical science without rats and mice would be in the Stone Age. Population dynamics without rodents would be in its infancy. Much progress has been made in understanding the ecological factors that limit rodent populations in temperate climates, and only recently has this knowledge been focused on rodents in tropical and subtropical countries, where agricultural pest problems are most serious. All of this has been achieved by the advent of ecologically based rodent management (EBRM), which has stimulated the progress summarized in this book. But, EBRM has gone beyond the purely ecological dynamics of rodent populations to integrate this knowledge with the social sciences that are so crucial to implementing management practices that minimize rodent damage to crops and maximize the productivity of farms and the well-being of farmers. This is an achievement that we should be proud of, both as scientists trying to understand the natural world and as human beings trying to help improve the livelihoods of the world's poor. Much is yet to be done, but this book is an encouraging progress report driven by scientists passionate about rodents, about people, about conservation, and about improving our knowledge of these species and the ecosystems they inhabit.

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Acknowledgments

The nucleus of this book was a conference held at IRRI in October 2009, titled “Impacts of rodent outbreaks on food security in Asia.” This conference would not have been possible without the strong support and encouragement of Dr. Achim Dobermann, deputy director general for research at the International Rice Research Institute (IRRI), and Dr. Bas Bouman, program leader, Sustaining Productivity in Rice-Based Systems, and head of the Crop and Environmental Sciences Division at IRRI.

Many donors and scientific foundations have been involved in supporting the contributions documented in this book. We particularly wish to thank those who supported the editors of this book: the Swiss Agency for Development and Cooperation, the Australian Centre for International Agricultural Research, the World Bank, the Research Into Use Programme of the UK’s Department for International Development, and the Chittagong Hill Tracts Development Facility of the United Nations Development Programme supported by the European Union.

We thank our colleagues at IRRI who assisted with the production of this book. We give special thanks to Rona Rojas and Cornelia Garcia for assistance with figures, to Emmanuel Panisales and Grant Leceta for the layout, to Juan Lazaro IV for the cover design, to Grace Cañas for assistance in editorial work, and to Jenny Hernandez for secretarial assistance.

All of the chapters were peer-reviewed by at least two reviewers, and we thank those people who generously gave their time to review the manuscripts. Finally, we thank the authors, drawn from five continents, for their time and commitment to make this book a reality.

Rodent outbreaks: an age-old issue with a modern appraisal

Grant R. Singleton, Steve R. Belmain, and Peter R. Brown

> "....the low ground (rice) crop has a peculiar and very destructive enemy in the rats, which sometimes consume the whole of it, especially when the plantation has been made somewhat out of season; to obviate which evil the inhabitants of a district sow by agreement pretty nearly at the same time; whereby the damage is less perceptible." William Marsden, *The History of Sumatra* (1811)

The impacts of rodents in both developing and developed countries are legendary. Myths and dogma about rodents and their outbreaks abound. They are imbedded in the culture and language of many societies. In many instances, it is the acceptance of these outbreaks by society that is our greatest challenge as crop protection specialists or conservation biologists. The reason these episodic outbreaks become etched in the socio-cultural psyche from the sparsely populated uplands of Laos to the considerably more affluent agricultural lands of Europe is that the impacts are often staggering—economically, socially, and even politically. There becomes a degree of acceptance of these impacts—rural people are born with rodents and will die with them. Their presence and impacts become a part of life; they become accepted and farmers become fatalistic about the losses they incur. Indeed, farmers in some areas of the Philippines say they "plant two rows of rice for rats, one for the birds, and seven for my family." This need not be the case given the progress of our knowledge on the factors that cause population outbreaks of rodents. Indeed, it is our responsibility as scientists to document and make this knowledge widely available, particularly with more than 1 billion people suffering chronic hunger and rodent pests contributing significantly to this burden (see Singleton 2003, Meerburg et al 2009). Moreover, in Asia, the 640 million people suffering from chronic hunger (FAO 2009) mainly rely on agriculture for their subsistence.

The impetus for this collation of contributions from Asia, Africa, Oceania (Australia and New Zealand), Europe, and North America was an international conference on "Impacts of Rodent Outbreaks on Food Security in Asia" held following an increase in reports during 2007-09 of population outbreaks of rodents in the rice-cropping systems of Asia. In Asia and Africa, there are few widely accessible publications on these outbreaks. Most appear in the gray literature as brief reports in the annals of provincial or state departments of agriculture. They are doomed to gather dust and be lost to future generations. If this happens, then the lessons from previous outbreaks are not learned and therefore the influence of myth and dogma often outweighs evidence-based scientific knowledge developed from our successes and failures of management actions undertaken during previous outbreaks. One message, among many, that we hope to convey to readers is that we have made strong advances in our understanding of the factors that lead to rodent outbreaks (see also Singleton et al 2010). And, with such knowledge, local people and officials should be better placed to reduce the potentially devastating impacts associated with "floods" of rodents in the agricultural, periurban, and natural landscapes.

Drawing lessons at a global scale

We have compiled contributions from different regions around the globe with the dual view of drawing generalities and highlighting differences. These contributions consider outbreaks across a wide range of agricultural and natural landscapes. Contributions come from Bangladesh, India, Indonesia, Myanmar, the Philippines, and Vietnam that focus on rice-based systems in Asia. Other authors consider agricultural systems dominated by wheat (mouse plagues in Australia, Brown et al), maize (multimammate rat in eastern Africa, Sluydts et al), grazing land and horticultural crops (in Europe, Jacob and Tkadlec), and mixed agriculture (in North America, Witmer and Proulx). An added dimension is the consideration of the impact of rodent population outbreaks on the conservation of native species in New Zealand (Ruscoe and Pech), and the need to balance the impact of rodent management actions so that they target pest species rather than nonpest species (see contributions from Laos and Mizoram). The latter is an important issue because many crop protection specialists and policymakers are surprised when rodent specialists indicate that less than 10% of rodent species are pests of agriculture (Table 1, Singleton et al 2007), and we stress that nonpest rodent species can provide important ecosystem services (see Dickman 1999, Suzán et al 2009). A core theme to emerge is the need to focus more strategically on strategies to reduce or prevent crop or conservation impacts caused by rodents rather than on simply killing rodents or reducing population size per se.

One country in Asia that we have not covered is China, where rodent population outbreaks are of major economic importance. In China, evidence suggests that occasional population irruptions of both Brandt's vole, *Lasiopodomys brandtii*, in the grasslands of Inner Mongolia (Zhang et al 2003) and of the Yangtze vole, *Microtus fortis*, in rice fields in the Dongting Lake region of southern China (Zhang et al 2010) are caused by a combination of intrinsic and extrinsic (mainly rainfall) factors. One region we had hoped to include was South America because of the occasional massive rodent outbreaks that occur there. Instead, we refer readers to two excellent reviews that provide detailed coverage of bamboo-masting events (*ratadas*) in Argentina (Sage et al 2007), Brazil, Chile, and Peru (Jaksic and Lima 2003), and other factors that have generated outbreaks in South America.

Another important theme to emerge from many of the contributors is the need to consider the cultural and social dimensions of both the impacts of rodent outbreaks and proposed management actions. Rodents do not respect farm borders and many move from fields to dwellings and vice versa. In many parts of Asia and Africa, farm holdings are less than 2 ha and rodents can rapidly colonize and distribute themselves

Table 1. The number of rodent species (Order Rodentia) in selected continents and countries, and the number of species that are considered significant pests of agriculture. After Singleton et al (2007), who also provide details of the literature upon which these figures are based.

Continent or country	Number of species of rodents	Rodent species that damage crops	Significant pest species in cropping systems
Africa	381	77	12–20
Australia	67	7	4
Europe	61	16	5
India	128	18	12 (5 in wide distribution, 7 in restricted distribution)
Indonesia (not Irian Jaya)	164	25+	13
Lao PDR	53	12+	4–8
New Guinea (not Bismarck or Solomon Is.)	73	10+	6

over areas of hundreds of hectares. Therefore, effective management of chronic rodent problems on an annual basis requires coordinated community action; during a rodent population outbreak, the need for community action becomes an imperative. Case studies of the tools, advantages, and challenges for community action when tackling the management of rodent populations are presented in contributions by two agricultural anthropologists and their co-authors. The one by Flor Palis examines a project in the Red River Delta in Vietnam and the other by Rica Flor considers the sociological learning from a high-profile community campaign against rodents conducted in Nueva Ecija in the Philippines.

Another cultural aspect that is ingrained in some societies is the language used to describe rodent outbreaks. This includes “rat floods” in Bangladesh describing the literal flood of rats moving from bamboo forests into neighboring rice fields or villages to cause damage (Belmain et al, Ahaduzzaman and Sarker); “mouse plagues” in Australia drawing on the use of a biblical reference for disease and pestilence (although mouse plagues are not related to bubonic plague) (Brown et al); “*nuu khi*” in Laos, the name ascribed to the rats involved with outbreaks—the translation literally means “mouse of the bamboo flower” (Douangboupha et al); and *ratadas* in South America to describe the outbreaks of rats (Jaksic and Lima 2003). Furthermore, in many Southeast Asian countries, the species that causes the most damage in rice agroecosystems is called the rice-field rat (referring to *Rattus argentiventer*). One reason for some of these descriptions is that farmers often perceive that, under normal circumstances, rodents seem to cause little damage, but then they suddenly appear and cause significant damage leading to widespread famine or major effects on livelihoods of smallholder farming families. Then the problem goes away, and people and governments often forget about them until the next time they suddenly reappear, which might be 3 years later, 10 years later, or 50 years later.

Strengthening our ecological understanding—a cause for hope and challenges ahead

In the 1960s to 1980s, research on rodent pests was dominated by a focus on the chemicals to control them. In the late 1980s and the 1990s, the development of resistance by rodents to many of these chemicals, particularly the anticoagulants, and societal concerns about the humaneness and ecological impacts of chemical poisons, led to a reassessment of research on rodent pest management. A paradigm that has emerged is ecologically based rodent management (EBRM). At the 4th International Conference on Rodent Biology and Management held in Bloemfontein in April 2010, papers presented from 25 countries across five continents made mention of EBRM. This rodent management paradigm has now taken center stage in Asia, Australia, and eastern Africa (Stenseth et al 2003, Brown et al 2006, Sluydts et al 2009, Jacob et al 2010) and is a common theme in the contributions in this book. However, there is still a scarcity of adequately trained rodent field biologists in most developing countries in Asia, Africa, and Central America. Therefore, there is an urgent need to build capacity in these regions.

An important message from this book is that there is now strong scientific agreement about the linkages between bamboo masting, rodent outbreaks, and famine in Mizoram (Aplin and Lalsiamliana), the Chittagong Hill Tract region of Bangladesh (Belmain et al, Ahaduzzaman and Sarker), and in Chin and Rakhine states in Myanmar (Htwe et al) (see also Normile 2010). Little had been documented about previous rodent population outbreaks in Asia. This is particularly important since outbreaks in the Chittagong Hill Tracts of Bangladesh, Mizoram in India, and Chin State in Myanmar occur every 48–50 years. A fascinating finding across the areas affected in 2007-10 is the spatio-temporal variation of masting events. In general, all the bamboo in a large region did not mast in one year; instead, the masting event took 2–3 years to complete. This is a vital finding because it changes our perceptions on the period required to help smallholder farmer communities to survive the impacts of these events, and we can use this information to better predict where bamboo flowering and masting might occur to better prepare government and NGO responses. The severe famine that often occurs at a local level may not be alleviated by a one-off provision of food aid; longer-term aid packages will be required in many instances.

Bamboo masting events and rodent population outbreaks provide only one subset of the outbreaks that beset smallholder farmers in Asia and parts of South America. Other outbreaks have nothing to do with bamboo. However, there are common precursors to the occurrence of most rodent outbreaks. These are pulses in food supply, adequate sites for breeding, and the presence of r-selected (see Krebs 2008) rodent species that have adapted well to environments modified by humans. The contributions in this book have extended our knowledge of the distribution, breeding biology, and dynamics of the species that undergo population irruptions. However, glaring gaps still exist in our knowledge. For example, we know little of the movement patterns of rodents during the buildup phase of a population outbreak, or over what scale in the landscape the respective species move (e.g., Belmain et al 2008). The strategy adopted by governments and NGOs has been reactive disaster management through providing food aid. There are extreme difficulties in assessing the prevalence of outbreaks and their impacts because of the remoteness and poor access to communication infrastructure for most affected communities. Therefore, the response is likely to be far smaller than the need. More research is necessary, particularly long-term studies on the ecology and dynamics of rodent populations.

The findings from the various contributions of this book reveal that outbreaks of rodent populations are predominantly a result of higher than normal amounts of food in the environment. However, when we consider the mechanisms that create this food, important differences emerge. We identify three general systems that influence the food supply in significantly different ways. One is life-cycle- or evolution-driven in the form of plant masting events, the second is climatic (mainly natural cycles that mean more food due to more rainfall in some years), and the third is anthropogenic responses associated with extreme climate events or market forces. Examples in the ensuing chapters of each of these systems are as follows:

1. Outbreaks triggered by masting (including bamboo and beech forests) (see chapters by Belmain et al (CHT), Ahaduzzaman and Sarker (CHT), Htwe et al (Chin), Aplin and Lalsiamliana (Mizoram), Douangboupha et al, Ruscoe and Pech, Witmar and Proulx). These are multiannual events triggered by the flowering and masting of bamboo species or other plants, and are not influenced by climate or farming systems.
2. Outbreaks driven by changes in abiotic conditions alone (aseasonal or unusual rainfall events, or major climatic events such as El Niño) (see chapters by Huan et al, Sudarmaji et al, Djafar et al, Brown et al, Jacob and Tkadlec, Singleton et al, Witmar and Proulx, Sluydts et al). These are irregular and rodent populations respond rapidly to the peaks in increased food availability.
3. Outbreaks driven by changes in cropping systems (Huan et al, Sudarmaji et al, Singleton et al, Douangboupha et al, Jacob and Tkadlec). These are driven directly by anthropogenic responses to calamitous events such as typhoons, cyclones, and drought, or responses to shortfalls of production of staple crops. Anthropogenic responses include delayed or asynchronous planting, which is often associated with calamitous weather events, or an increased intensity of cropping per unit area, which is associated with both climatic events and market forces. Rodent population responses can be rapid (within 4–6 months; see Sudarmaji et al) or delayed (up to 15 months later; see Brown et al, Singleton et al).

Climate change and extreme climatic events will increase the impacts of rodents on agricultural production (see case study by Singleton et al, this volume). There is food security pressure in some developing countries to grow three crops per year.

This pressure is a result of efforts by governments to make up production shortfalls in staples arising from these extreme events (storms, floods, cyclones, drought, etc.). However, the increases in copping intensity can be simply because proposed human population growth rates require an increase in the intensity of food production per unit area, or because of sudden changes in market forces, such as occurred during the food crisis in 2008 when the price of cereal staples such as rice tripled within three months (FAO 2009). An increase in cropping intensity reduces fallow periods and creates conditions ideal for rodents to breed continuously. Consequently, there will be an increase in the likelihood of rodent outbreaks and the associated negative impacts on food security. We have proposed four directions for future research that have emerged from the contributions on rodent outbreaks, their causes, their impacts, and their management (Singleton et al 2010). We paraphrase them here because we believe they provide important signposts for those developing policy for future investment in this emerging field of agricultural research in developing countries:

1. Rodent outbreaks are a consequence of enhanced reproduction, and natural mortality is of minor importance, particularly in rapidly increasing populations. Changes in cropping intensity that provide high-quality food (e.g., cereals at the reproductive and ripening stages) for longer periods of time per year will lead to an increase in the frequency of rodent-population outbreaks because females will breed for longer each year (Sudarmaji et al, Singleton et al). This is a major concern given the push for increasing the intensity of cropping in many developing countries. We need to focus on the factors that limit reproductive output for rodents in agricultural systems and the development of methods of disrupting reproduction in pest species (see Singleton et al and Brown et al for discussion of progress with research on fertility control of rodents).
2. A stronger understanding of the ecology of pest species and community dynamics will enable ecologically sustainable management. This will result in the development of appropriate management strategies that minimize damage to crops, reduce the reliance on rodenticides, provide greater protection to beneficial rodent species, and lead to better economic, social, and environmental outcomes for farmers (see Huan et al, Sudarmaji et al).
3. Rodent damage to agricultural production is a landscape problem that can be managed only by a widespread landscape approach that focuses on crop synchrony, and timely and coordinated community actions. The tools of landscape ecology and social anthropology (see Palis et al, Flor and Singleton) should be deployed for these problems. The success of community-based approaches to managing rodents in the lowland intensive agricultural systems needs to be promoted. The patchy structure of native and agricultural land can alleviate or enhance crop damage by pests (see Singleton et al).
4. A simple monitoring program that can serve as an early warning system for EBRM (see Brown et al, Sluydts et al) and a decision-support system for local farmers that flows from the monitoring data should be developed for

rodents. Many useful systems for managing crop pests are already in place for farmers (e.g., Heong and Hardy 2009 and references therein); simple systems need to be developed for rodents. There is growing evidence that such programs can be highly successful (Flor and Singleton, Palis et al).

This book provides a modern appraisal to an age-old problem through a better understanding of the mechanisms that lead to rodent outbreaks, why rodent population numbers increase under different circumstances, and the impact of outbreaks in a range of different agroecosystems in different parts of the world. We have made significant progress in many areas, as described in various chapters of this book, but more work needs to be done to raise the profile of the impacts of these outbreaks, particularly on poor rural households in developing countries, to incorporate better processes to disseminate the success of rodent management practices, and to influence the development of policy, particularly in countries that experience regular rodent outbreaks. We also need to encourage and mentor a new cohort of young biologists to continue to collect and publish rigorous ecological data to clearly describe the nature of the outbreaks, the damage they cause, and the effectiveness of different control strategies. Continued multidisciplinary research is essential to provide the necessary platform to change the mind-set of policymakers and the socio-cultural psyche of the diverse agricultural communities, so that we do not have to accept mindlessly the destruction that rodents cause to human society.

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Notes

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SECTION 1:

Rodent outbreaks and bamboo flowering in Asia

Chronicle and impacts of the 2005-09 *mautam* in Mizoram

Ken Aplin and James Lalsiamliana

The widely held traditional belief that bamboo flowering can lead to rodent outbreaks and famine is nowhere more deeply embedded in wider cultural values than in Mizoram, the southernmost of the northeast Indian states. This mountainous region supports extensive bamboo forests dominated by species of bamboo with semelparous masting reproduction and their schedule of highly synchronized reproduction is said to underpin a cycle of rodent outbreaks and famine, with events spaced approximately every two decades. The largest-scale events are associated with the flowering of *Melocanna baccifera*, an ecologically aggressive bamboo species that covers more than 26,000 km^2 of the northeast Indian states, extending also into adjoining areas of the Chin Hills of Myanmar and the Chittagong Hill Tracts of Bangladesh. This species has a lifespan of approximately 48 years, reproduces with a high degree of synchrony, and is a prodigious producer of fruits—up to 83.6 tons per hectare. Details of two previous *Melocanna* masting events, in 1910-12 and in 1958-60, are available from colonial sources; both events were followed by rodent outbreaks leading to extensive crop destruction and famine, with significant human mortality. A *Melocanna* masting event occurred on schedule in Mizoram in 2006-08. The unfolding of this event was carefully monitored by agronomists and forest ecologists. Although a detailed study of rodent population dynamics was not possible, attempts were made through repeated observations at several sites to understand the fundamental elements of outbreak ecology. We conclude that provision during the course of the dry season of large quantities of nutritious bamboo fruits stimulates the early onset of breeding in *Rattus rattus* and other bamboo forest-dwelling rats, thus causing a population increase several months earlier than during nonmasting years. The final stages of bamboo fruit production in July to August coincide with the first availability of maturing maize in *jhum* fields, and crop damage is observed from this time onward. Where rapid and severe damage is incurred at the ripening stage of rice, this is inflicted largely by large numbers of immature rats, thereby creating a characteristic but unfamiliar (to farmers) pattern of damage. We postulate that the severity of damage may be determined, at least in part, by the timing of first fruit production and associated rat breeding relative to the local cropping calendar. This hypothesis can be tested in the context of masting events involving other bamboo species and, if confirmed, it holds promise for developing predictive models that may alleviate much hardship associated with bamboo-related rodent outbreaks in several parts of the world.

Keywords: rodent outbreaks, bamboo mast, *mautam*, Mizoram, *jhum*

Seeing is believing

Perhaps some things just have to be seen to be believed. Throughout Asia, farming peoples believe that the episodic mass flowering ("masting") of bamboo causes rodent outbreaks and famine (Janzen 1976), and similar beliefs are also espoused among subsistence farmers in South America (Jaksic and Lima 2003). Many rural people in Asia claim to have seen it, quite often more than once in their lifetime. Until recently, however, no scientist has claimed to have been witness to either this chain of natural events or its aftermath. Strangely, although these beliefs are given a high level of credence and they have a high profile in the Indian literature on forest ecology and rodent management (Ghosh 1980, Lianzela 1997, John and Nadgauda 2002, Rao 2004), outside of this context the phenomenon has usually been reported with varying degrees of skepticism (Soderstrom and Calderón 1979, Singleton and Petch 1994 citing W. Roder, Schiller et al 1999) or, more often, simply ignored. Rather tellingly, recent reviews of the impacts of resource pulses on natural systems (Yang et al 2008, 2010) contain scant reference to what might be some of the most dramatic and large-scale examples of this ecological phenomenon.

To some extent, the skepticism or aversion of western scientists toward this issue has been well founded. As will be explored further below, many of the claimed attributes of these rodent outbreaks fall into the realm of the improbable if not the mythological. As with many myths, there may be embedded grains of truth in the notion that bamboo flowering causes an explosion of rats. But exactly what are the plausible elements in this particular case? From a scientific perspective, the principal issue has been dearth of what might be called "hard" evidence, that is, documentation using scientific methods by "qualified" scientists. In the Asian context, the one field study of rodent populations during a bamboo flowering event (Chauhan 1981, 2003, Chauhan and Saxena 1985) failed to produce evidence of large increases in rodent numbers or of extensive population movements of the kind often mentioned in the "anecdotal" accounts. Similarly, a study of historical records of rodent outbreaks in Laos (Douangboupha et al 2003) failed to yield a compelling case for bamboo flowering as a cause of the outbreaks, although this was certainly not discounted. In the South American context, previous analyses of these phenomena (e.g., Jaksic and Lima 2003) relied entirely on second-hand sources and it was only very recently that an ecological study of a bamboo flowering-associated *ratada* was completed (Sage et al 2007).

In the Asian context, one bamboo masting event surpasses all others in its scale and claimed impacts—this is *mautam*, the masting (and subsequent mass mortality—*tam* means death) of a particularly widespread bamboo called *Mau* by the regional peoples, *muli* by the wider Indian community, and *Melocanna baccifera* (henceforth, *Melocanna*) by the international scientific community. *Melocanna* bamboo forests cover huge areas of northeastern India and surrounding areas of Bangladesh, Myanmar, and Nepal, with a total area in India alone probably in excess of 26,615 km^2 (Rao 2004, Jeeva et al 2009). From historical records, it is believed that masting of *Mau* bamboo occurred across northeastern India in 1815, 1863, 1911, and 1959, suggesting an approximately 50-year flowering cycle (Nag 1999, Shibata 2009). Accordingly, the scientific community eagerly awaited *mautam* in the first decade of the 21st century. Here at last would be an opportunity to see bamboo flowering on a grand scale, and to obtain that elusive "proof" or, to return to a more scientific framework, to test some alternative hypotheses. Inhabitants of the northeast Indian states as well as adjoining parts of Myanmar and Bangladesh also awaited *mautam*, though with a genuine mixture of curiosity and dread.

But, before progressing to the special story of Mizoram, it is worthwhile making a brief side trip into the remarkable world of bamboo.

About bamboo

In many traditional Asian cultures, bamboo rivals rice as the single most important product of nature (Kurz 1876, McClure 1966). Not only is it the principal or sole building construction material, it is also essential for transportation; the manufacture of tools, furniture, paper, and clothing; and, in the form of bamboo shoots, it is an important food item. All of these uses continue today, but with the addition of new uses that take advantage of the remarkable natural fiber strength of bamboo. For the great majority of Asian peoples, bamboo is thus central to life and culture, and most people are familiar with its essential biological and ecological properties. In contrast, the majority of western scientists have little or no first-hand knowledge of bamboo other than as an ornamental garden plant. To begin thinking about possible ecological links between bamboo and rats, those of us who have not grown up with bamboo might begin by humbly asking, "What could be special about bamboo?"

In botanical classification, bamboos comprise the subfamily Bambusoideae, which is a specialized offshoot of the grass family Poaceae (Das et al 2008). More than 1,400 species of bamboo, classified into around 90 genera, are distributed throughout the tropical to temperate regions of all continents (Ohrnberger 1999, Wong 2004). The highest diversity of bamboos is found in China, but India and China together have the largest areas of bamboo, which often forms extensive, near-monotypic stands (Bystriakova et al 2003). Like most other grasses, bamboo species tend to be fast growing and to grow best under well-lit conditions. As a result, they tend to be particularly common in successional rather than climax plant communities, growing either in small gaps created in forest by tree-fall or landslides, or in larger clearings created by flooding, natural wildfires, or human activities, including agriculture. In Asia, they are a major component of early to mid-stages in forest regeneration following slash-and-burn or shifting cultivation (Lianzela 1997, Tawnenga et al 1996).

Bamboos vary enormously in growth form. They include both herbaceous (soft and grass-like) and woody (hard and tree-like) forms, and can grow either from a simple root stock (monopodial) or from a root stock that includes specialized roots called rhizomes that allow the plant to expand below-ground (sympodial), with culms arising from nodes along the rhizomes (McClure 1966, Sodestrom and Calderón 1979). Sympodial bamboos can be further classified as "clump-forming," where the rhizomes are short and the culms are closely grouped, or "spreading," where the rhizomes grow outward and the culms are more regularly spaced.

The reproductive biology of bamboos is remarkably varied and highly pertinent to the theme of rodent outbreaks (John et al 1994, Shanmughavel and Francis 2001). Three contrasting reproductive modes have evolved among the bamboos: a sporadic mode, a synchronized "masting" mode, and a semelparous masting mode. Under sporadic reproduction, an individual bamboo plant flowers and sets seed multiple times through its lifespan, usually on an annual basis, and with either no particular seasonal pattern or, more commonly, a general seasonality determined by annual climatic cycles. Synchronized masting bamboos also tend to flower and set seed multiple times through their individual lifespan but, in these species, reproductive activity is generally not annual. Instead, it appears to be triggered by dramatic environmental events such as fire or drought, and these often occur only on multiannual time scales. This reproductive mode presumably allows the bamboo to place maximum reproductive effort into the windows of greatest opportunity—the creation of large clearings in which a higher proportion of bamboo seed might germinate and flourish (Keeley and Bond 1999).

Most synchronized masting bamboos are also semelparous. Bamboos of this group reproduce only once in their lifespan and they do so in a highly synchronized manner—large numbers of plants flower more or less at the same time, and then all die shortly thereafter, bringing about a complete generational replacement of the species at a local to regional scale. The lifespan of semelparous bamboos varies between species and ranges from a decade or so up to more than a century (Janzen 1976). Many species of semelparous masting bamboos show local synchrony of flowering but vary considerably in the timing of flowering across larger geographic areas. In a smaller number of species, the synchronicity extends to all populations of a species, such that the vast majority of individual plants will flower and die within an interval of only a few years (e.g., Franklin 2004, Shibata 2009).

Reproductive activity in semelparous masting bamboos is controlled by an internal "clock" that signals to the plants when it is time to flower, set seed, and die, irrespective of external environmental cues. The strongest evidence for this remarkable biological property comes from numerous cases of transplanted semelparous bamboos flowering simultaneously even when grown in entirely different climates (Janzen 1976, Shibata 2009). Flowering in plants is a complicated process that is controlled by interactions among multiple gene products, including some that seem to regulate timing through dose-rate mechanisms (Mouradov et al 2002). The molecular mechanism of synchronized flowering in bamboos is only now starting to be understood (Tian et al 2005).

Semelparous masting bamboos can also undergo sporadic flowering but this does not result in the death of the plant and fruit generated in this way tends to be infertile (John et al 1994, Shanmughavel and Francis 2001). Within the main period of flowering activity, a few plants typically flower one or two years earlier and later than the main bulk of the plant, perhaps reflecting genetic diversity within local populations (Watanabe et al 1982, Franklin 2004). Widely distributed species often have spatial variation in the principal flowering time, so that the main flowering activity seems to move around or even across the landscape in a directional "flowering wave."

There is considerable debate over the evolutionary advantages of semelparity in bamboos, with two principal competing hypotheses—predator satiation (e.g., Janzen 1976) and the fire hypothesis (e.g., Keeley and Bond 1999, but see Saha and Howe 2001). Whatever its origins, semelparity is most prevalent among bamboos growing in tropical areas that experience strongly seasonal climates under monsoonal influence. Not surprisingly, India has the highest proportion of semelparous masting bamboos (70 out of 72 species, Gadgil and Prasad 1984, Campbell 1985), and eight of these species are regarded as strictly synchronous (Kelly 1994).

The flowering process itself is also unusual in bamboos. In most species, every culm can potentially develop into a flowering shoot (John et al 1994). When this begins to happen, the leaves turn brown and gradually all drop off, and the culm develops flowering spikelets at nodes and apices, and sometimes also along flowering side branches. A flowering culm can eventually have all of its originally leafy components transformed into flowering shoots (Wong 2004: 35). In some species, flowering shoots can also develop directly from rhizomes. The reproductive process of *Melocanna baccifera* was described in detail by Banik (1994, 1998) and Ramanayake and Weerawardene (2003).

Bamboo fruit (technically a “caryopsis”) contains a single propagule (John et al 1994). In most species, the fruit is dry and not much larger than a grain of rice or wheat (Chatterjii 1960, Wong 2004). In a few genera, the fruit is fleshy and much larger, resembling a pear or avocado fruit in size and shape. In some of the fleshy-fruited bamboos, the seed can germinate either after falling or while still attached to the parent plant (Kurz 1876, Stapf 1904). Bamboo fruit typically shows prompt and high germination rates and a marked decline in seed viability within a matter of months (Janzen 1976, Banik 1994). However, several temperate-zone bamboos appear to display seed dormancy (Matumura and Nakajima 1981, Taylor and Qin 1988). The nutritional value of bamboo fruits includes typically high starch and protein contents (Iwata and Nakajima 1942, Mitra and Nayak 1972). *Melocanna* fruit submitted by Rokhuma (1988: 131-132) for chemical analysis to the Forest Research Institute, Dehradun, yielded values of 50.3% starch, 11.6% protein, 3.0% ash, and 0.2% fats.

Mizoram—regional context and environment

Geographic setting

Mizoram is one of the six states that make up northeastern India—a region wedged between Bangladesh to the west and Myanmar to the east, and only narrowly connected with the rest of India (called the “mainland” by Mizo people) via a narrow bridge between Assam and West Bengal states (Fig. 1). Mizoram has a total land area of 21,087 km^2 and is bordered to the east by Myanmar, to the west by Bangladesh, to the northwest by Tripura State, to the northeast by Manipur State, and to the north by Assam. It supports a population (last counted in 2003) in excess of 922,000 people living in 22 towns and 700 villages, giving an overall population density of 44 persons per km^2 (Government of Mizoram 2003). However, more than half of the present population lives in urban centers, with more than 250,000 people located in the state

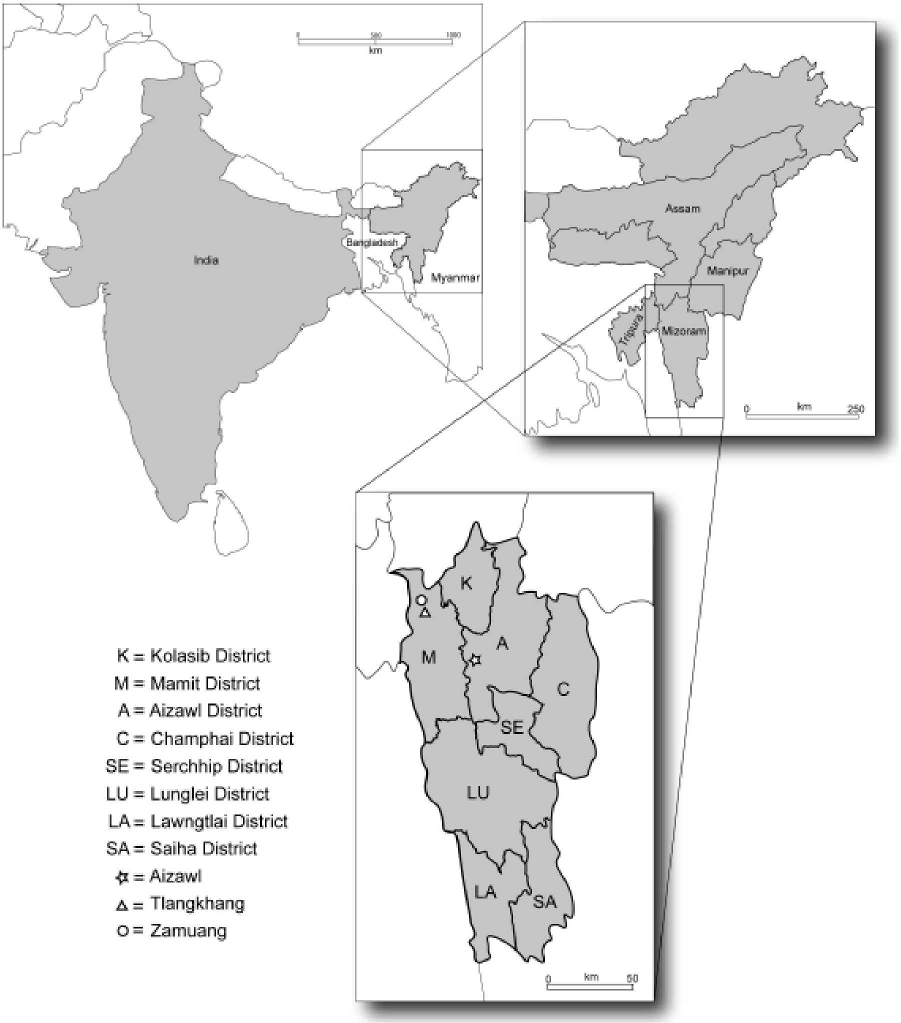

Fig. 1. Maps showing the location of Mizoram in northeastern India, district boundaries within Mizoram, and the location of towns and villages mentioned in the text.

capital Aizawl. A period of rapid population expansion through the 1980s and 1990s included large numbers of immigrants from Assam and the “mainland,” with the result that the population today has very mixed origin (Hazarika 1995).

Mizoram sits astride a geological collision or Suture Zone between the Indian landmass and the Indochinese region. This accounts for its remarkably rugged topography, which comprises numerous predominantly north-south-trending ranges, separated by narrow, deep valleys. The average height of the ranges is about 900 m, with the highest peak (Phawngpui—Blue Mountain) rising to 2,210 m. Mizoram has a mild climate with a winter temperature range from 11 to 21 °C and a summer range of 20 to 29 °C. The entire area is under the influence of the South Asian monsoon, which brings heavy rain from May to September. The average annual rainfall, measured at Aizawl, is 208 cm (Government of Mizoram 2003).

Flat land is a rare commodity in Mizoram, and most human settlements as well as agricultural fields are emplaced on ridges and steep slopes. This characteristic landscape and pattern of human settlement extend into bordering parts of both Bangladesh (the Chittagong Hill Tracts) and Myanmar (the Chin Hills), and also typify many other parts of northeastern India.

Land cover and Mizo agriculture

More than 87% of the land area of Mizoram is covered with forest (Government of Mizoram 2003, Nose 2009). The proportion of forested land is highest in the northern and eastern parts of Mizoram, and less in the south. Most of the remaining land area is occupied by active gardens, plantations, and early stages of regeneration after gardening.

According to Champion and Seth (1968), the natural vegetation of Mizoram is tropical evergreen and semi-evergreen forest at low altitudes, and subtropical to montane subtropical forest at higher elevations. Bamboo is present in all forest types but usually only conspicuous along streams and in areas recovering from natural disturbance (e.g., landslides, tree-fall). Much of the original forest that remains today is protected in wildlife and forestry reserves.

Outside of forest reserves, a large proportion of the forest cover is dominated by bamboo species. One species, *Melocanna baccifera*, dominates all others; in 2009, almost pure stands of this one species covered an area of 9,210 km^2 (Nose 2009). The extensive bamboo forests in northeastern India are regarded as an anthropogenic (i.e., created by people) forest community, a direct by-product of *jhum* agriculture (Lianzela 1997, Rao and Ramakishnan 1998, also see below).

Agricultural systems in Mizoram

In 2002-03, a total area of 158,397 ha was under cultivation in Mizoram, almost all of it farmed using the traditional slash-and-burn method, known locally as *jhum* agriculture (Government of Mizoram 2003). Irrigated fields, mainly located in Kolasib District bordering Assam State, amounted to 12,612 ha. A further 247,069 ha were land at various stages of fallow. Fruit orchards and vegetable fields occupied a further 57,858 ha and 40,970 ha, respectively.

The principal crop produced in 2002-03 was rice (109,205 tons), followed by maize (14,879 tons), sugarcane (7,443 tons), oilseed (5,285 tons), and pulses (4,986 tons). Just over 61% of total rice production came from *jhum* fields farmed using traditional methods. Total rice production in 2002-03 was estimated at only 40.8% of the state’s self-sufficiency target (Government of Mizoram 2003).

The *jhum* cropping cycle in Mizoram (Fig. 2) is typical of slash-and-burn practices followed across all of northeastern India (Ramakrishnan 1992) and into upland regions of Indochina (Roder 2001). The cropping activity is intimately linked to the

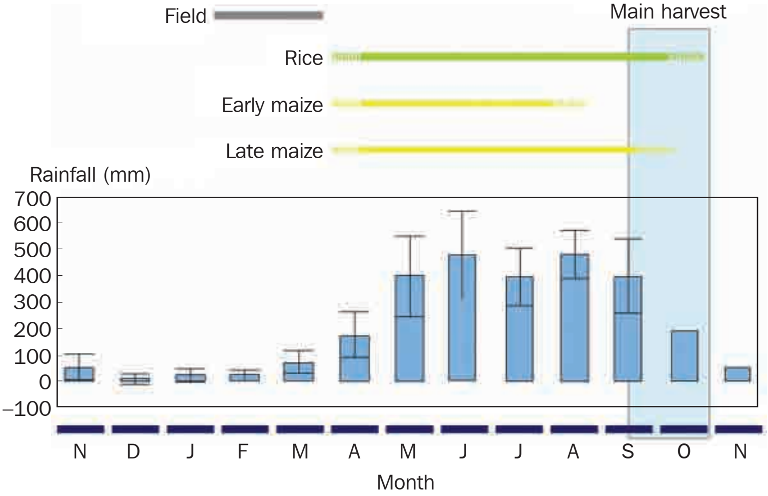

Fig. 2. The Mizo *jhum* cropping cycle and its relationship to the annual distribution of rainfall. Rainfall values are shown as means and standard deviations, based on the combined records for Aizawl for 1981-2006.

monsoonal cycle, with planting timed to coincide with the onset of rains in late April to early May. To be ready for this event, fields are cleared of standing vegetation in February to March, with debris typically burned in early April. The majority of *jhum* fields support a variety of intermingled crops—typically including maize, mustard seed, and numerous vegetables. Early-maturing maize is generally ready for harvesting in June, with late maize and rice usually harvested sometime between early September and early October. Farmers grow numerous rice varieties but two of the more popular are known locally as *tai* (a sticky rice) and *buhpui*. Both are slow-maturing varieties that are planted at the same time in mid- to late April and harvested in early to mid-September and mid-November to early December, respectively.

In the past, areas of primary or advanced secondary forest were selected for clearing. Today, areas of forest are typically reserved and *jhum* fields are far more likely to be created through cutting of *Melocanna* bamboo forest. Field preparation therefore involves the cutting and burning of the culms, leaving the underground rhizome mat to send up new shoots into the cleared space. Regeneration of the *Melocanna* bamboo creates a heavy burden of weeding in most *jhum* fields. *Jhum* fields are typically surrounded on one or more sides by dense stands of *Melocanna* forest.

Official state records begin in 1974 and show that the total land area under crop production has increased by only around 10% since that time (Government of Mizoram 2003). However, analysis of satellite photographs, the earliest dating from 1972, shows large-scale loss of dense forest cover across Mizoram during the 1980s (Lele and Joshi 2009), coinciding with the period of most rapid population growth. By 1999, much of these areas were again covered in dense forest, with large areas dominated by *Melocanna* forest.

Mizoram rodent ecology

The rodent fauna of Mizoram was documented taxonomically from early collections by Nath (1952) and Ghosh (1965), with more recent assessments by Agrawal (1980) and the present authors. The dominant rodent species in all human-associated habitats is the black rat (*Rattus rattus*), a remarkable opportunist that may have originated as a disturbance specialist in the subtropical forests of South to Southeast Asia but today occupies virtually every major ecological region of the world (Aplin et al 2003). Two critical features that seem to underpin the success of this species (or rather group of species, as it will very likely be taxonomically subdivided in the near future) are its relatively high reproductive potential, its apparent capacity to breed whenever food is available in sufficient quantity and quality, and its propensity to shift its diet depending on availability. *Rattus rattus* in its various forms is the dominant rat of agricultural environments as well as village habitats throughout much of Asia (Aplin et al 2004).

Other species found mainly in villages and fields across Mizoram are the Himalayan rat (*R. nitidus*), the Polynesian rat (*R. exulans*), and the house mouse (*Mus musculus*). Rats found exclusively in field and forest habitats include several species of white-toothed rats (*Berlymnys* spp.), spiny rats (*Niviventer fulvescens*), several species of mice (*Mus cervicolor* and *M. cookii*), and bamboo mice (*Chiropodomys gliroides*). Bamboo rats (*Cannomys badius*) are also found in fields and forests. The forest ecosystem also supports other small mammals, including tree shrews (*Tupaia* sp.) and a variety of squirrels (species of *Callosciurus* and *Dremomys*). Overall, the small mammal community of Mizoram resembles closely that of the uplands of Myanmar and Laos (Aplin et al 2007), with only minor differences in species composition.

Information on the ecology of Mizoram rodents derives from the ecological studies of Chauhan (1981, 2003) and Chauhan and Saxena (1985), carried out during the *thingtam* event of 1977-78, and from opportunistic observations by the present authors between 2004 and 2008. These studies suggest a fundamental commonality in rodent ecology with the better-studied upland agroecosystems of Laos (Khamphoukeo et al 2003, Aplin et al 2007, Douangboupha et al 2009). During nonmasting years in Laos, the annual population cycle of rats in the *jhum* environment is largely determined by the monsoonal pattern. Through the dry season, *jhum* fields stand in fallow and productivity in the forests is probably also low. Rats living in these environments show little or no reproductive activity through this period. With the onset of monsoonal rains, plant growth and insect activity increase in both forests and fields, and rats show the first signs of reproductive activity. Rodent damage to *jhum* crops increases through the cropping season as more young emerge from burrows to feed on the maturing crops. Harvest puts an end to this period of rapid growth in field-rat populations, as many are forced to fall back on the less prodigious forest resources. Where people reside close to their cropping areas, some rats (most notably *R. rattus*) follow the harvested crop into village habitats, where they continue to breed through the fallow period, feeding on stored grain. Estimates from Laos and Myanmar suggest that rats usually consume between 5% and 15% of the crop each year prior to harvest, with further losses during storage (Schiller et al 1999, Singleton 2003, Singleton et al 2010). Mizo farmers reported similar crop losses to rodents in “normal” years. Chauhan

(1981, 2003) reported strongly seasonal breeding in *R. rattus* and *R. nitidus*, with high reproductive activity in July to October and a cessation of breeding from January to April. Rats captured during Aplin's pre-*mautam* visits to Mizoram in 2004 and 2005 also showed reproductive activity consistent with this wider pattern (Table 1).

Cultural and historical background

Northeastern India is also a Suture Zone in a cultural sense. Its indigenous people belong to a number of tribal minorities, all of whom have strong ethnic affiliations with inhabitants of southern China rather than with the more proximate peoples of the Indian subcontinent. Mizo people themselves most likely migrated to their present homeland in several waves, starting around 500 years ago, and they have close relatives in Shan State and the Chin Hills of Myanmar, and in the Chittagong Hill Tracts of Bangladesh.

The recent political history of Mizoram is of special interest—not least because of the unique role played by rodents in shaping the course of events (Hazarika 1995, Nag 1999). Prior to colonial times, Mizo politics were dominated by a process of local alliances, raiding, and retaliation. In 1895, the Mizo Hills were formally proclaimed part of British India and, in 1898, became known as the Lushai Hills District of Assam State, with Aizawl as its headquarters. Missionaries arrived around the same time and today most ethnic Mizos are Christian. In 1919, the Lushai Hills along with some other hill districts were declared a Backward Tract and, in 1935, all of the tribal districts of Assam, including the Lushai Hills, were declared an Excluded Area.

As India prepared for independence following the end of World War II, Mizo people began to express political will. Various representations were made to the emergent Indian government by the Mizo Common People's Union (a group formed on 9 April 1946 and later renamed the Mizo Union) and also by a splinter group, the United Mizo Freedom Organization (UMFO), which preferred that Lushai Hills join Burma after independence. A degree of autonomy for the tribal regions was granted by the Indian government and administered through the Lushai Hills Autonomous District Council, which came into being in 1952. However, there was general dissatisfaction with this arrangement and, in 1955, tribal leaders met in Aizawl to form a new political party, the Eastern India Trader Union (EITU), which incorporated former members of both the Mizo Union and the UMFO.

In 1959, political maneuvers were interrupted by the arrival of *mautam*. Widespread flowering and death of *Mau* bamboo throughout the Mizo Hills was followed by plagues of rats that devoured crops and infested houses, consuming stored foods and possessions. Very little rice or other produce was harvested and many Mizos turned to the jungle to subsist on roots and leaves. Famine became widespread and many people died of malnutrition and diseases, notably including cholera. Although many organizations tried to provide famine relief, the ruggedness of the terrain and a limited network of established roads hindered movement of people and goods. One organization that figured prominently in these efforts was the Mizo Cultural Society, first formed in 1955. In March 1960, it changed its name to Mautam Front and soon thereafter to Mizo National Famine Front (MNFF), and it proved an effective body, not only for the distribution of relief but also for drawing wider attention to the plight of the Mizo people.

By 1960, *mautam* was largely a spent force. However, the experience had reinforced Mizo views of self-reliance and self-determination; the MNFF lived on and, in October 1961, it transformed itself into the Mizo National Front (MNF), with the expressed goal of achieving independence for Greater Mizoram (i.e., all of the territory occupied by the Mizo people). Political frustration soon reached a boiling point and, on 28 February 1966, large-scale violent disturbances broke out in numerous centers, including Aizawl and Lunglei. The insurgency launched on that day was to last for a full 20 years. However, a parallel process of political negotiations through that period brought a stepwise move toward peace and self-determination, first with recognition in 1972 of a Union Territory of Mizoram, next with a cease-fire in June 1986, and finally, on 20 February 1987, with the establishment of Mizoram as the 23rd state of the Indian Union. Notably, leading members of the once-outlawed MNF assumed prominent roles in the new state government, including the position of chief secretary. Rarely has armed conflict culminated in such a favorable political outcome for the insurgents. And, never before or since can a political movement trace its origin to an infestation of rats!

Past bamboo flowering events and rodent outbreaks in Mizoram

Dread and fascination often go hand in hand. As do adversity and community. A central pillar of Mizo society is *Tlawmngaihna,* an untranslatable term that implies an obligation of all members of society to be hospitable, kind, unselfish, and helpful to others. Mizo people link this concept to another, *Tampui Mitthi,* or Great Famine, which embodies the relentless cycle of hardship brought by natural causes that Mizo people endure, paramount among them the events associated with the mass flowering and death of two locally dominant bamboos, *Mau* (*Melocanna baccifera*) and *Rawthing* (*Bambusa tulda*).

Clues from deeper history

The phenomenon of bamboo flowering is deeply embedded in Mizo oral history and it is also a dominant theme running through the written history since colonial times. Taken in combination, these two major sources are a remarkably rich source of relevant information on past environmental events. The State Archive of Mizoram in Aizawl contains many hundreds of folders of information on the early colonial history of the Lushai Hills, and references to bamboo flowering, rats, food shortages, and food relief are commonplace. Though much of this information remains to be tapped, significant details are available from a number of secondary sources (Rokhuma 1988, Hazarika 1995, Nag 1999).

The earliest military forays into Mizoram by the British, made in the early 1880s in response to repeated Mizo raids onto the Sylhet Plains, encountered a people in the grip of a famine that they attributed to plagues of rats. Colonel E.R. Elles stated in a military report on the Chin Lushai Hills for 1881 that

> The famine arose from the depredations of rats, who multiplied exceedingly the previous year owing to the ample food they obtained from the seedling of bamboos (cited in Rokhuma 1988: 98).

In this case, the rat outbreak was attributed to widespread flowering of *Rawthing* bamboo (*Bambusa tulda*). According to one source, 15,000 people may have died as a consequence of the famine of 1881 (Chatterjee 1995: 13), out of a total regional population probably numbering less than 90,000.

As British administration and the various Mission Societies extended their influence, a more general awareness came about of the remarkable capacity of Mizo people to predict these events based on their understanding of regular (but noncoincident) flowering cycles for two locally abundant bamboo species. Prolific and widespread flowering of *Mau* bamboo (*Melocanna baccifera*) and a subsequent rodent outbreak and famine were widely anticipated by Mizo people for 1910-11. By this time, sufficient administration was in place for the bamboo flowering events, rodent outbreaks, and famines to be documented by both the district administration and various Mission Societies (Rokhuma 1988, Nag 1999).

Rokhuma (1988: 101-103) provided the most detailed summary to date of the events of the 1910-12 *mautam*. He noted that *mautam* was presaged by the swarming of a large pentatomid bug known locally as *Thangnang* (*Udonga montana*). This appeared in 1909 and 1910 and was consumed by Mizo people in huge quantities. Flowering of *Melocanna* bamboo occurred in 1910 in eastern parts of Mizoram and was followed by severe, albeit localized, crop damage by rats. The following year, *Melocanna* flowered everywhere and rat numbers were also seen to increase dramatically, with fields under attack “in the beginning of the autumn season” (i.e., August) (Rokhuma 1988: 101). A system of bounty payments was introduced in 1912 by the district administration and this led to the presentation of 179,015 rat tails. By then, however, damage to crops was already severe and widespread, and many people took to the road in search of surplus food from the previous year. Some additional rice was sourced by the administration in adjoining states and this was distributed by river and over land. However, the limited road network and generally poor communications meant that many people were unsupported. The population of what is now Mizoram in 1911 was probably around 91,000 people. There appears to be no estimate of mortality resulting from the 1910-12 *mautam*. Several large groups of Mizo people migrated west into Tripura State, where they still reside.

Rawthing bamboo flowered again across large areas of Mizoram in 1929 and 1930 and rats were observed to cause heavy damage in both years. However, good harvests in the preceding years had allowed the distribution of surplus; hence, famine impacts were localized and quickly countered (Rokhuma 1988: 104-106). A total of 1,500,000 rats and squirrels are said to have been killed during this period through the use of locally made rat traps and *Hnamtur* (*Gelsemium elegans*), the latter “a kind of creeping plant whose roots are very effective poison to rodents” (Rokhuma 1988: 154-155).

The 1958-60 *mautam*

Mautam returned to Mizoram in 1958. This time, it was documented in even greater detail, most diligently by Pu Rokhuma, a government employee and resident of Aizawl.

Rokhuma's records of this period fill many filing cabinets at his home (personal observation, May 2009) and are summarized in his self-published booklet (Rokhuma 1988: 110-113, 140-147). According to Rokhuma's account, *mautam* itself was preceded in 1956 by the gregarious flowering of another species of bamboo known to Mizo people as *Phulrua* (*Dendrocalamus hamiltoni*). In 1957, *Melocanna* itself flowered and produced fruit at scattered localities but the rice harvest was mostly unaffected. The following year, gregarious flowering and fruiting of *Melocanna* commenced in the eastern parts of the district, where a "great multitude of rats fed on these bamboo fruits," with extensive crop damage around the time of harvest (Rokhuma 1988: 111). Elsewhere in the region, good harvests were obtained in most areas. In 1959, *Melocanna* flowering and fruiting activity occurred throughout the region and "the rate of increase in rat population was beyond imagination" (*ibid*). By August, the *Melocanna* fruit was observed to be all eaten up and destruction of rice and other crops intensified. Crop losses were both widespread and severe, and the total regional harvest in October 1959 was judged sufficient to last only until February 1960. Although rat populations were observed to crash in 1960 with the absence of further *Melocanna* fruiting, poor harvests continued over several more years, and not until 1964 were good harvests obtained. Low harvests in the intervening years were blamed on drought conditions in 1960 followed by extensive wildfires resulting in a loss of soil fertility, and on the impacts of insect pests and diseases (Rokhuma 1988: 112-113).

Preparation for the 1958-60 *mautam* had commenced in 1951 with the formation of the Anti-Famine Campaign Organization (AFCO). The preparatory objectives of AFCO included the general improvement of both *jhum* methods and practices and transportation infrastructure, the diversification of cropping (including the promotion of large-scale banana production), and awareness training on the strategic use of rodenticides (Rokhuma 1988: 119-127). Many of the suggested famine-relief measures, including the planned distribution of rodenticide, were not supported by the Assam State government, which displayed open skepticism about the predicted famine. As a result, it was not until severe famine conditions became widespread in late 1959 that countermeasures were taken. Although these included rice importation, with distribution via air drops, motor boats, and jeeps (Rokhuma 1988: 142-146), too little assistance came too late for many communities. The number of deaths from malnutrition and associated diseases through this period is not accurately recorded; however, local sources estimated the number of excess deaths through this period at around 10,000, or about 5% of the total population of around 200,000 people (Hazarika 1995, Nag 1999). A high rate of infant mortality and local outbreaks of cholera contributed to this total, both probably exacerbated by malnutrition among many populations.

The 1976-77 *thingtam*

The anticipated *thingtam* of 1976-77 was treated with greater respect. Ecological studies of this event were carried out by several research groups: the Zoological Survey of India (Chauhan 1981, 2003, Chauhan and Saxena 1985, Pillai 1980); the Northeastern Hill University in Shillong (Prabhakaran and Michael 1980, Trivedi and Tripathi 1980); and the Indian Council for Agricultural Research (ICAR) Research

Complex in Shillong (Das and Sachan 1980). Rokhuma (1988) also maintained his vigil through this period and his accounts contain many important details regarding both the environmental events and governmental responses.

The ecological studies carried out through the 1976-77 *thingtam* failed to produce any clear association between bamboo flowering and rodent outbreaks. In a recent review of this evidence, Chauhan (2003: 267) remarked that "flowering of the bamboo had no measurable effect on rodent population dynamics." More specifically, he noted that

> Despite a constant vigil, no sign of rat migration from *jhum* to bamboo forest or vice versa was observed in Mizoram during flowering of *B. tulda*. The rats mainly inhabited paddy fields, and showed variation in their numbers in relation to the crop cycle during the flowering of *B. tulda*. Only a few rats were noticed in the forests during this period (Chauhan 2003: 270).

However, in assessing these comments, it is important to note Chauhan's admission that "Only in a very few places in the northeastern region did the bamboo flowering result in seed formation" (*ibid*) and also that his field monitoring activities were carried out exclusively in active and fallow *jhum* fields, rather than in established bamboo forest. Other scientists involved in the assessment of bamboo flowering events in Mizoram in 1976-77 seemed more open to the possible role of bamboo masting in stimulating rodent outbreaks (e.g., Das and Sachan 1980, Prabhakaran and Michael 1980, Trivedi and Tripathi 1980). However, in every case, their conclusions were qualified with reference to other possible ecological factors, including a decline of predators, the role of immigration, and general imbalances in the *jhum* ecosystem. Several of these researchers commented on the myriad difficulties of studying this particular phenomenon, including the large scale of the events, the difficult terrain and impenetrable bamboo forests, and the generally elusive rodents.

The course and impacts of the 1976-77 *thingtam* were recorded in even greater detail by Rokhuma (1988: 116-118, 147-157). He notes that gregarious flowering of *Rawthing* bamboo commenced in 1975 in Tripura State to the east of Mizoram but not until 1976 in the west of Mizoram. At that time, people reported "a swarm of rats came from the neighbouring Tripura" (1988: 116). More widespread flowering occurred in 1977 and "rats multiplied exceedingly great in numbers" (*ibid*). Some farmers had elected not to grow rice in anticipation of *thingtam* and many had grown ginger in response to government directives to produce cash crops rather than rice. However, according to Rokhuma (1988: 116), "it posed great difficulty in marketing ... (and) … thousands of mounds (sic) were unsold and left on the roadside rotting."

Preparations for the 1976-77 *thingtam* had commenced in February 1975 with the formation of the Rodent Control Committee in Mizoram State. The main objectives of the committee were to coordinate rat eradication measures across the state. After reports of widespread crop damage were received in the autumn of 1976, the Committee instigated two measures: a bounty scheme of 2 rupees per tail and a plan for large-scale distribution of rodenticide, including zinc phosphide, aluminum sulfide, and warfarin. In addition, all farmers were urged to grow high-yielding early rice varieties as well as tapioca and maize on a large scale, for which seeds and stumps were supplied. Records of the bounty scheme indicate that 553,045 rats were killed in

1976, mainly from the southern area of Mizoram. The highest number of rats killed by an individual person in 1976 was 7,000 (Rokhuma1988: 152-153). During 1977, bounty was paid on a total of 2,616,616 rat tails. Groups of students from various schools and colleges took part in systematic rat annihilation, with one group of 150 students from Pachhunga University College reportedly killing 22,133 rats "by means of various rat poisons and new tactics" (Rokhuma 1988: 155).

Strange events and speculation

Historical and anecdotal sources concerning *mautam* contain numerous references to extraordinary events and magical possibilities. Rokhuma (1988: 140) notes that both the 1911 and 1958 *mautam* were presaged by swarming of *Thangnang* bugs and by the passage of comets (Haley's in 1910, Mrkos in August 1957), which for Mizo people is a sign of impending misfortune (Rokhuma 1988; C. Lalbiaknema, interview with V. Grossman, 14 November 2002).

Many accounts of *mautam* refer to the rapidity of crop damage and for some people this was cause for doubt that rats were responsible. For example,

> In 1959 we had a 1.5 acre plot of shifting cultivation. The previous day we thought the *jhum* would not be very much affected. … In the night the paddy was all gone. The grain was all plucked out and taken away. On November 2 the paddy was still standing but all the grain heads were gone next day. ... It's a mystery how this happened. … It might have been birds, but no one knows how it happened. The tops were all cut off. The day before everything was fine; the grain was all there. (C. Lalbiaknema, interview with V. Grossman, 14 November 2002.)

Another recurrent theme in accounts of the rodent outbreaks is sightings of large numbers of rats moving together in a coordinated manner, sometimes described as "rat armies." According to Rokhuma (1988: 111), a man called Sanga of Lungleng Village observed a swarm of rats at dusk crossing a footpath "in thousands just as the hailstorm … the trail they left behind was just like those of the herd of wild boars." The sound of large numbers of rats moving across the landscape was sometimes described as being like heavy wind or a train approaching. Occasionally, these accounts were elaborated into the realm of the implausible—a newspaper account of 1960 (Amrita Baar Patrika 1960, cited by Pillai 1980) reported an instance of two rat armies that ignored crops to do battle with each other, the combined forces of 30,000 leaving behind 3,000 dead.

A final noteworthy observation of rat behavior during the 1958 *mautam* is mentioned in the interview transcript with C. Lalbiaknema—the finding after crop destruction in the *jhum* field of "up to ten live rats in the holes (burrows)." Most of the rat species found in Mizoram are essentially solitary animals; outside of masting-outbreak periods, it is rare to find more than one or two adults in a burrow, aside from a female with a litter of small dependent pups.

Many reports of rodent outbreaks during *mautam* and *thingtam* include speculation about the causation of the marked rodent population increases. Nearly all mention the avid consumption of bamboo fruits. For some, this seems sufficient explanation of the population increase. Others speculate further that it allows more young to survive due to a reduction in cannibalism of young under conditions of food surplus (Rokhuma 1988), or that the fruit contains special properties that either encourage mating, allow more rapid development of the young, or stimulate the production of larger numbers of young (Mahadevan et al 1961). For others, the increase in rat numbers is too great to be explained solely in terms of a local population increase, with the implication that large-scale immigration of rats must be occurring to take advantage of the locally abundant food (Das and Sachan 1980).

Studies of the 2007-08 *mautam*

As the date of the latest *mautam* approached, various preparations were made to both document and mitigate the impacts of the anticipated events. The official response included formation under the suggestion of the chief minister of the Mizoram government of the *Bamboo Flowering and Famine Combat Scheme* (BAFFACOS) (Government of Mizoram, undated a,b), whose interim achievements were reported several years later (Government of Mizoram, undated c).

Under the broader umbrella of BAFFACOS, staff of the Agriculture Department, most notably Lalsiamliana, variously facilitated and coordinated work in Mizoram by a number of external researchers. One of these was Dr. Valerie Grossman, then a graduate student of the Fielding Graduate Institute, who undertook participatory action research with Mizo communities to help them prepare for *mautam*. Her dissertation (Grossman 2004) contains extremely informative transcripts of interviews with Mizo people who had lived through previous rodent outbreaks and a number of these are cited here. Aware that she did not possess sufficient knowledge of rodent biology to offer advice on management actions, Grossman facilitated a visit in 2004 by John B. Bourne, a rodent control specialist from the Department of Agriculture, Alberta, Canada, who offered advice on the most effective use of rodenticides. Subsequently, Lalsiamliana made contact with Aplin, who visited Mizoram on invitation of the minister for agriculture on two occasions (March and November 2004) prior to the commencement of *mautam*. During these visits, Aplin and Lalsiamliana traveled to various parts of Mizoram, talking to Agriculture Department staff and local farmers, collecting rat specimens for identification of the major pest and nonpest species, and establishing a baseline on rodent ecology through examination of patterns of habitat use and breeding activity. This information was summarized in two unpublished reports presented to the minister for agriculture; each contained recommendations for further research activities and for possible mitigation actions. In November 2004, Mizoram was also visited by a team headed by Dr. Mohan Rao from the National Plant Protection Training Institute, Hyderabad. Their unpublished report to the minister for agriculture contained suggestions for surveillance of rat numbers in *jhum* fields and for effective rodenticide use in the event of local rodent outbreaks.

Ecological studies of gregarious flowering of *Melocanna baccifiera* were conducted by a research team headed by Dr. Shozo Shibata of Kyoto University, and by staff of the Department of Forestry, Mizoram University, principally Dr. F. Lalnunmawia.

Attempts by Aplin to secure further funding for more detailed ecological studies running through the *mautam* were unsuccessful. However, the opportunity arose in

2008 to join a *National Geographic* team making a documentary about *mautam*. This led to repeat visits in May, August, and September 2008, during which it was possible to establish a limited monitoring activity in one area and to make more general observations on the flowering and fruiting of *M. baccifera* and its consequences for rodents and people. Aspects of this activity are recorded in the Nova documentary titled "Rat Attack" (www.pbs.org/wgbh/nova/rats/).

The 2005-08 *mautam* in Mizoram

Flowering and fruiting of *Melocanna baccifera*

Sporadic flowering of *Melocanna* was recorded at three localities in July 2001, at 33 localities in February to July 2002, and more widely between February and July in 2003 to 2006 (Government of Mizoram undated c, Shibata 2009). This sporadic flowering activity resulted in some fruit production but not in the death of the culms.

Gregarious flowering occurred first in the northwestern district of Mamit in January 2005, covering an estimated 500 hectares. Widespread flowering occurred in the eastern, southern, and central districts in 2006, involving approximately 25% of the total area of *Melocanna* forests. Flowering continued throughout Mizoram in 2007 and extended into 2008 in the northwest, with similar phenology each year—flowering commencing in late October to January, followed by fruit production 3–4 months later. In many areas, the majority of *Melocanna* stands flowered in a single year. In some localities, flowering occurred over two consecutive years, usually in different stands but in some instances involving different plants within a single patch of forest. Mamit District was unusual in having both early and late phases of flowering activity. Around Aizawl, where the process was followed closely by the Kyoto University research team (Murata et al 2009, Shibata 2009), gregarious flowering started in November 2006 with shedding of dead leaves from January 2007. Seeds developed on the culms from February and began to fall in large numbers from May 2007. Fallen seed germinated from June, immediately upon the onset of monsoonal rain. Our observations in central and northwestern Mizoram suggest that the gregarious flowering activity of 2007-08 began in late October to November 2007 in all areas but that the timing of fruit production and fruit fall varied considerably. In February 2008, people across the whole of Mamit District worked to clear new *jhum* fields in areas of established *Melocanna* forest. In some localities (e.g., Tlangkhang Village), people reported that falling bamboo fruits posed a serious hazard when cutting the bamboo culms, whereas, in other places (e.g., around Zamuang), the bamboo fruit was at only an early stage of development during bamboo clearing.

The characteristics and total quantity of fruit produced by *M. baccifera* culms varied according to the disturbance history of sampled stands (Lalnunmawia 2008). Undisturbed stands produced heavier fruits (119.0 ± 7.0 g) than stands subjected to intensive harvesting of bamboo shoots (90.5 ± 7.8 g) or burning (72.3 ± 7.8 g). However, this difference was offset by the production of greater numbers of fruit in burned stands. Total fruit production on 25-m^2 quadrats amounted to 209 kg for undisturbed stands, 195 kg for burned stands, and 64 kg for harvested stands. These estimates of fruit production equate to staggering values of 25.6–83.6 tons per hectare. Estimates of fruit production in other bamboo species range from around 1 kg of seed per m^2 (i.e., 10 tons per ha) in *Bambusa arundinacea* (Gadgil and Prasad 1984) to 3.6 kg per m^2 (36 tons per ha) in *Dendrocalamus strictus* (Janzen 1976: 355). At Zamuang, fruiting of *Melocanna* was observed to be asynchronous on a single culm, with well-developed fruits present on some spikelets while others arising from different nodes were still at the flowering stage. Fruit production from a single plant thus seems to be spread over a period of many months.

One of the most remarkable features of fruit production is the capacity of *M. baccifera* to reproduce directly from the rhizomes (Fig. 3). Even where regrowth of culms in *jhum* areas is countered by continued weeding of new culms, the production of spikelets continues unabated and fruit litters the ground. For all practical purposes, the reproductive episode for *Melocanna* bamboo thus appears unstoppable.

Two other bamboo species underwent gregarious flowering broadly coincident with that of *M. baccifera—Dendrocalamus hamiltoni*, known as *Phulrua* to Mizo people, and *Pseudostachyum polymorphum*, known as *Chal* or *Rawte*. The former species appears to have a 48-year reproductive cycle, synchronized with that of *M. baccifiera*, and is the dominant bamboo species in some parts of Mizoram. The fruits of *D. hamiltoni* resemble grains of rice and develop in clusters of 150–190 grains (Lalsiamliana, personal observation), while those of *P. polymorphum* resemble those of *M. baccifera* but are much smaller, averaging 6 g in weight (Lalsiamliana, personal observation). Fruiting from rhizomes was not observed for either species.

Patterns of crop damage

Exceptionally heavy losses in both *jhum* and irrigated rice fields occurred in the eastern and central parts of Mizoram in 2006-07, and in the western parts in 2008. Figures for total *jhum* and irrigated rice production for Mizoram during each of these years show extreme depressions, with *jhum* production the worst hit—state-wide yields of just over 10,000 tons, compared with >60,000 tons through the preceding five years (Fig. 4). At no time since 1981, when the keeping of state records began, had rice production been so meager. In all areas, losses to maize were even more extreme than for rice, with almost no maize harvested at all during these periods.

These rather impersonal figures were given extra poignancy through interviews with affected farmers. At the village of Vawngawn in Mamit District, farmers had observed rat populations building inside the forest, which in this locality is a mixture of secondary evergreen forest and bamboo forest. In April, rats removed many of the maize seeds immediately after planting, and then consumed all of the surviving early-maturing maize over a period of 4–5 days in June. Later, they destroyed the slow-maturing maize and in August to early September they attacked the rice when it was approximately half-way through ripening, with most *jhums* devastated within a few days from the first signs of damage. Of 52 families in the village, only three managed to harvest any rice, and they obtained only 20% of the expected yield. No one among the people interviewed had any personal experience of crop destruction on such a scale or of such rapidity, but some said that it had happened in the time of their

Fig. 3. *Melocanna baccifera* fruits produced on spikelets growing out of rhizomes in a patch of forest cleared and burned for *jhum* planting. Photographed near Zamuang in May 2008.

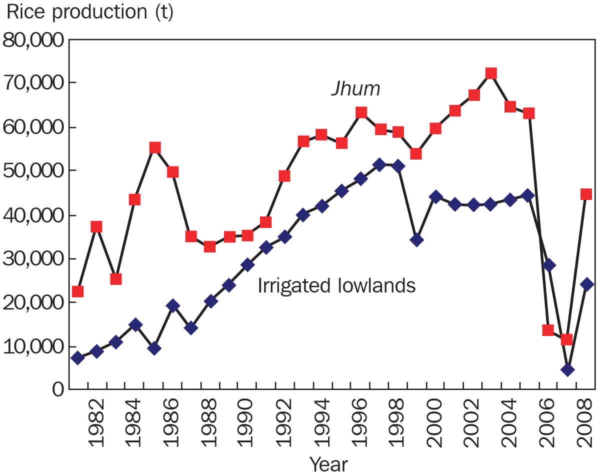

Fig. 4. Total rice production for whole of Mizoram for the entire period of record-keeping, 1981-2008. Production from *jhum* and from irrigated lowland fields is shown separately.

parents, during the previous *mautam*. Testimony of this kind is immediate, dramatic, highly consistent, and completely believable.

At the nearby village of Damdiai, large cropping areas had also suffered extreme damage in late 2007, with few farmers able to harvest any rice. Here, the interviews held in May 2008 focused on details of rat behavior during and after the periods of rapid destruction. Farmers remarked on several unusual aspects. Whereas the usual field rat (*Rattus rattus*, known to Mizos as *Zuin* or *Zuchang*) has a girth equivalent to a man's wrist, making it too large to sit atop a rice tiller, the damage done during outbreaks was said to have been done by smaller animals that could feed on individual grains within a panicle or snip through the stem of the panicle. Fields damaged during these events thus tend to have the heads damaged or removed, with most of the tillers left intact. Some people speculated that this might be caused by birds or even bats. Others claimed to have seen large numbers of small rodents sitting on top of the rice crop and referred to these as *Chaichim* (a Mizo name usually reserved for species of the genus *Mus*). The same group of farmers commented that, in the days after their crops were destroyed, they had dug burrows around the edges of the fields and found large numbers of rats sheltering together. At other times, it would be more usual to find only one rat per burrow or perhaps a mother with young. They also remarked that many rats had moved into the village after the period of crop destruction and that the village rat population had remained high ever since. When asked whether this had caused health problems, one young farmer noted that an old man had dropped dead (quite possibly of shock!) when a rat had leaped onto his back at night.

One of the more perplexing features of these reports of crop damage during *mautam* is the marked variability in outcomes at several scales. Of two villages in close proximity, one might suffer high damage and the other go largely unscathed. And, even within a single field complex, one group of fields might be spared while others, no more than a few hundred meters distant, might be devastated. This variability speaks volumes against simple explanations of crop damage, and encourages a search for mechanisms that involve simple thresholds or, perhaps, divergent outcomes based on conditions at particular critical points in time.

Observations on rat abundance and reproduction

Unusually high rat numbers were reported to the Mizoram State Agriculture Department in every area where *M. baccifera* underwent gregarious flowering. A bounty scheme was introduced to provide supplementary income for farmers affected by rodent outbreaks and to derive some measure of the relative abundance of rodents in different areas. A total of 1,400,000 tails were presented in 2007 for a payment of 2 rupees per tail. A sample of approximately 30,000 of these tails was stored for closer examination. This was done by Aplin in May 2008. The vast majority (probably >95%) of the tails were found to be derived from species of *Rattus*, with smaller numbers derived from species of *Berylmys*, *Leopoldamys*, *Niviventer*, *Mus*, *Tupaia*, and an unidentified squirrel. This particular sample was derived from Champhai District in the east of Mizoram. Tails of the two larger *Rattus* species found in Mizoram (*R. rattus* and *R. nitidus*) were indistinguishable.

Monitoring activities were established in May 2008 near the village of Zamuang in Mamit District (Fig. 5). In this area, some *M. baccifera* stands had undergone gregarious flowering in 2005 but large stands of the same species had commenced flowering in late 2007. By the time of our first visit to this site in mid-May 2005, the culms were laden with maturing fruits (Fig. 6), with a smaller number already fallen to the ground. Monitoring was established at two sites separated by approximately 10 km, with monitoring conducted in both established *Melocanna* forest and in a recently cleared *jhum* field at each site (Fig. 7). Rat activity at each site was monitored by four methods: (1) trapping with baited cage traps, (2) trapping with locally manufactured traditional snares (Fig. 8), (3) setting of wax candle blocks to record chewing activity, and (4) setting of grease-covered tracking tiles to record footprints. For each habitat, the monitoring effort comprised 16 cage traps, 15 snares, 15 wax blocks, and 15 tracking tiles. The snares, tiles, and wax blocks were set at a total of 15 fixed monitoring stations per habitat, with a minimum distance of 20 m between the stations. The cage traps were interspersed between and around these stations and the trap position was changed every few days to optimize capture rates. Grease was used on the tiles because of the high probability of regular, heavy monsoonal rain beginning in May. All cage traps were set on the ground in both forest and *jhum* habitats, whereas the local snares were usually set on fallen culms or logs in the forest and on the ground around the margin of the *jhum* fields. The occurrence of daytime and nighttime rainfall was noted for each day. All captured animals were euthanized and preserved whole in ethanol for examination of reproductive activity. The monitoring was carried out by Mizo farmers after training, and run continuously from 10 June 2008 until 13 August 2008. At this time, it was discontinued due to other demands on the time of the project participants.

The monitoring activity at Zamuang produced very low capture rates in both habitats, with 19 individuals trapped or snared at the two sites (Table 1). At one site, the forest habitat produced eight *R. rattus*, two *Berylmys berdmorei*, one *Tupaia* sp., and one *Herpestes javanicus* (small Indian mongoose). The *jhum* habitat at this site produced 13 *R. rattus*, one *Tupaia* sp., and one *Suncus* sp. (a shrew). At the second site, the two habitat samples were unfortunately mixed but the combined sample included 11 *R. rattus*, two *Tupaia* sp., and one *Callosciurus* sp. (a tree squirrel). At all monitoring locations, the majority of captures were made in early August and the *R. rattus* samples were dominated by immature individuals. The few adult females captured at these sites were either pregnant or showed recent uterine scars. Two immature male *R. rattus* captured in early June had snout to vent lengths of 85 and 90 mm; these were judged likely to have resulted from aseasonal breeding in the early months of 2008.

At both sites, the tracking tiles only rarely recorded rat activity through June and July (Table 2). This pattern changed abruptly with the onset of regular tracking tile activity, with the change occurring on 4 August in both habitats at one site, and on 8 August in both habitats at the other site. Marking of wax blocks also showed a sudden increase at the same time. The increase in rat activity at both sites did not correspond to any change in rainfall pattern and it seems likely that both sites expe-

Fig. 5. Typical Mizoram scenery during a *Melocanna* masting event, photographed near Zamuang in May 2008. Rolling hills in a broad valley system are blanketed with *Melocanna* forest, most of which has flowered and is now in the process of drying. People from several villages conduct their *jhum* agriculture within this landscape. A cleared *jhum* with associated field hut is visible near the center of the image.

Fig. 6. Profuse fruiting in a heavily disturbed stand of *Melocanna baccifera*, photographed near Zamuang in May 2008.

Fig. 7. One of two monitoring sites established in the vicinity of Zamuang, photographed in May 2008. Burned bamboo culms in the foreground show that the *jhum* field was cut from *Melocanna* forest. Masting bamboo forest surrounds the *jhum* field on all sides.

Fig. 8. Mizo field assistants setting a traditional snare in May 2008 as part of the monitoring activities conducted in the vicinity of Zamuang. Fallen *Melocanna* fruits are visible on the forest floor but no germination has taken place, pending the onset of the monsoon.

rienced an abrupt change either in patterns of rodent activity or in rodent abundance at this time. One possibility explored in the narrative of “Rat Attack” is that a highly synchronized onset of breeding activity in *R. rattus*, perhaps stimulated by the first maturation to palatability of *Melocanna* fruits, might lead to the more or less simultaneous emergence upon weaning of a cohort of young, giving a “pulsed” pattern of population increase.

Many *Melocanna* fruits were examined during this period but few showed signs of having been consumed. Those that did tended to be still attached to the culms but positioned close to the ground. A burrow located in bamboo forest near Zamuang was excavated on 24 May 2008. It contained partially consumed *Melocanna* fruits and a

Table 1. Results obtained using four different population monitoring methods at two localities in the vicinity of Zamuang. Bamboo forest and *jhum* habitats were sampled at each locality. Each habitat was sampled at 15 stations (i.e., one snare, one tracking tile, one wax block) per night, with 16 cage traps set in the same general area. The daily results are pooled for each week of monitoring effort. Monitoring at Site 2 commenced 1 week earlier than at Site 1. The values are the number of positive results over the full week of effort, that is, for Week 1 at Site 1, 16 cage traps set for 7 nights (total of 112 trap nights) resulted in one capture. Tiles were scored positive if they showed any small mammal footprints; wax blocks if they showed rodent gnaw marks.

Week	Site 1							
	Forest				*Jhum*			
	Snare	Cage	Tile	Wax	Snare	Cage	Tile	Wax
1	0	3	0	0	0	0	3	4
2	0	1	0	0	0	1	1	0
3	0	0	3	2	0	0	5	5
4	0	0	0	1	0	0	0	0
5	0	0	0	1	0	0	0	0
6	0	1	0	0	0	1	2	5
7	0	0	0	0	1	0	0	0
8	0	1	2	0	1	2	4	6
9	0	6	11	1	5	4	15	5

Week	Site 2							
	Forest				*Jhum*			
	Snare	Cage	Tile	Wax	Snare	Cage	Tile	Wax
1	0	1	6	1	0	0	6	1
2	0	4	6	1	0	0	3	0
3	0	0	3	0	0	0	4	0
4	0	1	0	0	0	0	0	3
5	1	0	1	1	0	0	1	0
6	0	0	0	2	0	0	2	1
7	0	0	3	0	0	0	0	0
8	0	0	2	1	0	0	1	3
9	0	1	6	1	0	1	3	6
10	1	4	14	6	0	2	11	7

Table 2. Details of capture location and date and reproductive status of specimens of *Rattus rattus* captured during fieldwork in Mizoram in 2004 (before *mautam*) and 2008 (under *mautam* conditions). Rats were captured either in *jhum* fields or inside bamboo forest. Codes for the condition of the vagina or testis are TND = testis not descended into scrotum; TPD = testis partially descended into scrotum, epididymal sac small; TPD = testis fully descended into scrotum, epididymal sac large; VIP = vagina imperforate; VP = vagina perforate. Values for lactation and recent scars are N = no; Y = yes. Criteria for assessment of uterine scars are described in Aplin et al (2004).

Date	Habitat	Sex	Weight (g)	Vagina/ testis	Lactation sets	Embryo count	Scar sets	Scar count	Recent scars
Aizawl District									
21-III-2004	*Jhum*	F	91	VP	N	0	0		
23-III-2004	*Jhum*	M	52	TPD					
24-III-2004	*Jhum*	M	77	TPD					
24-III-2004	Forest	M	49	TPD					
24-III-2004	Forest	F	107	VP	N	0	1	7	Y
Zamuang									
24-V-2008	Forest	F	16	VP	N	0	0		
24-V-2008	Forest	M	21	TPD					
24-V-2008	Forest	M	20	TPD					
24-V-2008	Forest	M	42	TPD					
24-V-2008	Forest	M	40	TPD					
24-V-2008	Forest	M	80	TFD					
20-VIII-2008	*Jhum*	F	92	VP	Y	0	1	9	Y
21-VIII-2008	*Jhum*	F	100	VP	Y	10	1	12	Y
21-VIII-2008	*Jhum*	F	93	VP	Y	9	1	7	Y
21-VIII-2008	*Jhum*	F	130	VP	N	0	≥ 4	42	N
Tlangkhang									
25-IX-2010	*Jhum*	M	20	TND					
25-IX-2010	*Jhum*	F	21	VIP	N	0			N
25-IX-2010	*Jhum*	M	70	TPD					
25-IX-2010	*Jhum*	M	19	TND					
25-IX-2010	*Jhum*	M	30	TND					
25-IX-2010	*Jhum*	M	35	TND					
25-IX-2010	*Jhum*	M	32	TND					
25-IX-2010	*Jhum*	F	55	VP	N	0			N
25-IX-2010	*Jhum*	M	40	TND					
25-IX-2010	*Jhum*	F	45	VIP	N	0			N
25-IX-2010	*Jhum*	F	36	VIP	N	0			N
25-IX-2010	*Jhum*	F	40	VIP	N	0			N
25-IX-2010	*Jhum*	M	44	TND					
25-IX-2010	*Jhum*	M	16	TND					
25-IX-2010	*Jhum*	M	22	TND					
25-IX-2010	*Jhum*	F	18	VIP	N	0			N
25-IX-2010	*Jhum*	F	45	VIP	N	0			N
25-IX-2010	*Jhum*	F	44	VIP	N	0			N
25-IX-2010	*Jhum*	F	34	VIP	N	0			N
25-IX-2010	*Jhum*	F	35	VIP	N	0			N
25-IX-2010	*Jhum*	F	45	VIP	N	0			N
25-IX-2010	*Jhum*	M	34	TND					
25-IX-2010	*Jhum*	F	29	VIP	N	0			N
25-IX-2010	*Jhum*	F	30	VIP	N	0			N
25-IX-2010	*Jhum*	M	35	TND					

litter of six furred but as yet unweaned pups of *R. rattus*. Another excavated rodent burrow also contained partially consumed *Melocanna* fruit and it seems likely that fruit was regularly carried into burrows or feeding retreats for consumption, thereby making assessments of rodent activity or seed predation unreliable if based solely on surface counts.

To learn more about breeding activity in forest and *jhum* rat populations, a larger sample of *R. rattus* was obtained in August by snaring and active hunting using nets. This sample included four reproductively mature females with body weights of 92–132 g (Table 1). Embryo and fresh uterine scar counts in these animals were consistent with estimates of litter sizes observed in upland field populations of *R. rattus* in Laos and other parts of Indochina (Aplin et al 2004), with no suggestion of increased litter size in response to either the quality or quantity of food. However, one adult female caught toward the end of the *mautam* period had an unusually large total uterine scar count (minimum of 42), whereas two were found to be at mid-term pregnancy while also lactating and showing recent uterine scars. Although too few individuals were examined to claim any general trend, there is certainly a suggestion that female *R. rattus* were undergoing more or less continuous breeding through the *mautam* event, with immediate postpartum mating perhaps being more common than under nonmasting conditions. Birth of a new litter would presumably cause the female to eject the previous litter of pups from the burrow at a younger age than might normally occur. The combined results from our work at Zamuang indicate that breeding in *R. rattus* during the *Melocanna* flowering and fruiting episode was exceptional in two respects: (1) the likely occurrence of aseasonal breeding prior to the onset of monsoonal rain, and (2) the likely increase in proportion of females that give birth to successive litters. In our view, the first of these is likely to be a consequence of the unusual availability of abundant, high-quality food in the form of *Melocanna* fruit at a time when resources are normally scarce. An early onset of breeding might be enough in itself to account for elevated crop damage during *mautam* years, with the early phase of population growth taking place largely within the forest habitat as suggested by many previous *mautam* theorizers (e.g., Das and Sachan 1980). Sustained access to high-quality food might also account for more closely spaced litters than usual.

Although the rat population at the Zamuang study site was likely undergoing a rapid increase, all of the *jhum* fields in this part of Mamit District were harvested in late August to early September, with relatively small losses (estimated at 10–30%) to rodents. In general, damage to rice plants in these fields was limited to areas around the margin in direct proximity to the bamboo forest. In contrast, maize was often heavily damaged by rats, even when the plants were located in the center of the *jhum*, many meters from the forest margin. From this observation, it was clear that rats were moving purposefully through the field to target particular food items but were likely returning to burrows or other sheltering places within the forest. A few weeks after our last visit to Zamuang, farmers reported finding large numbers of dead rats both in the forest and in the harvested *jhum* fields.

At the nearby village of Tlangkhang in Mamit District, rats were reported to have inflicted heavy damage to a large *jhum* field complex, just prior to the scheduled harvest. These fields were visited on 25-26 September 2008 and the pattern of damage inspected first-hand. Fourteen out of 37 families had lost their entire crop and no family had harvested more than 50%. Damage was visibly severe in many fields, with almost every rice panicle removed at its base. Rice grain was scattered across the ground but the impression was formed that many panicles had most likely been removed from the field. Maize plants in the same fields were also heavily damaged but this attack seemed to have occurred at an earlier time, as we had seen at Zamuang. Some fields in this *jhum* complex had suffered close to 100% damage and there was nothing remaining to harvest. However, other nearby fields suffered less damage and harvest was ongoing at the time of our visit. In these fields, piles of straw provided an opportunity to capture rats that might have been involved in the heavy damage to adjoining fields. A sample of 25 rats was duly obtained through the use of nets. This sample proved to contain exclusively *R. rattus*, all sexually immature individuals, and many of them probably no more than a week or two postweaning. For a field-rat population to be so heavily biased toward very young individuals is, in our view, highly unusual, even for an immediate postharvest sample. On the other hand, we suspect that it is entirely consistent with a population in the final stage of exponential growth, in which the majority of individuals in the population must automatically be very young. These very young rats are presumably the "mice" that farmers reported seeing climbing the rice tillers to feed on the panicle in place or else remove it by snipping through the base.

Questioning of farmers in Tlangkhang suggested that the only major difference in events between there and Zamuang was that the *Melocanna* bamboo had produced seed earlier in Tlangkhang. This fact was brought home when the farmers described having to wear protective helmets during cutting of bamboo culms in February because the *Melocanna* fruit was already large and loose on the culms. Early maturation of *Melocanna* fruit presumably would encourage an even earlier onset of breeding activity in *R. rattus*, with a correspondingly longer time for a population increase prior to harvest. This notion is encapsulated in Figure 9.

As a final observation, we note that the majority of the damage in the most heavily affected fields is probably done by very young rats. With body weights generally well below 50 g, these immature rats are capable of sitting atop rice tillers to either feed on the grains *in situ* or snip the panicle at its base. This is precisely the unusual behavior that many farmers reported seeing during *mautam* and that they tended to attribute to large numbers of mice (*Chaichim*). This is not to deny that mice (*Mus* spp.) may not also undergo a population increase during *mautam* and show the same behavior. However, at least at Tlangkhang there was no evidence for the role of mice, and plenty of very guilty looking baby rats!

Mitigation actions and their effectiveness

The Mizoram government was arguably better prepared (and funded) to meet the crisis of *mautam* in 2006-08 than ever before. The objectives of BACCAFOS (Mizoram Government undated b) represented a comprehensive program of proactive measures and mitigations to reduce the impact of the 2006-08 *mautam* both on the livelihoods

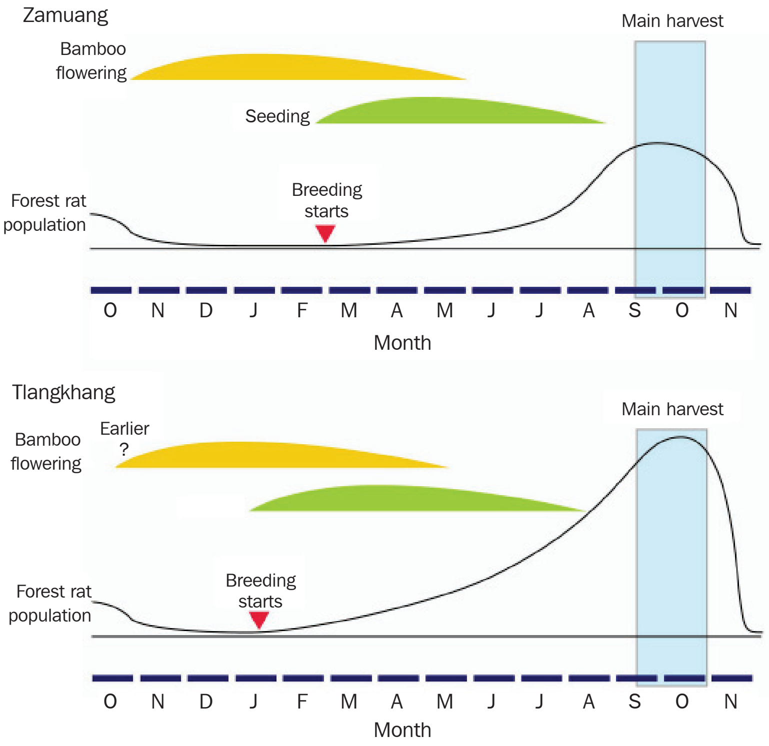

Fig. 9. Graphical summary of a hypothesis to explain variable outcomes under *mautam* rodent outbreaks, based on observations and information obtained from interviews at two localities, Zamuang, where the majority of farmers harvested most of their *jhum* rice, and Tlangkhang, where the majority of farmers lost their entire rice crop to rats. The timing of field preparation, planting, and projected harvest dates were essentially the same between the two localities, as was the flowering time of the *Melocanna* bamboo. The main contrast was in the timing of intensive bamboo fruit production, which was advanced by at least 6 weeks at Tlangkhang. The shape of the curve illustrating postulated growth of the bamboo forest rat population is hypothetical but not unreasonable given knowledge of seasonal population trends in similar agroecosystems in Laos (Aplin et al 2007, Bouangdoupha et al 2009) and the reproductive potential of the main rat species, *Rattus rattus* (Aplin et al 2004).

of Mizo people and on the Mizoram economy. Not surprisingly perhaps, many of the individual objectives were remarkably similar to those developed in the early 1950s and again in the mid-1970s in preparation for the last *mautam* and *thingtam* events. Familiar suggestions include the "need for control of rodent population through proper means," the "adoption of an intensified and diversified cropping system through mechanization," improved "connectivity of market linkage," and assistance for "farmers ... to adopt a more profitable, sustainable, and permanent system of farming." To avoid excessive crop losses, farmers were to be encouraged to adopt "crop diversification for bamboo shoot production," to favor "early-maturing rice and maize," and to plant “alternative crops like ginger, cotton, potato, Jatropha, sugarcane, sweet potato, and oilseeds/pulses.” Compared with earlier planning periods, considerably more attention was paid to the prospective loss of a major bamboo resource in both the short term, following the almost complete die-off of a species of major economic importance, and potentially in the long term if adequate regeneration of the *Melocanna* forest did not occur (Behari 2006). Plans were made for effective use of *Melocanna* forests prior to the flowering interval and fears were expressed that rodent damage to *Melocanna* seed might compromise its future in the region. Others considered the possibility of reducing the dominance of *M. baccifera* through artificial planting of other bamboo species in the period immediately after *Melocanna* flowering (Trivedi et al 2002), so as to produce a more diversified bamboo resource for forestry and one that might not create future havoc through gregarious die-off on such a vast scale.

Despite these multitudinous fears and plans, large areas of *M. baccifera* forest have been undergoing natural regeneration from seed in different parts of Mizoram since 2007 and 2008. And, despite the international focus on the possibility that *mautam* 2006-08 could initiate widespread famine (e.g., Anonymous 2008), a repeat of the 1956-58 experience, the great majority of people came through relatively unscathed. Largely because of the vastly improved road network that now connects most parts of Mizoram, albeit often in torturous fashion, food relief was usually delivered to those most in need, often through cooperative efforts of the government and various NGOs. At a deeper level, however, many people were badly affected by the events and some of the impacts were probably avoidable. In shades reminiscent of the *thingtam* of 1976-77, people who had grown cash crops such as turmeric rather than *jhum* rice were aggrieved that there was no market for their product. Other people who had lost their entire *jhum* rice crop, though grateful for the provision of food relief, expressed concern about their stock of grain suitable for replanting their *jhum* fields with desirable rice varieties for the year after *mautam*. Many problems, both large and small, face the Mizo people as they recover from their most recent experience of *mautam*—but none are able to counterbalance the pervasive sense that something truly remarkable has just taken place.

Understanding *mautam*—Do we have all the pieces of the puzzle?

We believe that the answer to this question is a qualified yes. At one level, the phenomenon of *mautam* is a classic example of a pulsed resource (Ostfeld and Keesing 2000, D’Andrea et al 2007, Yang et al 2008, 2009) and the major outcome is entirely predictable. *Melocanna baccifera*, a superabundant semelparous masting bamboo, is in the very occasional business of producing huge quantities of highly nutritious fruit. *Rattus rattus*, a rodent species characterized by its ecological adaptability and high reproductive potential, is at hand to consume the seed to its temporary great advantage, even though it is first presented at a time of year when food is generally scarce and no breeding occurs. That *R. rattus* should commence breeding in response to this windfall and then subsequently switch its attention to other available food reserves in its local environment, in the form of ripening *jhum* crops, is similarly consistent with its general propensity for opportunism.

One slightly unusual feature of *Melocanna* masting as a pulsed resource for a rodent is its location in a tropical environment—the best-known and most widely accepted examples are otherwise drawn from the deciduous forests of North America (Wolff 1996, McShea 2000) and from the cool-temperate forests of New Zealand (King 1983, O'Donnell and Phillipson 1996). Another is that this example has people thrown in the mix—people with their own propensity for mythologizing, for turning a simple matter into a tangled puzzle, and, sometimes, for oversimplification of a complex story.

Is *mautam* really so simple? As remarked earlier, one of the features of *mautam* that we find particularly striking is its variability of outcomes, even at quite small spatial scales. To our thinking, the next challenge is to better understand this variability. We suspect that the variability is largely produced by differences in the timing of various links in the chain of connection, especially the timing of *Melocanna* seed production relative to the initiation of cropping and harvest. In our simplistic version of things, earlier seed production means more time for the rat population to increase under the steady supply of food and, hence, greater risk of crop destruction prior to harvest. This notion is eminently testable but to do so with *M. baccifera* will now require a long wait. Alternatively, it might be tested by examining the biological interaction between various other species of masting bamboos and black rats, focusing on bamboo species with contrasting phenology. To do so could shed valuable light on the general issue of variability in ecological systems based on pulsed resources. More importantly perhaps, it might also lead to the development of predictive capability in regard to the numerous other species of semelparous masting bamboos found in both Asia and elsewhere in the world, many of which seem capable of generating rodent outbreaks on time frames much shorter than *M. baccifera* but with similarly dramatic consequences for human livelihoods.

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Notes

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The Chittagong story: studies on the ecology of rat floods and bamboo masting

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Rodent population outbreaks due to the 50-year cycle of gregarious flowering and seed masting of *Melocanna baccifera* were first noted in the Chittagong Hill Tracts (CHT) of Bangladesh during the crop production cycle of 2008. The wave of flowering has steadily moved southward through the region each year, with seed masting still occurring in some areas of the CHT during 2010. Because of a lack of surveillance, it is not yet known whether all *Melocanna* bamboo forests across the region have now initiated flowering. Ecological surveys carried out during the masting event have provided some preliminary evidence that nearly all rodent species are able to exploit *Melocanna* bamboo seeds as a food resource, with nearly 30% of the seed fallen in forests damaged by rodents. Breeding potential of the predominant species found, *Rattus rattus*, appears to confirm that aseasonal breeding occurs due to the abundant supply of bamboo seed during masting events. These preliminary results obtained from ongoing research surveys are discussed in the context of the management response to the regional famine triggered by the severe crop damage caused by rodent population outbreaks.

Bangladesh is a country well used to catastrophic events. Rising sea levels, monsoon floods, and cyclones can have dramatic consequences for the world’s most densely populated nation. Bangladesh’s location on the alluvial floodplain basin of the Ganges and Brahmaputra River Delta makes for a land of fertile, easy-to-cultivate soil. Nearly 70% of the country’s land is under active cultivation, with more than 50% of the nation’s 160 million people predominantly involved in agriculturally based livelihoods (CIA 2009). In this context, it should perhaps come as no surprise that rodents are a major agricultural pest in Bangladesh. Rodent species endemic to South Asia include *Bandicota indica* and *Bandicota bengalensis*, with *B. bengalensis* the more serious and dominant pest affecting rice production (Mbise 2002, Buckle and Smith 1994). Most damage by *Bandicota* spp. to rice production occurs relatively late, with nearly all damage happening between seed onset and ripening. *Bandicota* spp. are tremendous hoarders, cutting and carrying panicles of rice into their extensive burrow systems, thereby damaging much more than they eat (Islam and Hossain 2003, Islam et al 1993). Irrigated and rainfed agricultural production are typically asynchronous and many farmers plant 2–3 crops per year on their land, which would hypothetically provide conditions in which rodent populations could sometimes reach epidemic proportions through sustained breeding. However, despite quite serious chronic rodent damage to rice and wheat production (5–20% on average) throughout the country (Poché et al 1981, 1982), little evidence suggests that any rodent population outbreak phenomenon is occurring in the alluvial floodplains of Bangladesh. Annual monsoon flooding events, which put large parts of Bangladesh temporarily under water, are likely to help "reset" the rodent population by restricting harborage sites for the highly fossorial *Bandicota* spp., which have a relatively short breeding session at harvest times (Srihari and Govinda Raj 1988).

Rodent outbreaks are, however, documented to occur in one particular region of Bangladesh, the Chittagong Hill Tracts (CHT). The CHT can be found in the southeastern part of the country, sharing very little in common with the rest of Bangladesh. This is a semi-autonomous region in the foothills of the Himalaya, culturally of Tibeto-Burman ethnicity. This mountainous area of Bangladesh is sparsely populated, settled by 15 ethnically and linguistically distinct tribes following Buddhism, Hinduism, Animism, or Christianity but rarely Islam. The lush tropical jungle landscape remains largely intact and undisturbed in comparison to across the border in the Indian state of Mizoram, with its much higher human population and resource needs. The sparse indigenous population of the CHT has led to much immigration by the Bengali majority of Bangladesh in search of land. These settlers have been accused of committing genocides against the minority tribal people. Bengalis now make up approximately 50% of the total CHT population of 1.5 million people and, despite a peace accord signed between the Bangladeshi government and the Hill Tribes, civil unrest continues and is largely attributed to unresolved problems with resource rights and land ownership (Aziz-al Ahsan and Chakma 1989, Rashiduzzaman 1998). Economic development of the CHT has been hampered by these political disputes, most exemplified in the region's poor roads and communication infrastructure, with many mountain communities accessible only by long journeys by boat or on foot. Partly through this, the livelihood of the CHT people is almost entirely one of subsistence agriculture. In common with farmers in upland habitats across southeastern Asia (Roder 2001), farmers practice a form of rotational slash-and-burn agriculture as a way of dealing with hillside erosion and soil fertility loss, moving crop fields each year to allow the land to recover (Borggaard et al 2003, Gafur et al 2003).

Bamboo forest is a major component of the CHT upland landscape as well as forming the foundation of people's livelihoods and culture. The CHT is part of a larger eco-region that incorporates Mizoram and Tripura states of India to the north and Chin and Rakhine states of Myanmar to the east of the CHT. This mountainous eco-region is dominated by the bamboo species *Melocanna baccifera*. The cyclical gregarious flowering and seed masting of this bamboo species are well described in Aplin and Lalsiamliana (this volume). As has been described in the case of Mizoram, rodent outbreaks in the CHT are linked to this 50-year cycle of bamboo flowering/seed production. However, there appear to be some interesting disparities between what is known to have occurred in the recent outbreak in Mizoram and in the CHT, and these comparative differences will partly form the basis of discussion in this chapter. As is the case throughout this *Melocanna* eco-region, there is little historical information or references during previous bamboo flowering events from 50 and 100 years ago to draw upon to help inform the 21st-century outbreak, which continues in Bangladesh at the time of this book's publication. A list of relevant references regarding gregarious bamboo flowering can be found in a scientific assessment report prepared for the United Nations Development Programme (Belmain et al 2008). The authors of this chapter have been fortunate enough to have received funding to carry out some basic ecological research since early 2009 while the bamboo flowering and masting have been ongoing in the CHT. Preliminary data and conclusions from our research are presented, which offer scientific support of linkages between *Melocanna* seed masting, rodent population growth, and severe rodent damage to rice crops.

Rats, famine, and politics

In Bangladesh, the rodent outbreaks happening in the CHT have been referred to as "rat floods." This vivid terminology is culturally appropriate given the routine nature of water floods in Bangladesh, where the consequences of flooding on people's livelihoods are utter devastation and total crop loss. Flowering of bamboo was first observed in the northern parts of the CHT next to the Mizoram border in 2007. Communities in this area were reporting that rats were flooding out of the bamboo forest and into their rice crops during their next cropping season of 2008, with many of the same consequences as a water flood, with CHT farmers losing nearly 100% of their crops to unusually high numbers of rats.

Hill Tribe communities are economically and culturally tied to *Melocanna* bamboo, and they certainly were aware of the impending bamboo flowering, rat flood, and regional famine phenomenon through ancestral stories and village elders who were alive during the event 50 years ago. The CHT had also been prewarned about the current flowering event through communication with people across the border in Mizoram, where the event first started. Despite this forewarning, there was little to no preparation by local or national governments in Bangladesh. There are several reasons for this, namely, the infrequency of the event, little to no awareness about the event among policymakers and the general population, poor historical documentation (the country of Bangladesh did not exist 50 years ago), the famine affects only marginalized minorities, and possibly that natural and man-made disasters are so common in Bangladesh that the rat floods were not considered to be such a big problem. Perhaps the most important reason for the lack of preparation was that no one really knew what should be done in response to a rat flood or how severe any famine would be. As most of the local CHT population was not alive at the time of the last bamboo flowering, fear and apathy have ruled decision-making processes, with subsistence farmers having little knowledge or experience on how to save their crops from rat floods.

Once reports of severe food shortages in the CHT started to be heard in the local and national press, UN agencies, particularly the United Nations Development Programme and the World Food Programme, began to mobilize emergency relief efforts to feed communities in the rat flood–affected areas. The UN agencies also commissioned a number of fact-finding missions to establish what was happening on the ground, whether people really were without food, and what the subsequent effects were on health and food security (Zohir 2008, MSF 2008, HKI 2008a, b, Belmain et al 2008). All of these missions showed that the Hill Tribe communities were severely and unexpectedly malnourished, with local food supplies dangerously low. Turning anecdote into fact was extremely challenging for a number of reasons, but particularly due to the extreme remoteness of affected communities preventing the collection of accurate evidence from many areas that were assumed to have been worst affected. Variable access to communities had major impacts on information gathering, particularly related to socio-cultural demographics. The easiest places to reach in the CHT are the lowland areas around rivers, which are, by and large, settled by immigrant Bengalis. As *Melocanna* bamboo is not widespread in these lowland areas, there were few reports of rat floods in Bengali communities in the CHT. Hill Tribes in the upland areas where *Melocanna* is most preponderant are generally more remote, often requiring several days of hill walking to reach. Although several UN-sponsored reports established beyond doubt that the famine was real and was having major consequences for the nutritional health status of Hill Tribe communities, mixed messages on the food security status of CHT farmers continued, with perhaps unaffected Bengali farmers more readily listened to by local and national government than the Hill Tribe farmers who lost everything. Although UN agencies have worked hard to deliver emergency food relief, surveillance of the rat flood severity was complicated by a poor understanding of the phenomenon. Many affected communities have probably not received sufficient help. UN agencies operating in Bangladesh have not lost sight of the historical context of these rodent outbreaks, particularly how the famine 50 years ago encouraged militancy and civil war in Mizoram (see Aplin and Lalsiamliana, this volume), a socio-political situation that is not highly dissimilar to the current situation in the CHT, where the famine has been largely ignored by the Bangladeshi government and fighting continues between Bengali and Hill Tribe groups.

Studies on bamboo and rodent ecology

Much of what we know about the periodicity of bamboo flowering can be found in Daniel Janzen's 1976 review on "Why bamboos wait so long to flower" (Janzen 1976). As Janzen admits, hypotheses of seed predation driving the evolution of long supra-annual intervals in flowering and seed masting remain largely untestable (Silvertown 1980, Lalonde and Roitberg 1992). However, predation still remains the most likely explanation, which finds common scientific ground with tree species such as oak and beech that also undergo seed masting events with clear links to surges in seed predator populations (Clotfelter et al 2007, King 1983, Wolff 1996, Ostfeld and Keesing 2000, McShea 2000). In the case of *Melocanna baccifera*, anecdotal information suggested that flowering and seeding are not fully synchronized, with some annual variation of when a particular bamboo stand starts to flower, the subsequent timing of seed production, and the amount of seed produced. These factors would have major implications for rodent populations, particularly in the amount of time in which bamboo seed is available to promote rodent breeding. Early and abundant seed fall could mean that rodents can breed over more generations before the food runs out, leading to larger rodent population outbreaks.

Carrying out systematic research on this phenomenon has fortunately been possible since early 2009. The objectives of this research program have been to understand the linkages among bamboo seed production, rodent breeding rates, and habitat use of different rodent species. As this work is ongoing, we are able to present only some preliminary data and key observations. Ecological surveys on *Melocanna* bamboo seeding have initially been carried out in three large bamboo forests (>5 hectares) found near the villages of New Eden (22°02.947N, 092°25.186E), Mun Lai (22°02.125N, 092°25.362E), and Batsliang (22°06.570N, 092°27.596E) of Ruma Upazilla, Bandarban District (Fig. 1). Seed fall was measured monthly from 30 × 1-m^2 plots. Line

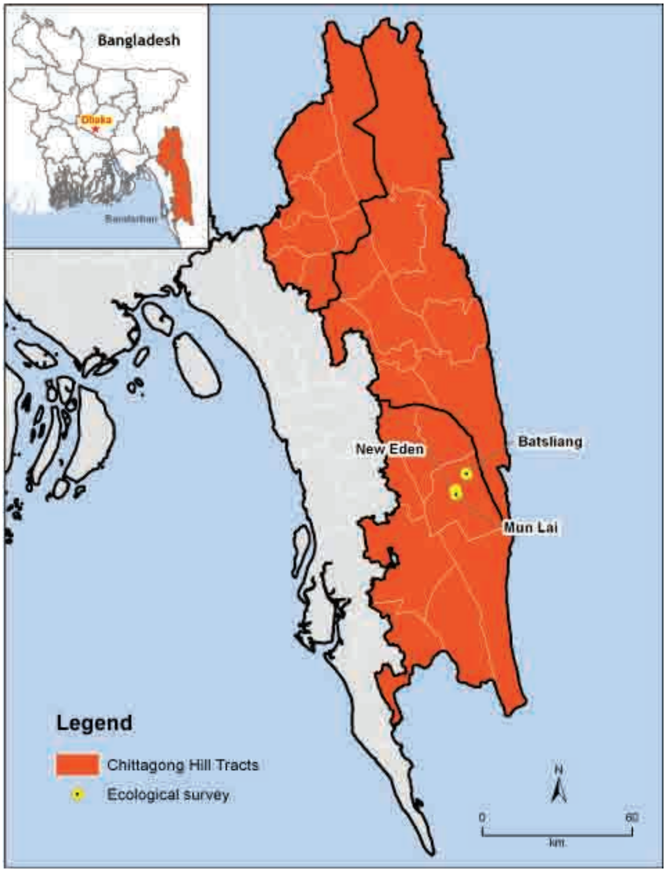

Fig. 1. Sites where ecological surveys have been carried out.

transects of 10 plots were established in each of the three forests with plots 10 m apart. The same plot was used for assessment each month. During each month, the number of bamboo seeds fallen was counted, noting the number of damaged and germinated seeds. From this, the timing of seed production and its fall to the ground followed the general expected patterns (Janzen 1976), and nearly 100% of the seed had fallen by the end of August (Fig. 2). From this study, we can confirm that the bamboo seeds are damaged by rats, with many seeds (approx. 30%) showing characteristic gnawing by rodent incisors. This rodent damage is documented to occur both before and after seed germination, continuing until the seed is virtually used up through germination. Further studies during the 2009-10 flowering cycle are ongoing to determine what percentage of fallen bamboo seed is physically removed by predatory animals. We have been able to confirm through observation that different *Melocanna* bamboo forests do not all follow the same flowering patterns. In some forests, different proportions of the same forest flower over a 2–3 year period, whereas other forests flower in their entirety in a single year. The reasons for this variation are by no means clear, but we speculate that this is related to different clonal varieties of *Melocanna* that may be intertwined in the same forest patch. Understanding the reasons for this variation in the commencement of flowering is beyond the remit of our research, and this requires further investigation to determine the importance of genetic and environmental cues

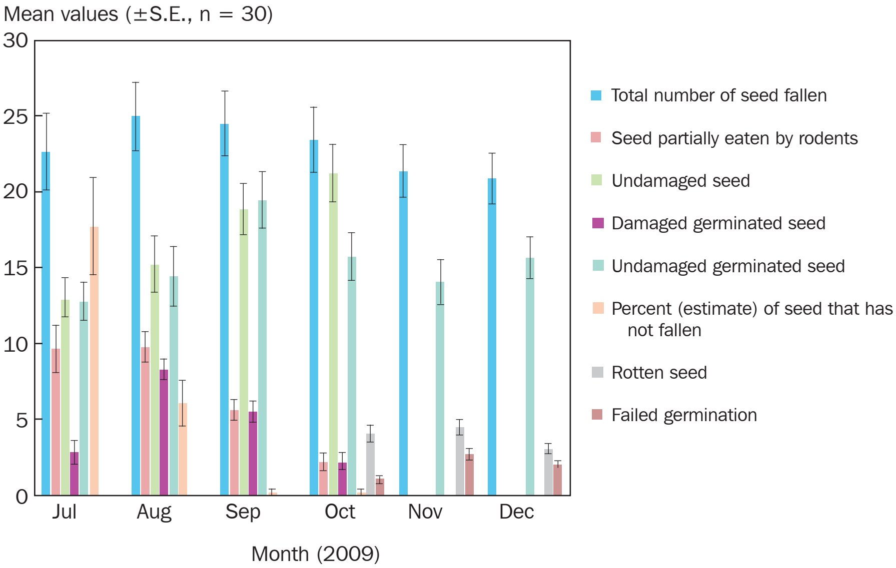

Fig. 2. *Melocanna baccifera* seed-fall survey carried out in three different forest localities of Ruma Upazilla, Bandarban District, Chittagong Hill Tracts. Survey transects in each locality consist of 10 1-m^2 plots, 10 m apart, that are assessed on a monthly basis, counting the number of seeds within the plot and noting their condition with regard to germination and damage by rodents.

that might explain our observations. Our data also suggest that seed fall timing may be influenced by altitude, with lower altitudes showing a delay in the flowering and seed production process. We are planning further surveys during the flowering/masting event of 2009-10, which may inform this process and explain potential variation in seed production. If confirmed, this may help explain why some of the more remote communities of the CHT, which tend to be at higher altitudes, appear to be worst hit by rat floods.

Trapping of rodents has been carried out using a number of different methodologies and trap types. Generally, we have been trapping in four different habitats: (1) bamboo forests, (2) crop fields, (3) inside houses, and (4) outside around villages, using a mixture of kill traps, single-capture cage traps, multicapture live-traps, and Sherman traps. All captured animals are processed to collect breeding and taxonomic data and preserved in 70% ethanol for in-depth taxonomic work at a later stage. From >1,000 rodent specimens collected, the diversity of rodent species is high (Table 1), with *Mus musculus* dominating inside houses and *Rattus rattus* dominating in forest and field habitats. With the exception of the bamboo rat, *Cannomys badius*, all rodent species maintained for short periods of time in captivity readily ate bamboo seeds when supplied alongside other foodstuffs such as banana, rice, or coconut. From this, we can reliably presume that bamboo seeds that have been observed to be damaged by rodents in the forest are, indeed, being consumed by the rodents. Further food-choice test studies are planned, particularly with *R. rattus*, to understand potential linkages between bamboo seed production and rodent breeding. We expect most

Table 1. Proportion of small mammals captured (1,050 specimens from March 2009 to January 2010) in three different localities of Ruma Upazilla, Bandarban District, Chittagong Hill Tracts, and the habitats from which they have been captured. Taxonomic identifications are preliminary, particularly within the *Mus* and *Rattus* species complexes, which will be confirmed through molecular typing at a later date.

Species	Percentage of captures	Bamboo forest	Crop fields	Inside houses	Outside around village
Berylmys bowersi	0.5	√	√		
Cannomys badius	0.2	√	√		
Mus boduga	0.1		√		
Mus caroli	1.0		√		
Mus cooki	0.1		√		
Mus musculus	39.0			√	
Mus terricolor	0.2		√		
Rattus nitidus	0.4	√	√		
Rattus rattus	55.0	√	√	√	√
Rattus sikkimensis	0.1		√		
Suncus murinus	3.4		√	√	√

rodent breeding in the CHT to occur over the monsoon months of June-September in "normal" nonflowering years, with virtually no breeding due to lack of food outside of this season (Aplin et al 2003). Preliminary data collected on the breeding of *R. rattus* suggests that aseasonal breeding is occurring during the bamboo masting event, with breeding females making up 30% of those captured in March 2009, ranging up to 80% of females caught in July 2009 (Fig. 3). Trapping surveys will continue in flowering/masting bamboo forests during 2010, and we hope to compare these results to breeding rates of rodents trapped in nonflowering bamboo forests over more than one season.

We believe that the data we have already collected provide conclusive evidence of linkages between bamboo masting and rat floods. Although flowering is largely gregarious, variation is considerable, with some forests taking up to 3 years to fully flower. This variation will affect the amount of seed produced in a single season, with some areas potentially suffering over several years when the forest continues to flower, potentially leading to even larger rat populations. Nearly all rodent species found in the CHT have been observed to eat bamboo seeds and a large percentage of bamboo seed in forests is damaged by rodents. We expect to complete this ecological picture through further surveys aimed at showing changes in rodent abundance relative to the development of bamboo seed production, and in comparison to other nonflowering/nonmasting habitats.

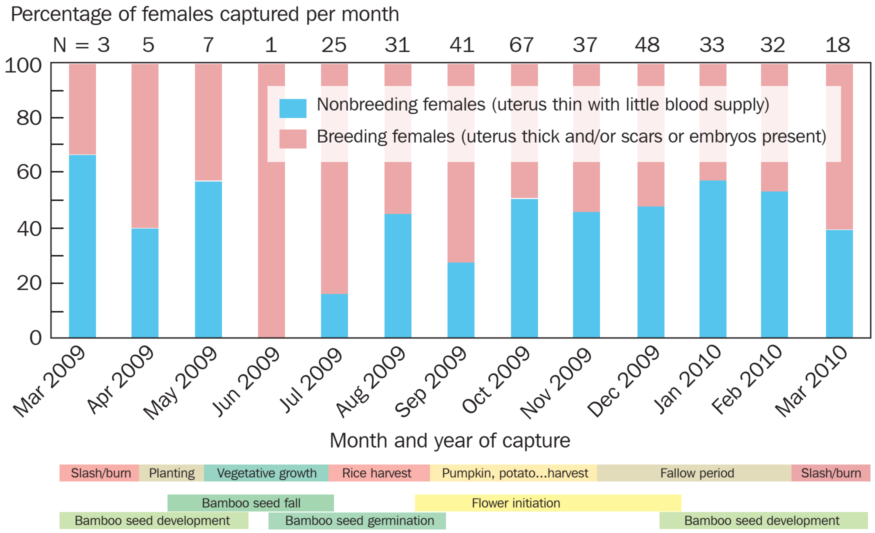

Fig. 3. Proportion of breeding and nonbreeding female *Rattus rattus* caught in three different forest localities of Ruma Upazilla, Bandarban District, Chittagong Hill Tracts. Sample size values at the top of each column vary, particularly as low numbers of captures were made over the months of March to June 2009. Colored bars at the bottom relate this to the CHT cropping cycle and the *Melocanna* bamboo flowering and seed development process.

Damage assessment and management options

During our ecological field surveys, we observed very high damage to rice and maize before harvest caused by rodents during the harvest of 2009. Our observations support the widely stated figures by farming communities of losses exceeding 80%, with many fields suffering nearly 100% loss. Most farmers practice intercropping of rice with maize, potato, cassava, and pumpkin, and all crop types have experienced very high damage. A systematic review of crop damage caused by rat floods is the subject of Ahaduzzaman and Sarker (this volume) and, hence, this aspect will not be covered in this chapter. It is mentioned only in the context that agricultural damage is very significant for CHT farmers and begs the question that management of rat floods is an essential issue to discuss.

If you ask CHT farmers what they do to manage rat floods and the damage caused, they will desperately throw their hands up and say there is nothing they can do. Rodenticides of any kind (chronic or acute) are not widely available in the CHT, and their cost is generally beyond the economic capacity of the subsistence farmers in the region who typically do not invest in any agricultural inputs (e.g., fertilizer, insecticides, herbicides). Managing large population outbreaks of any pest animal is not easy in terms of physical delivery or financial cost-benefit because the problem requires coordination over a very large scale to have any impact. In the case of mouse plagues in Australia, large aerial baiting with zinc phosphide has been shown to have some effect at limiting agricultural damage (Brown et al 2002), but there are few other examples for which population outbreaks of rodents have been successfully managed.

Despite CHT farmers' professed lack of rat flood management, further investigation has revealed that CHT farmers are not entirely despondent. Farmers do understand the basic ecology of the phenomenon whereby rats start to attack their crops when the bamboo seed starts to run out. Therefore, they understand the importance of getting their rice harvested as early as possible in order to preempt rat movements out of the forest. In this regard, the majority of CHT farmers have shifted their rice cropping toward more early-ripening varieties than what they would normally do in non-rat-flood years. In normal years, farmers would plant greater than 70% of their fields with late-ripening varieties (harvested in late September), which are higher yielding. During rat-flood years, however, the percentages of early- and late-ripening crops are inverted, with most farmers planting 70% of their fields with early-ripening varieties (harvested in early August). Unfortunately, the yield of the early rice crops is often 50% less than with a late variety. Farmers make the trade-off for a lower yield to avoid more unpredictable risks of rat-flood damage to late-ripening varieties, giving them some control over their food security. Thus, even if farmers escape direct losses from a rat flood, they are left with much less rice to eat.

Some CHT farmers construct fences around their crops, which have rat traps embedded in the fence to kill rats attempting to migrate into their field (Fig. 4). These fences are constructed of bamboo and may contain dozens of kill traps, which operate via a weight-sensitive trigger that releases a log that crushes the rat. These fences

Fig. 4. A rodent trap-barrier system traditionally made by Hill Tribe farmers to prevent rodent migration into their cropping fields. Bamboo is woven together to make the fence, which is interspersed roughly every 2 to 5 meters with single-capture kill traps. Traps are triggered by the weight of the rat, which releases a heavy log that crushes the rat.

are used in nonoutbreak years to help manage chronic rodent damage in crop fields. Considerable investment is made in these fences as they are highly labor-intensive to make. Unfortunately, as each trap can kill only one rodent, the current design is likely to have minimal impact on crop damage during rat-flood years. As part of our research program, we have been investigating whether these fences can be optimized and possibly used to protect crops during rat-flood years. Our design principles are similar to those first developed and promoted as community trap barrier systems for controlling rodents in lowland irrigated rice production systems (Singleton et al 1998). Instead of bamboo, the optimized fence is made of plastic sheeting, and the rat traps within the fence are simple multicapture cage traps (Fig. 5). These modifications should make the barrier more impermeable to rats and allow more rats to be removed from the environment on a daily basis. We will evaluate the cost-benefit of these optimized fences over the next two years.

Apart from these palliative actions discussed above, it is debatable whether there are other cost-effective ways to sustainably manage rat floods due to *Melocanna* bamboo masting. Recent experience from Mizoram, which was certainly better prepared than the CHT during the current outbreak (GoM 2007), would suggest that little else can be done beyond assisting communities through shorter-duration rice varieties, food aid, and livelihood support to help them through the difficult rat-flood years. However, adequate understanding of the ecological principles may mean that management resources can be better targeted at the communities most likely to suffer the worst rodent outbreaks. We believe that some aspects of the damage caused by

Fig. 5. An optimized rodent barrier using principles similar to those of trap-barrier systems developed in lowland irrigated rice crops. The entire farmer field acts as a lure crop, with the fence stretching around the perimeter of the field, interspersed with multicapture cage traps. Dying *Melocanna* bamboo forest can be seen at the bottom of the hill.

these rodent outbreaks can be much more effectively managed, for example, rodent-proofing household rice stores to prevent further losses to rice that is harvested and organizing communities to coordinate rat-killing campaigns over large enough scales to affect the rat population, tools and skills that will serve CHT farming communities well even in non-rat-flood years.

Conclusions

There is now broad agreement among rodent ecologists about the basic ecological principles driving rodent population outbreaks through bamboo masting events (refer to chapters by Aplin et al and Htwe et al, this volume). Variation is considerable in outcomes between localities, with some farmers experiencing much more serious crop losses than others. The variable losses experienced are related to the developmental rates of the rice varieties planted, the proximity of rice fields to bamboo forests, and the size of the bamboo forests relative to the cropping areas. Because of a lack of suitable cropping areas and a shortage of land that is allowed to be planted by the authorities, many CHT farmers are forced to plant their rice crops in areas recently slashed of bamboo forest, or adjacent to bamboo forests, thus greatly exacerbating the damage to their rice fields. This is because, once flowering of the bamboo has begun, cutting the bamboo down does not stop the flowering process, which is fed by the underground rhizomes of the bamboo plant. In these cases, bamboo flowers and subsequent seeds emerge directly out of the ground. Farmers remove some of the bamboo seed developing in the rice field, but they do not remove it all as they hope to one day have a new bamboo forest in its place. In this situation, which appears to be quite common, bamboo seeds are directly available within the rice crop, making it relatively easy for rats to switch from eating bamboo to eating rice.

Farmer outcomes are affected by other sources of ecological variation, which we are aware of, but do not fully understand yet. As described in Chapter 1, we know that the initiation of *Melocanna* flowering occurs as a wave in a northeastern to south-western direction. However, micro-variation exists within this process, with some areas flowering synchronously all in one season, and others taking 2 to 3 years to complete. Genetic and environmental factors may account for this variability, and this may be influenced by selective planting of bamboo by human populations. Some insights into this process can be made by comparing Mizoram and the CHT. Human population density is much higher in Mizoram than in the CHT, which has inadvertently led to a decrease in the amount of natural indigenous forest remaining in Mizoram, where much of the land is now covered in *Melocanna* bamboo. In comparison, the CHT has a much lower human population and more natural forest, and areas of *Melocanna* bamboo forest are relatively sparse and patchy. We speculate that the destruction of indigenous forest and the expansion of *Melocanna* bamboo are directly related to human population expansion, agricultural intensification, and particularly faster rotation of slash-and-burn agriculture, and the promotion of bamboo as an economic forest commodity. The large contiguous *Melocanna* forests of Mizoram seem to promote more synchronous flowering, sweeping through an area in a single year. The more patchy *Melocanna* forests of the CHT are not so tightly synchronized, more often taking 2 to 3 years to fully flower. Whether this difference is related to genetic clonal differences or potential environmental cues is currently unknown. CHT communities in areas where the bamboo flowers over more than 1 year do complain of exacerbated damage in subsequent years, arguably because rodent populations do not fully crash between the flowering cycles. As farmers continue to harvest various crops up to November (when new *Melocanna* flowers start to initiate), gaps without food resources in the environment are very short when new portions of the same forest subsequently flower. It is unlikely that we will be able to confirm this phenomenon of multiannual rodent population growth within our current research studies.

We also know that variation exists in the amount of seed produced per hectare and when the seed matures and falls to the ground. Some preliminary information from the CHT suggests that altitude plays a role in dictating the precise timing of when *Melocanna* flowers start to initiate in an area, leading to some delay in seed production in lower-altitude forests compared with higher-altitude forests. Farmers in more remote hilly areas of the CHT appear to be worst hit by rat floods, which may be because the *Melocanna* seed falls earlier in the season at these higher altitudes, giving more time for the rodent population to grow. Further surveys are required to confirm this effect of altitude, and a number of other factors, both genetic and environmental, may contribute to the variation in seed production.

Understanding the ecological and anthropological factors driving the temporal and spatial variation of bamboo masting events will not stop the entire process and prevent rat floods, but it may lead to effective prediction of rodent population outbreaks. Armed with such information, targeting limited resources to assist communities becomes more effective. Managing the socioeconomic outcomes of this 50-year event on people's livelihoods remains a daunting task, for which we hope to be better prepared next time.

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The Chittagong story: a regional damage assessment during a rodent population outbreak

S.K.M. Ahaduzzaman and Santosh K. Sarker

Rodent outbreaks, locally known as rat floods, are an acute socioeconomic problem in the Chittagong Hill Tracts (CHT) of Bangladesh. When rat floods happen, rodents suddenly become the number-one problem affecting the livelihoods of local people. All food crop types are severely damaged, with the exception of turmeric, *Curcuma longa* (Zingiberaceae), and bitter gourd, *Momordica charantia* (Cucurbitaceae), which are largely avoided by rodents. Ninety percent of the farmers surveyed indicated that damage to their field crops during rodent outbreaks was between 80% and 90%. Surveys carried out by the United Nations Food and Agriculture Organization with farmers throughout the CHT showed that all farmers believed that rat floods occurred whenever bamboo flowering events occurred. Farmers did not control rats in their cropping fields during nonoutbreak years because rodents were not normally a cause of significant damage. A majority (86%) of the farmers did nothing to try to control outbreaking rodent populations, perhaps because they had no routine experience in rodent management. Nearly all farmers (98%) indicated that they had never received any technological training on rodent management and had no easy access to rat poisons or traps in their local markets. Profound economic hardship was exacerbated by the large-scale bamboo die-off caused by the mass bamboo flowering. Many farmers sold their allotments of bamboo when flowering was first noted. However, the sudden glut of bamboo reduced market prices. Although market prices for bamboo have since increased, farmers have no bamboo to sell until it has regenerated from the newly germinated seed, a process that can take many years. The survey indicated increased incidences of dysentery, diarrhea, and fever diseases during rat flood years in comparison with nonoutbreaking years. The implications of the damage caused by rat floods for the livelihoods of CHT communities and potential ways to mitigate these effects are discussed.

Keywords: rodent damage, surveillance, impact assessment, rural appraisal, food security

Scientific background on rat floods in the Chittagong Hill Tracts (CHT) of Bangladesh has been provided in Belmain et al (this volume) as well as more widely about the same *Melocanna* flowering phenomenon occurring in India (Aplin and Lalsiamliana, this volume) and Myanmar (Htwe et al, this volume). Although some effort to assess the impact of rat floods in Bangladesh has been carried out under the auspices of the

United Nations Development Programme (UNDP) and the World Food Programme (WFP) (Belmain et al 2008, HKI 2008a, b, MSF 2008, Zohir 2008), these surveys have tended to focus on food security outcomes, looking at food availability and food needs of communities affected by rat floods. Similarly, food availability studies have been recently conducted in Laos by the WFP (2009). What has been lacking throughout the entire South Asian region is a systematic review of the damage being caused by rat floods, particularly to agricultural production. The current cycle of rodent outbreaks started in 2007-08 in Bangladesh. During the first year, damage to field crops by rodents was reported to be up to 80–100%. The unusually extreme losses seemed incredible to many people living elsewhere in Bangladesh outside of the CHT. The central government did little to assist the CHT, and it could be argued that this was partly due to the lack of authoritative evidence. Most information circulating about crop losses appearing in the popular press was anecdotal, and this may have encouraged skepticism regarding the levels of food insecurity. Official data on crop loss are necessary to inform public policy as a means of highlighting the scale of the damage and thereby mobilizing appropriate resources to counteract its negative impacts.

The present investigation was undertaken by the Food and Agriculture Organization of the United Nations (FAO), with the following objectives: (1) to identify the rodent species and assess the extent of damage that could be attributed to rat floods in the affected areas, (2) to identify the possible reasons for the massive rat infestations, and (3) to determine the assistance that is needed for implementing effective rodent control measures to protect farmers' crops and household materials in the CHT districts.

Methods

Selection of study areas

The Chittagong Hill Tracts comprise 24 upazilas (a Bangladeshi administrative unit, roughly equivalent to a county), which are spread across three districts (Rangamati, Khagrachari, and Bandarban). Of these, 16 upazilas reported rat flood occurrence since the 2007-08 agricultural season. These rat floods were documented through a combination of surveys done by the UNDP, the WFP, and the government Department of Agricultural Extension (DAE) (Fig. 1). These reports are largely based on observation and discussion with some affected communities and are by no means comprehensive or systematic. We selected four of these upazilas for our study: Barkal (Rangamati), Dighinala (Khagrachari), Roangchari, and Thanchi (Bandarban). Upazilas are further subdivided into unions, and four unions were selected from each upazila: Barkal Sadar, Aibachara, Bhushanchara, and Baraharina from Barkal upazila; Nowapatang, Alikhong, Taracha, and Roangchari Sadar from Roangchari upazila; Remakri, Tindu, Thanchi Sadar, and Balipara from Thanchi upazila; and Boalkhali, Merung, Kabakhali, and Dighinala Sadar from Dighinala upazila. In the CHT region, a union contains roughly 15 to 20 village communities and approximately 2,000 to 3,000 people. Our stratified regional selection represents approximately 10–15% of the rural indigenous ethnic population living in upland areas of the CHT.

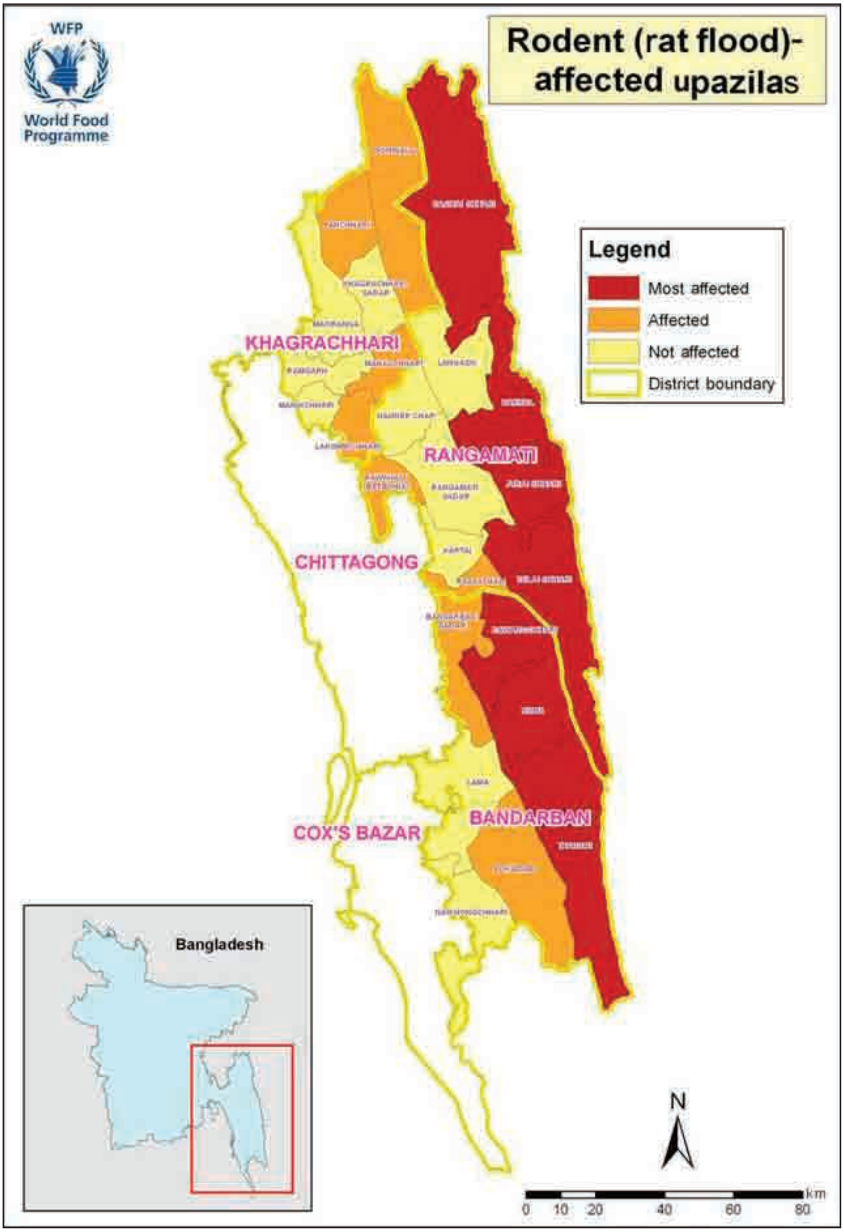

Fig. 1. Regional map showing which areas of the Chittagong Hill Tracts are affected by rodent outbreaks. Reprinted with permission from the United Nations World Food Programme.

Damage assessment and density index

Rice is the dominant crop produced, accounting for more than 90% of staple production, with some maize and potato also produced. Fresh rodent damage was assessed in rice-based upland fields. Damage data were collected from 20 randomly selected fields per upazila (5 per union, giving 80 fields in total). We counted the number of cut and uncut rice tillers within a 1-m^2 plot, with six plots per rice field. As rat damage is typically uneven on hillside plots, stratified random sampling of fields was carried out with sampling near the top, middle, and bottom of the slope (2 plots × 3 positions = 6 plots). As rodent damage is cumulative over time, these fresh damage assessments made at one point during the maximum tillering stage allow us to calculate potential yield loss. Burrow systems that contained fresh soil and signs of rodent movement were counted as active burrows. All active burrows in a field were counted from the same fields assessed for damage.

Rodent identification

Trapping in different habitats (fields, forests, and houses) in each union was done by using 50 kill traps, with two consecutive trap nights per union location. Traps were generally spread equally across the three habitats, but we were not able to strictly monitor this as trapping was done by the local communities. The total number of trap nights was 800 (50 × 2 nights × 2 unions × 4 upazilas). Captured rodents were weighed, measured, sexed, and reliably identified to at least the genus level and often to the species level. Captured rodents were processed for breeding data to assess maturity and evidence of current and/or historical breeding (e.g., uterine condition and size of previous litter).

Household interviews

A total of 200 upland farmers were interviewed (50 households per upazila) using structured questionnaires. From each union, 10–15 upland farmers were randomly selected on the basis of population, with each individual asked the same 33 questions. Themes within the questionnaire included the bamboo flowering relationship with rodent outbreaks, severity of damage (both crop field and postharvest storage in their house), rodent species, existing rat management system, cropping system, crop production level, and their future needs. The questionnaire was usually delivered in Bengali to facilitate consistency among farmers' responses. However, because some upland farmers do not speak Bengali, the questionnaire was translated into local languages as required. Questionnaires were completed between 24 August and 30 September 2009.

Key informant interviews

Key informants were drawn from several different local organizations operating in the CHT. These institutions included the Chittagong Hill Tracts Board (CHTB), the Department of Agricultural Extension (DAE), the Bangladesh Agricultural Research Institute (BARI), the Cotton Development Board (CDB), District and Upazila Parishad chairmen and vice-chairmen, Union Parishad chairman and members, and the village headman and *karbari* of each locality visited. A total of 118 personnel were interviewed and each key informant was individually asked about the problems caused by the rat flood, the relationship between bamboo flowering and rodent population outbreaks, crops and stored food damage, and their views on potential long- and short-term crop production and diversification programs.

Focus group discussions

Eight group discussions were organized, two per upazila. The aims of these facilitated discussions were to identify the major impacts of the rodent outbreaks, perceptions and awareness of the problem, and future needs. A total of 185 community members were involved in the discussions, approximately 20–25 people per group. The participants were drawn largely from local school teachers, community leaders, women leaders, farmers' group leaders, and NGO personnel operating in the locality.

Results and discussion

There was little difference in responses obtained from individual questionnaires, focus group discussions, and key informant interviews. Everyone knew that rat floods occur every 40–50 years. All households interviewed contained members who were more than 50 years old and who remembered the previous rat flood, and 10% of the households had members who claimed to remember two previous rat flood cycles. All the respondents believed that rat floods occurred whenever mass bamboo flowering events occurred. People from the CHT were clear in their understanding of the process of rat flood development, with 95% of the respondents indicating that rodents ate the bamboo flowers/seeds to increase their numbers. About 60–70% of household respondents were able to sell their flowering bamboo, with 30–40% unable to find a buyer. The land from which flowering bamboo was removed was subsequently used to plant crop fields in 80% of cases. In this situation, those interviewed partly removed bamboo seeds from their fields during crop cultivation, but intentionally left some bamboo seed in order for the bamboo forest to regenerate. The remaining 20% of the land cleared of flowering bamboo was left fallow for the regeneration of the bamboo forest. Out of 200 household respondents, 66% considered rodents their most important pest, with 20% indicating wild pigs, 12% insects, and 2% diseases. Insects and diseases of crops are considered the most important problems in nonoutbreaking years in the CHT. Farmers in the plains of Bangladesh routinely rank rodents the second most important agricultural pest after insects (Sarker 1993).

Rodent species found in the CHT

A total of 415 rodents were captured over 800 trap nights (52% trap success). Preliminary analysis suggests that six rodent species were found: *Berylmys bowersi, Rattus rattus, Rattus exulans, Bandicota bengalensis, Mus musculus*, and *Mus* sp. (most likely *Mus caroli*) (Table 1) . The most cosmopolitan and abundant species was *Rattus rattus*, comprising 80% of the sample in all localities. *Bandicota bengalensis* was not found

Table 1. Species captured from a regional survey carried out from 24 August to 30 September 2009. Trapping was carried out in two unions per upazila, with two trap nights per session and 50 traps set per night (800 trap nights, 52% trap success).

Upazila (district)	Species	Number caught	Percentage per locality
Barkal (Rangamati)			
	Berylmys bowersi	7	6.4
	Mus musculus	7	6.4
	Mus sp.	3	2.7
	Rattus exulans	5	4.5
	R. rattus	88	80.0
Thanchi (Bandarban)			
	Berylmys bowersi	8	7.5
	Mus musculus	6	5.6
	Mus sp.	2	1.9
	Rattus exulans	5	4.7
	R. rattus	86	80.4
Roangchari (Bandarban)			
	Bandicota bengalensis	5	5.6
	Mus musculus	6	6.7
	Mus sp.	3	3.3
	Rattus exulans	4	4.4
	R. rattus	72	80.0
Dighinala (Khagrachari)			
	Bandicota bengalensis	7	6.5
	Mus musculus	8	7.4
	Mus sp.	2	1.9
	Rattus exulans	4	3.7
	R. rattus	87	80.6

in Barkal and Thanchi upazilas but was present in Roangchari and Dighinala upazilas. Similarly, the species of *Berylmys bowersi* was present only in Thanchi and Barkal upazilas, which are relatively closer to the Mizoram and Myanmar border area. The majority (65%) captured were female breeding adults.

Preharvest damage assessment

The extent and severity of field damage depend on the crop stage and rat population. Rodent damage to upland rice crops was highest (16–18% per ha) in the rice fields of Remakri, Tindu, Alikhong, and Merung unions from Bandarban and Khagrachari districts. In Barkal upazila (Rangamati District), the highest damage was in the unions of Bhushanchara (10.8%) and Baraharina (10.4%) (Table 2). Assessments in Rangamati were done about 2 weeks earlier at the rice tillering stage, which may explain the slightly lower damage assessment figures. It was not possible to carry out yield loss assessments at the time of harvest; however, as rodent damage at the tillering stage is cumulative over time, our damage estimate would represent a yield loss that is 3–4 times higher (Singleton et al 2005). In other words, our damage assessments would estimate average yield losses of 40–65% at the time of harvest.

On average, there were 26 active rat burrows per hectare in upland rice fields (Table 2). Despite relatively lower damage levels, the highest count of active rat burrows (50 burrows in a field) occurred in Baraharina union. Preharvest rodent losses to maize and potato crops were not measured, but personal observation suggests that similar losses occurred to both crops as well as to most fruit and vegetable crops.

Household survey

The majority of household respondents (90%) suggested that all the major crops of rice, maize, sesame, sweet gourd, cucumber, cotton, pineapple, and banana were severely damaged during rat outbreaks. Minor crops such as bringal, chili, aroid, ash gourd, bottle gourd, yard-long bean, yam, lady’s finger, melon, and vegetables were moderately damaged. Only two crops, turmeric and bitter gourd, were not significantly damaged by rats. These answers are in stark contrast to responses about rat damage in nonoutbreaking years, with all respondents saying that rodent damage was moderate to low for all crops grown. All respondents indicated that severe damage occurred during outbreaks to stored foods, and moderate damage was also noted to household structural materials. Rat damage to stored food was considered a problem in nonoutbreak years, although to a lesser extent (Table 3).

Upland farmers routinely collect and preserve their own seeds at harvesting time for future planting. This seed is very important to plant the next season’s crops and minimal damage can be tolerated by farmers. On average for each household, 94 kg of seed material was damaged by rats. This loss is approximately 75% of all seed stock stored for next year’s crops. Many respondents (60%) indicated that severe rat damage occurred to late-ripening rice varieties, whereas 52% said that severe rat infestation occurred to early-ripening rice varieties as well (Fig. 2). Regional variation was apparent, but it is not clear whether this is related to differences in rodent populations or different rice varieties that may be preferred in different areas.

Table 2. Mean percentages of rice tillers showing fresh rat damage in upland rice fields. These measures were taken at one point in time only. (SEM = standard error of the mean.)

District	Upazila	Crop stage	Number of fields surveyed	Mean damage (%) per hectare (± SEM)	Mean number of active burrows per hectare (± SEM)
Rangamati	Barkal	Tillering	20	9.8 ± 0.41	21.4 ± 1.30
Bandarban	Thanchi	Ripening	20	16.5 ± 0.46	27.9 ± 1.72
	Roangchari	Ripening	20	15.2 ± 0.36	26.2 ± 1.77
Khagrachari	Dighinala	Ripening	20	15.4 ± 0.52	28.4 ± 1.92
CHT average			80	14.2 ± 0.36	26.0 ± 0.87

Table 3. Upland farmer perceptions on rat damage levels during rodent outbreaks and during normal nonoutbreak years.

Type of damage	Damage during rat outbreak year (%)	Damage during normal non-outbreak year (%)
Field crops	80–90	15–20
Stored foods	30–40	10–12
Seeds	50–65	8–10
Bamboo die-off	98–100	None

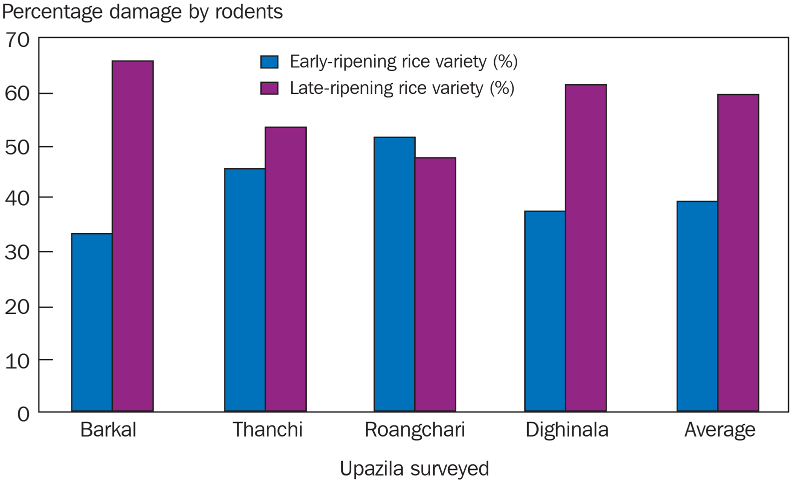

Fig. 2. Effect of the development speed of rice varieties on perceived levels of rat damage.

The annual cost of rodent damage, combined for both stored produce in houses and crops in fields, was estimated to range from about US$100 to $200 per year (Table 4). Generally, subsistence upland farmers sell very little of their rice and other crops because of a poor regional market infrastructure in the CHT. However, if these losses could be prevented and actualized into real cash, the losses would represent 25–50% of household annual income, which is estimated at $400 for the average hill tribe farmer (www.iwgia.org).

The majority of respondents recognized that rodent populations peaked around the time of rice harvesting, with high numbers continuing into the postharvest period (Table 5).

Most respondents (86%) did not control rats in crop fields before harvest, 88% of the respondents said that they did not know techniques for controlling rats in crop fields, and 98% said that they had never received any training or information about rodent management. All of the respondents indicated they were aware of different species of rodents, generally categorizing them into big and small varieties (rats and mice). Of the few farmers who did try to control rats, a variety of different control methods were used (Table 6). Poison use, particularly in house areas, was noticeably higher in Roangchari and Dighinala upazilas. This higher use may be related to relatively better market access and road infrastructure.

All respondents were clear on their needs for technical assistance to deal with their rodent problems. The majority wish to be provided with tools and knowledge to control their own problems as opposed to cash provided through bounty programs or for rat poisons. Across the upazilas, the respondents were unanimous in asking for training, traps, and rat-proof stores, with less than 10% of the respondents asking for cash handouts. All of the respondents indicated that they needed external assistance to help their families recover from the rat floods. The types of assistance needed fell into five categories (Fig. 3). The most important need across all upazilas surveyed was training in crop production.

The large majority of households surveyed believed that disease outbreaks had increased because of rat floods. More than 70% of the respondents said that fever and diarrhea diseases were higher during outbreaks of rodent populations (Fig. 4). Increased water and food contamination by rats was also seen as a bigger problem during rat floods.

The severity of rat damage during the rat flood years resulted in an 80–100% loss of farmers' upland rice crops. The second most important food items for upland communities are vegetables such as cucumber, pumpkin, and white gourd, which were also severely damaged (>60%). Wild foods such as bamboo shoots also declined because of the bamboo die-off, and this contributed to food security problems, particularly during the rainy season when household stocks ran out at a time when bamboo shoots were normally plentiful. All respondents noted that food prices in local markets were higher, and although this meant higher prices for any food items they sold, they generally had no spare food to sell (Table 7).

Table 4. Economic cost of rat damage as estimated by upland farming households (lowest and highest values reported in each district). Average annual income for upland farmers in the CHT is officially estimated at $400 (www.iwgia.org).

Upazila	Cost of rat damage per year during storage (in $)	Cost of rat damage per year to field crops (in $)
Barkal	42–85	64–120
Thanchi	56–120	78–137
Roangchari	49–79	56–117
Dighinala	54–92	65–111
Average cost	51–94	66–121
Total cost per year	117–215	

Table 5. Upland farmer responses as to when rat populations are highest.

Upazila	During harvest of crops (%)	During rainy season (%)	During winter (%)	Month of highest infestation in houses	Month of highest infestation in field
Barkal	85	15	0	Nov.	Oct.
Thanchi	78	22	0	Oct.	Sept.
Roangchari	80	20	0	Oct.-Nov.	Sept.
Dighinala	76	24	0	Oct.-Nov.	Sept.

Table 6. Rodent control methods employed by upland farmers in crop fields and houses.

Methods	Barkal (%)		Thanchi (%)		Roangchari (%)		Dighinala (%)	
	House	Field	House	Field	House	Field	House	Field
Nontoxic rat baiting and hand killing	45	26	52	30	35	26	38	40
Trapping	26	17	21	8	24	16	22	23
Poison baits	14	10	12	11	35	16	40	17
Cats	15	–	12	–	18	–	13	–
Trap barrier	–	–	9	–	–	–	–	–

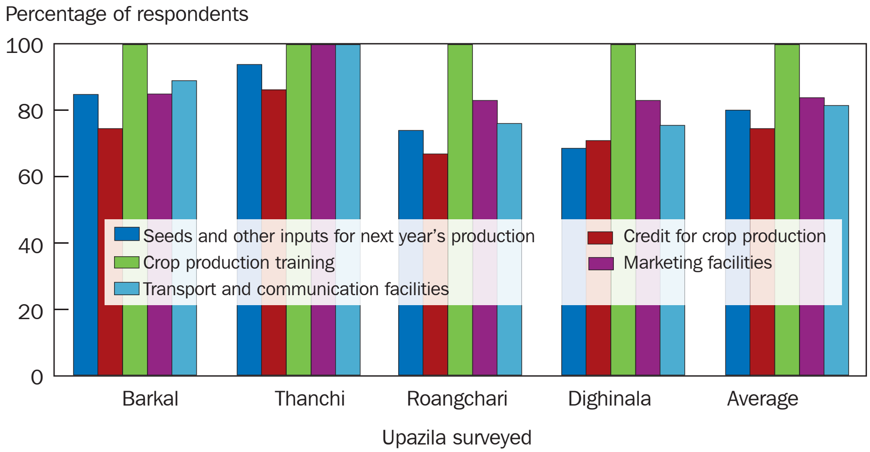

Fig. 3. Perceived assistance needed for recovery from rat outbreaks.

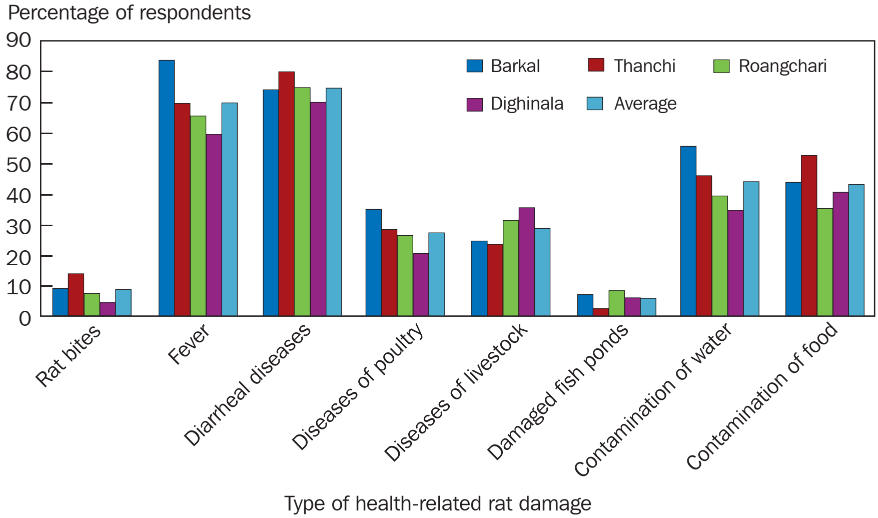

Fig. 4. Perceived problems with human and livestock health due to rodent outbreaks in upland communities.

Table 7. Impact of rat floods on food availability and food security, percentage of respondents answering "yes."

Impacts of rat flood	Barkal	Thanchi	Roangchari	Dighinala
Less food availability in the market	88	90	77	72
Price of food is rising	97	94	88	70
People still have enough food to eat	20	27	82	60
Less seed in the market	74	65	70	58
Changes affecting lives or short-term risks to lives	60	55	64	57

Beyond the agricultural and health impacts of the rat floods, most respondents noted other direct and indirect socioeconomic impacts of the bamboo flowering event. These included increased snake populations and increased incidences of snake bites, a lack of bamboo for household construction materials and furniture and handicraft industries, a lack of bamboo to export, and wild pigs damaging crops. It was not clear whether pig populations had increased or were simply searching wider for food as bamboo shoots became scarce.

The majority of the household respondents (55%) said that they had tried to overcome the problems caused by rat floods by increased collection of forest products (Fig. 5). Becoming indebted or having to spend family savings were also common strategies. Increased planting of nonfood crops such as turmeric was not generally noted as people realized it would be difficult to sell large quantities for a good price.

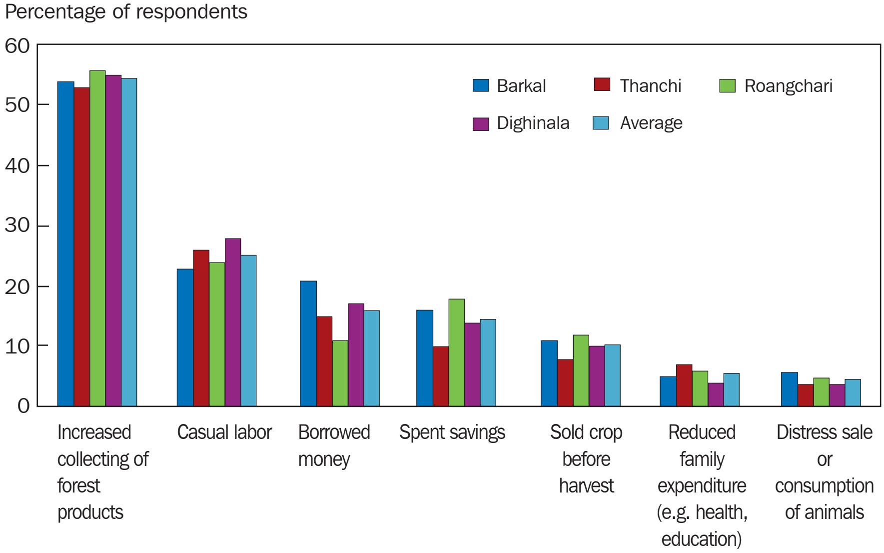

Fig. 5. Ways by which farmers tried to overcome problems caused by rat floods.

Conclusions

Increased surveillance of the rat flood problem needs to be established. The Bangladesh government DAE is best equipped to conduct such surveillance; however, guidelines and protocols need to be developed for DAE field staff to enable them to carry out monthly surveys on rodent populations and rodent damage, particularly focused on remote upland communities of the CHT. A community-based rodent management action plan in collaboration with different government organizations and NGOs needs to be formulated and implemented (see Belmain et al, this volume). Furthermore, the DAE should plan to create training courses targeting DAE and NGO sector institutions for capacity building, awareness raising, and technological knowledge dissemination to enable these institutions to provide similar knowledge and technology to communities affected by a rat flood. There should be a long-term plan for the dissemination of modern agricultural technologies that are appropriate for upland environments, with an emphasis on the diversification of crops and income streams for hill tribe communities. Strong market linkages through improved infrastructure at the local and regional level will help build resilience within communities to cope with the socioeconomic impacts of rat floods on their livelihoods.

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Notes

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Rodent population outbreaks associated with bamboo flowering in Chin State, Myanmar

Nyo Me Htwe, Grant R. Singleton, Aye Myint Thwe, and Yee Yee Lwin

From 2007 to 2009, rodent outbreaks in upland rice cultivation were reported in Chin State, Myanmar, after a widespread bamboo masting event. These outbreaks led to severe losses to crops and stored food, and resulted in severe food shortages. The dominant bamboo species in the Chin hills is *Melocanna bambusoides* and it began to flower in 2007 in three townships. A second bamboo species, *Bambusa polymorpha*, flowered in 2007 in one township. Generally, the highest rodent infestation occurred 2 months after the seed-shedding stage of bamboo. However, the flowering pattern in bamboo forests in southern Chin State was different from that in northern Chin State. In Paletwa Township, southern Chin, the bamboo forest flowered synchronously and all villages experienced rodent outbreaks for only one season. Thirty villages in the southern part of Paletwa were affected in 2007 by rodent damage after the bamboo flowered, and 77 villages in the northern part of Paletwa were affected in 2008 by rodent damage. In contrast, bamboo flowered sporadically around the villages in northern Chin State and these villages faced rodent outbreaks in two seasons. Farmers reported that rodent infestations wiped out crops in their village within 1 week. In 2007, one township, with 1,227 households, representing 6,749 people, faced a food shortage. In 2008, 5,286 ha of rice fields in 105 villages and 260 ha of maize in 16 villages were destroyed by rodents. In 2008, 31% of the population in three townships experienced food insecurity. In 2009, about 99 ha of rice fields in 51 villages were attacked by rodents. *Rattus rattus* was the most common species in and around rice fields during the outbreaks. For the first time in Myanmar, there is clear documented evidence of a direct association between bamboo mast events and rodent population outbreaks.

Keywords: rodent outbreaks, bamboo mast, Myanmar, Chin hills, rice, maize

Rice is the staple food of Myanma people, providing 68% of their daily calories (IRRI 2009). The annual consumption rate is 200 kg capita^{-1}, the highest rice consumption rate in the world (Shrestha and Bell 2002). Fortunately, Myanmar has a favorable natural environment and abundant cultivatable land for rice production. Therefore, Myanmar can produce more than enough rice for national consumption and it also has potential to regain its position as a major world rice exporter. However, Myanma farmers face many constraints to reach the potential yield of rice in lowland irrigated landscapes. Yields are affected by the infrastructure for irrigation, limited investment, pests and diseases, labor scarcity, low-quality seed, weed problems, and limited access to fertilizer (Myint and Kyi 2005). Climate change is also a constraint to rice production in Myanmar, particularly extreme weather events. Myanmar was the second most affected country in the world for weather-related crop loss from storms, floods, cyclones, and heat waves from 1990 to 2008 (Harmeling 2009). An example is the devastation caused by cyclone Nargis in May 2008, which produced a 6% drop in the country's rice production (IRRI 2008).

In Myanmar, rodents are considered the second most important pest in rice production by farmers, who state that rodents cause the most damage to their crops (Brown et al 2008). Chronic rodent damage in irrigated rice ranges from 3% to 5% annually and we have recorded losses up to 18% (Nyo Me Htwe, unpublished data). Acute rodent damage occurs episodically in rainfed cropping systems, where losses of greater than 50% are not uncommon; however, there are very few documented reports of these events and the impacts on rural communities have not been quantified until recently (see Singleton et al, this volume). Since 2007, rodent outbreaks in upland rice cultivation have been reported from different parts of Chin State after a widespread bamboo masting event. Reports from both the media and NGOs have highlighted severe negative effects of the rodent outbreaks on food security of the Chin people (FAO 2008, 2009). A widespread bamboo masting event is an unusual situation for Myanmar, happening approximately every 50 years (Singleton et al 2010). Prior to 2007, the link between outbreaks of populations of rodents and the flowering of bamboo had been documented only in folklore. Scientific studies have been lacking on whether there is a direct link between the flowering and fruiting of bamboo and rodent outbreaks.

In this chapter, we will present data from focus group discussions with farmers and key informant interviews of government extension staff conducted twice over 18 months: first in October 2007 in Paletwa Township, southern Chin State, and second in March 2009 in Hakha, Htalang, and Phalum townships, northern Chin State. We will report on the timing of the outbreaks in relation to bamboo fruiting in an upland region of Chin State, and document the impact of the outbreak, the main rodent species involved in outbreaks, and the response of farmers to the outbreak. We will conclude by considering possible proactive actions for local government and farmers in preparation for future events of bamboo masting.

Geography and agriculture of Chin State

Chin State is located in the west of Myanmar and consists of two districts, Phalum and Mindat. The state borders with Bangladesh (Chittagong Hill Tracts) and Mizoram, India, to the west, Manipur to the north, Rakhine State to the south, and Sagaing and Magway divisions to the east (Fig. 1). It is a mountainous region with limited transportation links and a low population density. Chin State remains one of the least developed areas of Myanmar, with very high poverty (FAO 2009).

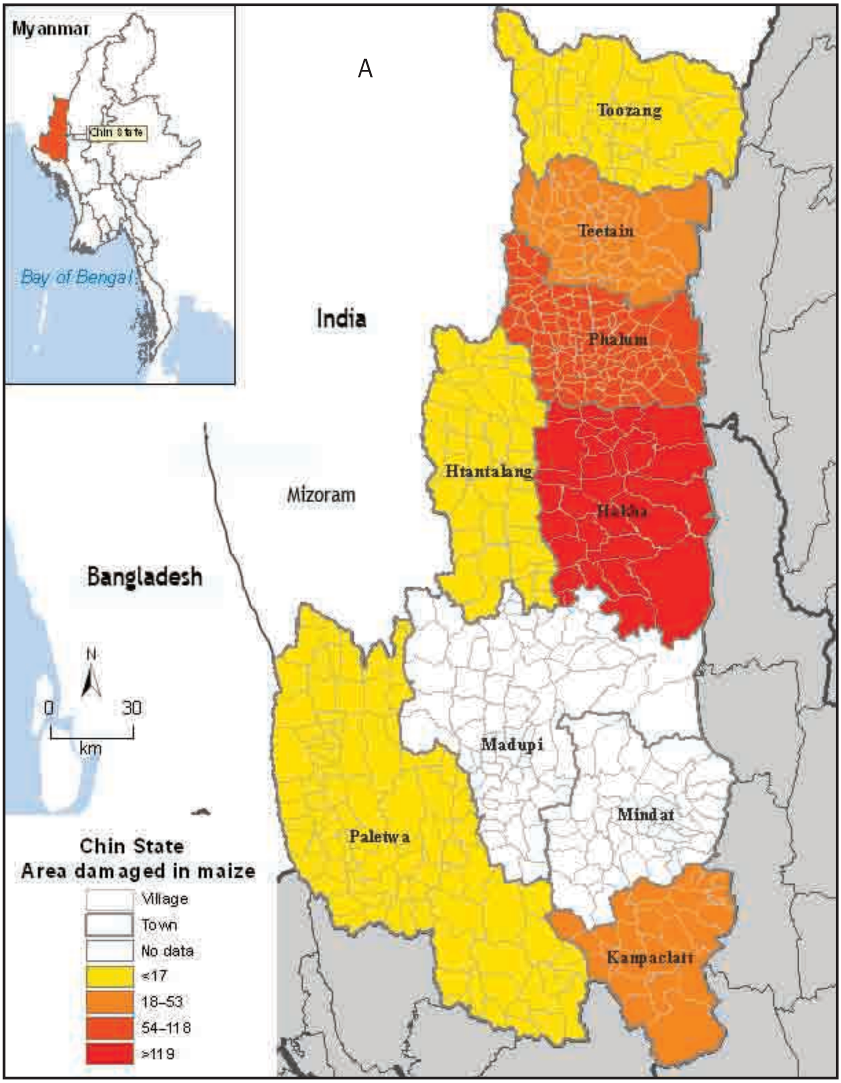
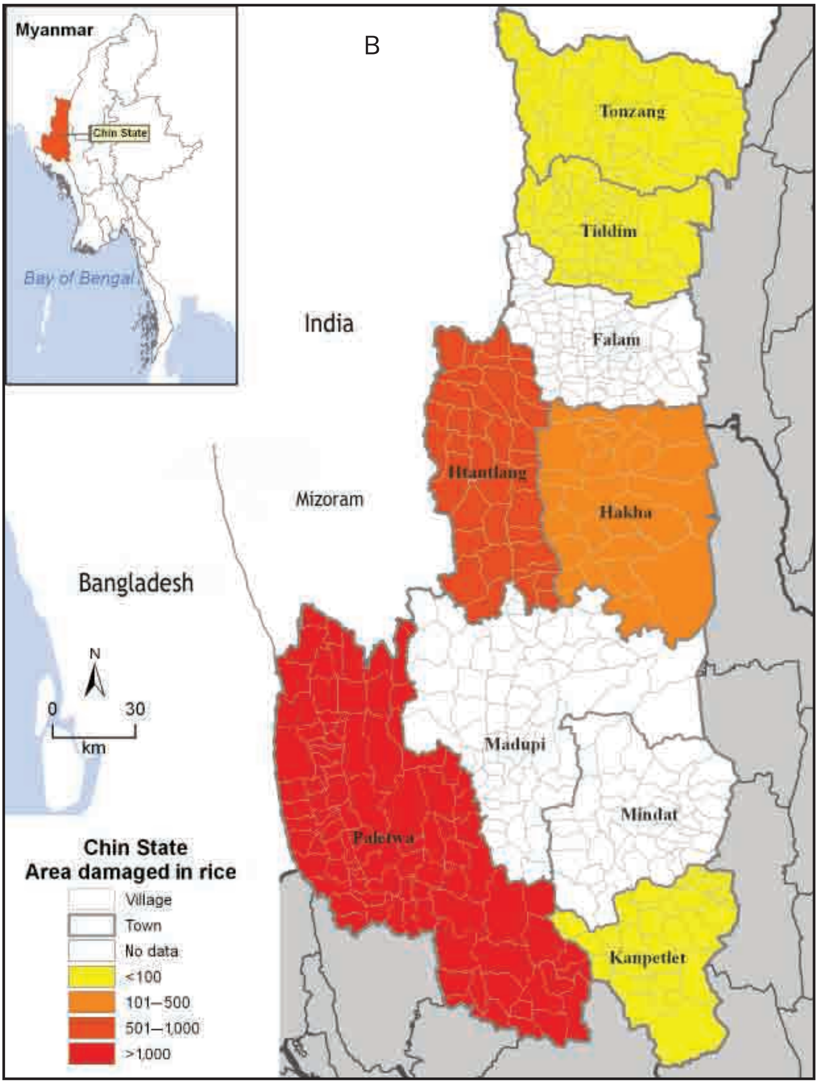


Fig. 1. Map of Chin State and rodent outbreak areas (2007-09) in (A) maize and (B) rice.


B
Myanmar
Chin State
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N
0
30
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Tonzang
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Falam
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Madupi
Paletwa
Mindat
Kanpetlet
Chin State
Area damaged in rice
Village
Town
No data
<100
101–500
501–1,000
>1,000

Table 1. Documented bamboo flowering of *Melocanna bambusoides* since 1909.

Years	Intermast period	Location	Source
1909-13	–	Rakhine	Tun (1998)
1933	–	Different places in Rakhine	Tun (1998)
1960	51	Chin	Tun (1998)
2007-early 2010	47	Chin	Myanma Forestry Department (1987), personal observation
Early 2009-early 2010	49	Rakhine	Myanma Forestry Department, personal observation

In Chin State, 97% of the land is covered with forest, 2% is occupied by water bodies, and only 1% can be cultivated for agricultural and horticultural crops (Myanma Agriculture Service 2004). Upland cultivation provides the main opportunity for Chin people to generate not only their food but also their family income. In the wet season, the main crop grown in upland cultivation is upland rice and horticultural crops. The latter are grown as their main cash crops. Maize is grown as a staple in some regions in northern Chin State. In the dry season, only a small percentage of farmers grow rice on alluvial soil near rivers; these lands are flood-prone during the rainy season.

The Chin people rely on upland rice for their daily calorie needs. However, upland rice cultivation faces many constraints such as low-yielding varieties, relatively high input costs, degradation of soil fertility, pest infestation, drought, and limited access to agricultural extension staff to learn of new technologies and practices. For these reasons, upland rice production is not able to meet local demand so people have to import rice from neighboring states. For example, Paletwa Township annually imports 6,135 t of rice from Rakhine State.

Massive population outbreaks of rodents occur about every 50 years in the Chin Hills (Table 1). This is called “Mautam” or “Maudam” by the Chin people; “Mau” is the Chin’s word for bamboo and “tam” or “dam” means rat famine. The people of northern Myanmar’s Kachin State coined “Yu Li Hku” for this phenomenon, meaning famine caused by rats. There have been some recent unsubstantiated reports of rodent outbreaks in Kachin State, a region where the ability to document outbreaks is lacking. In Chin State, rodents do not regularly cause large losses to rice crops; however, during outbreak years, losses commonly surpass 50%, with some farmers losing 100% of their upland crop (see the section on impacts of rodent outbreaks).

Background information on study sites

Paletwa

Paletwa is located in the southern part of Chin State and it borders with Mizoram

(India) to the south, Chittagong Hill Tracts (Bangladesh) to the southeast, and Rakhine State, Myanmar, to the north. It is a mountainous area and farmers practice two crop cultivation systems: shifting and slashing cultivation, and lowland cultivation. Upland rice, sesame, taro, ginger, and pineapple are grown as shifting and slashing cultivation. Sesame is grown as a mixed cropping system with upland rice. In lowland cultivation systems, crops are grown in alluvial soil near rivers after the rainy season. The main crops grown in the lowlands are rice, potato, mungbean, and groundnut.

Hakha, Htantalang, and Phalum

Hakha, Htantalang, and Phalum townships are located in the northern part of Chin State. Hakha is the capital of the Chin hills and it borders Phalum to the south, Htantalang to the west, and Matupi Township to the north. This township is situated on the slope of a large mountain. Phalum Township borders Mizoram to the west, Htantalang to the northwest, Hakha to the north, and Tiddim Township to the south. Htantalang borders Mizoram in the west, Hakha in the east, Matupi to the north, and Phalum to the south. Maize is the main staple food after rice in these regions. Sesame, sunflower, potato, yam, vegetables, banana, papaya, and pineapple are grown as cash crops in shifting cultivation systems. Peas, sesame, and other pulses are grown as either an intercrop or in mixed cropping systems with upland rice.

Rodent outbreaks and bamboo flowering in Chin State

Bamboo species in Chin State

Twenty percent of the hills of Chin State are occupied by a bamboo forest ecosystem including 9 genera and 17 species of bamboo: *Arundinaria* spp., *Bambusa* spp., *Cephalostachyum* spp., *Dendrocalamus* spp., *Dinochloa* spp., *Melocanna* spp., *Oxytenanthera* spp., *Pseudostachyum* spp., and *Teinostachyum* spp. (Tun 1998). Widespread outbreaks of rodent populations have occurred following the flowering of the dominant bamboo species in the Chin hills, *Melocanna bambusoides* (Myanmar name Kayin Wa) in Paletwa, Teetain, Htantlang, Phalum, Kyi Kha, and Tonzan townships. However, rodent outbreaks in Hakha Township occurred after the masting of *Bambusa polymorpha* (Myanmar name Kyathaung Wa) in 2007 and *M. bambusoides* in 2008. Generally, a masting event of *B. polymorpha* occurs once every 60 years, but prior data of flowering for this species in the Chin hills are lacking. Data for flowering in Bago Yoma are available (Table 2).

Timing of bamboo flowering and rodent outbreaks in Paletwa

In Paletwa, the first rodent outbreak was reported in September 2007 and farmers reported high rodent damage to the rice crop after the bamboo culms had died. This event is similar to findings from Mizoram, where rats increased in the month following seed shedding (Aplin and Lalsiamliana, this volume). During seed shedding, the high availability of food enhances the breeding performance of female rats; consequently, the rat population increases within a short time. When bamboo seeds germinate and the floor of the bamboo forest is covered by bamboo seedlings, food is not sufficient

Table 2. Documented bamboo flowering of *Bambusa polymorpha* since 1860.

Year	Location	Source
1860	Along Bago Yoma	Tun (1998)
1936	Gregarious flowering, district by district	Tun (1998)
2007	Hakha, Chin State	Myanma Forestry Department (1987), personal observation

for high populations of rats and they migrate into agricultural areas near the forest in search of food (John and Nadgauda 2002). Similar events have also been reported in Brazil and Argentina (D'Andrea et al 2007, Sage et al 2007).

Timing of bamboo flowering and rodent outbreaks in Hakha

Bambusa polymorpha bloomed and died in 2007. However, the timing of the rodent outbreak in relation to bamboo flowering was not clear in 2008 in this area. The flowering of *M. bambusoides* started in April 2008, and high rodent infestations were recorded by June at the seedling stage and tillering stage of rice, which also coincided with the fruiting stage of *M. bambusoides*. Perhaps high rodent populations had already built up during the seed shedding of *B. polymorpha* in August 2008. Upland farmers in Hakha Township did not report rodent damage at the booting stage in their upland rice. Perhaps the booting stage of the rice plant coincided with the seed-shedding stage of the bamboo and, when the rodents had abundant food in the forest, damage to the rice crop was low. High rodent infestation was reported in October 2008 at the harvesting stage of the rice crop, 2 months after the booting stage of rice and the seed-shedding stage of bamboo plants.

Timing of bamboo flowering and rodent outbreaks in Htantalang

In Htantalang Township, *M. bambusoides* flowering began in May 2007, and rodents attacked the rice crop in October 2007 during and after the harvesting stage (FAO 2008). In 2008, bamboo flowering started in April and rodent infestation of rice started at the seedling stage in June. Similarly, in Hakha Township, rodent infestations occurred at the seedling stage (May), the tillering stage (June and July), and harvest (October 2008).

Timing of bamboo flowering and rodent outbreaks in Phalum

Melocanna bambusoides flowered in June 2007 and continued flowering for 2 years to March 2009 (Fig. 2). In 2008, rodent damage occurred from seedling through to harvesting of the upland rice crop (May to October). Farmers mentioned that rodent damage to rice was highest at the fruiting stage of the bamboo plant, which coincided with the booting stage of the rice crop (August 2008). Some farmers reported high rodent infestation at the seedling, tillering, booting, ripening, and harvesting stages. Of note, Phalum farmers reported rodent problems at the booting stage, unlike Hakha and Htantalang farmers. However, these farmers were not able to identify the timing of the seed-shedding stage in the bamboo forest.

Fig. 2. Bamboo flowering, bamboo spikes, and bamboo fruits. Scale is in cm.

Generally, the highest rodent infestation occurred 2 months after the seed-shedding stage of bamboo; however, the flowering pattern of bamboo forest in southern Chin State was different from that in northern Chin State. In Paletwa Township, southern Chin, bamboo forest flowered synchronously and all villages experienced rodent outbreaks for only one season after the bamboo flowered. Thirty villages in the southern part of Paletwa were affected in 2007 by rodent damage after the bamboo flowered, and 77 villages in the northern part were affected in 2008 by rodent damage. In contrast, the bamboo flowered sporadically around the villages in northern Chin State and these villages faced rodent outbreaks in two seasons. However, we do not know whether the different flowering patterns of bamboo were related to different strains of the same bamboo species or to environmental conditions.

Impact of rodent outbreaks on food security

Paletwa

In September 2007, an initial bamboo masting event in two villages bordering Mizoram caused severe rodent infestation to upland crops. Shortly after, outbreaks of rodent populations were reported from another 26 villages that bordered the Chittagong Hill Tracts region. This “rat flood” was triggered by the high availability of food from bamboo forests. Once the bamboo plants died, the rodents invaded agricultural ecosystems and destroyed upland rice crops.

Farmers reported that rodent infestations wiped out crops in their village within 1 week. Upland rice was damaged by rodents at the ripening stage of the crop; therefore, the rice plant was not able to compensate for the yield loss (Buckle et al 1979, Singleton et al 2005) (Fig. 3). Thirty villages experienced rodent problems and 13% to 40% of the rice fields were damaged by the rat floods (Table 3). In nonoutbreak years, farmers in these villages usually experience a maximum of only 5% damage by rodent infestations. In 2007, the rodent problem was so severe that 22 farmers lost their entire crop, and the other farmers experienced partial damage to their crops (Table 3). These smallholder farmers were not able to harvest sufficient rice for their families. Farmers who practiced mixed cropping (rice and sesame) were waiting for the sesame harvest in order to get some income to buy food.

During the 2007 rodent outbreak, 1,227 households, representing 6,749 people, faced a food shortage. In 2008, an additional 1,218 t of rice were imported from Rakhine State; this was in addition to the usual amount of 6,135 t (Table 3). Even though local governments arranged to buy those surplus amounts of rice and sell them to farmers at a low price, most of the farmers could not afford to buy rice because the rats had devastated all of their agricultural produce. The coping strategies of farmers included borrowing rice from other farmers who suffered lower losses, and selling their possessions such as livestock. However, these strategies mitigated food insecurity for only a short time. For the longer term, many farmers had to rely on emergency food aid.

Fig. 3. The circle shows damaged area after high rodent infestations in an upland rice field in Paletwa, October 2007. Photo courtesy of Myanma Agriculture Service.

Table 3. Impact of rodent outbreaks on upland rice cultivation in Paletwa Township in Chin State in 2007. Damage refers to a minimum of 20% but in most cases farmers reported damage greater than 50%.

Village tract	Number of villages	Area of crop production (ha)	Area damaged (ha)	Percent of area damaged	Affected households (no.)	Number of farmers with 100% loss	Crop stage	Source
Miewa	1	88.33	20.83	23.6	93	9	Ripening	MAS
Pakawa	4	75.42	31.25	41.4	115	0	Ripening	MAS
Shweleitvi	3	125.83	43.75	34.8	154	4	Ripening	
Satchaing	4	282.08	70.83	25.1	245	0	Ripening	MAS
Kungtaung	3	135.83	18.75	13.8	126	2	Ripening	
Ahtet Balaing	5	137.08	37.50	27.3	177	0	Ripening	MAS
Duri Taung	3	42.50	14.58	34.3	42	4	Ripening	MAS
Waryone	7	160.42	54.17	33.7	240	1	Ripening	MAS
Meelatwa	1	64.17	8.33	13.0	36	2	Ripening	Focus group discussion
Tamanthar	1	66.67	12.50	18.8	–	–	Ripening	Focus group discussion
Total	30	1,178.33	312.50	26.5	1,227	22 (10.8 ha)		

Hakha, Phalum, and Htantalang

In 2007, bamboo masting was followed by rodent outbreaks in these three townships and this was still continuing in other parts of the townships in 2008. Three villages in each township, where farmers had faced high rodent infestations, were selected for farmer group discussions (FGD) during our second visit in March 2009, and we report here the outcomes of these discussions.

In 2008, most of the upland rice and maize crops in these three townships were devastated by rodents. Since sporadic bamboo flowering in these townships began in 2007, the rodent population had already reached high densities before the main planting season of 2008. Therefore, in 2008, rodents were able to attack crops from the seedling stage until harvest. Overall damage to upland rice was 67.7% in Hakha Township, 21.9% in Htantalang Township, and 38.9% in Phalum Township. The total upland rice area in Htantalang was greater than in Hakha; therefore, more people in Htantalang were affected by these rodent outbreaks. In 2008, 97 households, representing 543 people in three villages, faced a substantial food deficit in Htantalang, and 94 households, with 526 people in three villages, were affected by a food shortage in Htantalang. In Phalum, 18 households, representing 101 people, were affected by rodent outbreaks in three villages. Across the three study sites, we estimated that 31% of the population experienced food insecurity because of the 2008 rodent outbreaks (Table 4).

Maize is the main staple food after rice for farmers in these regions. In Hakha and Phalum, maize fields were also attacked by rodents in 2008. Hakha faced the highest rodent infestation not only in upland rice but also in maize, with average damage of 73%. In Phalum, the overall damage in maize fields was 37%. In 2008, Hmawlzauk Village, Phalum, had 100% of maize crops damaged. The next highest intensity of damage to maize was in Loankwe Village, Hakha (37%), in northern Chin State.

Table 4. Impact of rodent outbreaks on upland rice in three villages in Hakha, Htantalang, and Phalum townships in Chin State in 2008. Damage refers to a minimum of 20% but in most cases farmers reported damage greater than 50%.

Township	Village	Area of crop production (ha)	Area damaged (ha)	Percent of area damaged	Total households (no.)	Affected households (no.)	Affected households (%)
Hakha	Loankywe	64.63	62.10	96.06	61	50	82
	Lamtuk	41.67	16.67	40	52	13	25
	Vantalan	67.92	39.17	57.76	82	31	38
Total		174.22	117.94	67.70	194	94	48
Htantalan	Sopum	72.29	32.10	44.38	107	26	24
	Htanzan	420.83	84.17	20	145	67	46
	Sihhmuh	57.50	4.38	7.61	46	4	9
Total		550.62	120.65	21.90	298	97	33
Phalum	Waibula	36.67	0.54	1.48	102	0	0
	Zalang	0	0	0	41	0	0
	Hmawlzauk	22.50	22.50	100	40	18	45
Total		59.17	23.04	38.9	183	18	10

Source: Myanma Agriculture Service.

In 2008, of those households relying on maize as their staple crop, 41 households representing 230 people in three villages in Hakha and 16 households representing 90 people in three villages in Phalum had a food-deficit problem. At the three study sites, masting events of bamboo and rodent outbreaks in 2008 led to food shortages for 13% of the population (Table 5).

In both upland rice and maize cultivation, some farmers completely lost their crop whereas some farmers were able to harvest only 10% of their crop. Farmers did not have enough food for the whole year. Moreover, their valuable stored grain was attacked by rodents; farmers estimated that 210 kg of their stored grain were consumed by rats within a week—an amount that could feed the whole family for 4 months. Even though the smallholder farmers did not experience severe starvation, they did not have enough food and they did not have money to buy food. Some families received money remittances from their relatives working overseas. However, a majority of people had to sell their livestock. They became desperate after they sold all of their livestock (chickens, pigs, and cows) to buy food. Furthermore, household items such as blankets and pillowcases were also gnawed by rats. However, nobody reported being bitten by rats.

Table 5. Impact of rodent outbreaks on maize in three villages in Hakha, Htantalang, and Phalum townships in Chin State in 2008. Damage level was not defined.

Township	Village	Area of crop production (ha)	Area damaged (ha)	Percent of area damaged	Total households (no.)	Affected households (no.)	Affected households (%)
Hakha	Loankywe	50.42	49.9	99.0	61	20	33
	Lamtuk	33.33	12.5	37.5	52	5	10
	Vantalan	56.67	39.58	69.9	82	16	20
Total		140.42	101.98	72.62	194	41	21
Htantalang	Sopum	0	0	0	107	0	0
	Htanzan	50.42	0	0	145	0	0
	Sihhmuh	0	0	0	46	0	0
Total		50.42	0	0	298	0	0
Phalum	Waibula	66.67	15.52	23.3	102	6	6
	Zalang	29.38	10.83	36.4	41	4	10
	Hmawlzauk	14.17	14.16	100.0	40	6	15
Total		110.22	40.51	36.75	183	16	9

Source: Myanma Agriculture Service.

Overview of the impact of rodent outbreaks in Chin State (2007-09)

In September, 2007, the first rodent outbreak occurred in Paletwa Township, southern Chin State, following a large masting of *M. bambusoides*. Six townships from the northern part of Chin State, Teetain, Phalam, Hakha, Htantalang, Toozang, and Kyikha, reported rodent problems on their agricultural lands shortly after the Paletwa rodent outbreak. FAO reported the impact of the rodent outbreak in 22 villages in Htantalang and 5 villages in Toozang (FAO 2008). A swarm of rats attacked not only upland rice but also maize in these townships; 1,322 ha of upland rice fields in 85 villages and 400 ha of maize in 32 villages were damaged by rodents in 2007 (Tables 6 and 7**).**

Table 6. Impact of rodents on upland rice in Chin State (2007-09): a combination of information from different sources.

Year	Township	Villages	Area of crop production (ha)	Area damaged (ha)	Percent of area damaged	Source
2007	Paletwa	30	1,178.33	312.5	26.5	Personal observations; MAS
	Teetain	2	1,386.25	82.2	5.9	MAS
	Htantalang	22	1,351	659.4	48.8	FAO (2008)
	Phalum	7	1,433.33	48.3	3.4	MAS
	Hakha	9	992.5	192.6	19.4	MAS
	Kyikha	10	537.5	27.33	5.1	MAS
	Toozang	5	N/A[a]	N/A	N/A	FAO (2008)
Total	7	85	6,878.91	1,322.33	19.22	
2008	Paletwa	77	4,797.92	455.80	9.5	MAS
	Htantalang	12	7,890.42	170	2.2	MAS
	Hakha	9	2,452.92	198.33	8.1	MAS
	Phalum	7	7,070.83	119.30	1.7	MAS
Total	4	105	22,212.09	943.43	23.8	
2009	Paletwa	50	2,647.5	15.83	0.6	MAS
	Hakha	1	134.58	82.92	61.6	MAS
Total	2	51	2,782.08	98.75	3.6	

[a] N/A = not available

Table 7. Impact of rodents on maize in Chin State (2007 and 2008): a combination of information from different sources.

Year	Township	Villages	Total area (ha)	Area damaged (ha)	Percent of area damaged	Source
2007	Teetain	2	3,653.33	30.55	0.8	MAS
	Kyikha	10	251.67	43.57	17.3	MAS
	Phalum	7	2,861.67	68.29	2.4	MAS
	Hakha	9	2,475.00	204.67	8.3	MAS
	Kanpaclatt	4	910.83	52.61	5.8	MAS
Total	5	32	10,152.50	399.70	3.9	
2008	Hakha	9	6,113.75	210.73	3.5	MAS
	Phalum	7	695.83	49.71	7.1	MAS
Total	2	16	6,809.58	260.44	3.8	

Masting events continued in Paletwa, Htantalang, Hakha, and Phalum until 2008 and different media reports highlighted famine in Chin State because of the severe rodent infestation. In 2008, 5,286 ha of rice fields in 105 villages and 260 ha of maize in 16 villages were destroyed by rodents (Tables 6 and 7). Chin people suffered from a severe food crisis because of rodent infestations in both 2007 and 2008. For Chin's upland farmers, 2007 and 2008 were dreadful disaster years, since they faced not only rodent outbreaks but also severe weather conditions. Farmers who did not experience rodent infestations had a reduced harvest because of drought (FAO 2009).

Subsequently, in 2009, about 99 ha of rice fields in 51 villages were attacked by rodents, according to MAS. Massive bamboo mast events, the subsequent surge in rodent numbers, and the famine that followed ravaged the remote and impoverished smallholder farmers in Chin State for three years. Their cash crops were also devastated by rodents. There are important long-term social effects of the rodent outbreaks. Farmers could not afford to send their children to school, particularly college students who need to travel to other parts of Myanmar for their higher education. Although some villages received aid from INGOs and NGOs, a lot of villages in late 2009 were facing a food crisis.

Farmers and extension staff were ill prepared to respond to these rodent outbreaks because baseline information from the rodent-induced famine in the late 1950s was lacking, and the relationship between rodent outbreaks and massive bamboo mast events was still considered a myth by many Myanma people.

Impact of rodent outbreaks on health

Rodents are a reservoir of more than 60 human diseases that are transmitted directly from rat bites, or rodent fleas and lice, or indirectly by eating or touching food or water contaminated by rodent urine and feces (Gratz 1994, Meerburg et al 2009). Rodent-borne diseases were not reported during the rodent outbreaks in either southern or northern Chin State. Belmain et al (2008) reported the potential of a bubonic plague outbreak in the Chittagong Hill Tracts given the rodent outbreaks in neighboring Myanmar. Bubonic plague was historically reported from 1964 to 1994 in the region (WHO 2000). However, during 2007-09, there were no reports of bubonic plague in Chin State. There were also no reports of leptospirosis or murine typhus, diseases expected in rural populations when high-density rodent populations occur, particularly in the hot and humid wet season of the subtropics (Meerburg et al 2009). The lack of reports of rodent zoonoses may be because people in this area rarely visit hospitals for diagnosis or treatment.

The Myanmar government officials we interviewed in Chin State were not aware of rodent-borne diseases. Reduced caloric intake combined with rodent zoonoses could have severely debilitating effects on people in smallholder rural communities, especially breast-feeding women and children. The lack of data on the impact of rodent zoonoses on human health during these rodent outbreaks is an important gap in our knowledge.

Biology of the main rodent species involved in the rodent outbreak

Paletwa

Rattus rattus was the most common species in and around rice fields during the outbreaks (Fig. 4A, B). Four adult males, 19 adult females, and 3 juveniles were caught near rice fields. Rats were identified following the taxonomic key of Aplin et al (2003). The demographic parameters of *R. rattus* captured in Paletwa are different from those of *R. rattus* caught in Yangon in the lowlands during three nonoutbreak years (2003-05). The body weight of adult *R. rattus* ranged from 250 to 300 g, much heavier than *R. rattus* in Yangon (134.8 ± 2.45 (S.E.), n = 99) (Table 7).

The mammary formula was 1+1+3, consistent with *R. rattus*. No adult females were pregnant but 10 females out of 19 had 4–5 recent uterine scars. Although the average uterine scar number is less than that for female *R. rattus* in Yangon, about 50% of the adult females had previously been pregnant.

Hakha, Phalum, and Htantalang

Three adult females, 4 adult males, and 15 juvenile *R. rattus* were caught in one night. Only one adult female (n = 3) had uterine scars. In Mizoram, there was also a high proportion of juveniles caught in the crops during the period of high losses (Aplin and Lalsiamliana, this volume). However, data on the population demography of rodents in the affected crops are sparse in both northern and southern Chin State.

Fig. 4 (A) *R. rattus*, main species involved in rodent outbreaks. (B) *R. rattus* collected by hunting in one night. Photos courtesy of Myanma Agriculture Service.

In northern and southern Chin State, the main rodent species involved in the population outbreaks is *R. rattus*. According to farmers, *R. rattus* is rarely found in rice fields in normal years, when *Mus* sp. is the common species in rice fields and the major pest for rice crops. People in the Chittagong Hill Tracts, Bangladesh, assumed that the rats caught during the rodent outbreaks there may have dispersed from Myanmar—this assumption needs to be documented (Belmain et al 2008). However, the amount of rodent material collected in the Chin Hills in both outbreak and nonoutbreak years is not extensive. More material needs to be collected before we can be more definite about which species are common in the forests, rice fields, and other cropping systems during outbreak and nonoutbreak years.

Moreover, detailed population studies on the relationship among the timing of bamboo masting, rodent breeding ecology, rodent movements (over what geographic scale), and the timing of rodent outbreaks are lacking. Collection of such data is a priority in order to be able to estimate the time window we have for targeted management actions between the bamboo fruiting stage and rodent outbreaks. If we can estimate this period, then it may be possible to prepare for managing rats before the eruption of a rodent population occurs.

Rodent control activities of farmers at the two study sites

Paletwa

During the outbreak, farmers used a variety of methods to try to control high rodent populations. These included trapping with local traps, driving rats away by shouting, driving rats into nets set around rice fields, putting the dead bodies of rats inside rice fields to deter other rats, and rat hunters who hunted at night. One rat hunter was able to catch 60 rats per night (Fig. 5). These rats were roasted and then sold at a local market. Prior to the rodent outbreaks, farmers mainly relied on rat hunters for controlling rodent populations.

Some farmers controlled rats by hitting tin cans to frighten rats away from their rice field. One farmer said, "I have been hitting a can for the whole night. I will continue all of the next day." Even though this particular farmer was already exhausted when we interviewed him, he was desperate to continue because his neighbor had already lost 95% of his crop.

Some farmers harvested the rice crop before it was ripe enough to harvest because they were besieged by high rodent infestations in their fields. Myanma Agriculture Service extension staff were keen to practice continuous baiting systems and they thought that rodenticides were the best solution to control rats effectively during the outbreak season. However, farmers and their families in Paletwa eat rats for extra protein, particularly when they suffer high crop losses, and they were reluctant to use rodenticides.

Fig. 5. Rat hunter with full basket (more than 60) of rats collected in one night. Photo courtesy of Myanma Agriculture Service.

Hakha, Htantalang, and Phalum

In Hakha, Phalum, and Htantalang, farmers used different kinds of traps as well as rodenticides, and rat hunters. Again, the rat hunters barbecued and sold their rats for their daily income during the outbreak. Some farmers used catapults and crossed bows to shoot and kill rats, which is a clear indication that there was an exceptionally high population density of rats. In these three townships, 50% of the farmers set traps every night to control rats. Farmers said that a single locally made trap was able to catch 10 rats per night.

Some farmers (15%) relied only on rat hunters for controlling rats. Because all of the farmers had rat problems in their fields since the seedling stage, they could not wait until rat hunters visited their fields to hunt rats. In contrast with Paletwa, 35% of the farmers in Hakha, Htantalang, and Phalam used rodenticides for controlling rats. In Hakha, rodenticide was applied twice a week during peak densities of rodents in the field. Acute rodenticides, such as zinc phosphide, were distributed freely by the United Nations Development Programme (UNDP) and farmers applied five packets per month in Htantalang.

Despite all efforts by farmers to control the impacts of rodents after bamboo masting, they were not able to prevent high crop losses. The following facts possibly contribute to this lack of success in reducing rodent damage to their agricultural crops:

1. Many of the rice fields are far from human dwellings, so farmers visit them only 3–4 times in a cropping season.
2. Roads are poor, which limits access to fields and bamboo forests.
3. Few extension workers help farmers to manage rodent outbreaks, and none of the extension staff have a background in rodent biology and management.
4. MAS staff elsewhere in Myanmar have limited knowledge on rodent biology.
5. Farmers controlled rats through individual actions after they saw rat damage in their field. We now know that coordinated community actions are more effective in managing rodent pests in agricultural landscapes (Palis et al 2007).

Lessons learned and future challenges

Bamboo mast events on some occasions in the past have been reported in many different locations in addition to the ones reported here, and they can last for up to 5 years (Table 1). Although upland rice cultivation contributes only a small amount (15%) of Myanmar rice production, rice is the main subsistence crop in many rainfed areas. In Chin, Shan, and some parts of Rakhine State, upland rice underpins the food security and general livelihoods of smallholder farmers. Rodent outbreaks following bamboo masting in 2007-09 clearly threatened the food security of upland farmers. This masting event could continue until 2011 in Chin, and may be happening in other parts of Myanmar. Reports in mid-2009 of massive bamboo flowering in different places of Chin Hill and Rakhine State indicate that masting and rodent outbreaks could cause a food crisis in Myanmar from 2009 through 2011.

There is an urgent need to identify effective rodent management systems and make them available to farmers. A major constraint in Myanmar is that too few rodent ecologists can conduct research and disseminate knowledge about rodent ecology and rodent management systems. Recruitment of rodent ecologists needs to be a national priority in many of the rice-growing countries of Southeast Asia. Moreover, there are limited numbers of extension workers to disseminate new technologies to farmers. One possible additional avenue for information dissemination is to liaise with NGOs and agencies of the United Nations such as FAO and the World Food Program. In terms of health education about rodent-borne diseases and malnutrition problems after a rodent outbreak, MAS staff from the Ministry of Agriculture and Irrigation should link with the Ministry of Health and NGOs to alleviate the medical problems that arise from rodent outbreaks.

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Rodent outbreaks in the uplands of Lao PDR

Bounneuang Douangboupha, Grant R. Singleton, Peter R. Brown, and Khamouane Khamphoukeo

Lao PDR is one of the poorest countries in Southeast Asia. About 50% of rural households risk being food-insecure. In the upland environment, rodents are considered one of the most important pests of upland rice, maize, Job's tear (sorghum), and other crops, with mean yield losses estimated at 20%. Upland rice farmers generally rate them as being second only to weeds as the overall most important constraint to upland rice cultivation. Rodent outbreaks have been reported in the upland agroecosystems of Lao PDR for more than 50 years. The frequency and duration of rodent outbreaks vary markedly from one province to another. Bamboo masting and rodent (*nuu khii*) outbreaks are episodic but such population outbreaks occur in many parts of Laos. These are sometimes responsible for extreme crop losses (50–100% losses), occasionally leading to localized or widespread famine. In 2008, severe food shortages due to *nuu khii* outbreaks were reported in seven upland provinces. In Oudomxay and Luang Prabang provinces, outbreaks occurred in seven districts, with 49 villages and 800 households severely affected. The main causes of these outbreaks appear to be bamboo masting events and changes in cropping patterns. A range of rodent species are involved in these outbreaks. Six different ethnotaxa (Lao species) reported to be involved historically in *nuu khii* outbreaks are *nuu khii*, *nuu ban*, *nuu american*, *nuu na*, *nuu mon*, and *nuu thongkao*. Future rodent outbreaks will continue to occur; therefore, there is an immediate need to apply rodent management strategies that have been tested locally and found effective at a village scale. Also, a national rodent management network must be established and strengthened. Detailed community ecology studies on different bamboo species and their relationship with the dynamics of rodent demographic changes are needed. Capacity building on rodent management in the extension system also needs stronger emphasis.

Keywords: rodent, outbreak, upland, bamboo masting, damage, rodent species

The Lao People's Democratic Republic (Lao PDR) is one of the poorest countries in the Asian region. It is classified as a least developed country by the United Nations Development Programme (World Food Program 2009). The upland farming systems of Laos are changing rapidly in response to a range of factors, including the rapid increase in human population growth, government pressures for restricting shifting cultivation, and new economic opportunities. The population of Laos in 2009 was approximately 6 million. More than 80% of the population is living in agricultural households, and about 40% of the population is fully or partially involved in shifting cultivation in the upland environment. The population in northern Laos accounts for about one-third of the Lao population. The most represented ethnic groups are the Austroasiatic and Hmong miem. Sixty-five percent of these families depend on shifting agriculture for their livelihoods. With mounting pressure on the upland agricultural systems of Laos, the impacts from pests, weeds, and diseases will likely increase in the future (Aplin et al 2006). Rodents are major pests of agriculture in the uplands of Lao PDR. They cause, on average, annual preharvest losses of 5–30% in rice crops. However, occasional outbreaks of rat populations can lead to severe crop losses of up to 100% and can lead to food shortages for Lao people (Khamphoukeo et al 2003, Brown and Khamphoukeo 2007).

Rodent outbreaks have occurred in the upland agroecosystems of Lao PDR for more than 50 years (Douangboupha et al 2003) and more likely hundreds of years. The severity of the impact of rodents on agriculture (and also because they provide an important source of protein in their diet) has led Lao farmers to generally have a good knowledge of their local rodent communities. Farmers often distinguish ten or more different kinds of rodents (Douangboupha et al 2003). This familiarity often extends to forest species, which are actively hunted and trapped for consumption or sale.

In 2008, northern Laos was affected by a severe rodent outbreak, the worst recorded since a major outbreak in 1992 (Singleton and Petch 1994) (Table 1). In the affected areas, upland farmers experienced major production losses of rice, maize, Job's tear (the local variety of sorghum), and other important cash crops. These outbreaks seriously affected household food security, generating an immediate need for food assistance (World Food Program 2009). Most upland farmers usually suffer an annual rice shortage, but these rodent outbreaks led to severe damage to crops and seriously compounded food insecurity for these farming communities that consist largely of subsistence farmers.

Little was known about the biology of the rodent community in Laos prior to collaborative research between scientists from Australia and Laos that began in

Table 1. Area of rice crops in the uplands and lowland pockets with significant rat damage (>10%) in northern Laos in the 2008 and 2009 wet season. The damage was more severe per hectare in 2009 (30–100% loss).

Province	2008 Area (ha)	2008 Value (US$)[a]	2009 Area (ha)	2009 Value (US$)[a]
Bokeo	1,499	4,700	1,047	378,450
Sayaburi	427	1,500	427	154,650
Houaphanh	500	3,260	334	120,720
Luang Prabang	1300	6,890	60	21,830
Luang Namtha	700	3,710		
Phongsali	600	3,660		
Oudomxay	5,000	25,000		
Total: 7	10,000	48,720	1,868	675,650

[a] Exchange rate US$1 = 8,300 kip.

Source: Lao Department of Agriculture.

1999, with input from the International Rice Research Institute (IRRI) in 2002-03 and 2008-09. The research focused on the upland rainfed environment, with the aim of quantifying the impacts of rodents on agricultural production, identifying the key pest species while also recognizing those that need to be conserved, and developing strategies of ecologically based rodent management (EBRM) (Singleton et al 1999). This chapter summarizes some key findings from these studies and of recent reports of rodent outbreaks in northern upland provinces. We will summarize our understanding of the factors leading to rodent population outbreaks, some impacts of the outbreaks, and the success and failures of management actions.

Bamboo flowering and *nuu khii* outbreaks

Upland farmers in Lao PDR and local governors are concerned about the impacts of these outbreaks. The impacts are so important that they are etched into folklore with local language used to describe the phenomenon. One of the distinguishing features of the outbreaks is that they are episodic and irregular, and they vary spatially in their extent. Reactive strategies such as bounty systems, application of rodenticides, and traditional techniques have been implemented to manage the problem in an ad hoc manner. The results have been disappointing.

These outbreaks are often responsible for extreme crop losses, occasionally leading to localized or widespread famine (Douangboupha et al 2003). In some situations, localized outbreaks of rodents can lead to complete loss of crops (Singleton and Petch 1994). Farmers typically associate these outbreaks with the gregarious flowering and seeding ("masting") of certain bamboo species and they commonly refer to them as *nuu khii* events (*nuu khii* literally means "mouse of the bamboo flower"). The link between bamboo masting and rodent outbreaks is made across many other parts of South and Southeast Asia, wherever there are extensive tracts of bamboo (Chauhan and Saxena 1985, Nag 1999, Aplin et al, this volume, Belmain et al, this volume, Htwe et al, this volume). Similar phenomena are reported in South America, where severe rodent outbreaks occur (Jaksic and Lima 2003). There is now an irrefutable ecological link between bamboo seeding and rodent outbreaks (Aplin and Lalsiamliana, this volume, Belmain et al, this volume, Htwe et al, this volume); the production over 1 to 2 years of large quantities of highly nutritious bamboo seed triggers an explosive increase in rodent populations within the bamboo forest habitat. Mass emigration of rodents into adjacent agricultural habitats follows the depletion of the seed resource.

In Laos, the frequency and duration of rodent outbreaks vary markedly from one province to another (Figs. 2 and 3) (the provinces of Laos are shown in Fig. 1). In Luang Prabang Province, the outbreaks seem to occur infrequently but tend to last 2–4 years. In Houaphanh Province, in the northeast of the country, they tend to be more frequent but typically fall within a single year. Although these historical records suggest that many outbreaks are localized to a particular district, there also is evidence of more widespread outbreaks, such as in 1989-93, when an outbreak affected most districts of Luang Prabang and Oudomxay provinces in northern Laos (Singleton and Petch 1994, Douangboupha et al 2003). Because Laos has many species of bamboo,

Fig. 1. Provinces of Laos. Rodent outbreaks associated with bamboo flowering and masting generally occur in the upland agroecosystem in the northern parts of Laos.

each with a patchy distribution in the landscape, and each with a different flowering interval, irregular and localized outbreaks of the kind observed are consistent with the bamboo flowering hypothesis. In contrast, widespread and prolonged outbreaks are more likely caused by some wider environmental factors. One possible alternative cause is the El Niño Southern Oscillation (ENSO) that has a strong influence on the climate of Laos (Holmgren et al 2001, Aplin et al 2006). The association between weather patterns that generate extreme climatic conditions (extended dry periods or above-average annual rainfall) and the subsequent flowering and masting of bamboo species, or simply the generation of other abundant food resources in response to favorable rainfall events, needs further research.

A survey of upland farmers in Luang Namtha and Luang Prabang revealed that 99% of the farmers indicated that rodent outbreaks were frequent (as opposed

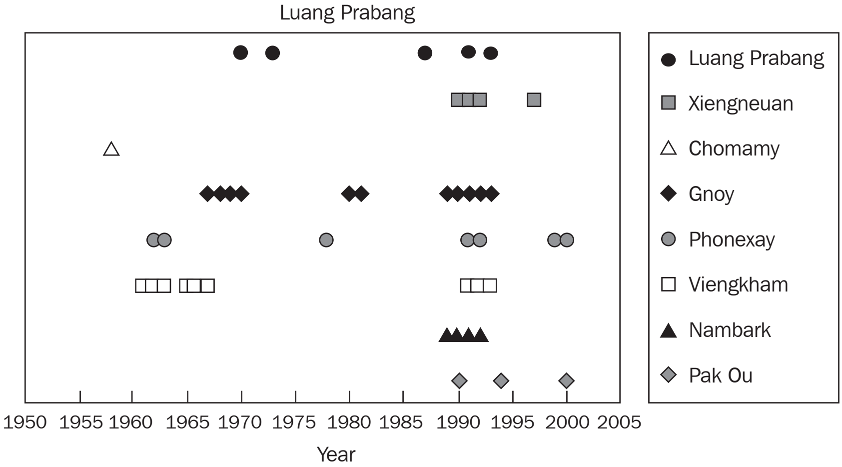

Fig. 2. Rodent outbreaks in eight districts of Luang Prabang Province (source: Douangboupha et al 2003). Each symbol represents a year when an outbreak occurred.

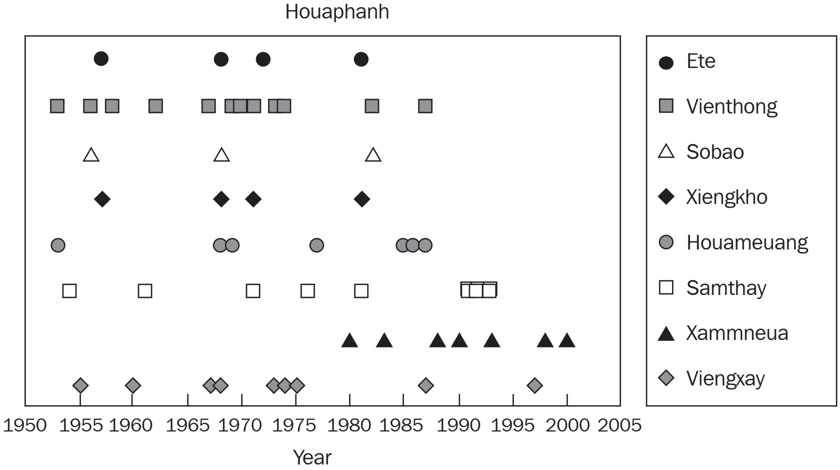

Fig. 3. Rodent outbreaks in eight districts of Houaphanh Province (source: Douangboupha et al 2003). Each symbol represents a year when an outbreak occurred.

to occasional or rare) (Brown and Khamphoukeo 2007). Furthermore, when farmers were asked when the rodent outbreaks occurred, there was wide variation in their responses. Even within the same villages or in nearby villages, the timing of the outbreaks appeared to be spread over a number of years (Fig. 4). Furthermore, the memory of outbreaks seems to fade as time passes, although some farmers recalled the outbreaks that occurred from 1989 to 1993, which confirms the published accounts of the outbreaks mentioned above.

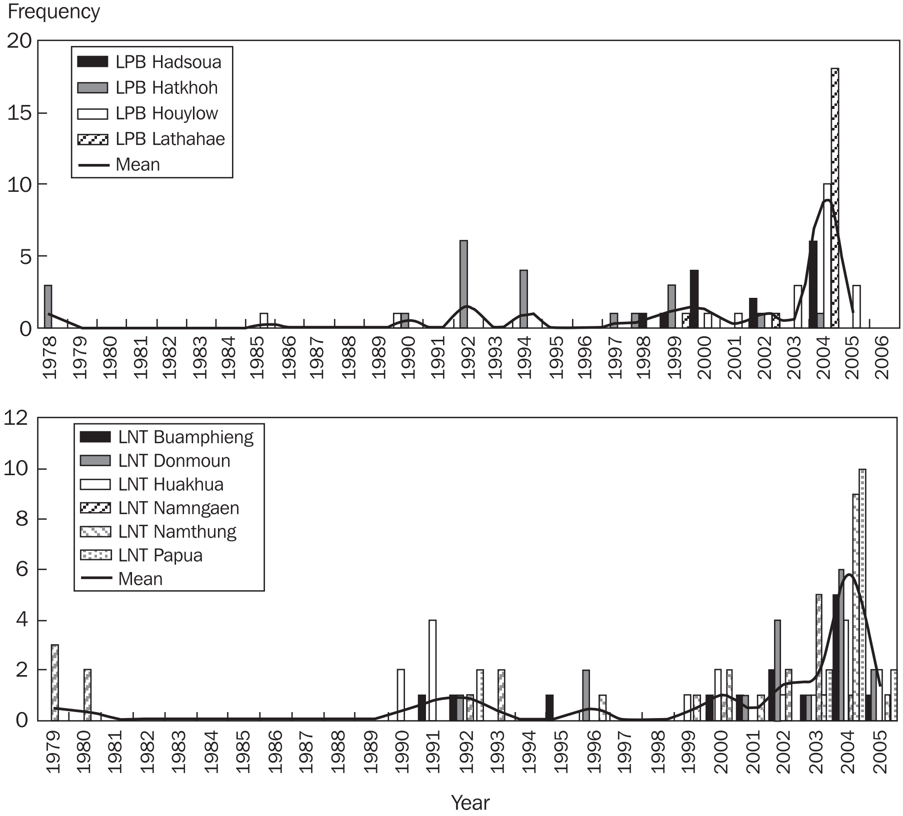

Fig. 4. Occurrence of rodent outbreaks from four villages in Luang Prabang (LPB) Province and six villages in Luang Namtha (LNT) Province in upland areas of northern Laos. Data were gathered from a survey of farmers who were asked, "Can you remember any specific years in the past when there were very high rat numbers? If so, which years?"

The species of rat or rats responsible for *nuu khii* outbreaks remains in doubt. Douangboupha et al (2003) listed six different ethnotaxa (Lao species) reported to be involved in historical *nuu khii* outbreaks: *nuu khii*, *nuu ban*, *nuu american*, *nuu na*, *nuu mon*, and *nuu thongkao* (refer to Table 2 for classifications). The following species were collected during an outbreak in Houaphanh Province in northern Laos in 2001: *Mus cervicolor* (identified as *nuu khii*), *Rattus rattus* (several specimens, variously identified as *nuu khii*, *nuu ban*, *nuu mon*, and *nuu tongkao*), *Berylmys berdmorei* (identified as *nuu mon* and *nuu waay*), and *Bandicota indica* (identified as *nuu american* and *nuu na*). Many rodent species are quite adaptable and willing to change their diet as different food resources become available. Accordingly, different rodent species could quite likely use the temporarily abundant bamboo seed resource and then participate in the *nuu khii* outbreaks. Some forest-dwelling nonpest species therefore might become temporary agricultural pests during an outbreak period (Aplin et al 2006).

Table 2. Lao rodent names with equivalent scientific names.

Lao name	Scientific name	Comments
Dtun	*Cannomys* and *Rhizomys* species	Literally "stout"
Nuu american	*Bandicota indica*	Literally, "American rat" (so named on account of its large size), also called *nuu puk* in Sayaburi Province in western Laos
Nuu ban	*Rattus rattus* group	Literally, "house" rat
Nuu ghi	*Mus cookii?*	Identified as a small mouse of upland fields and forest
Nuu khii	*Mus* species	"Mouse of bamboo flower," see text for discussion of this name
Nuu mon	*Berylmys* species	Literally "gray color rat"
Nuu na	*Rattus rattus* group	Literally, "field" rat
Nuu ta-suat	*Rattus exulans*	Literally, "big-eyed field rat"
Nuu na thong-khaw	*Rattus rattus* group	Literally, "white-bellied field rat"
Nuu noi	*Mus* species (probably *M. caroli*)	Literally, "small mouse" (identified as a long-tailed rice field mouse
Nuu puk	*Bandicota* species	Used for *B. indica* in Sayaburi Province but probably for *B. savilei* in Luang Namtha Province in northwestern Laos
Nuu si	*Mus* species (probably *M. cervicolor*)	Identified as a short-tailed rice field mouse
Nuu sing	*Crocidura* spp.	Not rodents; small long-nosed shrews found in upland fields and forest
Nuu thammadaa	*Rattus rattus* group	Literally, "ordinary mouse," an alternative name for *nuu ban* (house rat), used in Luang Prabang Province
Nuu waay	*Leopoldamys* species	Literally, "rattan rat"

Recent outbreaks in the uplands appear to have particularly serious impacts on the livelihoods of smallholder farmers, many of which are subsistence farmers. In the wet seasons of 2008 and 2009, rodent outbreaks led to unbearable conditions for rural families because practically all the crops and stored grains were destroyed. Severely affected villagers were left with little food, no seeds, and no cash because they obtained no produce from their crops. Emergency food assistance was required for 85,000 to 145,000 people (World Food Program 2009). For these people, rice stocks were gone and, without assistance, they ate only one or two poor-quality meals a day (World Food Program 2009).

In 2008, severe food shortages due to *nuu khii* outbreaks were reported in seven upland provinces: Phongsali, Houaphanh, Louang Namtha, Louang Prabang, Sayaburi, Bokeo, and Oudomxay (Fig. 1). More than 10,000 ha of upland crops were destroyed. In Oudomxay Province alone, the damaged crop area amounted to 5,000 ha, affecting 1,257 ha of upland rice, 622 ha of maize, and 707 ha of Job's tear (unpublished report, Lao Department of Agriculture). The outbreaks occurred in four districts, with 28 out of 32 villages affected very seriously in the district of Pak Beng. In Louang Prabang, the outbreak occurred in seven districts, with 49 villages and 800 households severely affected (Douangboupha 2009). The outbreaks resulted in a dramatic rise in food insecurity: people lacked cash, food, and seed. The main causes of these outbreaks appear to be bamboo masting events, in combination with changing agroecosystems and cropping patterns. A number of different rodent species were involved in these outbreaks, but no systematic sampling or taxonomic identifications were conducted.

In the 2009 wet season, rodent outbreaks were reported from four provinces of northern Laos: Houaphanh, Louang Namtha, Sayabouly, and Bokeo (see Fig. 1). More than 4,000 ha of upland crops were destroyed. In Houaphanh alone, 2,600 ha of lowland rice, upland rice, sweet corn, and soybean were destroyed. The Lao government approved about 4.6 billion kip (approx. US$5.5 million) for Houaphanh Province to help the families affected.

In 2008 and 2009, there seemed to be no consistency in the timing of the rodent outbreaks over the different regions and districts. Focus group discussions were held with farmers and local agricultural staff in a few of the affected provinces. The farmers reported that outbreaks in general occur every 10–15 years. However, in most provinces, the impression of farmers and agricultural staff is that the occurrence of high rat populations is now more frequent (about 4–5 years apart). Currently, the cause of the outbreaks is not clearly understood, except that they are observed to be closely linked with the time of bamboo flowering and masting, which usually starts around January. Apparently, the availability of abundant bamboo seed enabled the rat populations to build up rapidly. By April-May, crops are planted with the onset of rain and by then there were high numbers of rodents in response to the bamboo mast events. After depleting the bamboo seeds, the rats were reported to have migrated from the bamboo forests to eat and destroy the agricultural crops (Douangboupha 2009).

Impacts of rodent outbreaks on the livelihoods of Lao people in upland areas

Lao farmers living in upland environments generally draw a clear distinction between rodent damage suffered every year (chronic damage) and that suffered during rodent outbreaks (irregular but severe damage). The damage suffered during outbreaks is sometimes so severe that it entails the rapid and complete destruction of all standing crops.

In the upland environment, rodents are considered the most important pest of rice and many other crops, or second only to weeds as the most important constraint to upland rice cultivation (Schiller et al 1999, Brown and Khamphoukeo 2007). However, although farmers are able to control weeds through regular weeding, they currently lack any effective means for controlling rodents (Brown and Khamphoukeo 2007). As such, rodents are the production constraint over which they have least control (Schiller et al 1999). Preharvest grain losses have not been properly quantified, but have been estimated to be 15% of the rice harvest annually (Schiller et al 1999, Brown and Khamphoukeo 2007). Since there is a chronic shortage of rice for upland farmers, this loss can further impair the livelihood of the chronically poor.

In a study of rodent damage in six villages in Louang Prabang Province, damage to crops occurred mainly at planting and at harvest but with some differences between villages. This information can be used to refine the timing of rodent management strategies so that control is conducted before damage occurs. Farmers reported that stored rice was the commodity that was damaged most by rodents, but rodent damage to upland rice was considered the main problem in some villages. In terms of the highest losses, farmers identified upland rice, maize, and stored rice, while other stored crops, including sesame, suffered less damage (Harman 2003).

A two-year study was conducted with farmers in a participatory learning framework to identify rodent management strategies for the rainfed upland farming system of Laos (Brown et al 2007). The main principle for rodent management in this complex system was to encourage farmers to work together at key times. Management of rodents was encouraged in the village environment, lowland irrigated cropping areas near villages, and upland environments more remote from villages. The main practices recommended were to set traps continuously, use pitfall traps, establish baited trap-barrier systems, and work together to hunt rats in field stores (Brown et al 2007). Some villages established rules to ban the use of rodenticides in village environments and encouraged the keeping of cats and dogs to help keep rodent numbers low. Farmers also adapted the trap-barrier system (see Singleton et al 1998 for description) to protect their grain stores in the villages. A survey of farmers two years after they had begun implementing the recommended practices revealed that trapping rats remained the most important control strategy for farmers and was considered the most effective. Farmers were more aware of the problems of rodents and were interested in adopting ecologically based rodent management strategies (Brown and Khamphoukeo 2010).

Rodents are generally not considered a major problem in the rainfed lowland rice agroecosystem or in the lowland irrigated environment. A survey of lowland farmers in 1993 from nine districts of seven provinces in the Mekong River Valley indicated that, in most districts, rodents were not regarded as a significant production constraint (Khotsimauang et al 1995, Schiller et al 1999). Another survey of farmers in areas of lowland cultivation in Vientiane Municipality and the provinces of Savannakhet and Champassak conducted in 1994 showed that rodents were a significant problem in only one area, where 30% of the farmers reported that rodents were pests. Most farmers claimed that they could manage the rodent problems encountered (Rapusas et al 1997).

How people cope with the rodent problem

Traditional methods

In efforts to combat rodent outbreaks, most farmers depend on various traditional means that include using snap traps, hunting with dogs and sticks, shooting with catapults or arrows, and burning a small fire and guarding the field at night (Brown and Khamphoukeo 2007). Out of desperation, a few have also resorted to using chemical rodenticides (mainly zinc phosphide); this generally happens after significant damage has already occurred. Lao farmers use a variety of locally made traps and snares for rodent control, sometimes in combination with drift fences made of sticks or bamboo. These are used throughout the year, with increases in activity as the upland rice crop matures and after harvest. Captured animals are often eaten or the meat smoked and sold in local markets. Intensive hunting for rats is often carried out by men and children after harvest. A common focus of effort is piles of rice straw and Job's tear (a form of sorghum) stalks that are stacked around upland fields. Hunters generally place fishing nets along one side of the pile and then either disturb the pile or light a fire on the opposite side. Rats are also hunted at night with the use of air guns, cross bows, or slingshots.

Rodenticide use

Until the mid-1990s, there was little use of rodenticides for controlling rodents in Laos. In the last decade, rodenticides have become more widely available and their use has increased in some areas of the northern part to a chronic level. The most widely used poison is a clear liquid of Chinese origin, supplied in ampoules with little if any labeling, and the small amount of labeling is in Chinese characters that the Lao farmers cannot read. Analysis of three ampoules found a compound similar to 1080 (sodium monofluoroacetate) in two, and no obvious active ingredient in the third (H. Leirs, personal communication). Anticoagulants such as coumatetralyl, and zinc phosphide of Russian and Japanese origin, are also widely available. Rodenticides are applied in the field only when rodent numbers are high and heavy crop damage has already been observed. Poison use around villages is regarded as dangerous and is generally avoided.

When mixed with paddy grain and applied in the fields, the "Chinese poison" has an immediate and visible impact against rodents, with many carcasses lying around the following day. Unfortunately, the baits are also highly effective against various nontarget animals, including domestic cats, dogs, pigs, and fowl, either through direct consumption of the bait or from scavenging of carcasses. In many parts of Laos, regular rodenticide use has drastically reduced the numbers of domestic animals in villages (Khamphoukeo, unpublished data based on key informant interviews with farmers). Farmers are painfully aware of this fact but claim to have little alternative other than to continue using these highly toxic baits. Native wildlife presumably also suffers nontarget mortality but nothing is known of the long-term impact on these species. The Lao government has a policy to discourage the use of rodenticides, particularly banning the use of the Chinese one. However, the chemicals can still be purchased illegally in local markets in many areas. The Lao-Australian-IRRI collaboration since 1999 has strengthened our understanding of (1) which species cause the greatest impacts on agricultural crops (pre- and postharvest), (2) their breeding ecology and habitat use, and (3) the timing of their population buildups in relation to bamboo masting and agricultural practices. This information provides a potential platform to develop ecologically based rodent management in the uplands of northern Laos.

Future perspectives

Experiences with rodent outbreaks in Lao PDR and many places elsewhere in Asia (e.g., Bangladesh, India, Myanmar) and South America (e.g., Argentina, Brazil, Chile) have illustrated consistently that outbreaks of rodents occur in association with bamboo flowering (Chauhan and Saxena 1985, Nag 1999, Aplin and Lalsiamliana, this volume, Belmain et al, this volume, Htwe et al, this volume, Jaksic and Lima 2003). These occurrences are both a historical and biological fact. As such, it would be naïve not to expect further rodent outbreaks in the future since bamboo in the northern uplands of Lao PDR is part of the vast natural forest environments. Recognizing this, it would be prudent to be prepared by focusing more effort on developing sound management measures that can deal effectively with rodent outbreaks.

Extension staff at the local level in particular need the know-how to protect crops from rodent attack so that they will be in a position to guide farmers to implement appropriate management. For the longer term, sound strategies for managing rats to avoid future outbreaks need to be developed. However, until this is achieved, there must be in place a mechanism whereby funds can be made available quickly so as to reach those farmers in need without undue delay.

Adopt a preventive strategy

Far too many cases of failure in efforts devoted to combat rodent (and other pest) outbreaks are largely due to reacting to a crisis situation when the pest populations have reached extraordinary proportions and this is true with the recent rodent outbreaks in Lao PDR. It would be wiser to develop and implement a preventive strategy whereby the rodent population is maintained at manageable levels and prevented from escalating into outbreak proportions. This could be achieved by educating farmers to apply the management technologies recommended by the National Agriculture and Forestry Research Institute. Agroecological based rodent management technology needs to be delivered to the community and this requires group action. Each farmer should act as a rodent control actor at specific times of the year. In doing so, farmers' crop production would be sustained, managing the rodent problem would be less costly, and the hardships and trauma experienced during a crisis of rodent outbreaks avoided.

Conduct studies on bamboo flowering and its relationship with rodent outbreaks

Rodent outbreaks are closely associated with bamboo masting. Other than this cursory observation, little else is known of the biology of bamboo flowering in Laos and how it relates to rodent demographic responses. Thus, there is a need to embark on studies to understand more about bamboo—the different species, their distributions, flowering cycle (multiyear or a single year) and timing, and rodent population responses to abundant supplies of bamboo fruits. For example, knowing how quickly rats can build up soon after flowering and the resulting fruit production could help predict population buildups, and provide early warning to implement actions, and when and where to conduct them. In undertaking the studies, it is desirable to involve closely the local farming communities that are familiar with the bamboo and associated biological events that happen in their areas.

Conclusions

Rodents have been a major pest in the uplands of Lao PDR and they continue to be a problem. In 2008-09, upland farmers were affected by the most severe rodent outbreaks in decades, which caused significant impacts on the poor, leading to widespread famine and hunger. Rodent outbreaks are closely associated with bamboo masting. However, there is an urgent need to embark on studies to understand more about bamboo and the effect of high seed production on individual rodent species. Important steps toward developing ecologically based and ecologically sensitive rodent management for Laos include (1) minimizing the use of indiscriminate poisoning with rodenticides; (2) focusing rodent management efforts on the manipulation of habitats and the selective culling of pest species at key times in their population cycles; (3) community-based agroecological rodent management techniques suited to particular cropping systems and particular pest species; and (4) building capacity nationally and regionally, which is urgently needed, as currently only one rodent specialist covers both research and extension in Lao PDR.

In summary, there have been far too many cases in the past of failure in efforts devoted to combat rodent outbreaks in Lao PDR. Reactive strategies have been practiced but have proven ineffective and expensive; therefore, there needs to be a major shift toward the adoption of preventive strategies.

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SECTION 2:

Rodent impacts in lowland intensive rice systems in Southeast and South Asia

Rodent impacts in lowland irrigated intensive rice systems in West Java, Indonesia

Sudarmaji, Grant R. Singleton, Peter R. Brown, Jens Jacob, and Nuraini Herawati

Most Indonesian people rely on rice as their staple food. Rice demand is growing as the human population increases at a rate of 1.5% per year. Apart from population growth, there are many challenges to maintain increases in rice production. These include the degradation of agricultural lands and conversion of rice fields to housing and industrial use, periodic high losses to pests and diseases, increases in cropping intensity, global climate change, and increases in extreme weather events. Some of those factors will change the physical and environmental conditions, which in turn provide favorable conditions for pests and diseases, particularly rodents. Increases in drought and flooding generate asynchronous planting, as do increases in the annual rice harvest index to three crops per year. We provide case studies that support the contention that these situations favor rapid rates of growth of rodent populations, thus exacerbating the impacts on rice production of the rice-field rat, which is already a dominant pest in rice crops in Indonesia. Intensive rodent monitoring and management programs are required to cope with the increased reports of outbreaks of rodent populations. Ecologically based rodent management at a community level has provided promising results and is the recommended strategy for managing rodent populations in lowland rice ecosystems in Indonesia. A clear lesson to emerge is that we need to be careful when implementing schemes to increase the intensity of rice production in response to El Niño or La Niña events, or to national demands associated with food security. The ability of rodent populations to respond rapidly to changes in cropping systems and to unusual climatic events highlights the challenges that lie ahead. In Indonesia, these challenges are acute because of recent policy directions that promote the growing of three or four rice crops per year or seven crops in 2 years.

Keywords: rice, population increase, climate change, rats, outbreaks

Rice in Indonesia

Rice is a significant crop in Indonesia, both in terms of food security and for cultural and lifestyle reasons. It has been grown as the main staple crop in Indonesia for thousands of years.

The total area that is planted to rice is 12.7 million ha, or approximately 6.7% of the 1,900,000 km^2 of land area of Indonesia. Indonesia has approximately 228.5

million people, with 25.4 million farmer households (42.1% of the total work force) engaged in rice farming throughout the country (Indonesian Statistics Bureau 2008). Rice is generally grown in two seasons each year, a monsoon or wet-season rice crop and an irrigated dry-season rice crop. In some areas, only one crop is possible, but, in other areas, more than two crops per year are possible, depending on the varieties of rice grown and the availability of irrigation water to support the production. Annual rice production for the entire country is 62.5 million t, with a mean yield of 4.9 t ha^{-1} per season. The island of Bali has the highest rice production of all provinces in Indonesia, followed by provinces in Java.

Annual rice yields have been increasing steadily through higher-yielding varieties and the development of new areas for production (Table 1). This is despite the annual loss of approximately 35,000 ha of important rice production areas to urban and industrial development. In 2008, Indonesia achieved self-sufficiency in rice production for human consumption.

The main challenges for rice production

There are some significant challenges to maintain a high level of rice production in Indonesia. The high rate of annual consumption of rice by the human population (137 kg per capita) coupled with a high rate of population increase of 1.5% per year (USAID 2008) means that there is ongoing pressure to produce sufficient rice. A national 2020 vision for rice production in Indonesia was developed in December 2008; the first priority is to increase rice production to 74.4 million t of paddy rice by 2020 to meet the population demand (Indonesian Agriculture Department 2009). Significant challenges to rice production in Indonesia until 2020 include land degradation, the conversion of land from rice farming to other purposes, potential problems associated with global climate change, limited water availability, impacts of pests and diseases on yield, and a labor shortage because of migration of labor from rural to urban areas

Table 1. Summary statistics of rice production in Indonesia, 2000-09.

Year	Yield area (ha)	Productivity (t ha^{-1})	Production (million t)	Production increase (%)
2000	11,793,475	4.40	51.89	–
2001	11,499,997	4.40	50.46	–
2002	11,521,166	4.50	51.49	–
2003	11,488,034	4.53	52.14	–
2004	11,922,974	4.53	54.09	–
2005	11,839,060	4.57	54.15	–
2006	11,786,430	4.62	54.45	–
2007	12,147,637	4.71	57.16	4.96
2008	12,327,425	4.89	60.33	5.54
2009[a]	12,668,989	4.94	62.56	3.70

[a] Numbers for 2009 are estimates; % production increase is based on previous year.
Source: Indonesian Statistics Bureau (2009).

(Indonesian Agriculture Department 2009). Important rice pests and diseases that directly affect yield are described in Table 2. The two most important pests are rats and stem borers. In 2008, significant rat damage (>20% of the standing crop) was reported for 138,740 ha, with no yield being attained for 1,631 ha (Directorate General for Food Crop Protection 2009).

In this chapter, we will document some of the rodent problems, their impacts, and management options in the lowland irrigated intensive rice cropping systems of Indonesia, with a focus on West Java (Fig. 1). We will present data on the breeding ecology and habitat use of the main pest species, and then relate the demographic

Table 2. Rice pests and diseases in lowland rice in Indonesia in 2008.

Pest or disease	Damaged area (ha)		Distribution
	Damaged	No yield	
Rat	138,740	1,631	All provinces
Stem borer	144,634	110	All provinces
Brown planthopper	24,152	608	28 provinces
Rice blast	15,171	17	29 provinces
Tungro virus	10,849	363	28 provinces
Bacterial leaf blight	95,045	43	28 provinces
Total	428,591	2,772	

Source: Directorate General for Food Crop Protection (2009).

Fig. 1. Location of key study sites referred to in the text.

responses of the rodent populations to the agricultural practices of smallholder farmers. Management recommendations have been validated and verified at the village level (80–120 ha) in Cilimaya using an ecological approach to rodent pest management in the context of adaptive research (Singleton et al 2005, Jacob et al 2010). We will report on the lessons learned from this farmer participatory adaptive research approach and the challenges that need to be overcome to enable the sustainable and widespread adoption of ecologically based rodent management.

West Java has chronic problems caused by rodent populations leading to losses in rice production of 10–15%. First, we will consider the acute population outbreaks (losses >15% over areas >500 ha) and then return to the chronic outbreaks because the lessons learned from the outbreaks provide a strong platform for developing broad management recommendations.

Rodent problems in Indonesia—chronic losses and occasional outbreaks

The area damaged by rats varies markedly between years. In some years, a significant yield loss (>20%) is recorded on a large spatial scale, such as in 1977-78 (450,000 ha) and 1997-98 (>200,000 ha) (Fig. 2). In some of these areas, 100% yield loss occurred;

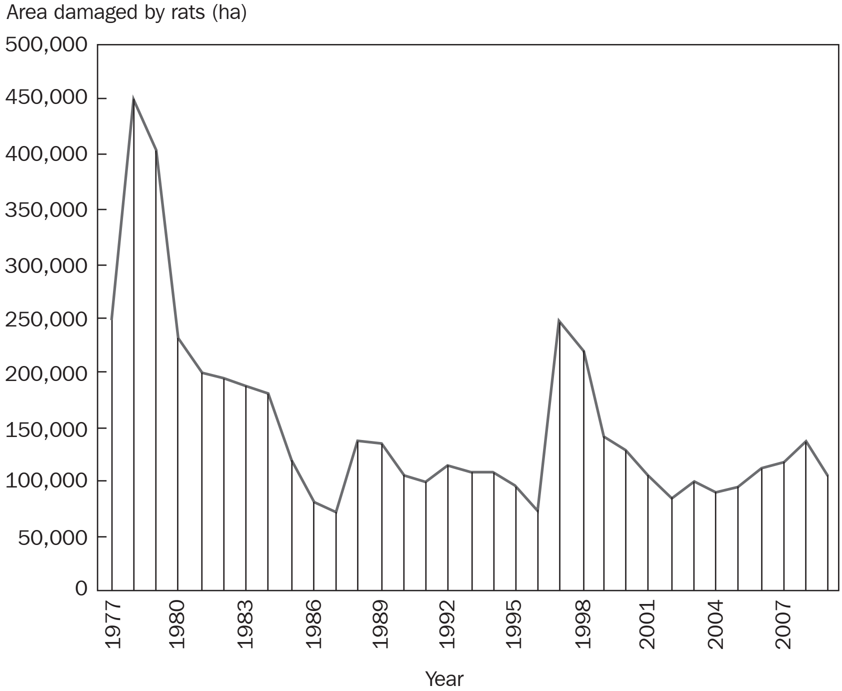

Fig. 2. Area (ha) of rat damage to rice crops across Indonesia (Directorate General for Food Crop Protection 2009, with some modification).

losses above 40% are often devastating to smallholder farmers and can have long-term consequences on their ability to access credit. Overall, however, the area of rat damage is slowly decreasing. Although there are specific years when the area of rat infestation is high (outbreak years), damage is perceived as chronic and seasonal. Consequently, management action is taken in almost every year in all cropping seasons.

The provinces that are regularly affected by significant rat damage are West Java, Central Java, and South Sulawesi. These provinces are three of the four highest rice-producing provinces; therefore, limiting yield losses caused by rodents is an important challenge that needs to be managed to ensure the food security of Indonesia.

Nine species of rodents have been identified as potential pests of rice crops in Indonesia. However, the dominant pest species is the rice-field rat, *Rattus argentiventer*. This species represents 98.6% of the rodents captured in the rice-field agroecosystems of West Java (Sudarmaji and Herawati 2008). It is a significant pest pre- and postharvest, but the largest losses are caused to the growing rice crop. Over the past decade, the most severe losses to rice crops caused by rats occurred in West Java in 2008, where there were high losses reported on 134,814 ha of rice crops. The second-highest damage report was in Central Java, where 83,735 ha of rice suffered high damage in 2008 (Directorate General for Food Crop Protection 2009).

The factors leading to outbreaks of rodent populations

The outbreaks of rodent populations and subsequent high damage have been attributed to a range of factors. We provide case studies to support each of these factors.

1. Unusual climatic events

(a) *Droughts causing asynchronous planting*. In West Java, the wet season usually begins in October and ends in April. The 1997-98 El Niño was one of the most severe recorded; no rain was recorded in October and November, and rainfall was low in December 1997. Losses caused by rodents were 17–22% during the 1997-98 wet-season rice crop and higher in the 1998 dry-season crop. In one region of West Java, on average, 222 rice-field rats were caught per ha over 230 ha during an eradication campaign (see Leung et al 1999). The rodent population outbreak in 1998 appeared to be related to the staggered planting of the rice crops during the 1997-98 wet season. In Karawang, West Java, the release of irrigated water for transplanting of the rice crop occurred over 12 weeks rather than the usual 4 to 6 weeks.

The breeding of the rice-field rat is strongly associated with the stage of the rice crop; breeding commences just prior to maximum tillering and continues until just after harvest (Lam 1983, Leung et al 1999). The asynchrony of planting of the rice crops in Karawang led to an extension of the breeding season of the rice-field rat, which in turn generated a population outbreak.

(b) *Unusual rainfall events*. The 2000-01 wet-season crop was harvested in April 2001. The harvest was followed by unseasonal heavy rain, which prevented farmers from plowing in their rice stubble and led to the growth of a ratoon rice crop. The ratoon crop extended the survival and breeding of the rice-field rats and led to high population densities in June 2001. During the subsequent 2001 dry season, 24% to 31% of the tillers were damaged by rats and yield losses reached 0.8 t ha^{-1} (Singleton et al 2005).

(c) *Occasional floods lead to migration of rats*. In 2007, a massive rat migration occurred during 12-19 December to Citarik Village, West Java, because of flooding in an adjacent village, which was identified as the source of the rat population (Table 3). The farmers in Citarik had planted rice for a third time within a year as part of the IP Padi program (see next section) but were not able to obtain a yield from this crop, which was at the booting stage at the time of the rat invasion.

2. Increased cropping intensity

The 1997-98 El Niño event led to a substantial reduction in rice production. The government of Indonesia responded by designating some cropping areas to produce a third crop in a year (IP Padi 300 program). The extended availability of high-quality food and reduced fallow period led to an increase in rodent populations and required a large investment in remedial control activities.

The 2020 vision for rice production in Indonesia raised the possibility of growing three (IP Padi 300) (Indonesian Agriculture Department 2009) or four crops (IP Padi 400) in one year (Indonesian Center for Rice Research 2009). The following requirements would need to be met to implement IP Padi 300 and IP Padi 400: a location with enough water supply for at least 11 months; a nonpest disease-endemic area; the area should be close to a secondary water channel; and the area should be a minimum of 25 ha with a synchronous planting system. Especially for the IP Padi 400 program, a rice variety with very short maturity (± 90 days) is required (Indonesian Center for Rice Research 2009).

3. Asynchronous planting by more than 2 weeks due to the complexity of the farming system within a large area

Asynchronous planting of rice crops by more than 2 weeks has been observed in several areas in Indonesia where water schedules are different in adjoining crop lands (see

Table 3. Rats captured in Citarik and Bojongsari villages (both in the same subdistrict) from a 100-m linear trap-barrier system (LTBS) following the flooding of fields in a neighboring village. The rat migration occurred during the 2007 wet season after heavy rains in early December.

Treatment site	Time	Rats captured
Citarik (1 unit LTBS)	October	32
	November	24
	December	417
Bojongsari (1 unit LTBS)	18-23 October	63
	7-26 November	195
	1-14 December	153

example below), and a shortage of labor occurs at transplanting. Two typical situations lead to asynchronous planting of rice. The first is when farmers have a continuous water supply. These farmers usually plant different rice varieties with different maturation dates. This leads to asynchrony in planting, causing significant rat and tungro virus problems. An example is the Klaten area in Central Java. The second scenario is when farmers have a shortage of water. An example is Cilimaya in Karawang District, West Java (Fig. 1), where El Niño occurred in 1997-98. El Niño led to a marked decrease in the supply of irrigation water, causing water schedules for planting to be extended from 4 to 9 weeks for the Cilimaya irrigation turn-out area (13,106 ha). Therefore, the planting time was extended within a locality and this caused asynchronous planting, which in turn extended the breeding season of the rice-field rats. Consequently, the farmers located in the downstream areas planted last, and suffered high rat damage to their rice crops.

The impact of asynchrony of rice cropping on rodent populations was clearly demonstrated when different planting schedules were applied on a large national seed farm at Perum (1,400 ha) and on a neighboring farm (400 ha) at the Indonesian Center for Rice Research (ICRR) in Sukamandi, West Java (Fig. 1). The rice seed farm and the ICRR farm share a border; they are separated only by a 6-km stretch of a national highway.

Large numbers of rats invaded ICRR after the seed farm was fallow in May/June in 1995, 1996, and 1997 (Singleton et al 2003). The annual migration of rats was associated with the asynchrony of rice planting (Fig. 3). The problem was managed through the development of rat barriers and multiple-capture rat traps to intercept the tide of rats moving from the rice seed farm to ICRR. Rats were captured using multiple-capture traps (eight) located in water channels underneath the highway (Sudarmaji and Anggara 2000). Some 10,142 rats were captured in a 3-week period in 1995, 11,844 in a 3-week period in 1996, and 26,289 in a 3-week period in 1997. The maximum number of rats captured was in excess of 2,000 per day in 1997. When the cropping

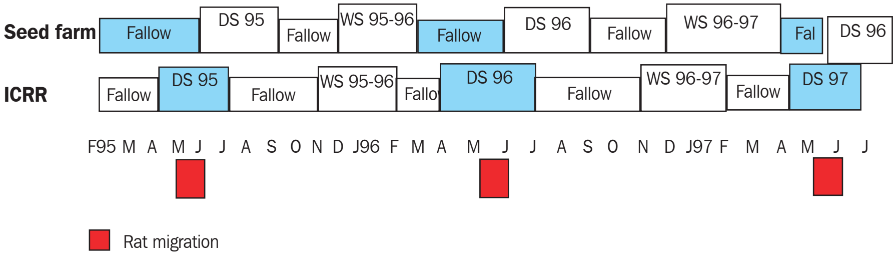

Fig. 3. Cropping schedule of the Perum Seed Farm and the neighboring farm at the Indonesian Center for Rice Research (ICRR); the two farms are separated by a highway. In 1995, 1996, and 1997, significant migration of rats from the seed farm to the ICRR farm occurred each May and June when the ICRR was growing its dry-season rice crop and the seed farm was fallow. This asynchrony of cropping led to significant crop damage and yield loss at the ICRR farm. DS = dry season; WS = wet season.

schedule was synchronized (that is, crops all transplanted within the same 2-week period), the rodent problem dissipated (Singleton et al 2003).

A second case study of local rodent movements associated with asynchrony of cropping was associated with a deliberate decision by ICRR to delay its 2008 dry-season crop so that the rice crops would be at an early ripening stage for an outdoor display during the 3rd National Rice Week held at ICRR. The rice crops at the seed farm and neighboring villages were harvested more than a month earlier. ICRR staff coordinated community action with neighboring villages after a pulse in rat migration from the seed farm was detected in early June from trap-barrier systems (TBS) (see Singleton et al 1998 for details of a TBS) and linear trap-barrier system set up on the ICRR farm (Fig. 4). Three days of community action were conducted over a week in mid-June, involving between 70 and 150 farmers. Approximately 4,000 rats were caught on the first day, 1,230 were caught 2 days later, and 817 a week later.

Population dynamics of rice-field rats in response to more intense cropping

Populations of the rice-field rat undergo seasonal growth patterns in response to the availability of food resources supplied by the rice crop (Jacob et al 2010). The trappable population peaks about 6–8 weeks after the cessation of breeding, which occurs just after the harvest of the rice crop. The length of the fallow period between crops appears to be important for limiting population growth in the subsequent rice crop. The fallow season is unfavorable for rice-field rats because of a significant reduction in food supply, shelter, and nesting sites in the fields. We hypothesize that the longer the fallow season, the smaller the founder population for the next cropping season. However, more quantitative data are required from the fields of farmers to substantiate this relationship, particularly because the 2008 national food shortage led the government of Indonesia to recommend a third rice crop a year where water was sufficient (Indonesian Center for Rice Research 2009). These areas generally plant only two rice crops per year and have a 2–3-month fallow prior to the wet-season crop.

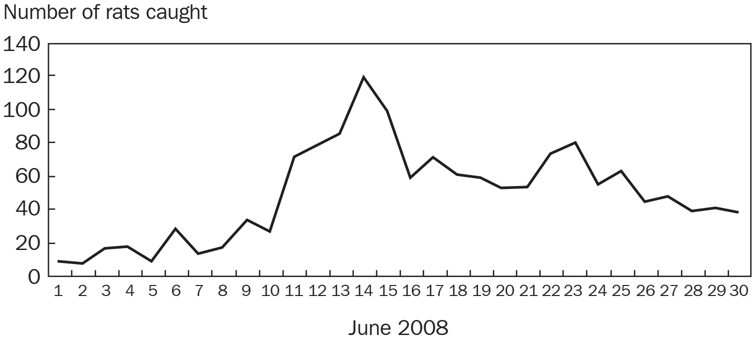

Fig. 4. Daily captures of rats in June 2008 at the Indonesian Center for Rice Research, Sukamandi, West Java, from trap-barrier systems and linear trap-barrier systems. The rice crop was at the maximum tillering stage.

In 2009, ICRR set up three rice crops a year on parts of its farm and this led to massive numbers of rats in August during the generative stage of the third crop (Fig. 5); more than 35,000 rats were captured each week from June to August. However, the growing of a third crop also led to asynchrony of cropping, so there was a combination of asynchrony and seasonal cropping on the 400-ha farm. We need to understand more about what happens with rodent population densities when three crops are grown each year, but in synchrony. On a positive note, the use of trap-barrier systems in conjunction with the changes in cropping systems was sufficient to protect the ICRR rice crops from significant rodent damage.

Impacts of rodent outbreaks

The impacts of outbreaks of rodent populations are important at the national and individual (farmer) level. At the national level, widespread outbreaks could cause a critical shortage of food in specific provinces, which in turn could impinge on national rice stocks and lead to national food security issues. At the individual level, the impacts for farmers include severely reduced yields of their rice crop (or no yields in some cases), lack of cash income for daily expenditures and investment in their farming business, and the need to seek rural credit at high interest rates. As a result, there is an increase in the number of poor people (farmers) after rodent outbreaks. For example,

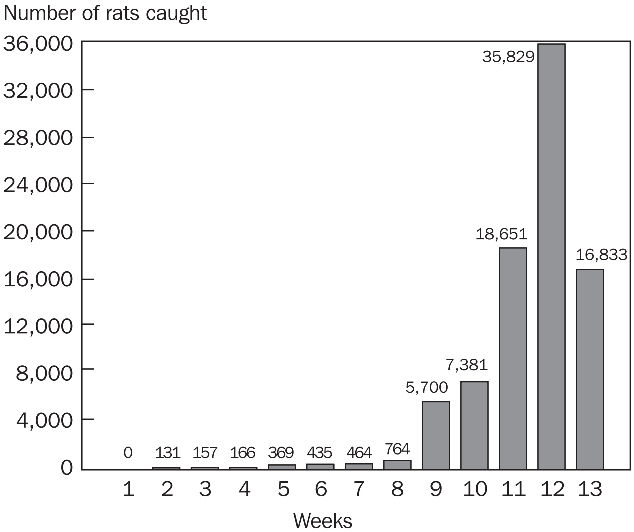

Fig. 5. Rat migration onto the farm of the Indonesian Center for Rice Research (June-August 2009) due to a high-intensity rice-cropping program of three rice crops per year (IP 300) over 300 ha, whereas the surrounding cropping areas were fallow. In June (week 1), the third rice crop was planted. Four linear trap-barrier systems were set along the border of the ICRR farm: 271 multiple-capture traps were set approximately 10 m apart into these plastic barriers.

most farmers in West Java rely on rice farming as their sole job with small parcels of land owned (0.3–15 ha). Therefore, substantial losses in rice production would make these people jobless because their financial support comes from rice farming (Sudarmaji et al 2003). Financial losses can be substantial, especially if prices for rice on the world market are high, as they were in 2008. If rice production cannot satisfy the needs of Indonesia, then the area of cropping is likely to be extended. This could lead to the transformation of areas of conservation value into rice fields, and place at risk the ecological sustainability of lowland rice production.

Pesisir Selatan District, West Sumatera Province, provides a clear example of the social and economic impacts of rodent pests if they are not managed. Surantih Village in this district had a history of chronic rodent outbreaks. The farmers of this village did not have access to knowledge on the biology of the pest species or on the control technologies that could be effective given this knowledge. Compounding the problem is that many of the farmers in this village believed that it is forbidden to kill rats based on a long-held legend. The local farmers called rodents "Si Putri," which means "The Princess." If the rodents are killed, then the others will be angry and the damage to their crops will become more severe. The impact of the rats was such that rice yields were only 1–2 t ha^{-1}, well below the national average of 4.9 t ha^{-1}. Thus, the local rice farmers were unable to provide for their family without taking on another job, such as motor-bike servicing or casual labor. In 2006, staff from ICRR introduced ecologically based rodent management to these local farmers and successfully protected their rice crop from the depredations of the rats. These farmers were able to obtain yields of 7–8 t ha^{-1}. Thereafter, the farmers developed strong self-confidence in their ability to manage the rice-field rat and were able to return to rice farming as their main job and source of income.

The successes and failures of management actions

Since the mid-1990s, scientific research has examined and documented the problems of rodents in the lowland irrigated rice-cropping system of Indonesia, and concurrently developed a strong understanding of the ecology of the main pest species (Leung et al 1999, Sudarmaji and Herawati 2008, Jacob et al 2010). We now have a good understanding of the species involved, the nature of the damage it causes to rice crops, the basic biological and ecological factors that lead to increases and decreases in rodent population abundance and breeding, and how changes in cropping systems influence these demographic parameters (see Jacob et al 2003, Singleton et al 2004, 2005). This knowledge has provided a strong platform to explore alternative methods for control, particularly alternatives to the use of rodenticides. A range of ecologically based rodent management strategies was developed and tested at a relatively large scale in replicated "village"-level studies over a 4-year period (Singleton et al 2005, Jacob et al 2010). The key strategies that proved effective are outlined in Table 4.

The results of adaptive management field trials at a village level (four sites each of 120 ha) over six cropping seasons from 1999 to 2002 demonstrated a significant reduction in yield loss of rice and in the costs of rodent management after the implementation of EBRM strategies (Singleton et al 2005, Jacob et al 2010). Importantly, there was a mean 6% relative increase in rice yield after the implementation of EBRM strategies in the villages treated with these strategies. Indeed, the study showed that, for every 1% reduction in damage to tillers per ha, there was an increase in yield of 58 kg. A subsequent study in a nearby region of West Java, using similar EBRM strategies, also showed an increase in the yield of rice over 10 seasons. The increases in yield were significant for five of the seasons. The mean relative increase in rice yield was 5% (Sudarmaji et al 2010).

At the ICRR farm, prior to 1998, rice yields were 3–4 t ha^{-1}, with rat damage regularly in the range of 30–50%. After implementation of EBRM (and particularly the use of the TBS throughout ICRR, with a catch of >15,000 rats per season from an area of 200 ha), rice yields have increased to 6–8 t ha^{-1}.

Lessons learned

In Indonesia, losses to rats in irrigated lowland rice are of paramount importance for smallholder farmers and for food security at the national level. An environmentally sustainable method of rodent management has been developed and refined through long-term farmer participatory adaptive management. The development of EBRM required 5 years of basic ecological studies, with an emphasis on documenting seasonal changes in population dynamics, breeding ecology, and habitat use, and on the association between rodent population density, crop damage, and yield loss (Leung et al 1999, Brown et al 2001, Jacob and Wegner 2005, Sudarmaji and Herawati 2008, Singleton et al 2005, Jacob et al 2010).

Management approaches needed to be developed in close cooperation with smallholder farmers because sustained community action at key times and at an appropriate scale (at least 100 ha) is essential for effective management. An important challenge has been to identify how to link with existing community groups to facilitate the adoption of community actions. Formal surveys of the knowledge, attitudes, and practices of smallholder farmers on rodent pests and their management (Sudarmaji et al 2003) provided essential information on the social and cultural context for the development of appropriate management strategies.

A clear lesson to emerge is that we need to be careful when implementing IP 300-type schemes in response to El Niño events, La Niña events, or national and international demands associated with food security. The ability of rodent populations to respond rapidly to changes in cropping systems (e.g., changes in timing and intensity of cropping), and to unusual climatic events, highlights the challenges that lie ahead. In Indonesia, these are lessons we need to build upon because of the recent policy that seeks to increase the areas where three crops of rice are grown per year, and even promotes the growing of four crops per year or seven crops in two years (Indonesian Center for Rice Research 2009). Add to this the ever-increasing likelihood that climate change will lead to unusual climatic events becoming the usual rather than the unusual; thus, we will need to conduct more basic ecological research on understanding the mechanisms and drivers of rodent population outbreaks.

In the lowland intensive rice systems of Indonesia, both chronic and acute rodent problems are driven by the availability of extended periods of high-quality food and nesting sites. Whatever the cropping system and intensity, it is essential to promote synchrony of cropping over reasonably large contiguous areas. This highlights the need to integrate rodent management in partnership with effectively managed irrigation scheduling.

One word of caution is that ecological research in Indonesia has focused on one species, *R. argentiventer*, and for good reason, given it is the dominant species in most lowland rice systems. However, other species such as *Rattus exulans* and *Bandicota indica* have been reported as significant pest species in mixed cropping systems. Also, these species, together with *Rattus rattus* and *R. norvegicus*, are likely to have a larger impact on stored grain.

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Rodent outbreaks in South Sulawesi, Indonesia: the importance of understanding cultural norms

D. Baco, R. Nasruddin, and H. Juddawi

A high priority for the South Sulawesi government was to improve rice production, with a target of producing more than 2 million tons in 2009 for export to other provinces in Indonesia as well as to other countries. Rodents are one of the most important pests threatening rice production in several districts of the province. In the absence of appropriate rodent control measures, the province suffered significant rodent damage, with more than 45,000 ha of rice fields damaged by an outbreak of rats in 1998-99. At this time, high rodent abundance occurred in the western part of South Sulawesi during the dry season, whereas high rodent abundance occurred in the eastern part during the wet season. Several factors have likely contributed to this outbreak but evidence suggests that a change in climatic conditions was the main factor that led to a change in cropping patterns by farmers. Continuous rice planting (at least two crops in a year) and asynchronous planting and harvesting provided an abundance of food for rodents, leading to an outbreak of rodent populations. For many years, smallholder farmers and even policymakers have been guided by various myths and beliefs in their efforts to manage rodent populations. In recent years, we have facilitated the integration of science into traditional cultural practices and beliefs. This has led to an effective platform for the implementation of ecological rodent management in several irrigated rice districts, thus successfully curbing the growth of rodent populations and their effects.

Across Indonesia, rodents are considered the number-one pest of rice crops and South Sulawesi Province is no exception (Directorate of Food Crops Protection, unpublished data). There are limited precise data on annual losses to rodents at a district level in South Sulawesi; however, at the provincial level, the estimated value of yield losses incurred was 248.85 billion Indonesian Rupias (IDR) (equivalent to US$27.65 million) during the rodent outbreak in 1998-99. Geddes (1992) found that, for Indonesia as a whole, rodents caused yield losses of around 17% each year. According to Meerburg et al (2009), annual yield losses in Indonesia caused by rodents could feed 39 million people per year, which is far greater than the number of undernourished people in Indonesia. Postharvest losses caused by rodents vary from 5% to 10%.

South Sulawesi is one of Indonesia's most important rice-growing areas outside of Java. The province produces a surplus of >1 million tons annually (Central Statistic Bureau 2006). In May 2008, the governor of South Sulawesi developed a program to increase the surplus of rice to 2 million tons per annum through increases in productivity and harvest area, a decrease in yield losses, and improvements in farmer knowledge and practices (South Sulawesi Government 2008). This is not easy, especially since growth in yield is slowing down, yield growth is lagging behind population growth, and less area is suitable for rice planting because of urbanization and industrial development. For generations, this rice-growing area has been well known to be suitable for many kinds of pests and diseases, especially rodents. To illustrate the importance of rats in South Sulawesi, the late Ir. Soenardi, the first director of food crop protection, visited South Sulawesi in 1978 and said in Paddakalawa Village, Pinrang District: “If some time in the future, we want to build an Indonesian Rodent Research Institute, I remind all of you to put the institute in this village.”

According to farmer surveys in Pinrang in 2007 (Baco et al, unpublished data), rats are the first-ranked pest in terms of destruction of rice and the most important pest to be controlled. In South Sulawesi, rats also seriously attack cocoa pod, especially when cocoa plantations and rice fields are adjacent to each other (Baco et al 2007).

Rodent outbreaks

Myths and dogma of rodent outbreaks

In many countries around the world, both developing and developed, many beliefs exist on what influences the population dynamics of rodent pests and what leads to rodent outbreaks (see Singleton et al 2003). Some common examples from South Sulawesi Province follow.

In South Sulawesi culture, *Lontara* is a traditional practice of climate prediction and can include pest and disease outbreaks in certain years. *Lontara* methods are based on observations since ancient times. *Lontara* methods correlate the position of the stars for a particular month to climate, plant growth, and animal behavior. The *Lontara* prediction is based on the Arabic calendar, so the name of the year is given using the Arabic alphabet. This infers that *Lontara* was influenced by the culture of the Muslim religion hundreds of years ago although it seems to bear no relation to the religion. *Pallontara* (the experts of *Lontara*) are usually male socialites who made climate, pest, plant growth, and yield predictions in one year or one season. There was usually one in every district. Unfortunately, most *Pallontara* do not continue these observations seriously any more; they just read the *Lontara*, which was written or told long ago.

Some *Lontara* predictions are difficult to understand or verify, whereas others have a sound scientific basis. As an example, a statement of *Lontara* describes the “roguishness of the government” as one of the factors considered to cause an outbreak of rodents. We tried to clarify this *Lontara* statement with some *Pallontara*. The *Pallontara* gave an example that, if the government breaks its promise to prepare water irrigation at a certain time, planting dates will not be synchronized and rodent populations will irrupt as a consequence.

There are many other myths in this region related to rodent outbreaks. The behavior of dogs and where they leave their feces are used by some communities to predict rodent outbreaks. If many dogs leave their feces in the middle of the street, this is a predictor of a rodent outbreak. Heavy rain during the night compared with during the day is also thought to be an indicator that rodent populations will irrupt. One belief is that some environmental variables are connected to outbreaks of rodent populations. For example, if there are bamboo shoots growing very tall, this means there will be heavy rain and then there will be a rodent outbreak. Another indicator of outbreaks in the rice field is when the leaves of bamboo are cut by rodents. If many leaves of bamboo are cut, this means that a rodent population irruption is imminent. However, we clarify that the species of bamboo found in South Sulawesi is not the *Melocanna* type found in India, Bangladesh, and Myanmar, which leads to the 50-year cycle of outbreaks (Aplin and Lalsiamliana, this volume, Belmain et al, this volume, Htwe et al, this volume).

In addition, farmers believe they can predict the climate and rainfall for the coming season by the location of rodent nests in the field. If a nest is found in the middle of the rice field, in a canal, or in other lower places, it is an indicator that the next season will be dry. However, if nests are found in hills or in other higher places, farmers predict that the next season will have heavy rain or floods.

Farmers have a strong belief that planting rice at the wrong time will cause damage by pests and diseases, especially rodents. Farmers also believe that increased rodent abundance and outbreaks occur after applying any rodent control measure. Most farmers in this region do not like to use anticoagulant rodenticides. They think that the rodenticides are not effective in controlling rodents and they believe that the use of rodenticides triggers a more serious rodent infestation.

Rodent outbreaks in the last 20 years

Rodent infestations in rice fields in South Sulawesi normally affect around 10,000 ha annually, although the area affected can at least double under certain conditions. In 1998-99, the area of rice fields that was damaged by rodents was >45,000 ha (Fig. 1). At this time, the average intensity of crop damage was more than 35%. In other years, damage varied between 25% and 35%.

In general, there is a belief that a change in climatic conditions, especially rainfall, followed by a change in cropping pattern usually precedes a rodent outbreak in South Sulawesi. The 1998-99 outbreak was preceded by a dry period in several districts in South Sulawesi early in 1998, which was attributed to El Niño conditions. In late July to December 1998, high-intensity rain events occurred, which were attributed to La Niña conditions (Fig. 2). Because of these changes in climatic conditions, cropping patterns also changed: some irrigated rice fields were not planted in the dry season of 1998 in the western part or in the wet season of 1998 in the eastern part of South Sulawesi. In addition, in September-October 1998, which is usually dry in this area and most fields are fallow, many farmers planted rice, especially in the eastern part of South Sulawesi. Farmers normally plant only twice in a year, but, in 1998, they planted three crops of rice in sequence, although the total area planted was similar to or less than in subsequent years. The total area of rice fields planted in 1998 and 1999 was 948,368 ha and 915,772 ha, respectively, whereas, in 2000, 1,037,013 ha were planted.

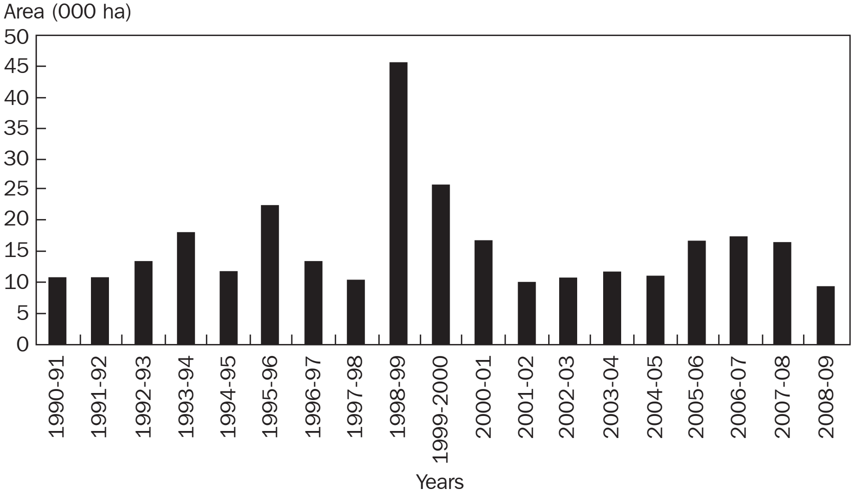

Fig. 1. Area (ha) damaged by rats in rice crops in South Sulawesi, Indonesia, 1990-2009 (source: Food and Horticulture Crop Protection Institute, Maros). Note: The average damage was >35% in 1998-99 and between 25% and 35% in other years.

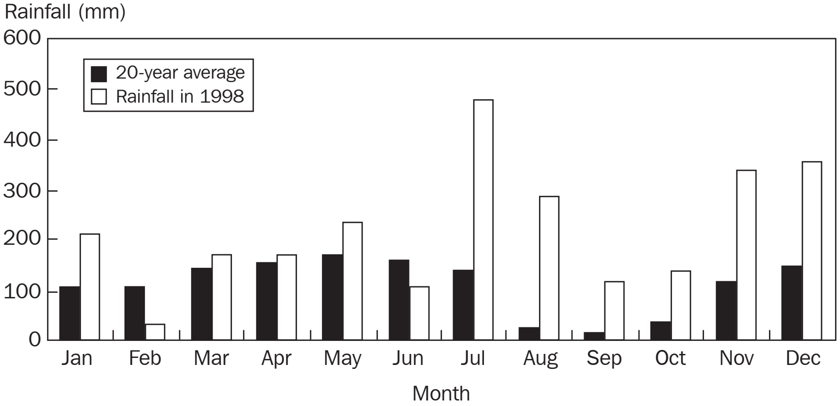

Fig. 2. Mean monthly rainfall (mm) at Congko Climatology Station, Soppeng District, in the eastern part of South Sulawesi, Indonesia (20-year average and monthly rainfall in 1998).

In the western part of South Sulawesi, rodent infestations are generally worse in the dry season (Fig. 3A), whereas, in the eastern part, infestations tend to be worse in the wet season (Fig. 3B). Infestations are not affected by the area of rice grown. For example, the total area of rice fields is always much greater in the wet season than in the dry season, in both the western and eastern regions. Rainy seasons also do not have a major direct effect on the population size of the rodents. A majority of

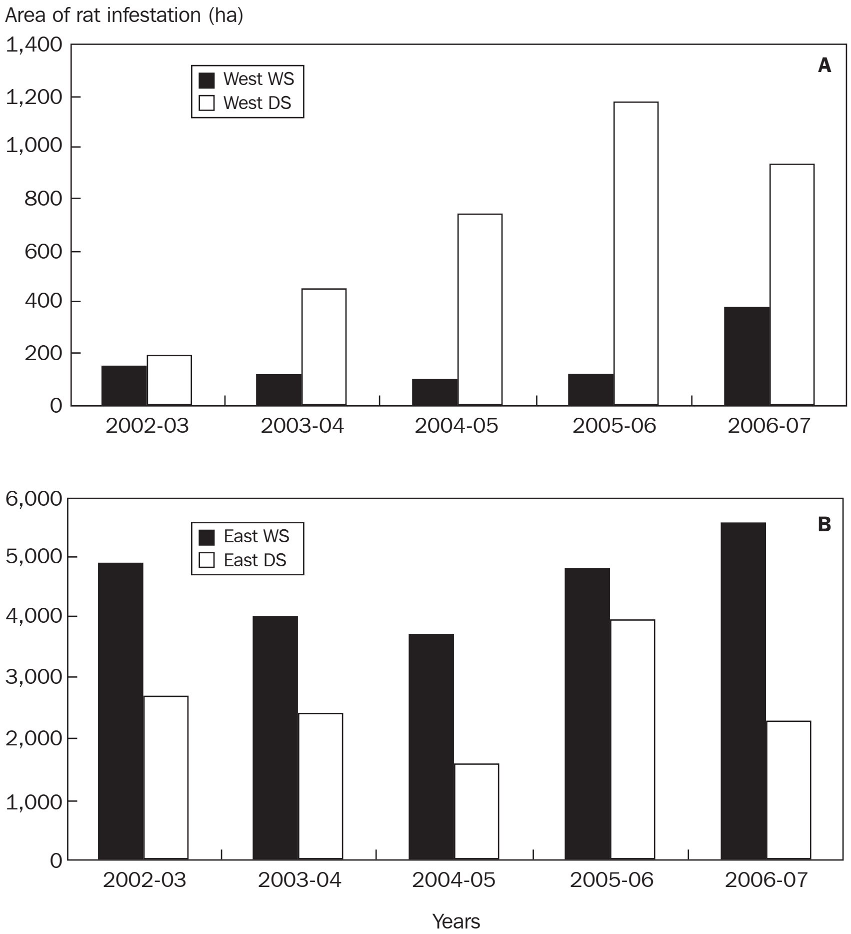

Fig. 3. Rodent infestation in the wet season (WS) and dry season (DS) in the (A) western part and (B) eastern part of South Sulawesi (source: Food and Horticulture Crop Protection Institute, Maros). Note: Crop damage usually varies between 25% and 35%.

the damage caused by rodents to rice crops is thought to be related to the continuous availability of food.

In the western part of South Sulawesi, farmers plant dry-season rice around April, as soon as possible after harvesting the wet-season rice in March. Dry-season rice is harvested around August and the planting of wet-season rice is postponed until December. In the period of September to November, little food is available in fields.

The situation is opposite in the eastern part, where farmers delay the planting of dry-season rice until around December, after the harvest of the wet-season rice in August. Wet-season rice is planted as soon as possible after harvesting the dry-season rice crop in March or April. We propose that the key factor leading to the population outbreak in 1998-99 was the continuous availability of food, although other extrinsic and intrinsic factors, such as predators, diseases, and social behavior, cannot be ignored (Wolff 2003, Krebs 2003).

Local outbreaks at district or subdistrict levels tend to coincide with asynchronous planting in neighboring areas. Rodents can easily move from one area to another where rice or other kinds of food are available, especially at the booting stage of the rice crop (Brown et al 2001). Rodents can then move back after harvest (Jacob et al 2003). The distance that rodents can move can be up to several hundred meters and rats can make good use of irrigation canals for moving around a landscape. Conversely, farmers have observed on several occasions that outbreaks did not always occur when asynchronous planting occurred. The role of environmental factors and the intrinsic behavior of rodents in supporting outbreaks need to be examined carefully.

The impact of rodent outbreaks

According to information from farmers in Pinrang, thousands of people migrated in 1968-70 and 1974 from Pinrang and Sidrap to East Kalimantan and Sabah Malaysia because of serious rat attacks on their rice crops. Unfortunately, we were unable to locate written documentation of this situation. In this period, asynchronous planting of rice occurred in Pinrang and Sidrap districts. The peak of irregularity of planting occurred in 1973-74. Such asynchronous planting meant that it was not possible to differentiate between wet-season and dry-season rice crops. Consequently, rice was seriously attacked by pests and diseases, mainly rodents and tungro virus. Because of this phenomenon, the regional government started to coordinate with the elders of the farming communities, and with local and regional crop protection specialists. The government linked into the traditional culture *Tudang Sipulung* ("sitting together"), leading to a modern *Tudang Sipulung*, which involved a diverse group of stakeholders that included key farmers, the Agriculture Department, the Irrigation Department, Commercial and Industry departments, seed and fertilizer companies, researchers, and academics at the district and provincial level. The modern *Tudang Sipulung* started in the 1970s in Sidrap and Pinrang districts after population outbreaks of rodents and other pests and diseases. Pinrang and Sidrap districts are the main areas of irrigated rice fields in South Sulawesi. *Tudang Sipulung* is conducted every year beginning at the village or subdistrict level, then at the district level, and lastly at the provincial level. *Tudang Sipulung* conducted at the provincial level is usually held either in the capital city of the province or in the capital city of a selected district.

Another important impact of the 1998-99 rodent outbreak for farmers was the switch from growing rice crops to growing other crops such as cocoa. At that time, many rice fields were converted into fish ponds and cocoa plantations. Unfortunately, cocoa fruit was also attacked by the rodents (Baco et al 2007). More than 10,000 ha were converted to fish ponds at that time.

This historical account of two major outbreaks of rodent populations in South Sulawesi (the early 1970s and 1998-99) clearly shows that, even though major rodent outbreaks occurred only twice in 25 years, the socioeconomic impacts were long-lasting. Both outbreaks had significant social impacts that led to substantial changes in farming practices. The net result was a decrease in the relative importance of rice (and hence effort devoted to its production), which in the long term affected the distribution of rice and consequently led to a general instability in the livelihoods of the affected communities.

Based on the data of Figure 1, with an average of 10,000 ha/year infested and 30% intensity of damage, the mean value of the yield loss is 47.400 billion IDR, equivalent to $5.27 million/year. In 1998-99, 45,000 ha were damaged with an intensity of 35%, with an estimated yield loss of 248.85 billion IDR, equivalent to $27.65 million. All calculations are based on the assumption of a yield potential of 5 t/ha, milling recovery of unhulled rice to hulled rice of 63.2%, and a price of hulled rice of 5,000 IDR/kg.

Rodent management

Before the introduction of modern technologies, rodent management was based on advice that had its origins in *Lontara*. With no chemical control available, one of the methods implemented was a form of biological control of rodents through encouragement of natural predators such as dogs and cats. An example appears in the old Bugis literature La Galigo, episode Meong Palo Karellae (Yellow Stripe Cat) (Fachruddin 2003). This parable relates that the rice became very angry toward a man who hit a cat because the cat ate one fish, which he had just bought from the market. The rice reported the case to the god about the bad character of men. The meaning of this legend is that farmers should take care of cats as an animal predator of rodents. It must be remembered that, in these early times, there was only one rice crop grown per year (wet-season rice), and so losses to rodents of this important staple were a major concern.

The above story highlights the importance of rice and rats in the culture of the Bugis, the traditional residents of South Sulawesi. In modern times, the impacts of rodents have again become a major concern since about the 1970s because of the increase in intensity of rice cropping (two or three crops per year) associated with the availability of irrigation water. The rodent problem escalated and traditional control methods are no longer adequate.

The government of South Sulawesi considers both the *Lontara* and information from modern weather forecasts in making policy decisions, including rodent control. Synchronized cropping is now recognized by farmers as an important factor in limiting the growth of rodent populations. Most districts in this province conduct traditional *Tudang Sipulung* meetings every year to decide what time is best for planting and for the application of other technologies.

Selecting the date for synchronized planting of rice in South Sulawesi has many challenges, including (1) the uncertain climatic conditions for the past several years in this area; (2) the poor condition of many irrigation canals, resulting in difficulties with water management; (3) the lower market price if all farmers harvest at the same time; (4) inefficient use of mechanical equipment; and (5) the observation that the ceremonial aspects of the traditional *Tudang Sipulung* seem to be becoming more dominant than the implementation of decisions.

Many methods have been applied by farmers in South Sulawesi to control rodents. Chemical control, especially acute rodenticide, is commonly selected by farmers because it is easy to conduct and results are immediately visible (Baco and Tandiabang 2003). However, adaptive research conducted in farmers' fields in Java (Sudarmaji et al, this volume) and in South Sulawesi has highlighted the need for communities to work together to tackle the rodent problem. This message is now beginning to take hold in the rural communities. As with their forefathers, the Bugis now accept that coordinated community action provides a basis for successful management of rodent populations. Crop protection specialists have become involved in the modern *Tudang Sipulung* and have been able to provide knowledge of the biology of the rodent pest species as a basis for management actions. These actions include good hygiene at a landscape level, synchronized planting of the rice crop at an appropriate time, and community action to manage rodent populations early in the rice-cropping season prior to the main breeding season of the rats.

The integration of science into traditional cultural practices and beliefs provides hope that effective management of rodent pests will become the norm rather than the exception in Bugis communities in South Sulawesi. However, the province has a mix of ethnic groups and also many different Bugis farmer groups. Progress in our fight against rodents in this province is still gaining momentum, and we are confident that the lessons learned from the cultural context of rodent management will assist in the effective diffusion of community-based rodent management.

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Notes

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Rodent impacts in lowland irrigated intensive rice systems in Vietnam

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Rice is a significant crop for Vietnam, culturally, socially, and economically. Rodents have significant cultural and economic aspects; they are one of the 12 signs of the Lunar New Year, but they are also considered one of the three most important problems faced by the agricultural sector. Rodents normally damage around 100,000 ha of rice crops each year (with estimated yield losses of 10%), but, during outbreaks, up to 700,000 ha can be severely damaged (with estimated yield losses of 20–30%). High crop losses during an outbreak in 1996 to 1999 were attributed to unusual rainfall events, which led to asynchronous planting and harvesting of rice crops over large areas. This outbreak led to the development of a national policy to reduce the rodent problem, and a subsequent reduction in losses. A number of studies were conducted to understand the biology and ecology of rodent pest species and it was found that the breeding and behavior of the main rodent pest species (particularly *Rattus argentiventer* and *R. losea*) were linked to the development stage of rice crops. A range of community-based rodent control options were tested and were found to be relatively inexpensive to implement and they resulted in reductions in yield losses. These included community actions such as synchronized cropping, rat control campaigns at key times, field hygiene, and the use of community trap-barrier systems (CTBS) when damage was likely to be high. A coordinated approach is required across communities and villages, and research and extension agencies at the provincial and national levels, to implement effective rodent management.

Rice is a significant social and cultural phenomenon in Vietnam. Much of the culture in lowland environments revolves around growing rice, which remains a significant activity for the majority of rural households throughout the country, and has been for many thousands of years. A typical image of Vietnam is farmers tending their rice fields wearing their conical hats. Rice is the dietary staple, with most people eating three meals of rice a day. Rice consumption in Vietnam is 218 kg per capita per year (170.3 kg milled rice), the second largest after Myanmar (Maclean et al 2002), and the crop provides 65% of the calorie intake for Vietnamese. Rice is usually consumed jointly by family members. In Vietnamese, the word "com" refers to both cooked rice and a meal with cooked rice served with other condiments. Vietnam is the world's second-largest exporter of rice (www.fas.usda.gov/grain /circular/2007/05-07/graintoc.htm; accessed June 2010). Rice contributes significantly to the gross domestic product of the country and enables national food security.

Rice is grown in many areas throughout Vietnam, but the two principal areas are the Red River Delta, in northern Vietnam, and the Mekong River Delta, in southern Vietnam. Outside of these two areas, rice is grown along the coastal strip and in some areas in the inland mountainous areas, where it is primarily grown for self-sufficiency. Some of these mountainous areas are probably subjected to outbreaks of rodents similar in nature to those described in Laos because of bamboo flowering and masting (Doungboupha et al, this volume).

Rodents also are ingrained into the culture of Vietnam. The rat is one of the 12 signs of Tet (the Lunar New Year), and people born in the Year of the Rat are considered as resourceful (cunning) and productive. Vietnamese people eat a wide variety of foods, and one such delicacy is rat meat (see appendix of this volume for recipes), especially for men while socializing over a rice whisky or beer. Rodent meat is also eaten to bestow good fortune and fertility on newlyweds during wedding ceremonies. To service these demands, there is a vibrant rat meat market in the Mekong River Delta, which supplies fresh rodent meat to Ho Chi Minh City and Can Tho (Khiem et al 2003).

In Vietnam, rodent pests are considered one of the three most important problems faced by the agricultural sector (Huynh 1987). As in other areas of Asia, the rodent problem in Vietnam has increased since the 1970s in rice-based farming systems (Singleton 2003). The most likely reasons for this are increases in the area and intensity of rice production, and asynchronous planting of crops (Singleton and Petch 1994, Singleton 2003). New varieties of rice can be grown for a shorter duration and they have higher yields, which enable farmers to plant more crops per year if conditions are suitable. Furthermore, farmers' rodent control practices are generally reactive and rely essentially on chemical and physical methods (Tuan et al 2003, Palis et al 2007), and so are often inadequate to prevent serious damage to crops by rodents.

In this chapter, we will document rodent problems, their impacts, and management options in the lowland irrigated intensive rice-cropping systems of Vietnam. This will be given within the context of the population and breeding dynamics of rodent pests to better understand the mechanisms that drive outbreaks and significant yield losses experienced by farmers.

Rice in Vietnam

Vietnam has a range of climatic zones, from temperate in the north to tropical in the south. Approximately 20% of the land area of Vietnam is arable, and about 7% of the land has permanent crops (CIA 2010). The area of rice grown each year in Vietnam surpasses 7.6 million ha for the production of 24.3 million t of milled rice (www.fas.usda.gov/grain /circular/2007/05-07/graintoc.htm). Agriculture's share of economic output for the country was about 21% in 2009 (CIA 2010). Agriculture contributes 21% of GDP, with industry (40%) and services (39%) the other significant components. However, more than half the labor force is engaged in agriculture (52%).

Three rice crops per year are possible in the Mekong Delta because of access to irrigation water and ideal tropical monsoon climate conditions. Average yields in the Mekong Delta are 4 to 8 t ha^{-1}. In the Red River Delta, two rice crops are generally grown per year. The more temperate climate conditions in the northern part of the country mean that the winter season is too cool to allow sufficient growth and development of rice, so other crops are grown at that time such as vegetables.

A range of pests affect rice crops in Vietnam. In southern Vietnam, the An Giang Plant Protection Department identified 14 pests from field surveys (Brown and My Phung, unpublished data). These were broadly grouped into insect pests (brown planthopper, panicle rice mite, rice bug, rice leaffolder, rice stem borer, and whitebacked planthopper), diseases (bacterial leaf blight, leaf blast, leaf streak, neck blast, red stripe, rice grassy stunt virus, and sheath blight), and rodents. The top four pests were identified as (1) brown planthopper (*Nilaparvata lugens*), (2) rice leaffolder (several species, including *Cnaphalocrocis medinalis* and *Marasmia patnalis*), (3) leaf blast (*Pyricularia grisea*), and (4) rodents (species not defined) (Brown and My Phung, unpublished data). This follows on from a survey of pests that was conducted in the mid-1980s, in which rodents were found to be the third most important pest to control in rice systems (Huynh 1987). Other challenges to rice production arise through poor irrigation facilities and systems, drought, typhoons/cyclones, flooding, poor use of fertilizers and pesticides (Escalada and Heong 2004), poor soil conditions such as acidic soils, and salt-water intrusion in some parts.

Rodent problems in Vietnam and factors leading to rodent population outbreaks

On average, about 100,000 ha of rice are severely affected each year by rodents, which is about 1.3% of the area planted. In some years, however, the area of severe damage can reach 700,000 ha (Fig. 1) or 8.9% of the area planted. Rodent-induced losses to rice crops of less than 10% within individual areas are not included in these statistics.

High crop losses to rodents occurred in Vietnam during 1996 to 1999 (Fig. 1). The cause of these outbreaks was attributed to unusual rainfall events, which led to asynchronous planting and harvesting of rice crops over large areas. The unusual rainfall patterns were thought to be related to an El Niño event (Lan et al 2003). However, the association between widespread El Niño events and rodent outbreaks is complex. According to Lan et al (2003), there are complex associations between the period of time that intensive cropping has been undertaken and landscape and hydrological factors that affect the extent and duration of flooding between inland inundated regions and the more elevated and better drained coastal and eastern zones of the Mekong River Basin.

In 1998, the severity of the impact of the rodent outbreak led to the development of high-level national policies aimed at reducing the rodent problem. On 18 February 1998, the prime minister promulgated *Instruction No. 09/CT-TTG* on the urgent method of rat management. *Circular 05/1998/TT-BNN-BVTV* was subsequently issued by the Ministry of Agriculture and Rural Development (MARD), providing detailed guidelines for provinces in implementing *Instruction No. 09/CT-TTG*. MARD officially requested that the provinces implement *Instruction No. 09/CT-TTG* by focusing on the following key measures: traditional practices to catch rats such as trapping, digging,

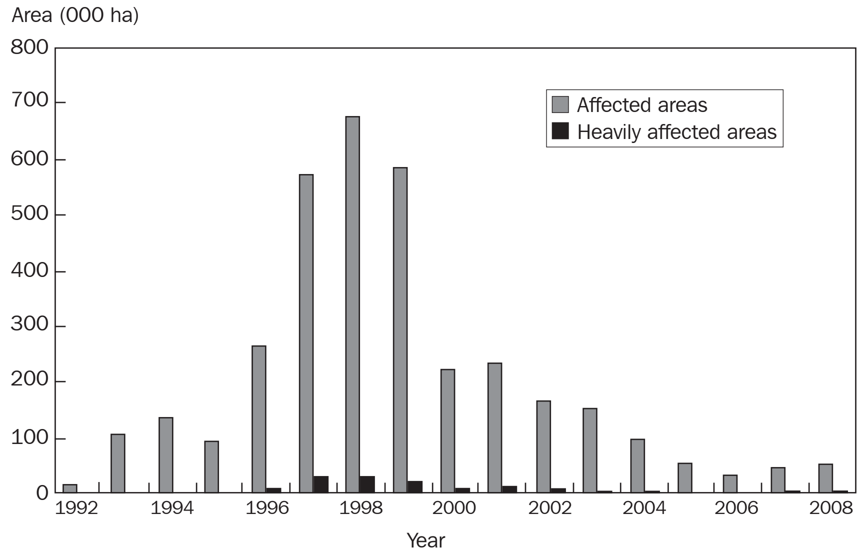

Fig. 1. Infestation of rats in rice crops throughout Vietnam, 1992-2008. Shown are the total area affected (>10% yield loss) and the areas identified as severely affected by rodents (up to 100% crop losses attributed to rodents). Source: Hung et al (1998), Plant Protection Department annual reports.

sticky baiting, etc., restrict the use of highly toxic chemicals, ban the use of electric current for rat control (previously in use around flooded rice fields), and encourage the production of biochemical products that are not harmful to human health and the environment.

Bac Lieu Province in the Mekong River Delta is a province that experiences chronic rodent problems. Rice is cultivated over approximately 215,000 ha, and about 2,000 ha per year suffer high rat damage (Giap NV, unpublished data). In the mid-1990s, the impacts of rodents on rice crops in Bac Lieu Province increased markedly (Fig. 2). Since 1998, farmers have increased their efforts in rodent management by several means, including the use of traps, digging of burrows, plastic fences with multiple-capture traps, and chemical rodenticides (Lan et al 2003).

In southern Vietnam, during 2002 to 2005, the total rice area affected by rats varied from 3,838 ha to 47,699 ha (Table 1). For most of the provinces in southern Vietnam, the area of rice that was planted was similar for the spring-winter season (first rice crop) and the autumn-summer season (second rice crop). Therefore, the observed changes in area damaged by rodents reflect small-scale changes in the availability of irrigation water and therefore cropping patterns and synchrony. This would influence the timing and location of high-quality food to maintain breeding of rodents, resulting in localized outbreaks of rodent populations at different times in different locations. A more detailed analysis was conducted for An Giang (see below).

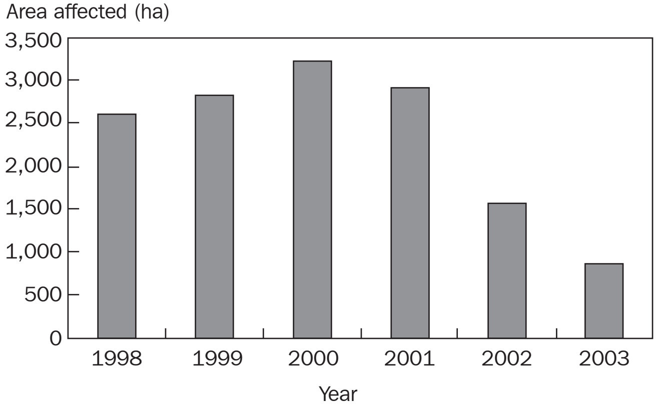

Fig. 2. Area of rice crops with high rat damage in Bac Lieu Province (1998-2003).

Table 1. Area of rice production severely damaged by rodents during 2002-05 in southern Vietnam. SW = spring-winter season; AS = autumn-summer season.

Province	Rice area[a]	2002	2003		2004		2005
	(thousand ha)	AS (ha)	SW (ha)	AS (ha)	SW (ha)	AS (ha)	SW (ha)
An Giang	477.2	7,605	3,511	28,774	2,950	13,889	92
Ba Ria-VTau	25.2	–	–	–	640	–	–
Bac Lieu	169.8	–	630	–	690	250	175
Ben Tre	99.6	–	168	–	20	70	–
Bình Duong	23.8	209	–	–	209	–	38
Bình Phuoc	15.1	–	10	–	–	–	–
Bình Thuan	87.3	150	–	–	–	6	–
Ca Mau	130.5	750	–	–	2,461	–	–
Can Tho	229.9	2,097	6,902	2,368	–	–	–
Dong Nai	80.4	574	529	642	640	946	1,167
Dong Thap	426.4	725	3,860	1,077	10,452	1,753	80
Hau Giang	228.4	–	–	–	–	1,057	108
HCM City	56.2	200	1,158	569	209	846	–
Kien Giang	575.9	50	1,927	–	1,839	1,855	–
Lam Dong	33.6	–	14	–	–	8	–
Long An	433.3	4,847	–	2,930	1,681	1,455	–
Ninh Thuan	30.3	–	5	–	–	–	–
Soc Trang	354.9	3,205	2,932	4,614	3,069	1,215	580
Tay Ninh	165.6	3,101	5,356	4,921	9,167	3,571	448
Tien Giang	265.0	762	735	419	683	174	40
Tra Vinh	235.8	533	1,840	86	286	–	19
Vinh Long	209.8	1,500	7,664	1,299	3,550	1,231	1,091
Total	4,454.0	26,308	37,241	47,699	38,546	28,326	3,838

[a] Total rice area per year (2002 data) (http://fsiu.mard.gov.vn/data/trongtrot.htm). Source: Southern Plant Protection Center, Long Dinh, Tien Giang.

An Giang Province, one of the largest rice-producing provinces in the Mekong River Delta, experienced higher losses than other provinces (Table 1). The An Giang Plant Protection Department conducted weekly assessments of fresh rodent damage in each district of the province, which enabled an assessment of the timing of rodent damage to rice crops over a 5-year period (2004 to 2008). The overall mean range of crop losses generally increased for each rice crop grown as the year progressed. Damage was lowest in the first rice crop when the monsoon rains caused flooding and effectively re-set the rodent population (Brown and My Phung, unpublished data). The average seasonal minimum and maximum estimates of crop losses for the monsoon-season rice crop were 0–10.4%; for the first dry season, crop losses were 0.3–14.8%; and, for the second dry season, crop losses ranged from 0.1% to 15.0%. The maximum weekly estimated mean yield loss was 50% recorded during the first dry-season crop in 2007 (Brown and My Phung, unpublished data). This high damage occurred near the end of the crop after some areas of the first dry-season crop had already been harvested, and it seems the rats had focused their feeding activity and damage on a few unharvested areas, leading to complete crop loss in some areas, so damage was relatively severe in a few districts. The asynchrony of planting and subsequent asynchrony of harvesting of the rice fields meant that the fields harvested latest suffered severe losses.

In a field study of rats in rice crops in Vinh Phuc Province in the Red River Delta, Brown et al (2006) calculated that yield losses caused by rodents reached 10% in 1999 at a time when rodent population abundance was considered “moderate” and 1–2% in 2000-02 when rodent population abundance was considered “low.”

Population dynamics of rice-field rats

A good understanding of the ecology of rodent pest species is important in designing and implementing appropriate control strategies (Singleton et al 1999). According to Tuat et al (2005), 30 species are described belonging to Muridae in Vietnam, accounting for 45.5% of all rodent species in the country. Not all are pests. The most important rodent pest species in rice fields are *R. argentiventer*, *R. losea*, *R. rattus*, *Bandicota indica*, and *B. savilei* (Aplin et al 2003, Brown et al 1999, 2003, 2006). The dominant rodent pest species in both the Red River Delta and the Mekong River Delta is the rice-field rat, *Rattus argentiventer* (Brown et al 2003). Other species found in lowland irrigated rice agroecosystems are *Mus* species, *R. norvegicus*, and *Suncus murinus* (an insectivore).

In Vietnam, the rice-field rat, *R. argentiventer*, and the lesser rice-field rat, *R. losea*, both synchronize their breeding with the development of both the winter and spring rice crops. Breeding commences at the maximum tillering stage of the rice and continues until the rice is harvested (Brown et al 2005a). Furthermore, these rodent species appear to respond, in terms of rates of increase of their populations, to the quality of food crops rather than rainfall per se (Brown et al 2005a). Therefore, if there are three rice crops per year and if the rice crops are not planted in synchrony, the breeding seasons would be extended considerably, leading to greater abundance and therefore greater damage to rice crops. Furthermore, if there is a short period between breeding seasons, the survivorship of rats will be higher. These species have a particularly high capacity to rapidly recover from control efforts through immigration and recruitment (Brown and Tuan 2005).

A radio-tracking study of *R. argentiventer* revealed that, during the nonbreeding period, rats preferred to use the bank/channel habitat during the day and preferred vegetable gardens at night (Brown et al 2005b). During the breeding period, rats preferred using rice fields both during the day and at night. This preference during the breeding period was strongly influenced by the availability of abundant cover and food offered by the ripening rice crops. Rats were moving about the rice fields in random directions and were not influenced by the control efforts of farmers at nearby locations.

Rodent outbreaks have been reported also in Kien Giang Province at the border region with Cambodia in the Mekong Delta. Local farmers reported that the rats were swarming into Vietnam from Cambodia. In 1996-97 and 1997-98, a 1.5-km plastic fence was constructed along the border for 4–6 months. Multiple-capture traps were set into the fence every 30 m, with consecutive traps facing opposite directions (see Singleton et al 2003 for details). The study clearly showed that seasonal rat migrations tracked the availability of high-quality food on a local geographical scale. Indeed, during the beginning of the monsoon, rats moved from Vietnam to Cambodia. The movements from Vietnam corresponded to completion of the harvest of rice in Vietnam and the booting stage of the rice crop in Cambodia. After waters had subsided in Vietnam in December and January, rats began moving from Cambodia (Singleton et al 2003). National borders did not define a high net flow of rats in one direction; rather, it was the asynchrony of cropping linked to the growing of short-duration modern varieties of rice in Vietnam and traditional long-duration rice varieties in Cambodia.

Impacts of rodent outbreaks

Rodent outbreaks cause significant impacts at different scales, from farmer household livelihoods through to regional food security. The high losses (up to 100%) caused by rodent outbreaks (Tuan et al 2003) can lead to significant economic losses and food security problems for farmers, thus affecting household livelihoods. The impact is especially severe for rice farmers that have few alternative income opportunities. Regionally, damage of 20–30% can lead to rice crop losses of 1.2–2.2 million tons, which is equivalent to feeding 12.2 million people for a year (Singleton 2003).

For chronic rodent problems, most of the impacts are directly related to damage of the growing rice crop resulting in yield losses, and then the time and resources required to manage the problem. Farmers normally spend around 5–16 days per cropping season controlling rodents (Sang et al 2003, Tuan et al 2003), which is a big imposition of time if they grow three crops per year. Furthermore, chronic losses of 10% of yield would translate into a loss of 2.1 million VND (Vietnamese dong) per ha (US$109) using a price of rice of 4,200 VND per ton and a rice yield of 5 t ha^{-1}.

Success and failures of management actions

In the past, governments have tended to respond to outbreaks rather than chronic problems and farmers have relied on chemical and physical methods applied after rodents have already damaged the crop (Palis et al 2007). A survey of farmers in Tien Giang and Soc Trang provinces, Mekong River Delta, showed that poison chemicals and field sanitation (cleaning up food sources and piles of rubbish that provide rodent habitat) were the most common practices for rodent control (Table 2) (Sang et al 2003). Digging of burrows to catch rats was also a popular practice adopted by approximately 50% of farmers. Electrocution of rats was a common practice in Soc Trang Province, but this is a dangerous measure and has been officially banned by the national government as a method of rodent control (Sang et al 2003).

As a consequence of the widespread outbreaks of rodent populations in the 1990s, a concerted effort was made to study rodent population ecology, the damage rodents cause, and to design appropriate management strategies. The Australian government, through the Australian Centre for International Agricultural Research, funded collaborative research from 1996 to 2002, concentrating on the basic ecology of the major pest species, and developing and validating management options, and, from 2006 to 2010, concentrating on adoption, outreach, and impact assessment (see http://aciar.gov.au/project/ADP/2003/060). These projects led to increased capacity within the country and also rigorous assessment of community-based rodent control strategies tested through participatory engagement with farmers and extension agencies.

The high-level national policy by the prime minister in 1998 consolidated the knowledge collected in the previous 3 years and the proclamation catalyzed a reduction in the area of rodent damage observed throughout the country after 1999. It is believed this was due to a combination of

1. Increasing awareness on rodent management at the commune level, which encouraged coordinated farmer participation at that level.
2. Local governments regularly prescribed a high-profile launch day of community rodent management via local People's Committees before each crop season began.
3. Promotion of the community trap-barrier system (CTBS) (see Singleton et al 1998 for details) at the commune level in the Mekong River and Red River deltas.

Table 2. Rodent management actions of farmers in two provinces in the Mekong River Delta based on household surveys. Shown is the percentage of farmers reporting each method.

Method	Dry season		Wet season	
	Tien Giang	Soc Trang	Tien Giang	Soc Trang
Use of poison	64	78	60	73
Field sanitation	65	47	69	47
Digging	45	54	39	53
Electrocution	0	41	0	37

A large replicated village-level study in Vinh Phuc Province, Red River Delta, demonstrated the value of community approaches to rodent management over large areas (100–150 ha). Prior to the implementation of ecologically based rodent management, 60–90% of farmers used rodenticides and 40–100% used plastic barrier fences to surround their fields to try to prevent access by rodents (Brown et al 2006). On treatment sites, farmers used a combination of CTBS and a range of community actions[1] and this was found to be equally as effective as typical conventional practices for rodent management, but farmers at the treated sites spent considerably less money applying rodent control practices and achieved benefit-cost ratios of up to 17:1 compared with 3:1 at untreated sites (Brown et al 2006). Furthermore, these results were achieved with a 75% reduction in the use of rodenticides and plastic barrier fences (Brown et al 2006).

In 2010, the national approach to rodent management follows ecologically based rodent management (EBRM) principles (after Singleton et al 1999) and builds on the achievements gained from 1996 to 2010. These control strategies have been developed through participatory engagement with farmers, extension specialists, and government researchers, and have been tested and validated at the village level (Table 3). The outcomes from this research have generated some well-founded concepts to

Table 3. Ecologically based rodent management strategies that have proven successful to reduce the damage that rats cause to rice crops in Vietnam.

Control action	Reason for action	Timing for management
Community actions	Get the farming community to work together over large areas to identify rodent burrows and destroy them systematically.	At land preparation stage up until tillering stage.
Synchrony of cropping	Synchronizes planting of crops (within 2 weeks) and limits the length of the breeding season of the rats.	Needs to be set up prior to land preparation.
Rat campaign	Concentrates on source habitats.	Before planting.
Small bund size in fields	Rats do not dig burrows in bunds smaller than 30 cm wide.	Needs to be established before cropping is done.
Field sanitation (field hygiene)	Clearing long grass and weeds around irrigation canal banks and other noncrop areas to reduce refuge habitat for rodents when no crop is present.	From land preparation to tillering stage.
Community trap-barrier system (CTBS)	To reduce damage to crops through capture of rats.	Needs to be established 3 weeks prior to transplanting of surrounding rice fields.
Linear trap-barrier system (LTBS)	A plastic fence is set up with multiple-capture traps to intercept rats moving between source and sink habitats.	Can be set up at any time, depending on where rats are residing and where damage is occurring.

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[1] Community actions included destroying rat burrows in refuge habitats soon after planting (before the rats re-establish in the fields and before the onset of breeding), synchronizing planting and harvesting of the rice crops, cleaning up weeds and piles of straw (field sanitation), and keeping bund (embankment) size small (<30 cm) to prevent burrowing.

enable successful rodent management. These include the need for

- Management to be implemented during the early stages of rice growth while population abundance is low before the main breeding season commences and before rodents are living within the rice crop.
- Management to be conducted over large areas, at least 100 ha, but preferably more. This reduces the chances of reinvasion from nearby areas.
- Management to be coordinated at the community level at key times and in key habitats.

The adoption and use of the EBRM strategies that were developed in replicated field trials have been scaled out to other districts and provinces in both the Red River Delta and the Mekong River Delta. These have led to an overall reduction in the use of rodenticides and a more coordinated community approach to rodent management rather than an ad hoc reactive management strategy based on when rodent damage is observed (Palis et al, this volume). There has been an emphasis on ensuring adequate training of resource persons and extension staff in the provinces that are affected by rodent damage through Training of Trainers programs, and also through the dissemination of resources and communication materials (e.g., brochures and field guides).

Lessons learned

The most important lesson learned through the last 15 years of ecological research and testing of integrated rodent management has been the need to develop strong cooperation between institutes at a range of levels (Fig. 3). A key component of this cooperation has been the inclusive nature of decision making based on the understanding provided by biologists on how rodents respond to local agroecosystems and farming systems. The partnerships developed among key players at different stages of the research-to-impact pathway (see Flor et al, this volume, and Palis et al, this volume)

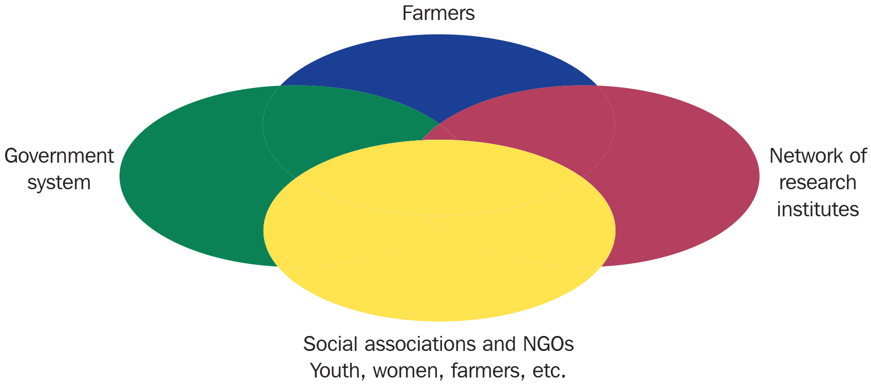

Fig. 3. Relationship among various stakeholders in the development and implementation of rodent management in Vietnam.

have enabled the development of an effective network of local through to regional and national stakeholders. Local champions with wide reach into rural communities, such as key extension staff from the Southern Regional Plant Protection Center (that services 22 provinces in southern Vietnam), have provided an effective communication pathway and a sustainable resource of knowledge to advise local communities when they face sporadic rodent outbreaks.

A key outcome of recent scientific research has been to focus farmer rodent control efforts on community actions, as outlined above and in Table 3. Another control method that has proved to be effective under some circumstances is the community trap-barrier system (see Singleton et al 1998 for details). Some of the limitations of the CTBS are that it is expensive and requires constant maintenance, and that it can be problematic to set it up 2–3 weeks prior to planting the surrounding area because of constraints in the availability of suitable land and availability of irrigation water. The latter is more of a constraint in the Red River Delta than in the Mekong Delta. The key conditions for CTBS use are

- In the Mekong River Delta in areas where flooding routinely occurs each year, the CTBS is unlikely to be needed during the first crop season, but be prepared to use the CTBS in the second season.
- In the Mekong River Delta in areas where flooding does not normally occur, the CTBS could be used during the first rice crop and the second rice crop. This is important for provinces near the mouth of the Mekong Delta (e.g., Bac Lieu) because monsoon floods do not reset the rodent population.
- In the Red River Delta, the CTBS is unlikely to be needed during the first crop season because rodent numbers are generally low and serious damage does not normally occur to this crop. Also, it is difficult to establish an early “trap crop” inside the plastic fence because of the cooler weather.
- In the Red River Delta, consider using an aromatic variety of rice instead of planting an early-planted “trap crop.”
- It is useful in areas with large farm sizes.

Further research is required on implementing these EBRM strategies at the national level and scaling out these technologies to allow effective diffusion and adoption. Also, the EBRM strategies need to be incorporated into other national management strategies and programs for other pests, diseases, and water-related problems for lowland rice agroecosystems such as “Three Reductions, Three Gains” (Huan et al 2008), “1 Must Do, 5 Reductions,” integrated pest management, etc., to ensure the universal applicability and harmonization of rodent management.

Conclusions

The key drivers of outbreaks of rodent populations in lowland irrigated rice-based agroecosystems in Vietnam have been a result of the following:

- Rodent breeding patterns linked to the development of rice crops. Rainfall patterns alone do not directly affect rodent populations (particularly when *Rattus argentiventer* is the main rodent pest species); instead, it is the availability of high-quality food provided by irrigated rice plants from the maximum tillering stage of plant development that is the trigger for breeding. Smaller outbreaks are likely when there is asynchrony in cropping (>2–3 weeks), which extends the breeding season.

- Large-scale outbreaks are caused by significant weather events, which lead to widespread changes in the timing of when rice crops are planted over large areas. This widespread asynchronous planting and harvesting of rice enable rats to breed continuously in some circumstances, and this therefore also enhances the survival of rats through the continuous availability of high-quality food.
- Large-scale outbreaks caused by significant changes in cropping systems. This includes asynchrony of cropping by >2 weeks, growing three crops a year where previously two crops were grown, or growing five crops over 2 years instead of four crops. This increase in intensity of rice cropping enables rats to have greater survival as the interval between successive rice crops is shorter.
- Better understanding of the relationship between cropping systems and rodent population dynamics and damage has led to an overall reduction in area and intensity of rodent damage in the last 10 years. This impressive progress has been strongly facilitated by national policy initiatives.

If synchronized planting of rice crops is possible over large areas of the irrigated lowlands (crops planted within about 2 weeks), and control actions are applied at the community level and before the maximum tillering stage of rice crop growth, rodent population outbreaks should be preventable. When localized outbreaks do occur, they can be effectively managed to minimize their impacts if they are reported early and management actions are coordinated at a community level.

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Socio-cultural factors influencing the adoption of ecologically based rodent pest management

Florencia G. Palis, Grant R. Singleton, Peter R. Brown, Nguyen Huu Huan, and Nguyen Thi Duong Nga

Ecologically based rodent pest management (EBRM) offers an alternative and more effective approach than the reactive use of rodenticides following high losses in rice crops. EBRM combines both cultural and physical rodent management practices, requires a solid understanding of the ecology of the major rodent pest species, and targets community actions at key times of the year. This chapter illustrates the integration of socio-cultural factors in the implementation of EBRM in Vietnam to bring about farmer adoption. Particularly, it highlights the importance of building on farmer knowledge, experiential learning, social capital, culture, and history to ensure the adoption of EBRM. The adoption of EBRM is an important technological development in Vietnam, where rodents are one of the top three pests that limit rice production. Outbreaks of rodent populations occur episodically, causing major economic effects on smallholder farmers.

EBRM was implemented in Binh Luc and Kim Bang districts of Ha Nam Province, with a "before and after" framework employing two treatments—community action alone and community action with a community trap-barrier system (CTBS). Baseline and postbaseline surveys—knowledge, attitudes, and practices and socioeconomic (KAP & SE) data—were conducted among 302 respondents in the two districts. Farmer participatory action research was employed for farmers to "learn by doing," and enabled farmers and extension specialists to refine EBRM strategies to suit local conditions.

The EBRM adoption in Ha Nam generated a significant change in farmers' rodent management practices, from heavy use of rodenticides to the practice of community action for rodent management. The involvement of farmers in integrated community actions doubled, from 36% presurvey to 62% postsurvey. Also, some of the key results and impact noted were a rice yield increase (9.4%), a reduction in rat-damaged area (93.5%), a reduction in rodenticide use (>50%), a reduction in yield losses due to rat damage (91.7%), and an increase in net returns (35%), which can partly be attributed to better rodent management practices.

Technology adoption in agriculture has always been a concern because of poor rates of adoption (Röling 1990, Bonifacio 1994, Stür et al 1999, Utama 2002). Many new agricultural technologies are published in journals but not practiced by the end-users, especially by the many resource-poor farmers of Asia. This chapter aims to illustrate the importance of understanding the social and cultural context of smallholder farmers in Vietnam and involving them in the implementation of new technologies. This chapter has two objectives: (1) to describe the adoption of ecologically based rodent pest management (EBRM) and (2) to discuss the socio-cultural factors that influence the adoption of EBRM. The adoption of EBRM is an important technological development in Vietnam, where rodents are one of the top three pests that limit rice production (Singleton 2003) and outbreaks of rodent populations occur episodically, causing major economic impacts on smallholder farmers (Huan et al, this volume).

Developed in the late 1990s, EBRM is an alternative paradigm to the heavy use of rodenticides to manage rodent pest populations in agricultural landscapes that are applied reactively in response to high losses to crops, and are ultimately less effective. EBRM is more ecologically sustainable and affordable for rice-based farming communities in Asia. The development of EBRM requires a solid understanding of the ecology of the major rodent pest species and it targets community actions at key times of the year in specific habitats when the rodent populations are most vulnerable (Singleton et al 1999a).

In Asia, EBRM combines both cultural and physical rodent management practices such as (1) targeting synchrony of cropping (crops planted within 2 weeks of each other); (2) implementing short 2-week rat campaigns at key periods such as 1 week before transplanting, or within 2 weeks after transplanting—these are done in focal habitats such as village gardens and the banks of main irrigation channels; (3) reducing the width of irrigation banks in fields to less than 30 cm to prevent nesting by rats; (4) improving general hygiene around villages and village gardens; (5) promoting synchronous fallow; and (6) if chronic losses are >10%, using a community trap-barrier system (CTBS); this would usually be only for one crop per year, for example, a CTBS is only recommended for the summer-autumn rice crop in the Red River Delta of Vietnam (Singleton et al 2005, Brown et al 2006, Huan et al, this volume). Most importantly, EBRM requires holistic systems with participation of the community, not just farmers, to carry out these management actions in an integrated manner.

The CTBS entails the establishment of an early-planted “trap crop” to lure rodents to the traps, which ideally should be planted approximately 2 weeks before the planting in surrounding rice fields. The trap crop is usually 20 × 20 meters and is surrounded by a plastic barrier that has at least one multiple-capture live-trap along each side. The traps have an entry point for rodents leading directly into it; these are monitored daily for trapped rodents. One CTBS provides a “halo effect,” reducing rodent damage over 10–15 hectares (ha) (Singleton et al 1999b). One distinct advantage of the CTBS is that it does not use poisons. Management and labor costs may be higher than for typical baiting systems but only if the responsibility falls on individual farmers.

EBRM implementation in Vietnam

This section discusses the implementation of EBRM in Vietnam during 2006-09. The project was implemented in both the Mekong and Red River deltas to reduce rat damage, increase yields, and reduce reliance on rodenticides. However, for illustration purposes, the discussion focuses only on the Red River Delta, from which EBRM was introduced in Ha Nam Province in northern Vietnam.

EBRM was implemented in two districts of Ha Nam Province, Binh Luc and Kim Bang, with two communes/agricultural cooperatives in each district and 10 hamlets in each commune (Fig. 1). A “before and after” framework with two treatments—community action alone and community action with CTBS—was employed to assess the impacts of the EBRM intervention. Community action was introduced in all 20 hamlets of the two districts, whereas CTBS together with community action was tested only in 10 hamlets (five hamlets for each district). Thirty CTBSs were established in the four agricultural cooperatives across the two districts.

Baseline and postbaseline surveys to gather knowledge, attitudes, and practices and socioeconomic (KAP & SE) data were conducted among 302 respondents in the two districts (Table 1). Focus group discussions, key informant interviews, and field observations were likewise employed. Farmer participatory action research was employed for farmers to learn by doing, and this enabled farmers and extension specialists to refine EBRM strategies to suit local conditions.

Knowledge of these technologies was transferred through training and the “learning by doing approach” through active partnerships and close cooperation among project partners, including scientists from the Commonwealth Scientific and Industrial

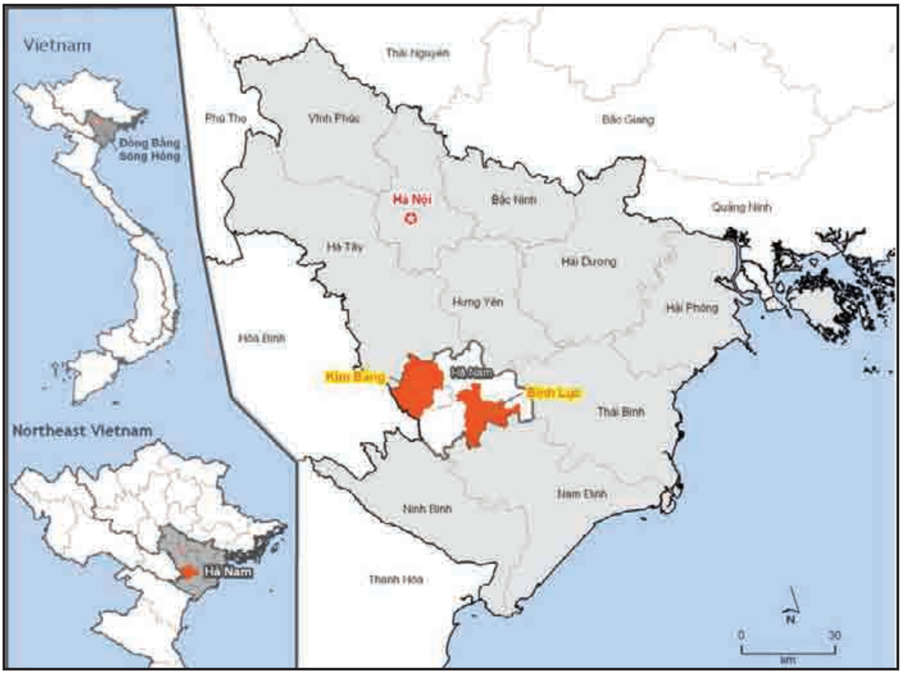

Fig. 1. Map of Vietnam highlighting the province of Ha Nam and the two project district sites: Kim Bang and Binh Luc.

Table 1. Research design of the ecologically based rodent management (EBRM) interventions, Ha Nam Province, Vietnam.

District/commune, cooperative	Hamlet	Area (ha)	Treatment[a]	Members (no.)	Sample size (no.)
Binh Luc District					
Mai Luong cooperative		216		788	70
	Mai Dong	81	CA + CTBS	320	35
	Ben	56	CA alone	190	8
	Thuong Dong	49	CA alone	167	14
	Cau	30	CA alone	111	13
Binh Minh cooperative		324		974	72
	Vy Thuong	67	CA + CTBS	159	7
	Vy Ha	79	CA + CTBS	234	10
	Cua	54	CA + CTBS	159	6
	Cua Trai	25	CA + CTBS	77	3
	Duy Duong	63	CA + CTBS	216	9
	Dong Quan	36	CA alone	129	35
Kim Bang District					
Ngoc Son		308		1,439	80
	Thuy Xuyen	49	CA + CTBS	229	7
	Ma Nao	120	CA + CTBS	546	17
	Phuong Ke	83	CA + CTBS	344	11
	Danh Xa	56	CA alone	320	35
	Mã Não		CTBS halo + CA	546	5
	Danh Xá		Imaginary CTBS halo + CA	320	5
Le Ho		468		1,800	80
	Phuong Thuong	200	CA + CTBS	943	21
	An Dong	93	CA + CTBS	232	5
	Dong Thai	56	CA + CTBS	228	5
	Dai Phu	44	CA + CTBS	156	4
	Phuong Dàm	75	CA alone	241	35
	Phuong Thuong		CTBS halo + CA		5
	Phuong Dàm		Imaginary CTBS halo + CA		5
			Total respondents		302

[a] CA = community action, CTBS = community trap-barrier system, Halo = expected area of protection with CTBS; CTBS halo was included only in Kim Bang District.

Research Organisation (CSIRO) and the International Rice Research Institute (IRRI), extension specialists from the Plant Protection Department (PPD), local officials from the People's Committee (the local executive body) of the respective communes, and farmers through the commune or village agricultural cooperatives. Other partners include the National Institute for Plant Protection (NIPP), World Vision Vietnam (WVV), and the provincial Department of Agriculture and Rural Development (DARD).

The partnership

CSIRO is the national science agency of Australia, with a vision of delivering quality science and innovative solutions for industry, society, and the environment. The organization fosters collaborative international programs to help solve the problems facing developing countries, particularly in Southeast Asia. One of its six strategic goals is partnering for community impact.

IRRI is the oldest and largest international agricultural research institute in Asia. It is an autonomous, nonprofit, rice research and education organization and one of the 15 centers of the Consultative Group on International Agricultural Research (CGIAR). Its mission is to reduce poverty and hunger, improve the health of rice farmers and consumers, and ensure that rice production is environmentally sustainable. It works closely with most rice-producing and rice-consuming countries. Particularly, IRRI works with national agricultural research and extension systems (NARES) as well as farming communities and a range of international, regional, and local organizations.

PPD, the key partner under the Ministry of Agriculture and Rural Development (MARD) in Vietnam, has a network system from the central to the local level, whose main function is the management of plant protection and extension of appropriate crop protection technologies to farmers at district, provincial, and national levels. There is a sub-PPD at the provincial level and a plant protection station, or PPS, at the district level. Over the past 15 years, PPD has collaborated with many international organizations and in-country institutions to implement many projects focusing on integrated pest management (IPM) in rice and other crops.

NIPP is a government research organization, also belonging to MARD. NIPP provides the needed local scientific support to the extension programs of EBRM.

WVV is a nondenominational, Christian humanitarian aid and development agency aiming to empower the poor and encourage governments and people to support the poor. WVV has strong agricultural programs through its area development programs.

The People's Committees are the executive bodies that carry out local administrative duties. They are represented at the provincial, district, and commune levels. They are also responsible for administration functions over agricultural cooperatives in their respective locality. Each People's Committee has an agricultural officer who is usually the chairman or vice-chairman of an agricultural cooperative.

Agricultural cooperatives, with their mission to support agricultural development and farmers in the commune, provide a number of services for farmers in agricultural production, such as the maintenance of irrigation infrastructure, extension services, input services, and crop protection. Agricultural cooperatives exist in all communes in northern Vietnam. Within an agricultural cooperative is a pest control group that is responsible for managing rodent populations. Many communes have a designated rodent control group, which was organized as a response to the policy issued by the Vietnamese prime minister in 1998 (Policy No. 09-1998/CT/TTG, see Huan et al, this volume, for details of the policy) encouraging farming villages to organize groups for rodent control. In the absence of a rodent control group, a plant protection security group is responsible for plant protection surveillance of the village.

Training

In 2006, a "training-of-trainers" (ToT) course was developed and held twice early in the project for the staff of partner agencies, especially PPD, WVV, and provincial extension staff working in Ha Nam. The training aimed to (1) introduce the basic aspects of rodent biology and taxonomy; (2) provide theoretical and practical experience in identifying rodents and rodent damage to rice crops, and assessing rodent breeding and biology; (3) develop awareness of some of the key rodent management strategies; and (4) develop the skills of the staff so that they can "echo" the training to other staff and be able to teach farmers about rodent management.

Five farmer training courses were conducted involving 150 farmers. These training activities for farmers were usually done either a day before or on the day they conducted their community action. Training was also incorporated into the IPM (integrated pest management) farmer field schools (FFS) for diffusion of knowledge (169 FFS involving 6,474 farmers). WVV incorporated the principles of EBRM training into its area development programs. An example is the promotion of EBRM by WV in Bac Binh, Binh Thuan Province, central Vietnam, and Hung Yen Province in northern Vietnam. A training manual on EBRM was developed by WV in the local language and was used for training programs of both WV and PPD.

Community action campaigns

Active linkages with local and national government institutions were established to mobilize mass community actions against rats for strategic intervention, where the timing of actions was based on the population dynamics and breeding ecology of the main rodent pest species, *Rattus argentiventer*, at each locality. Some 104 community action (CA) campaigns were conducted, including 16 done outside project sites and one by a local authority, with a total of 8,300 farmers involved. In addition, PPD Ha Nam conducted dissemination activities through (1) national and provincial TV coverage on EBRM through local and national programs; (2) production of a video CD on how to conduct EBRM at the commune level, and its distribution to farmers' clubs and associations; (3) interactive dialogue on local TV programs; (4) local radio programs; and (5) announcements in the village to disseminate information and to coordinate community campaigns.

Findings from surveys and qualitative assessments identified gaps in training, the needs of farmers for extension materials, the need for wider distribution of the manual on field methods for PPD and sub-PPD staff, and, most importantly, gaps in refining community actions (and CTBS if necessary) based on the common practices used by farmers in rodent control.

Adoption of EBRM in Ha Nam, Vietnam

Farmers' common rodent control practices

Farmers in Vietnam use a variety of rodent control methods, ranging from chemicals to digging and hunting with dogs, trapping, electrocution, and, particularly in the north, placing plastic barrier fences around entire crops (Tuan et al 2003, Sang et al 2003). Smallholder farming families are primarily responsible for their own rodent and pest management actions. The mean farm size is 0.3 ha (range 0.02–2.1 ha), equivalent to 8 *sao* (1 *sao* = 360 m^2). Farmers normally grow two rice crops a year. Rodenticide use and trapping were practiced individually, whereas digging and hunting were conducted arbitrarily by community groups, indicating that Vietnamese farmers would conduct collective actions for rodent control. The most popular traps were kill-traps (mechanical traps made of metal or wood) and sticky-traps. The former were preferred for use in the field and the latter for use in the house. The rodenticides commonly used were warfarin (Rat–K; an anticoagulant poison), zinc phosphide (an acute poison), and one from China, which is very toxic and whose active ingredient is not known. At night, many farmers hunted rats around the borders of their crops, using either sticks or dogs.

Changes in farmers' rodent control practices

With the active promotion of EBRM in Ha Nam, farmers' rodent management practices were significantly changed, from the heavy use of rodenticides to the practice of community action (Table 2; Figs. 2 and 3). Rodenticide use declined by more than 50%, and its use was mostly as an individual practice. Similarly, the involvement of farmers in integrated community actions doubled, from 36% presurvey to 62% postsurvey. The implementation of integrated practices by groups also increased from 32% to 44%. This usually refers to activities coordinated by the rodent control group. In effect, strategic community action was strongly accepted and adopted.

Ngoc Son Cooperative of Kim Bang District had six rodent control groups (RCGs) for four hamlets. One RCG had four to nine members composed of both male and female farmers. The females were focused more on the preparation of rodent baits (a mixture of rodenticide and rice) and the application of baits along runways of rats, in areas of high vegetation cover, along banks, and in raised fields where water levels were lower. The males conducted other rodent management actions from land preparation to harvesting; they dug burrows, hunted mostly with dogs, and trapped within areas surrounding the rice fields. They set traps early in the evening, checked them between 2100 and 2200, emptied the rats caught, placed the traps back in the same position, and in the morning checked and collected them. Normally, there were only 200 traps per RCG, so they rotated the placement of traps from paddy to paddy.

Rodent control groups were paid by farmers. In this particular cooperative, each farmer paid 2,200VND (US$0.12) per *sao* (360 m^2) for each crop season. The

Fig. 2. Hunting by dogs.

Fig. 3. Pumping water into burrows.

Table 2. Changes in farmer rodent control practices obtained from household surveys on knowledge, attitudes, and practices, and socioeconomics of smallholder farmers in Ha Nam, Red River Delta, Vietnam.

Control practice[a]	Presurvey (baseline) (n = 302) (%)	Postsurvey (n = 148) (%)
Rodenticide	99	47
Individual	7	33
Group	26	7
Community	71	7
Electricity	2	0
Individual	2	–
Group	0	–
Community	0	–
Integrated	100	99
Individual	90	57
Group	32	44
Community	36	62

[a] Control practices were categorized as individual, group, and community. The postsurvey covers only 50% of total sample size. Integrated includes synchronized cropping, hunting, barrier system, digging, field hygiene, smoke-out, trapping, and water pumping.

respective RCGs manage the distribution of their budget to cover their activities and salaries. With EBRM, rodenticide use of the RCG decreased (Table 2). For Ngoc Son Cooperative, rodenticide usage declined from three to one application per season. Further, with EBRM, farmers and the rodent control groups worked together for community action, particularly during land preparation.

Community actions for the strategic management of rodent populations were practiced four times a season at all of the pilot sites. Usually during land preparation, 10–15 days after transplanting (DAT) of the rice crop, 30–45 DAT, and at the booting stage of rice, the main foci of effort, based on the ecology of the main pest species, were the first two periods. Integrated community actions included synchronized cropping, hunting and digging (especially hunting with dogs), improved field hygiene, the use of smoke or water to flush rats out of burrows, and trapping. Nearly all farmers participated in at least two community actions, particularly during land preparation and at 10–15 DAT. About 40% participated in the last two community actions, when the most involvement was from rodent control groups that do community trapping for the whole season. Participation in community action was mainly by members of farmers' or agricultural cooperatives, farmers and their household members, and the rodent control group. Farmer household members include the spouse and children. The community actions were usually organized by the sub-PPD and respective plant protection stations (PPS) of the district, in collaboration with the agricultural cooperative and the People's Committee of a village.

After implementation of EBRM, nearly all farmers conducted field hygiene and synchronized cropping. These two rodent management strategies are also beneficial for the control of brown planthopper (BPH), a pest that re-emerged as a major problem in Vietnam in 2007-08.

The adoption of CTBS, however, was low in the study villages; it was practiced only at the pilot sites. The reported constraints were high investment costs (66% of respondents), which included both monetary and transaction (time involved) costs. Also, where there was a government subsidy, farmers would not practice it because of the difficulty in doing early planting, considering their small farm sizes (72.2% of respondents). However, the high adoption of the other EBRM practices meant that rodent densities were not sufficient to require the implementation of CTBS during the study.

Changes in rat damage to crops and rice yields

Some of the key results and impacts of EBRM for farmers were an increase in rice yields, reduction in area damaged by rats, reduction in cost of rodent management, and increases in net returns. At the farm level, the mean area of rice crops affected by rodents fell from 9.6% (2001-05) to 1.1% (2006-09) (Table 3). At the provincial level, the mean area of rice crops damaged by rats fell by 93.5% and the quantity of rice lost decreased by 91.7% after the implementation of the project (Table 4). Paddy yield increased by 9.4% and net income per ha of rice increased by about 35% (Table 4), partly because of better rodent management practices.

The use of rodenticides decreased significantly from 230–990 kg/year (up to 2005) to 92–144 kg/year from 2006 to 2009 (sub-PPD Ha Nam reports). This was a

Table 3. Area (ha) of rodent infestation in rice crops in Ha Nam Province, Red River Delta, 2001-09. Project activities commenced in 2006, after which there was a 93.5% reduction in the average area affected by rodents from 9.6% (2001-05) to 1.1% (2006-09).

Year	Rice area (ha)	Affected area (ha)	Affected percentage (%)
2001	75,213	11,947	15.9
2002	76,107	7,956	10.5
2003	74,315	5,680	7.6
2004	73,318	4,975	6.9
2005	72,165	4,894	6.9
2006	71,006	2,786	3.9
2007	70,706	199.6	0.3
2008	68,440	186.4	0.3
2009	34,282	318.2	1.0

Source: Sub-PPD Ha Nam.

Table 4. Contribution of EBRM to rice production in Ha Nam Province, before and after the project.

Criteria	Before (2005)	After (2009)	Change (After – before)	
			Δ (000 VND)	as % of 2005
Area damaged (ha)	4,894	318.2	–4,575.80	–93.50
Rice loss due to rat damage (tons)	1,318.1	108.9	–1,209.23	–91.74
Yield (tons/ha)	5.25	5.74	0.49	9.36
Net income (000 VND/ha)	6,547,038	8,828,635	2,281,597	34.85

Sources: Computed from reports of Sub-PPD Ha Nam, various issues.

reduction of 62–90%, which has a positive implication for the health of the environment, humans, and livestock. Overall, the adoption of EBRM meant better rice yields, higher economic returns for farmers, reduced human health risks, and fewer toxic chemicals in the environment.

Key socio-cultural factors for EBRM adoption

Four key socio-cultural factors underlie the adoption of EBRM in Vietnam: (1) farmer knowledge, (2) experiential learning, (3) social capital, and (4) culture and history.

1. Building on farmers' indigenous knowledge

Farmers' indigenous or local knowledge is unique in a given culture and society. This knowledge is reflected in their perceptions and practices, and is transferred across generations. The indigenous knowledge can be observed in their rodent control practices, which are embedded in their rice production system. Understanding farmers' perceptions, knowledge, and beliefs of rodents and rodent management practices helps scientists and extension specialists to interpret how farmers manage their rodent pest problems, and this enables a better fit of scientific recommendations within the context of the existing practices of farmers. The indigenous knowledge can be captured through field observations, farmer interviews via focus group discussions, key informant interviews, and informal and spontaneous interviews. A platform to support these methods was participant observation, which is the hallmark of anthropological methods.

In anthropology, the concepts of "emic" and "etic" are relevant when building on farmers' indigenous knowledge. The "emic" refers to the insider's point of view or farmer's point of view and can be referred to as farmer knowledge. For example, these include how farmers perceive rodents, cataloguing their local rodent control practices, and determining how they perceive the effectiveness of these control practices. The "etic," on the other hand, refers to the outsider's point of view or scientist's point of view, and can be redefined in this context as scientific knowledge (Harris 1993), for example, what is the current scientific knowledge about rodent ecology and rodent control practices. Reconciling the emic and etic through an understanding of evolving ecological practices and accumulated knowledge of farmers could lead to a better understanding by scientists of farmers' indigenous knowledge and, correspondingly, a better appreciation by farmers of scientific agricultural knowledge. Together, this will enhance research design, technology transfer, and adoption; provide a better appreciation of farmer adaptation of a technology; and increase the rate of diffusion of the technology. This also provides a strong platform for farmer-scientist-extension collaboration and enables research to be responsive and complementary to the needs and knowledge of farmers.

The community actions implemented in northern Vietnam incorporated farmers' indigenous rodent control practices, especially the benefits of synchrony of cropping, digging of burrows and hunting with dogs, and the use of local rat traps. As a result, Vietnamese farmers rapidly adopted the EBRM recommendation to synchronize cropping and to conduct community actions for managing rodents at specific key times in a season, at a landscape level.

In Binh Minh Cooperative of Binh Luc District, farmers practiced synchronous planting. Planting was done within 10 days, implying that land preparation was also carried out at almost the same time. This was easily implemented because an irrigation group of the cooperative is responsible for ensuring the release of irrigation water on time. Farmers raised the water level in their fields during land preparation because the rats moved up to higher ground, enabling farmers to easily catch them.

The common practice of digging and hunting arbitrarily was consequently transformed into a community working together and prior to rodent damage occurring to their crops. Likewise, the common practice of using chemicals decreased, an outcome of the knowledge gained by farmers from their training on the biology and ecology of rats.

Before the introduction of EBRM, farmers took action only when they saw symptoms of rodent damage. Often, the trigger for action was high numbers of cut tillers of rice, which often happens during the booting stage. However, the rice plant cannot compensate for losses at this stage of the growing season, so farmers were responding after high losses had occurred. There was little motivation to conduct rodent control before the start of the cropping season and at the early stage of the rice crop. But, with the introduction of EBRM, more farmers were equipped with a better understanding of the biology of rats and subsequently took part in community action (Table 2). The farmers developed a clear understanding of why trapping one rat at the early stage of the crop was equivalent to catching 100 rats at the later stages of the crop, and why synchrony of cropping was so important in limiting the breeding season of the main pest species, *Rattus argentiventer*.

2. Experiential learning

The adoption of an innovation is closely intertwined with the way farmers effectively learn or gain knowledge, such that the likelihood of success in extending such innovation or technology will be greater. According to Kolb (1984), learning is the process whereby knowledge is created through the transformation of experience. Kolb and

Fry (1975) argue that effective learning entails the possession of four elements, which represent the experiential learning cycle: (1) concrete experience, (2) observation and reflection, (3) the formation of abstract concepts, and (4) testing in new situations.

Experiential learning has been reported to be effective in adult education and technology adoption in an agricultural context (Palis 2006). A challenge for the extension of natural resource management is that most of the technologies in this domain are knowledge-intensive. An important example of effective transfer of knowledge-intensive technologies in agriculture is the experiential learning that occurred in FFS that resulted in increased adoption of IPM. Farmer participants used their concrete experiences to test ideas and consequently change their pest management practices through group experimentation.

During the duration of the project, in every community action, farmers and PPS staff counted the male and female rats collected. During maximum tillering and booting stage of the rice crop, farmers saw pregnant female rats. And, when they conducted a necropsy of these pregnant rats, they saw numerous embryos. Likewise, they saw many baby rats in the burrows at the side of the rice paddies. These experiences enabled farmers to understand why it is important to hunt rats at the early stage of the crop before they begin to breed. In this context, farmers interpreted observations, facts, and experiences both individually and as a group, and generated a consensus that is culturally enforced (Pontius et al 2002).

The implementation of EBRM interventions (particularly community action) uses the experiential learning approach in which farmers are actively engaged in the technology development and validation process resulting in EBRM local modifications, such as developing their own decisions on the timing of community action. Participatory experiments were conducted in setting up the CTBS, and dialogues between the implementers and farmers took place before and after community action was implemented. Farmers met and discussed the timing of their community actions in farmer cooperative meetings together with the village extension staff and the head of the commune's People's Committee. They discussed when and how to organize themselves in hunting rats. Consequently, EBRM was incorporated in the IPM FFS. By 2009, EBRM was included in 169 FFS involving 6,474 farmers.

3. Capitalizing on social capital

Social capital refers to features of social life such as networks, norms, and trust that facilitate collective action (Putnam 1995). It also comprises the resources derived from social relations and these resources are the products of the process of social relations (Palis et al 2005). Social relations, in turn, are the products of enculturation. Hence, the sources of social capital and the type of social capital formed are largely determined by culture. Since culture among societies varies, the sources of social capital likewise differ. Although there may be some commonalities in some societies, most sources of social capital are distinctly associated in each society.

Most studies of adoption of agricultural technologies focus on individual attributes as factors contributing to successful adoption (Palis et al 2005). But human behavior is the result of interactions and interrelations among people. Social capital as an analytical concept shifts the focus of analysis from the behavior of individuals to the pattern of relations among individuals, social units, and institutions; it reinserts issues of value into the heart of social scientific discourse such as terms of trust, sharing, and community that are central to it; and it directly generates questions about the assumptions on human behavior on which analysis and policy are based (Schuller et al 2000).

The effective pathway for EBRM implementation in northern Vietnam was through the strong coordinated linkages between the local political organizations (People's Committee at provincial, district, and commune levels) and extension institutions (plant protection system: sub-PPD for provincial level and PPS for district level), as well as the involvement of a government research institution (NIPP) and an NGO (WVV). The sub-PPD Ha Nam and PPS in respective communes, which are responsible for extending crop-protection technologies such as EBRM, have strong linkages with the People's Committees at the provincial, district, and village levels.

The sub-PPD Ha Nam and PPS in respective communes provided the technical support for the EBRM implementation to farmers and agricultural cooperatives. These agricultural cooperatives served as a bridge between the government and farmers. The head of an agricultural cooperative is an official of the village People's Committee, responsible for agricultural functions. Also, all plant protection concerns of the agricultural cooperatives are under the supervision and guidance of the plant protection system (sub-PPD and PPS). Agricultural cooperatives are the avenue for organizing and mobilizing farmers' participation in community actions, and for better targeting the actions of rodent control groups for rodent community action.

The People's Committee provides the political and at times financial support to the agricultural cooperatives. The PPD also provides financial support through the Department of Agriculture via farm demonstrations, training, and field days. As a result, from 2006 to 2009, there were 104 community action campaigns, including 16 conducted outside project sites and one by a local authority, with more than 10,000 farmers involved. The involvement of NIPP, a government research agency, and WVV facilitated the capacity-building and dissemination activities. EBRM was incorporated in the IPM-FFS of the Department of Agriculture in Ha Nam, and into the area development programs for agriculture of WVV.

4. Understanding and using people's culture and history

Understanding the history and culture of the people, especially the norms and values adhered to, and the common practices for rodent control is an important consideration for implementing strategies to bring about adoption of EBRM. The classical definition of culture is that it is a complex whole that includes knowledge, belief, art, law, morals, custom, and any other capabilities and habits acquired by humans as members of society (Tylor 1871). Culture is also viewed as a product of the people's or society's own unique history (Boas 1920). There are various definitions of culture but there is a common ground: the existence of learned routines of thought and behavior in social groups. And, learned routines of thought include "meanings, symbols, understandings, knowledge, ideas, values, norms, etc." (Brumann 1999).

In Vietnam, coordinated community action is the norm rather than a novel concept. The Chinese influence of Confucianism, which is viewed as both a philosophy of life and as a religion, emphasizes the importance of loyalty, respect for authority, and peacefulness (Quang 2003). Respect for social hierarchies is therefore basic to Vietnamese families and society. By far the most important of these values are those associated with family and community, where individual interest is subordinate, if not irrelevant, to the welfare of the whole group (Muoi 2002). Further, their experience in collective farming in the past has provided a strong foundation for effective collective action.

The spontaneous adoption of EBRM is most likely associated with the norms and values adhered to by Vietnamese farmers and their experience in collective farming in the past. Since respect for social hierarchies is basic to Vietnamese families and society, the lower-level authorities and the general community spontaneously adhere to a directive coming from higher authorities. This cultural context enabled rapid adoption of community actions for rodent pest management and its subsequent inclusion as seasonal practices in the rural communities involved in the project.

Before each rice-cropping season, agricultural cooperatives receive documents from the district DARD and PPS regarding crop schedules and other related activities. Field hygiene is recommended to be done by the community before transplanting. Usually, the cooperative announces the timing of the activity through an amplifier system. Synchronized cropping is likewise done in the community as recommended and required by cooperatives. Timing of transplanting is not necessarily the same for the whole rice area in one commune; it may be slightly different among villages, depending on irrigation schedules, availability of labor, and weather conditions.

5. Challenges for the future

The sustainability of the adoption of an agricultural intervention has been a perennial challenge. The sustained adoption of EBRM, particularly through the expressed need for community action, is a greater challenge. Community action is implemented through multistakeholder partnerships between government institutions—political, research, extension—and agricultural or farmer cooperatives. In the Red River Delta, the development of an effective alliance of these different institutions with clearly coordinated linkages paves the way for sustainable adoption of EBRM. An important group at the grass-roots level that will foster success is the plant protection security group or rodent control group. These occur in each agricultural cooperative but, for any community action for rodent pest management, a small investment of funds is necessary for mobilization, and these can simply involve provision of food or snacks for the participants. What is lacking is a mechanism for the surety of funds for the implementation of community action. We recommend that the Department of Agriculture and PPD allocate funds in every cropping season to support community action. For a small investment, there is a high likelihood of a significant return on investment through sustainable adoption of community actions for EBRM. Some communities impose a small tax based on rice production levels that is invested in crop protection, but, until this becomes the norm, government assistance may be required. If such government support is provided at a regional level, then outbreaks of rodent populations in the irrigated lowlands of the Red River Delta may become an occurrence of the past.

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Notes

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Response options to rodent outbreaks following extreme weather events: cyclone Nargis, a case study

Grant R. Singleton, Nyo Me Htwe, Lyn A. Hinds, and Win Soe

Compelling evidence exists of an increase in the occurrence of unusual or extreme weather events as a consequence of global warming. The effect of these extreme weather events on the health and livelihoods of smallholder farmers in developing countries can be severe. We report on a major and widespread outbreak of rodent populations in the Ayeyarwaddy Delta of Myanmar 13 months after the devastating cyclone Nargis in May 2008. From mid-June to mid-September 2009, more than 2.6 million rodents were collected through well-coordinated community campaigns covering 305,717 ha of rice crops. Although these campaigns may have dampened the impact of the rodent species on rice production, the devastation was still severe. We present two explanations for the outbreak; both have cyclone Nargis as their genesis. One is that Nargis caused a high death rate of predators, which released the rodent populations from the limitation provided by predators. The second hypothesis relates to the response of rodent populations to asynchronous and aseasonal planting of rice crops and to increased neglect of some crop lands in the 12 months after cyclone Nargis. Together these provided ideal conditions for high population growth. We suggest that the second explanation is more parsimonious given our understanding of the ecology of the rodent pest species. Unfortunately, the data collected during the outbreak were insufficient to distinguish unequivocally between the two possible explanations. We provide recommendations of immediate response options for managing rodent populations when there are early indications of increases in rodent numbers; an update of research on fertility control of rodents, which offers a promising longer-term response option; and an outline of the minimum biological and economic data that need to be collected when there is a report of a rodent outbreak in tropical or subtropical lowland agricultural landscapes.

Keywords: extreme weather, rodent outbreaks, Ayeyarwaddy Delta, cyclone Nargis, Myanmar

Weather events and rodent outbreaks: a common story?

Outbreaks of rodent species that lead to substantial impacts on agricultural production and the livelihoods of rural communities have often been reported to be associated with unusual rainfall events (e.g., Leirs 1997, Jaksic and Lima 2003, Stenseth et al 2003), with high rainfall during specific periods (Pech et al 2003, Sudarmaji et al, this volume) or with droughts or drought-breaking rains (Saunders and Giles 1977, Krebs et al 2004). Interestingly, the link between rodent population outbreaks and rainfall is not restricted to semiarid and Mediterranean environments. In the subtropics and tropics, the occurrence of prolonged rainfall at the end of a cropping season or low rainfall at the beginning of the monsoon season can both lead to rodent outbreaks in Indonesia (Sudarmaji et al, this volume) and the Philippines (Singleton, unpublished data).

More and more evidence suggests that there has been an increase in the occurrence of unusual or extreme weather events as a consequence of global warming (Jentsch et al 2007) and that these can have effects on insects (Branson 2008) and birds (McKechnie and Wolf 2010). We are not aware of published reports of increased impacts on rodent pest species in agricultural landscapes linked to unusual weather events and possible global warming. For this article, we will define unusual or extreme weather events to be at least a once-in-50-years phenomenon. The effect of extreme weather events on the health and livelihoods of smallholder farmers in developing countries is well documented. Two recent examples are cyclone Nargis, which struck southwestern Myanmar in 2008 (Post-Nargis Tripartite Core Group 2008), and typhoon Ketsana (Ondoy) in 2009 that devastated Manila (highest rainfall associated with a typhoon since records have been kept) and central Vietnam (flood levels in Quang Nam eclipsed those last seen in 1964) (http://en.wikipedia.org/wiki/Typhoon_Ketsana). Typhoon Ketsana in the Philippines led to 464 people perishing due to its impact; another 210 people (192 in Manila) died from leptospirosis, a rodent-borne zoonosis, in the 2–4 weeks after the typhoon (WHO 2009). Globally, of particular note is that, from 1990 to 2008, nine developing countries in the tropics and subtropics were the most affected by weather-related loss events (storms, floods, cyclones, heatwaves) (Harmeling 2009).

What is not well understood is the impact of climate change on rodent populations as manifested by the occurrence of unusual weather events. Given that sustained access to high-quality food is a principal driver for rodent population outbreaks (see the first chapter, Singleton et al, and other contributions in this volume), we hypothesize that, if an unusual weather event generates conditions favorable for sustained food availability at a time when rodent population densities are low, then a rodent population would take 6–18 months to build up to outbreak densities. Therefore, we expect a marked time lag from when the unusual weather event occurs to when rodents have significant impacts on agricultural production and the general livelihoods of rural communities.

In this chapter, we will discuss four main topics:

1. A case study of a rodent outbreak following a major weather event in the Ayeyarwaddy Delta in Myanmar.
2. The immediate response options for managing rodent populations when there are early indications of increases in rodent numbers.
3. The minimum biological and economic data that need to be collected when a rodent outbreak is reported.

4. A longer-term response option that targets the key population mechanism that leads to outbreaks—the high breeding potential of rodent pest species when conditions are favorable.

Cyclone Nargis in Myanmar: a case study of a delayed rodent outbreak

The lowland ecosystem provides Myanmar with the main bulk of its rice production to meet the demand for national consumption and exports. Preharvest rodent damage to rice in Myanmar is often as low as 5% but, in some years in some regions, losses can be as high as 40% (Singleton 2003, Htwe 2006). One household survey indicated that farmers estimate preharvest losses from rodents to be 15% for lowland rice production (Brown et al 2008).

Ayeyarwaddy Division in southwest Myanmar is the rice bowl of Myanmar, providing 32% of national rice production (Fujita and Okamoto 2006). On 2 May 2008, cyclone Nargis struck the Ayeyarwaddy Delta (Fig. 1). Over just 2 days, the destruction was immense and led to the death of approximately 140,000 people. The high winds, high rainfall, and a 3.6-m storm surge led to the loss of 450,000 houses and severe effects on the livelihoods of an estimated 2.4 million people through loss of family members, loss of draft animals, loss of farming tools, loss of labor, loss of good-quality rice seed, and high salinity in their fields (Post-Nargis Tripartite Core Group 2008). The latter was transitory but it occurred at a time when the land was being prepared and planted for the main monsoon rice crop. Nargis also had a significant effect nationally, with a 6% drop in rice production in Myanmar (IRRI 2008). One of us (GRS) visited the Ayeyarwaddy Delta in August 2008, and the resilience of the rural households to the Nargis tragedy was amazing. Some communities, with the help of aid, had already planted their monsoon rice crop, and many others were on the path to resuming rice farming. From a pest management perspective, there were no reports at that time of unusual pest problems; however, the recovery process at a landscape scale led to crops being planted asynchronously and established 1–3 months later than usual.

In June 2009, farmers in the cyclone-affected areas were threatened by high populations of rodents, when they were still struggling to reestablish their livelihoods primarily via their income from rice-based cropping. The affected area was large (Fig. 1); rats were everywhere in the rice fields and granaries, and were in high densities inside and around the houses. Farmers said that bandicoot rats (= *Bandicota bengalensis*) were the most common in the rice fields, and rats and mice were dominant around and inside the houses (*Rattus* and *Mus* species) (Myanma Agriculture Service, MAS, unpublished data). The townships mainly affected were Laputta, Mawkyun, Bogale, Phyapone, and Daedaye, and each of these areas was severely affected by Nargis (townships in the Ayeyarwaddy Delta typically have 700 to 1,000 villages; the number of people in a village ranges from 500 to 1,000). These five townships typically provide 70% of the rice production in Ayeyarwaddy Division. Of these townships, the rice fields in Laputta, Mawkyun, and Bogale were the most severely affected by high population densities of rodents. Here, the farmers faced rodent problems from

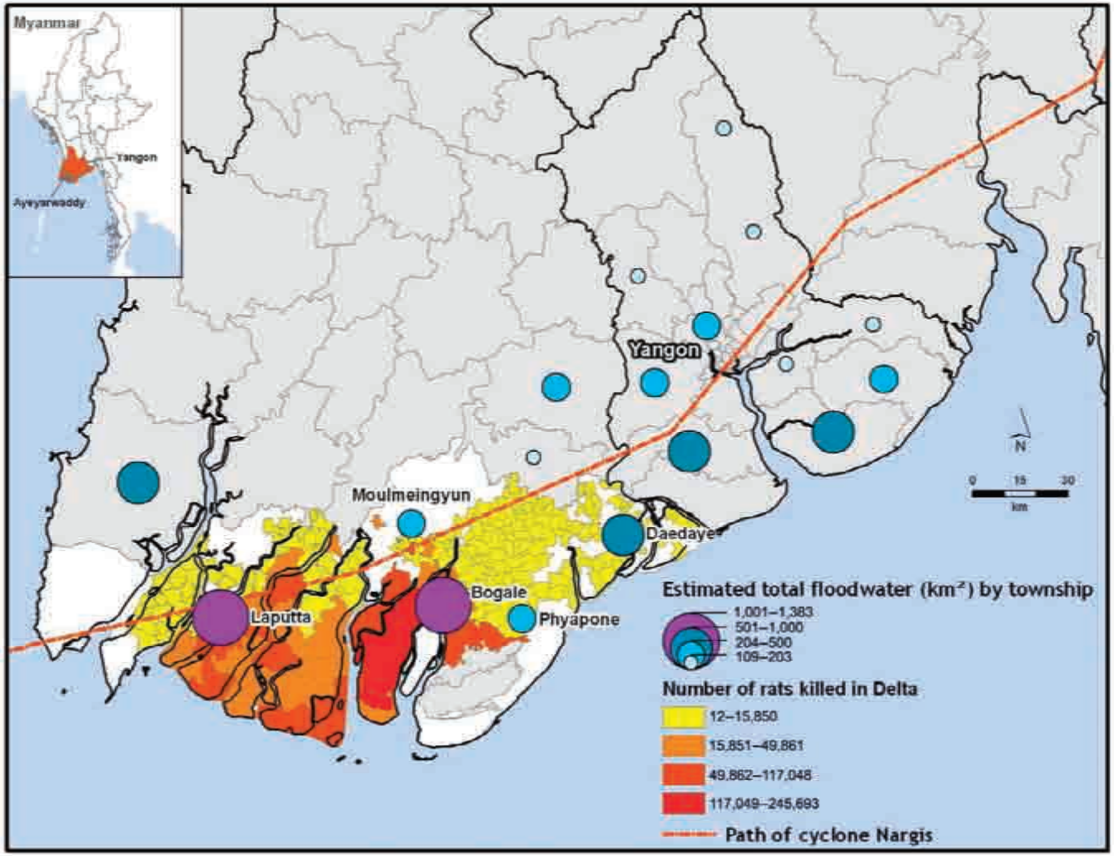

Fig. 1. Areas in Myanmar affected by cyclone Nargis in May 2008, and the number of rats killed in the Ayeyarwaddy Delta region within the three months of 12 June to mid-September 2009.

the time their rice was at the seedling stage in their nurseries. Seedbed nurseries of 260 villages in Laputta Township, eight villages in Mawkyun Township, and 13 villages in Bogale Township were affected by rodents. After cyclone Nargis, there was a shortage of good-quality rice seed, resulting in seed being imported from other states and divisions. During the rodent outbreak, precious good-quality rice seedlings were completely destroyed by rats in 98 ha of seedbeds in Laputta Township, in 1 ha in Mawkyun, and in 18 ha in Bogale—1 ha of seedlings can be transplanted to 10 ha of rice field (Table 1). Losses of this magnitude would be severe in a normal year but, for farmers who were still recovering from the effects of Nargis, the losses were devastating. Management of the rodent populations during the seedling stage was either ineffectual or lacking. The growth of the rodent populations therefore continued relatively unabated and led to high damage to the rice crop at the booting stage (prior to flowering). In the other two townships of Phyapone and Daedaye, rodent damage was also high during the booting stage of the rice crop (Table 1). The mean rice yield in the Ayeyarwaddy Delta in the wet season is 5 t ha^{-1} (Department of Agricultural Planning 2008). In 2009, the reported losses to rodents were extremely conservative because the MAS recorded losses only greater than 80%. Despite this, the loss of rice was significant at the township level. For example, in Laputta, the minimum loss was estimated to be 5,885 t—this amount of rice could feed 26,694 Myanmar people for a year.

However, rodent damage would have been underestimated because, although rice tillers damaged by rats are able to generate new tillers, if the damage occurs after the maximum tillering stage, then the new growth is only vegetative (Buckle et al 1979, Cuong et al 2003, Islam and Hossain 2003). Plant protection specialists who are not vertebrate biologists tend to severely underestimate these losses because they see healthy growing tillers. Unfortunately, as noted above, in the MAS reports of the Ayeyarwaddy rodent outbreak, only extreme losses were documented. Quantification of the full extent of the damage and yield loss caused by rodents is urgently required during future outbreaks so that the magnitude of the impact on livelihoods can be better understood.

Species involved and timing of damage

The MAS reported that the main rodent species involved in the rodent outbreak were *B. bengalensis* and *Bandicota indica*. Farmers reported that the rodents primarily caused high damage to the rice crop at the seedling and booting stages. The lack of reports of damage at later stages of crop growth may reflect that a comprehensive community campaign to control rat populations had begun, or it simply reflects the lack of awareness of rodent damage when the crop has a lot of green re-growth during the flowering and ripening stages, as discussed above. Certainly, high numbers of rats were collected during community campaigns in late August and early September when the crop was at the flowering and grain-filling stages. In Laputta Township alone, 600,000 rats were collected in the last week of August from 128,822 ha of rice fields when the rice crop was at the milky stage. From previous research in lowland rice systems in Yangon Division, Myanmar, damage caused by *B. bengalensis* and

Table 1. Estimates of area severely damaged by rodents (>80%) at seedling and booting stages of the rice crop, and of yield loss in five townships in Ayeyarwaddy Division, in the 2009 wet-season crop. Rice germinated in seedbeds is transplanted as seedlings at 15–21 days. Rice that is sown by broadcasting the seed by hand directly into the fields is “direct-seeded rice.”

Township	Village tracts (no.)	Villages (no.)	Total area of rice fields (ha)	Damaged area at sowing (ha)		Damaged area at booting stage (ha)	Estimated yield loss (tons)
				Seedbeds	Direct-seeded rice		
Laputta	43	260	128,822	98	0	1,177	5,885
Mawkyun	2	8	3,749	1	0	12	60
Bogale	2	13	12,237	18	42	493	2,465
Phyapone	2	14	85,078	No data	No data	43	215
Daedaye	6	35	75,831	No data	No data	77	385
Total	55	330	305,717	117	42	1,802	9,010

B. indica to rice crops is highest at the harvesting stage (Htwe 2006). Similar findings were observed in Bangladesh (Islam et al 1993) and India (Sultana and Jaeger 1992) and this is consistent with *Bandicota* species storing cut grain in their burrows (Sheikher and Jain 1991).

In the Ayeyarwaddy Delta region, there have been no previous reports of massive rodent outbreaks during the last three decades, except in deepwater rice in areas such as Thabaung and Yegyi townships (Htwe, unpublished report). In an outbreak in deepwater rice crops in 2000, the major pest species was a *Mus* sp. Nevertheless, the annual losses to rodents vary markedly from place to place, and data are sparse on the level of damage and yield loss.

A rodent control campaign

Shortly after reporting the population outbreak, rodent management campaigns were coordinated by plant protection specialists from MAS, with assistance from local government officials and NGOs. They conducted farmers' meetings and motivated farmers to undertake different rodent management practices in the field. Management actions that were promoted included improved sanitation, encouraging predators (particularly barn owls), applying rodenticides (coumatetralyl, active ingredient), trapping, digging burrows, and spraying endosulfan as a deterrent for rats. Intensive community campaigns were conducted and these focused on killing rats by trapping and digging burrows. Initially, the local government provided farmers with rice as an incentive—1 kg of rice per 5 rat tails, and some NGOs provided 100 kyatt per tail (approx. US$0.10). However, so many rats were collected that, after 1 month of the campaign, rice could no longer be provided. Thereafter, each household was required to submit 5 rat tails during the latter part of the campaign.

Within 3 months, the rodent campaign returned more than 2.6 million rats from 700 villages drawn from five townships (Table 2, Fig. 1). Since the rodent outbreak had started in the nursery stage in Laputta, Bogale, and Mawkyun, campaigns to catch rodents started earlier there than in the other two townships. Generally, MAS and the local government were able to successfully organize community mass action, resulting in impressive numbers of rats being caught (Table 2). According to MAS staff, rodent damage was brought under control within 3 months.

Many of the recommended rodent management methods that farmers mainly relied upon during these outbreaks were nonspecific culling methods. These included application of rodenticides, spraying with endosulfan, and trapping. Endosulfan in particular presents a high risk to nontarget biota. Important challenges with large-scale rodent management programs are to minimize nontarget risks, avoid contamination of the environment, and conduct control humanely (Singleton et al 2007). In Myanmar, plant protection specialists generally have a poor knowledge of the major rodent pest species and are not able to identify sustainable rodent management practices based on the ecology of these species. This is particularly evident given the recommendation to spray endosulfan around the margins of crops as a repellent for rats. Endosulfan is a persistent organic pollutant. It is banned in most developed countries and there is currently a well-argued recommendation that this pesticide be banned globally

Table 2. Number of rodents collected in the Ayeyarwaddy Delta region from mid-June to mid-September 2009. A village tract is the basic administrative unit in Myanmar and it consists of multiple villages. The number of villages per village tract depends on the human population density.

District	Township	Village tracts (no.)	Villages (no.)	Families (no.)	Action start date	Number of rodents collected		
						Buried	Burned	Total
Laputta	Laputta	43	260	28,276	12.VI.09	345,481	1,121,757	1,467,238
	Mawkyun	22	181	5,549	24.VII.09	242	150,425	150,667
Total		65	441	33,825		345,723	1,272,182	1,617,905
Phyapone								
	Phyapone	5	32	11,808	31.VIII.09	29,877	12,000	41,877
	Bogalay	68	131	19,727	10.VII.09	756,614	99,665	856,279
	Daedaye	47	96	10,716	31.VIII.09	47,879	n.a.[a]	47,879
Total		120	259	42,251		834,370	111,665	946,035

[a] n.a. = not available.

(Secretariat of the Stockholm Convention 2009, International Institute for Sustainable Development 2009). In October 2009, the Plant Protection Division of MAS, together with IRRI and FAO representatives, reviewed the mass rodent control campaign in the Ayeyarwaddy Delta and recommended the suspension of the use of endosulfan.

What led to this severe rodent outbreak in the Ayeyarwaddy Delta?

A review of the 2009 rodent outbreak led to the development of two explanations for the occurrence of what is considered the most severe and widespread impact of rodents on rice production that has ever been documented in the Ayeyarwaddy Delta. Both explanations have cyclone Nargis as their genesis and this is consistent with the geographic range of the path of cyclone Nargis and the mapping of the intensity of the rodent outbreak (Fig. 1), and that the affected townships are the main rice-producing areas of Myanmar.

Explanation 1—reduced predator pressure

Local MAS staff suggest that the dominant factor leading to the rodent outbreak was the loss of predators during cyclone Nargis. They contend that the cyclone led to high losses of predators, including snakes, cats, and dogs, and in addition culling by humans declined substantially post-Nargis. Indeed, many “rat hunters” perished during the cyclone. These rat hunters make their living by hunting and selling rats for human consumption. Farmers also spent less time on rodent management actions because of their focus on rebuilding their livelihoods following the cyclone. The main argument revolved around the high loss of snakes; this is curious because snakes are more likely to survive floods and storm surges better than rodents and snakes have a low rate of food intake so are unlikely to be major rodent suppressors. The main proponents of this argument are crop protection specialists who have a good knowledge of integrated pest management (IPM) for insects. IPM for insect pests is built around the foundation of promoting beneficial predatory insects. Using the analogy that reduced predator pressure “released” an important factor that limits the population growth of rodents, these proponents suggest that encouraging barn owls to nest in the rice fields would provide the basis for sustainable management of rodents in the future. However, this recommendation is not supported by the scientific literature on predator-prey relationships for small mammals that have a high intrinsic reproductive potential (r-selected) (Singleton et al 2003).

Predators can influence rodent populations directly (preying upon rodents; e.g., Sinclair et al 1990) and indirectly (sublethal effects through modifying feeding behavior and habitat use; e.g., Ylönen et al 2002, Arthur et al 2003). However, these effects are not sufficient to prevent occasional widespread population outbreaks on agricultural lands (Sinclair et al 1990, Ylönen et al 2002, Vibe-Petersen et al 2006). Although there are opposing views, the most compelling evidence of predators being able to limit rates of increase of small mammal populations is in Scandinavia, where a number of specialist predators have coevolved with vole populations (see Klemola et al 2002). Generalist predators, such as barn owls, may increase the period when populations of small mammals are at low density; however, they will not prevent population outbreaks when conditions are favorable (see Korpimäki et al 2004 for review).

Although population models support the potential of barn owls to regulate rodent populations in oil palm plantations and rice fields in Malaysia (see Hafidzi and Mohd Na'im 2003 for review), field studies in cereal systems do not support this potential elsewhere. In maize fields in eastern Africa, Vibe-Petersen et al (2006) conducted large-scale experimental field studies and observed that predators do not play a major role in the regulation of the population dynamics of rodents, even when nest boxes and perches for avian predators are provided. They concluded that compensatory mechanisms operate at a population level when rodents are exposed to high levels of predation risk. In Pakistan, Hassan et al (2004) conducted a diet study of barn owls in an agricultural landscape and found that most barn owls preferred sub-adult *Millardia multada*; *B. bengalensis* and *R. rattus* contributed only 2% and 1% to their diet, respectively. Apart from the ecological studies, there is also the practical limitation of how much a nonspecialist predator such as a barn owl can consume. A barn owl needs to eat 85–110 g of food a day (Martin et al 2003); the body weights of adult *B. bengalensis* and *B. indica* range from 300 to 350 g and 600 to 700 g, respectively. Therefore, the predation rate of barn owl on these two species would not be high enough to limit their populations in rice landscapes in Myanmar.

Explanation 2—extended availability of high-quality food

The main breeding season of rodents living in rice field environments is strongly determined by the availability of high-quality food—especially rice during its generative stage of development (Leung et al 1999, Brown et al 2005). This association appears also to hold for the main pest species of rodents in Myanmar (Thwe 2007, Lwin 2007). After cyclone Nargis, the timing of rice planting in the Ayeyarwaddy Delta was different from place to place. As mentioned in our Introduction, the recovery process at a landscape scale led to crops being planted asynchronously and becoming established 1–3 months later than usual, leading to an extended period when rice crops were being grown.

We propose that the predominant reason for the outbreak of rodent populations in June 2009, some 13 months after cyclone Nargis, was an extended availability of high-quality food. There are two contributors to extended food availability. The first is asynchronous and aseasonal planting of rice crops during 2008, which extended the availability of high-quality food and consequently lengthened the breeding season of the rodents. Some other cases of rodent outbreaks in rice agroecosystems in Southeast Asia have been related to asynchronous planting or volunteer (ratoon) rice crops that extend the growing season and hence the breeding season of rice-field rats (Sudarmaji et al, this volume; Singleton and Htwe, unpublished report). The second is a high amount of land cropped only once per year or not at all, associated with the shortage of labor and functional cropping equipment following the cyclone. Prior to cyclone Nargis, these lands were cropped twice a year. The neglect of these lands by farmers for at least 7 months of the year led to volunteer crops of rice and, together with the growth of grasses and other weeds, rodents had plenty of food and cover—an ideal combination for increased rates of population growth.

We therefore contend that the more likely biological explanation for the widespread and massive population outbreak of rodents is related to the impact of cyclone Nargis on the timing of the planting of rice over the affected area, and changes in land management. This explanation is consistent with how long it would take a rodent population to respond to a major climatic event that not only had a major impact on the lives of humans and their draft animals but also reduced the rodent population to low densities. Rodent populations would take a minimum of two cropping seasons to build up to high densities and it would therefore be the third season post-Nargis that would bear the brunt of a major population irruption. Biologically, this is similar to the time it takes for mouse populations in Australian wheatfields to build from low densities to >1,000 mice per ha when an extended period of favorable conditions occurs (see Singleton et al 2005), and is consistent with the fact that rodent outbreaks in Indonesia and Vietnam take at least two seasons to build up from low densities to densities that cause significant losses to rice crops (Brown et al 2005, Brown et al, this volume, Sudarmaji et al, this volume).

Immediate response options for managing rodent population outbreaks

Once rodent populations reach high densities, the main response option is to blanket areas with acute poisons such as zinc phosphide (see Singleton et al 2005). Such an approach has health risks to the applicators of the poisons and to nontarget species. Moreover, the efficacy of blanket poisoning in tropical agricultural landscapes using acute poisons has been questioned (Hoque and Sanchez 2008). In Myanmar and other Southeast Asian countries, the small holdings of farmer households (most <2 ha) mean that sufficient people are available to cover most of the available rodent habitats if a community culling campaign for rodents is recommended. Indeed, the magnitude of the community involvement in the rodent campaign post-Nargis in the Ayeyarwaddy Delta was impressive. Similar community-based bounty systems have proven effective in generating high captures of rats in Vietnam, Lao PDR (Singleton et al 1999), and the Philippines (Flor and Singleton, this volume) but often these campaigns are conducted after the rodents have inflicted high damage to crops (Singleton et al 1999). In Myanmar, the ability to mobilize community action effectively over a large area raises the potential of implementing a “smart bounty” scheme. Such a scheme would require quick action to implement community campaigns once there were signs of impending high rodent densities—for example, triggered in response to observations of high rodent damage in rice nurseries. Rural communities would then be paid a bounty for rat tails for a limited, but biologically important, period. In this instance, it would be from the sowing of the rice to the maximum tillering stage—prior to the onset of the main breeding season of rats.

However, reliance on community action alone may not be sufficient. There have been no studies of the benefit-cost of community campaigns, and one expects that if, in the Ayeyarwaddy Delta, some 2.6 million rats were collected over 3 months, then, given the efficiency of catching rats, one would expect perhaps many more rats not removed from the affected agricultural landscape (305,717 ha). Perhaps an efficient strategy would be to undertake the following:

1. Apply community campaigns until a week prior to maximum tillering, which includes good hygiene within and around the crop area.
2. Conduct an assessment of rodent densities at the completion of the campaign (e.g., number of active rat burrows per length of irrigation canal; percentage of fresh damage to rice tillers).
3. If densities of rodents are still high, then implement sustained baiting using bait stations. Anticoagulant baits appear to be most effective (Buckle and Smith 1994); endosulfan and other such chemicals that are not registered for rodent control should never be used.

However, rodents have the ability to rapidly reinvade areas and, through their high intrinsic breeding rate, can rapidly compensate for the removal of animals from a population (Brown and Tuan 2005). Good quantitative studies of the efficacy of culling campaigns, be it through catching rats, applying poisons, or a combination of both, are urgently needed.

Minimum biological and economic data to collect during a rodent outbreak

During rodent outbreaks, plant protection staff and local government officials often seem content to report the numbers of rodents or rat tails that have been collected. Large numbers of rats make impressive reporting for local and national media. However, generally lacking are good quantitative data that allow us to learn important biological answers as to the genesis of the outbreak, and on the effectiveness of control campaigns. Such answers will make us better equipped to manage future outbreaks.

The following information needs to be documented, as a minimum, during rodent outbreaks:

1. Document spatial mapping of the impact of rodents based on reports from townships and villages to characterize the geographic area affected, to provide baseline data for the critical examination of possible causes for the outbreak, and to raise the profile of rodent impacts on rice production.
2. Do spatial mapping of the timing of planting and harvest date of the previous crop, and the planting date of the current crop. If there is marked asynchrony in these activities, the reasons need to be documented.
3. Collect quantitative data on damage to crops in a few selected areas to modulate the qualitative estimates obtained from activity 1.
4. Characterize and document which actions are effective in reducing rodent numbers. Ideally, this would include establishing an area where limited control is conducted (except around houses, where control is essential to reduce the possibility of rodent zoonoses), with compensation to the farmers, to provide a baseline for assessing efficacy.
5. Involve rodent specialists who can identify the main rodent species, assess the breeding dynamics of the population (including cohort analysis), and conduct

specific informant interviews to collect key information on farmer management practices in the season(s) leading up to the population outbreak.

These activities need to be supported with short, specialist training courses for extension staff on the biology of the pest species, assessment of damage to the growing crop, and the association between damage to tillers and yield loss. Staff members also need to be debriefed by the rodent specialists after the outbreak is over so that they can learn from the experience and become more aware of the most likely factors that lead to the eruption of rodent populations.

Longer-term response options for managing rodent population outbreaks

Additional techniques that reduce the economic impact of either chronic rodent infestations or of outbreaks without affecting nontarget species or the environment are still needed to assist in the strategic management of rodents. Manipulating the reproductive rate, particularly of females, instead of increasing the mortality rate of a population (Caughley et al 1992, Barlow et al 1997) has the potential to reduce the impacts of the pest rodents and thus the use of lethal agents (such as rodenticides, endosulfan, etc.). If sufficient information is collected after an unusual weather event to enable predictions of the timing of major increases in rodent numbers (Leirs et al 1996, Davis et al 2003, Krebs et al 2004, Singleton et al 2005), then pro-active application of a range of ecologically based techniques, including fertility control agents, may be able to prevent outbreaks and thereby prevent major yield losses and economic hardship. What are the prospects for affecting the reproductive success of short-lived rodent species that are highly fecund? While enclosure and field simulation studies as well as modeling outputs (Chambers et al 1999, Shi et al 2002, Davis et al 2003, Jacob et al 2004) suggest that fertility control could reduce recruitment such that outbreaks would not occur, no broad-scale application of specific agents has been achieved.

Chemical fertility control approaches for rodent control were first suggested in the late 1960s and early 1970s (see Marsh 1988, Gao and Short 1993 for reviews). Initial research focused on the use of synthetic steroids to impair reproductive function but problems associated with the need to maintain continuous exposure and overcome poor palatability and the lack of species specificity curtailed interest in the approach. During the last 20–30 years, contraceptive approaches based on inducing immune responses against targeted reproductive proteins (immunocontraception) have gained momentum (Kirkpatrick et al 1997, Kirkpatrick and Turner 2008, Miller et al 1997) although broad-scale delivery of these agents has not been developed. Viral-vectored immunocontraception (Tyndale-Biscoe 1991, Shellam 1994, Hardy et al 2006, Redwood et al 2007), in which a species-specific reproductive protein is expressed by a species-specific viral vector, promised an excellent disseminating mechanism for delivery of this control agent. However, for the wild house mouse, although a recombinant virus (murine cytomegalovirus) that expresses mouse zona pellucida 3 induced 100% infertility in infected mice, transmission of this recombinant virus to naïve mice was very poor (Redwood et al 2007).

Subsequently, the focus for rodent fertility control has turned again to oral delivery of chemosterilants. For oral delivery of any fertility control agent, several characteristics are essential. The agent must be (1) orally effective after a minimum number of feeds (preferably one dose); (2) permanent or have long-lasting effects, particularly in females; (3) specific for the target species; and (4) humane and safe to use in the environment.

Recent studies using synthetic steroids quinestrol (oestrogen) and levonorgestrel (progesterone) have been undertaken in hamsters, gerbils, and Brandt's voles (Zhang et al 2004, Zhao et al 2007) in China. Field trials have begun to assess the effects of a combination of steroids on the reproductive behavior and population dynamics of plateau pika (Zhibin Zhang, personal communication). This approach shows promise for species that cache baits in their burrows and therefore maintain a more continuous intake of these steroids. A nonsteroid agent that has been trialed in blacktailed prairie dogs is daizacon, an inhibitor of cholesterol production (and therefore of steroid synthesis), but continuous intake of this agent is required to maintain its inhibitory effects on the reproductive system (Nash et al 2007). Other immunocontraceptive products that have been developed for wildlife are OvoControl and GonaCon (Fagerstone et al 2008) but these require multiple applications and small mammals have not been targeted for their use.

Another industrial chemical being tested is 4 vinylcyclohexene diepoxide. This chemical specifically depletes the pool of primordial and small primary ovarian follicles in mammals, particularly in mice and rats, but does not affect the numbers of preantral and antral follicles. In the ovary, the pool of primordial follicles is finite and nonregenerating; thus, eliminating this follicle type leads to premature ovarian failure (Mayer et al 2002, 2004). Currently, studies of the effects of VCD are being undertaken in the rice-field rat, *Rattus argentiventer* (Hinds, Herawati, Mayer, and Dyer, unpublished results). The challenge remains to achieve rapid depletion of the pool of primordial follicles, and to formulate the chemical in a bait that is both attractive and palatable to rats in the rice-cropping systems of Southeast Asia.

Concluding remarks

For most biologists and agricultural scientists, their consideration of possible scenarios linked to increased frequency of extreme weather events generally focuses on possible losses of biodiversity (flora and fauna, McKechnie and Wolf 2010) or their direct impacts on agricultural production (Battisti and Naylor 2009), particularly the physiological impacts of warming temperatures on crops such as rice (Peng et al 2004). In this chapter, we raise the importance of considering the likely elevation of impacts of rodent pests on agricultural production with increased frequency of extreme weather events. This association may be overlooked in the absence of a good understanding of the population biology of the pest species, particularly when the increase in the rodent population and the subsequent impacts on crop production are likely to be delayed by 9–18 months. We postulate that asynchronous and aseasonal planting of rice in the 12 months after cyclone Nargis were the main driver of the widespread and severe population outbreak in the Ayeyarwaddy Delta. Unfortunately, the data required to test this contention were not collected and, upon follow-up inquiries with regional MAS offices, they do not appear to be available. Focus group discussions and household surveys would be required to facilitate the recall of farming communities of their timing of planting of crops to be able to test whether this explanation is the most parsimonious to explain the rodent outbreaks—spatially and temporally.

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Notes

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Analysis of communication pathways and impacts of the Boo! Boo! Rat! campaign

Rica Joy B. Flor and Grant R. Singleton

To help rice farmers overcome problems of chronic rodent infestation, the Boo! Boo! Rat! campaign was implemented in Zaragosa, Nueva Ecija, Philippines. The campaign promoted ecologically based rodent management (EBRM) as a community-level management approach. Our study was conducted one year after the campaign to evaluate its success in promoting EBRM messages, to provide insights on effective pathways to communicate and diffuse EBRM, and to document its impacts on the community. We conducted focus group discussions with farmers in nine villages within Zaragosa, and a quantitative survey among a random sample of 86 respondents to measure differences in knowledge, attitudes, and practices.

The Boo! Boo! Rat! campaign successfully created awareness of EBRM, especially in the intensive-campaign village. The most effective pathways to reach farmers were personal interaction with those who champion EBRM, high-profile activities including the campaign launch and TV coverage, implementation for at least one cropping season, and constant visibility in the media. Mechanisms in place in the intensive-campaign village also facilitated the practice of EBRM by farmers. There were significant differences in knowledge and attitudes between those who were influenced by the campaign and those who had not heard of it. Moreover, there was a shift away from reliance on pesticides, the use of methods that are harmful to humans and the environment, and no action at all. Where intervention occurred, farmers in the dry season (DS) got higher yields of about 1 ton/ha. Farmers also emphasized that a stronger social cohesion was created because of the EBRM activities introduced in the campaign.

Keywords: campaign, impact, ecologically based rodent management, communication pathways

Encounters with rats are common in Philippine communities and are recorded in folktales or traditional narratives (Manuel 1962). One of the earliest written accounts is from 1521, which told how the crew from expeditions to the Philippines ate rats or biscuits infested with rat urine (Woods 2006). Since the 1950s, the government of the Philippines has implemented many rodent control programs, which included community drives to reduce pest populations (Cuaterno 2008, Palis et al 2008). To boost the research effort, a national Rodent Research Center was established in 1968 (Hoque and Sanchez 2008). However, by the late 1990s, the research funding and effort were minimal. Despite these previous research and extension efforts, rodents still have a significant impact in many rice-growing areas in the Philippines, especially in the Central Luzon Region—the rice bowl of the Philippines. In this region, rice yield losses from rodents are patchy, but, in affected fields, losses often amount to 30–50% (Singleton et al 2008).

In the early 1990s, proactive rodent control based on rodent ecology was one of the recommended actions (Quick 1990). In the late 1990s, ecologically based rodent management (EBRM) as a management paradigm for agricultural landscapes was detailed (Singleton et al 1999) and has since been widely adopted in Southeast Asia. In the Philippines, the Philippine Rice Research Institute (PhilRice) undertook research on the ecology of rodent species prior to field demonstrations of ecologically based rodent management (Duque et al 2008). In 2006, the Irrigated Rice Research Consortium (IRRC) at the International Rice Research Institute (IRRI), PhilRice, and other local government partners piloted the promotion of EBRM as a community-level management approach based on the understanding of when and where it was best to implement management actions (Zagado 2008). EBRM was introduced through a campaign in Zaragosa, Nueva Ecija, a town with 6,209 ha of rice in which severe rodent infestations had been reported (Roque 2006). The campaign was completed in 2007.

This paper will report on the campaign, evaluate its success in promoting the message of EBRM, and provide insights on effective pathways to communicate and diffuse EBRM. The need for a systematic identification of effective components of a campaign to understand its impact on communities is an identified gap in communications literature (Coffman 2003, Potter 2008). Our study will evaluate how strategic communications of a technology can add value in getting technologies adopted (Coffman 2003). Specifically, we aimed to address three research questions: (1) What elements of the campaign influenced its adoption or nonadoption? (2) What facilitating mechanisms and communication avenues were effective in influencing the behavior of smallholder farmers? (3) What were the resulting changes or impacts after the campaign?

The Boo! Boo! Rat! campaign

The campaign in Zaragosa was called Boo! Boo! Rat! *Palay mo'y Ligtas 24 Oras*, which promotes shooing away rats from fields and having a secure crop all the time (Zagado 2008). Zaragosa is located in the flood-prone sector of the Central Luzon plains, northern Philippines (Fig. 1). This area provides a favorable habitat for rats and farmers complain of chronic infestation, resulting in losses of up to 70% of their rice crop (Roque 2006, Zagado 2008). To overcome the problem, farmers, local government officials, the development council of the village, and the provincial agriculturist, who leads extension staff in the area, collaborated with IRRI and PhilRice to introduce EBRM to the community.

In the 2006 wet season, the Boo! Boo! Rat! campaign was started in one village, Sta. Lucia Young. Three main messages were promoted: community action,

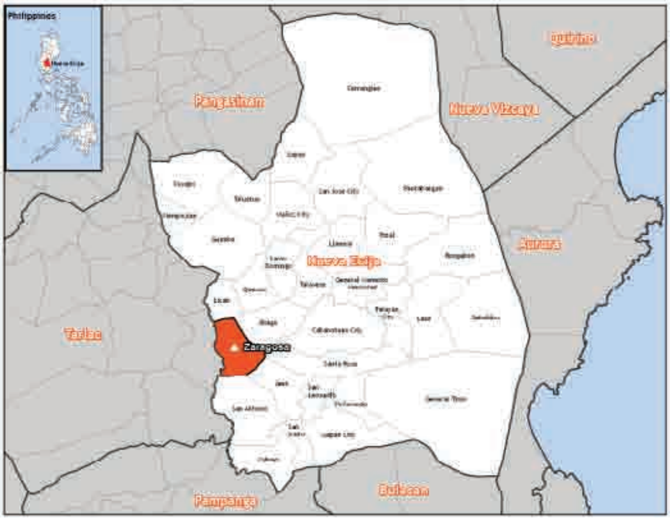

Fig. 1. Map of the Philippines showing Zaragosa, Nueva Ecija. Source: www.philmug.ph/forum/showthread.php?t=48277.

right timing, and integrated rodent control methods. Actions were developed through consultation with the community, and were based on a combination of knowledge provided by scientists on the ecology of rodents and knowledge provided by farmers on cropping systems and community use of the landscape. Following the consultations, the community decided on which rodent management actions it would use and where in the landscape it would focus its effort. The communications activities were a joint decision among the community, the local government, and PhilRice (Zagado 2008). In Sta. Lucia, intensive campaign activities, which included meetings to inform farmers of EBRM, demonstrations of EBRM methods, and establishment of a rat task force, were implemented (Table 1). A communication drive, which included the whole town of Zaragosa, was the main dissemination activity. In other villages, Municipal Agricultural Office technicians conducted meetings with farmers regarding EBRM. To raise more awareness of rats, the campaign concluded with a high-profile Mr. and Ms. STAR contest ("rats" spelled backwards)—a pageant open to elementary-school children. Families could support their preferred contestant by gathering the most rat tails.

The communication drive targeted farmers to change their behavior: from not doing any action to implementing rat management; from doing individual control to adopting community actions; from being reactive to proactively timing their control actions; and from using single methods to using integrated methods of management. The community was targeted through different media avenues, including television (though coverage done by a well-known personality on national TV), radio (through a jingle from a popular song), T-shirts, banners, posters on the back of tricycles (the main mode of public transportation within the towns), leaflets, and billboards. The campaign also tried to reach farmers through their children. So, the campaign targeted

Table 1. Activities of the Boo! Boo! Rat! campaign from May 2006 to August 2007 in Zaragosa Township, Nueva Ecija.

Date	Activity	Place
May 2006	Consultation meetings (experts, farmers, etc.)	Sta. Lucia Young
Jun-Nov 2006 (wet season)	Field school/weekly meetings (CTBS,[a] rat hunting)	Sta. Lucia Young
Aug 2006	Communication drive	Entire Zaragosa
	Meetings with MAO technicians and farmers	
Launch of the media campaign	Some villages	
Oct 2006	Established rat task force	Sta. Lucia Young
Aug 2007	Mr. and Ms. STAR contest	Sta. Lucia Young

[a] CTBS = community trap-barrier system.

school children, giving printed bookmarks and T-shirts to raise awareness about rats. Zagado (2008) provides a detailed account of the campaign.

Theory of change and impact pathways

An important starting point in evaluating the Boo! Boo! Rat! campaign would be an assessment of the theory of change that was assumed in the campaign. According to Coffman (2003), this critical driving force allows the researcher to make connections between activities and what they tried to achieve (outcomes). This form of impact analysis looks at variables though which behavioral change is assumed to occur. Previous studies of communication campaigns in public health have developed theories of change and generalities. These were derived from evidence-based studies as well as subjective opinion and personal ideology (Frumkin 2002). Our study is a combination of such approaches.

Following the models presented in Coffman (2003), we developed a visualization of the campaign theory of the Boo! Boo! Rat! campaign (Fig. 2). Three major activities were mapped. The selection of these particular communication activities was influenced by local needs and ideas of "what the communities would want to know." The activities were geared toward short-term outcomes, which are awareness of the campaign and its messages, change in knowledge and attitudes about rats and rat management, change in attitude toward self-efficacy (belief that the end user has the ability to perform effective rodent control actions), and change in social norms on rodent management. The campaign promoters assumed that these outcomes would then lead to a targeted change in behavior leading to longer-term impacts.

We are interested in learning about which aspects of the strategic communication of EBRM were effective, what are the identifiable outcomes, and is there evidence of impact. We do not, however, seek to obtain conclusions on the causal links between the campaign and the changes that occurred.

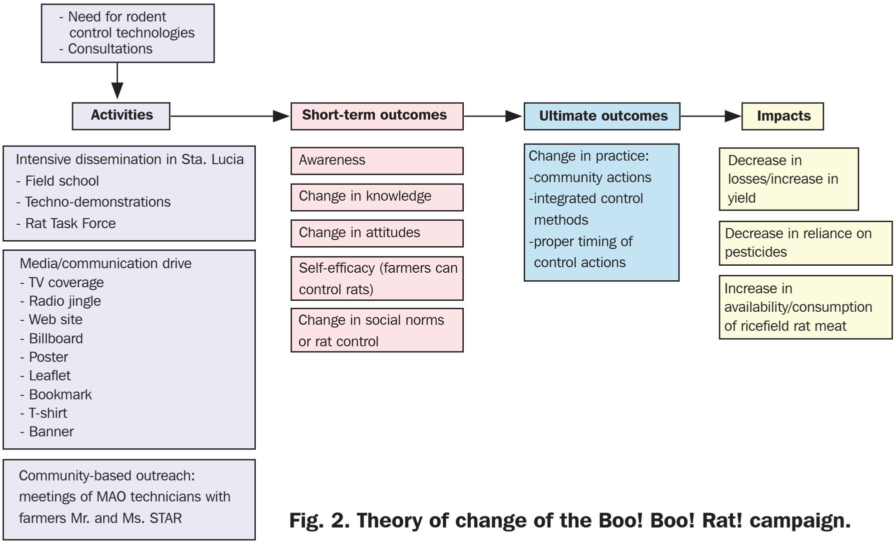

Fig. 2. Theory of change of the Boo! Boo! Rat! campaign.

Methodology of the study

The Boo! Boo! Rat! media campaign in Zaragosa ran for about 1 month in August 2006 and had a catchment area of 19 villages. A final activity was conducted in August 2007 to reinforce the campaign (Table 1). Our study began in August 2008 with qualitative on-the-ground focus group discussions that allowed the communities to express their views, and provided a sense of the adoption status of EBRM in different villages in Zaragosa. A random sample of 8 out of the 19 villages was included in focus group discussions and informal interviews with farmers, village residents, and officials. This follows the idea of Clifford Geertz (1986) that in gaining what is considered significant by others, a "thick description," or expression of the local points of view is imperative. The intensive campaign village, Sta. Lucia Young, was also included, making a total of nine villages.

The theoretical lens of the Stages of Change Theory was adapted in the study to look at changes in behavior. Prochaska et al (1992) hypothesized that behavior change after a campaign goes through five main stages, not necessarily linear. We observed that the villages implemented different activities (Table 2), and were at different stages of change toward adopting EBRM practices. This was our starting point in connecting interventions and the observed changes in the area.

A quantitative survey was conducted in September 2008 in the same nine villages. The sampling for the quantitative part of the study, with 86 respondents, was influenced by the theoretical lens developed from the qualitative interviews (Table 2). Each respondent was asked specific questions designed to detect whether there had been significant differences in their attitudes, knowledge, and practices (KAP) among the villages. The farmers' KAP were obtained *ex post* using Likert Scale questions and analyzed using the Kruskal Wallis test. As suggested by Potter (2008), this mini-

Table 2. A mini-survey characterization of the Boo! Boo! Rat! campaign activities experienced by each village and the "stage of change" of each village in relation to the campaign.

Village	Activity	Stage of change	Respondents (n = 86)
Sta. Lucia Young	Intensive campaign	Maintenance	24
Mayamot	Media and technician visits	Action	10
Sta. Rosario Young	Media only	Preparation	13
Sta. Rosario Old	Media only	Preparation	10
Del Pilar	Media only	Contemplation	5
San Vicente	Media only	Contemplation	6
Concepcion	Media only	Contemplation	8
Carmen	None (possibly media)	Precontemplation	5
H. Romero	None (possibly media)	Precontemplation	5

survey methodology provides a quantified sense of awareness, changes in knowledge, attitudes, or behavior, and effective mechanisms in the campaign. Data on yields of rice crops pre- and postcampaign were also collected but are not presented here.

Influence of Boo! Boo! Rat! campaign on smallholders

Awareness and sources of information

There was awareness of the Boo! Boo! Rat! campaign among 50% of all respondents interviewed. In Sta. Lucia (Y), where intensive campaign activities took place, most farmers (96%) had heard of the campaign, compared with only 32% of the respondents from nonintensive villages (Fig. 3). In nonintensive villages, more farmers had heard of the campaign in the village where there was a media campaign plus technician visits (70%) than in villages where there was media only or no facilitated interventions by local government officials. In these villages, 24% and 30% of the farmers, respectively, had heard of the campaign.

Farmers mostly gained awareness through personal interaction with local officials (42%), extensionists (35%), and PhilRice staff (14%) (Table 3). The banners/streamers that were in the major thoroughfares in town were also an identified source of information (12%). Some materials geared toward reaching more farmers, such as the "bookmark," were not mentioned. These were designed to reach farmers through children, but both "bookmark" and "son/daughter" were not mentioned as sources by the respondents (Table 3).

Campaign activities and materials remembered

Activities that were remembered most by the respondents were those that were implemented in the area over a longer period of time and high-profile activities. The farmer

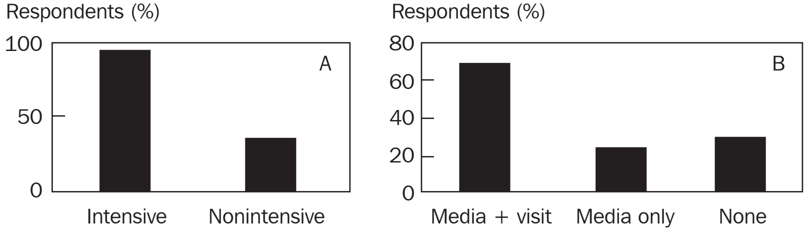

Fig. 3. Proportion of farmers (%) that were aware of the campaign (A) from intensive and nonintensive villages and (B) from different intervention types within nonintensive villages.

Table 3. Sources of information that created awareness among farmers of the Boo! Boo! Rat! campaign.

Source	%	Source	%
TV	2	Local government official	42
Radio	–	Son/daughter	–
T-shirt	–	Relative	–
Sticker	2	Farm neighbor (near)	2
Billboard	–	Farm neighbor (far)	–
Streamer/banner	12	House neighbor (near)	–
Poster	5	House neighbor (far)	–
Leaflet	–	MAO technician/extensionist	35
Bookmark	–	Rat task force	5
Internet	5	Friends	7
PhilRice staff	14	*Huntahan* (talking with others)	2

field school (23%) and the community trap-barrier system (CTBS) demonstration (19%), among the most recalled activities, were carried out for at least one growing season (4 months). Furthermore, the campaign launch (23%) involved many officials, invited many residents of the town, and also brought in guests from outside the town. At least 20% of the villagers participated in the hunting activities led by visiting researchers from PhilRice (16%).

Respondents were also asked to recall communication media used in the campaign (Table 4). Initially, more respondents recalled having seen the banners, stickers, posters, and leaflets than the other media. When participants were shown pictures to aid recall, their highest recall was of stickers and banners (62.8%), billboard (58.1%), and the TV feature (53.5%). Interestingly, the aided recall increased the positive response

Table 4. Communication media recalled by respondents either unaided (no prompts) or aided (shown pictures of activities).

Media recalled	Unaided	%	Aided	%
Jessica Soho TV feature	4	9.3	23	53.5
Campaign jingle	1	2.3	18	41.9
T-shirt	3	7.0	18	41.9
Sticker	7	16.3	27	62.8
Billboard	4	9.3	25	58.1
Banner	12	27.8	27	62.8
Poster	6	14.0	19	44.2
Leaflet	6	14.0	15	34.9
Bookmark	1	2.3	14	32.6
CTBS poster[a]	5	11.6	15	34.9

[a]CTBS = community trap-barrier system.

for banners and stickers with simple messages markedly more than the knowledge-intensive CTBS poster.

Other mechanisms for information dissemination

In group discussions, farmers in Sta. Lucia Young attributed their participation and knowledge gained from the campaign to some mechanisms that facilitated their learning and involvement. These mechanisms were observed to be in place in the intensive-campaign village of Sta. Lucia Young only. There were four mechanisms mentioned in that village. The first was associated with a high level of support provided by local government officials to the activities of the campaign. The village leader (*barangay* captain) herself was very active and involved her team of village councilors in mobilization for campaign activities. Some of the village leaders were also members of the trained rodent task force. The task force was in charge of informing and organizing farmers for many of the activities. A second mechanism that was mentioned was the support of a well-informed technician/extensionist. The municipal technician, who was assigned to the village, worked closely with rodent experts and provided an important source of knowledge for the villagers as the season progressed. A third mechanism was the visits from rodent experts who explained the different management actions as well as the reasons behind the need for such actions. A fourth mechanism was that trained farmers from the field school were present to provide help to other farmers. In the other villages, technicians held regular meetings with farmers. However, with regard to rodent management, the technicians at these villages were mostly contacted by farmers to provide free rodenticides at times of infestation.

Outcomes of the campaign

After the campaign, farmers in the intensive-campaign village of Sta. Lucia Young said they observed changes in attitudes, knowledge, and practices among those who knew what was taught in the campaign. Knowledge of rodent management differed significantly in 2 of the 9 knowledge-related Likert Scale questions based on who had heard and who had not heard of the campaign. This concurs with what some farmers mentioned in the group discussions that "what was taught about rodent management in the campaign was not new." Farmers have some knowledge, especially on the methods to control rodents.

In the intensive-campaign village, farmers had attitudes leaning toward the importance of increasing yields by controlling rats, the importance of working with other farmers, and the need for control from land preparation through to the early tillering stage of the rice crop. These farmers had significantly higher mean rank scores than those from the nonintensive villages (Kruskal Wallis test $P<0.05$). There was no significant effect on the attitudes of the farmers based solely on whether they had heard of the campaign. Therefore, in the nonintensive villages, even if some farmers had heard about the campaign, their attitudes were not significantly different from those who had not heard about it. Farmers in the intensive-campaign village felt they benefited from implementing action for rodent management, and that effective rodent management required working together as a community and implementing control at the right time. These indeed were the main messages of the campaign.

Interestingly, some farmers in the area believe that rat control "must be left to fate," or that they should "just pray rats will not do much damage." Many farmers refuse to kill rats because "it might only anger more rats." Because of these beliefs, some farmers do not act to manage rodents. For most of the questions on rodent management, both the farmers who had heard of the campaign and those who had not shared a similar level of knowledge; but, on the issue of them being able to control rats, thereby increasing their yields, farmers who had heard of the campaign had a significantly higher mean rank score (Kruskal Wallis test $P<0.05$). Thus, the campaign was successful in convincing farmers that rodent management can be accomplished effectively with the caveat that some commonly-held beliefs prevented some farmers from implementing rodent management.

Before the campaign, most farmers used rodenticide (zinc phosphide) because it is provided free by government technicians. Some farmers hunted rats or allowed others to hunt in their field (daytime and nighttime hunting). Few respondents conducted community action, although some hunted together in small groups. Occasionally, a clean-up of the canals, riverside, and other areas would be done by small groups of farmers. Farmers individually maintained hygiene in their own fields. To protect the seedbed, farmers usually put mesh or fish net around the plot. Similarly, farmers said they had observed 1–3 farmers occasionally putting a 220-volt live-wire around the field to electrocute the rats. Farmers also killed rats by putting used motor oil in the flooded rice bays near burrows. Lastly, a few farmers did not take any action at all; they simply left it to fate or prayer. At best, some would talk to the rats to convince them to leave some rice for the farmers.

After the campaign, farmers in the nonintensive villages said they would use rodenticides only as a last resort and did not use them in the 2008 dry season (DS). There was an increase in hunting, maintaining hygiene, and community action, especially in the intensive-campaign village, and a reduction in harmful control methods such as electrocution.

The changes in behavior are difficult to capture one year after the campaign because of the reliance on the recall of the farmers. Although farmers tried the practices introduced, many still say that they retained their practices from the past. Prochaska's transtheoretical model of behavior change explains this as part of the process wherein individuals at the earlier stages of change leading to the action stage (adoption of EBRM for example) are still working through "cognitive, affective, and evaluative processes" (Prochaska et al 2008). After this stage, to maintain the practice of such behavior, they would need "commitments, conditioning, contingencies, environmental controls, and support" (Prochaska et al 2008). Some farmers still depended on their past actions and the outcomes of their actions on-farm to describe their practice. In the intensive-campaign village, the presence of mechanisms that support community actions helped farmers to maintain their newly acquired behavior. In public health campaigns, this social influence effectively changes behavior (Haines 1996).

Impacts of the campaign

After the campaign in 2007, farmers were asked what they found to be the most significant change in their community in relation to rats, rice production, and the community in general. A majority of farmers (60%) felt there was more community participation; people of different ages had become more active in farming activities. The new rodent community actions "encouraged unity and closeness" in the community. People now "know better ways to manage rats" so there are fewer in the fields and rat damage is less. Some farmers highlighted an increase in sales and consumption of rat meat. However, during the group discussions, other farmers said that their households still refuse to eat rat meat. The reduction in rodenticide use was validated by the local government technician who indicated that there were no requests for free rodenticides from the intensive-campaign village in the 2008 DS rice crop.

Farmers identified increased yield as a significant change. In a with-or-without scenario, those who had heard of the campaign had higher mean yield (>10% increase), of approximately 1 t ha^{-1} (Flor and Singleton, unpublished data). There was no significant difference in yield between the treatment groups in the seasons prior to the campaign.

The total area covered by those who were influenced by the campaign was 440.2 ha. The higher rice yields experienced by farmers after intervention provide clear evidence that EBRM was successful where farmers had heard of EBRM and also had guidance from local extension specialists.

Conclusions

The Boo! Boo! Rat! campaign was successful in promoting awareness of EBRM, especially in the village with intensive campaign activities. Personal interaction with extension specialists, scientists, and/or local politicians who champion EBRM is an effective source of knowledge and influence, since many of the respondents recalled that they heard through this avenue. High-profile activities such as the campaign launch, where a large group of people gathered with guests, as well as activities implemented through at least one season (4 months) are most remembered. Similarly, where the communication media were high-profile or constantly seen, the campaign reached farmers and was captured in their memory. The communication activities most recalled by respondents were a television feature hosted by a famous TV personality, and banners that were attached to tricycles plying the public transportation route through the town. Generating media coverage and providing increased visibility of the campaign has also been found to promote campaign success in the public health arena (Spina 2009).

Although EBRM is based on a series of simple actions, the whole package can be knowledge-intensive. Also, it is crucial that farmers implement the whole management package rather than individual components; otherwise, rodent management will be largely ineffective. In some instances, farmers indicated that they were already aware of particular components of EBRM mentioned in the media and then disengaged because they did not think they would learn anything new. Therefore, the clear message to researchers and extension specialists from this anthropomorphic study is that it is not only communicating the knowledge but also providing supporting mechanisms that effectively communicate EBRM. As Prochaska's Stages of Change Theory (1992) supports, after farmers became aware, they may have to go through stages of recognizing it as a problem (contemplation) and then intending to address it (preparation). Evaluation of media campaigns in public health have concluded that multilevel communication programs are needed. It is difficult for any single mass media campaign to achieve cultural change because of the range of social and environmental factors that play a role. Mass media campaign messages have to be reinforced with other mechanisms (Spina 2009).

Mechanisms that helped farmers adopt EBRM at a community level included the support of local government officials, visits of rodent experts, consultations with technicians, establishment of a rodent task force, and the training of key farmers who could act as intermediaries for passing on knowledge on rodent management. This was evident from the comparison of the intensive-campaign village of Sta. Lucia with those villages with less intensive interventions. Our findings concur with the idea of subjective norms that influence a person's intention toward specific behavior (Ajzen and Fishbein 1980). The mechanisms provide the norms or motivating conditions that encourage farmers toward practicing what they have heard (Coffman 2002).

Hearing the campaign messages convinced farmers that rats can be controlled and yields increased. This self-efficacy aspect in controlling rats is important because some farmers would not control rats because of beliefs and perceptions. After the campaign, there was a significant difference in the attitudes of farmers between villages that conducted different levels of facilitated interventions, but not between those who had heard or not heard the campaign message. Therefore, hearing the messages alone provided knowledge but may not be sufficient in changing attitudes. Furthermore, there was a significant difference in mean rank scores between intensive and nonintensive interventions, further highlighting that, to encourage community actions for the control of rodents, communication media must be supported with other mechanisms. Structural or social issues play an important role in a person's ability to enact behavioral change (FHI 2002). These issues become increasingly important, especially with the adoption of EBRM, which requires that communities work together at key times of the crop cycle and in key habitats.

Some changes in practice are documented. There is a shifting away from reliance on pesticides, the use of methods that are harmful to humans and the environment, and no action at all. Farmers in the intensive-campaign village said they still use rodenticides but only when needed. Instead, they do hunting, do community action, and maintain hygiene. After the campaign, no farmers from the campaign village did nothing to control rats.

Apart from increases in rice yield, a significant change identified by respondents was the improved cohesion in the village because of more community action in hunting, synchronizing of farm activities, and improving hygiene levels in the community.

Further studies are needed to examine whether adoption was sustained, to identify other impacts (e.g., gender and cultural impacts), and to quantify how much can be attributed to the campaign.

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Notes

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SECTION 3:

Rodent outbreaks in other regions: a search for generalities

Rodent outbreaks in Europe: dynamics and damage

Jens Jacob and Emil Tkadlec

Rodent outbreaks have been occurring in Europe for thousands of years. More than two millennia ago, Aristotle (384-322 BC) pointed out that small rodents can appear in great numbers and cause complete crop damage overnight (Aristotle 1872). Aelurius (1625) documented a rodent outbreak in 17th century Bohemia: “It has been terrifying when walking across fields/ mice were in troops … and had consumed grass, linseed, green seedlings, and the heads of grain/ …in the same year … many people in the shire starved to death.”

Luckily, modern Europe has no starvation because of crop damage by rodents. However, plant production in agriculture and forestry can suffer substantial losses during rodent outbreaks, putting the existence of individual farming businesses at risk. In addition, structural damage by gnawing and burrowing can occur. The risk of transmission of zoonoses can be increased during periods of high rodent abundance.

The most famous examples of rodent outbreaks in Europe are lemming cycles in northern Fennoscandia that were described by Charles Elton (Elton 1924, 1942). Intense investigation of fluctuations of Fennoscandian rodent species led to great advances in the understanding of rodent population dynamics and shaped the view of northern rodent cycles (Korpimäki et al 2004, 2005, Ims et al 2008). However, typical rodent cycles also occur elsewhere in Europe (Tkadlec and Stenseth 2001, Lambin et al 2006).

In Europe, clear cyclicity seems to phase out from north to south, from high to low altitude, and from continental to marine conditions (Tkadlec and Stenseth 2001, Lambin et al 2006, Ims et al 2008). However, even in areas without clear population cycles, rodent abundance does not persist at low abundance. Irregular fluctuations are documented for a number of arvicoline species that can cause great problems in plant production.

This chapter provides an overview of rodent outbreak dynamics in Europe focusing on the species most relevant for crop damage. Related damage and cost in plant production are presented partially based on local publications not easily accessible internationally. The data demonstrate the economic significance of rodent outbreaks in Europe. We also summarize management approaches for minimizing the impact of small rodents in European agriculture and forestry. Time series of vole dynamics are vital for assessing the mechanisms behind outbreaks. Such data and recent advances in understanding basic principles of rodent outbreaks can also be used to further rodent management. This is especially the case for developing predictive models.

Rodent outbreaks and their regularity

Multiannual fluctuations in population numbers, referred to as population cycles, are particularly pronounced among northern vole populations at latitudes above 60°N. Even there, the dynamic patterns are not uniform, changing from purely seasonal dynamics in southern Fennoscandia to strongly cyclic dynamics in northern Fennoscandia (Hansson and Henttonen 1985). Despite cyclicity, the direct impact of rodents at high latitudes is low because populations occur mostly in natural habitats and the peak numbers are usually low. From an economic perspective, it is the vole outbreaks in temperate regions at latitudes between 40°N and 60°N that cause the heaviest damage to farm crop and forest production. There are four widely distributed irruptive vole species: common vole (*Microtus arvalis*), field vole (*M. agrestis*), bank vole (*Myodes glareolus*), and water vole (*Arvicola* species; the former *Arvicola terrestris* was split into *A. amphibius* and *A. scherman*, Panteleyev 2001).

The herbivorous common vole favors open grasslands and is the major European rodent pest in the most productive lowland areas. The remaining three species harm trees and are pests in forest nurseries and orchards. All four species show evidence for cyclic variation in numbers at least for some populations.

The common vole, one of the smallest voles, has two exceptional features that seem to provide the basis for explosive dynamics: (1) females mature extremely early in life and can mate at 2 weeks of age (Tkadlec and Zejda 1995); (2) being highly social, they form large groups of related individuals (colonies) inhabiting underground burrows (Frank 1957). As a result, peak populations regularly attain densities much above 1,000 individuals (ind) ha^{-1}, which is one order of magnitude higher than in other voles. The maximum Jolly-Seber estimate of population density that was corrected for the edge effect by the method of Wilson and Anderson (1985) is 2,233 ind ha^{-1} (Bryja et al 2005). High amplitude and a prevailing cycle period of 3 years have long been documented in agricultural areas from the west to the east of Europe (Fig. 1) (Elton 1942, Frank 1957, Tkadlec and Stenseth 2001, Lambin et al 2006). In contrast with the pattern of north European voles that predominantly belong to first-order feedback (direct density dependence), populations in eastern and western Europe can be governed by first- or second-order feedback (delayed density dependence) (Tkadlec and Stenseth 2001, Turchin 2003, Lambin et al 2006). In particular, the tendency to cycle varies geographically, from more stable northern coastal populations to more variable and cyclic populations in the interior of Europe (Delattre et al 1992, Tkadlec and Stenseth 2001). This gradient is a reversal of that in Fennoscandia. Because the fluctuations are accompanied by the same suite of demographic features (e.g., summer decline, the density-dependent variation in body mass known as the Chitty effect), it is argued that there is little qualitative difference between the dynamics of central and northern European populations (Lambin et al 2006, Inchausti et al 2009).

The field vole occupies western and northern Europe and is the main *Microtus* vole in Great Britain. Since Elton's (1924) paper, systematic research on its biology and demography has developed quickly in the laboratory (e.g., Ranson 1934) and field (Elton 1935, Chitty 1952, Myllymäki 1977). By presenting evidence for second-order

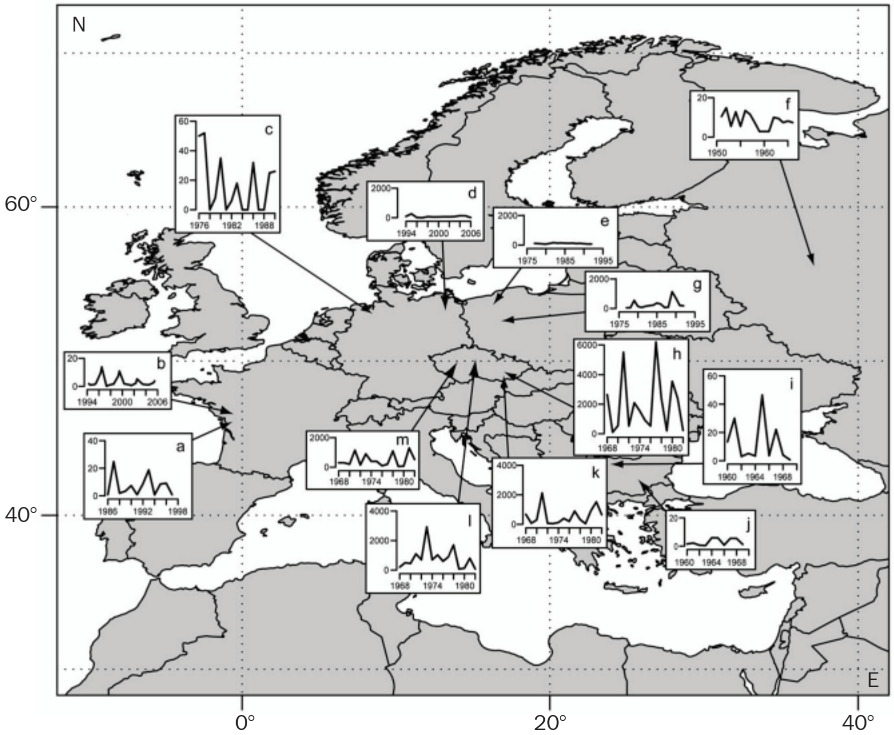

Fig. 1. The temporal dynamic patterns observed in populations of the common vole (*Microtus arvalis*) across Europe: (a) Rochefort, France; (b) Deux-Sèvres, France; (c) Weser-Ems region, Germany; (d) Mecklenburg-West Pomerania, Germany; (e) Koszalin, Poland; (f) Tula region, Russia; (g) Poznan, Poland; (h) Brno, Czech Republic; (i) Knezha, Bulgaria; (j) Chirpan, Bulgaria; (k) Břeclav, Czech Republic; (l) Kutná Hora, Czech Republic; (m) Příbram, Czech Republic. Population dynamics in a–c, f, i, and j are based on percentage trapping index. Population size in d, e, g, h, and k–m was measured as the number of reopened burrow entrances per hectare. Data compiled and redrawn from (a) Salamolard et al (2000); (b) Lambin et al (2006); (c) Lauenstein (1990); (d) personal communication, Nagel 2009; (e, g, h, k, l, m) Tkadlec and Stenseth (2001); (i, j) Straka and Gerasimov (1971); (f) GPDD (1999).

feedback, the cyclic nature of its outbreaks has been demonstrated for Finnish, Swedish, and British populations, mainly with 3–4 year periods (Turchin 1993, Hörnfeldt 1994, Lambin et al 2000). Evidence for chaotic dynamics was found for northernmost populations in Fennoscandia (Turchin 1993). Peak densities usually vary between 100 and 400 ind ha^{-1} (Myllymäki 1977, Jędrezejewski and Jędrezejewska 1996, Lambin et al 2000). Recent time-series analyses indicate a weakening of the cyclic dynamic pattern in Sweden and Britain, possibly due to climate changes resulting in a less seasonal environment with shorter winters and temperatures often fluctuating around 0 °C (Hörnfeldt 2004, Bierman et al 2006).

Demography and patterns of variation in bank vole populations have been studied intensively across Europe (e.g., Koshkina 1957, Zejda 1967, Bergstedt 1965, Bujalska 1970). Later time-series analyses indicate clearly that northern populations exhibit cyclic dynamics regulated by second-order feedback, with regular peaks at 3–5-year intervals (Hansson and Henttonen 1985, Turchin 1993, Bjørnstad et al 1995). Peak densities rarely exceed 100 ind ha^{-1} (but can rise up to 600 ind ha^{-1} on lake islands, Bujalska 1995). In a temperate region, the pattern can vary from purely seasonal dynamics (e.g., Poland and central Russia) to multiannual cyclic dynamics, driven to a large extent by exogenous factors such as mast seeding (Pucek et al 1993, Hansson et al 2000, Stenseth et al 2002).

Most European semi-aquatic populations of the genus *Arvicola* are fairly stable in time, with mean densities ranging spatially from 0 to 100 ind ha^{-1}. This is not the case with the smaller fossorial form *A. scherman* that inhabits dry grasslands and meadows in mountain farmland (Saucy 1994, Morilhat et al 2007). This species irrupts regularly at intervals of 5–7 years in eastern/central France and western Switzerland (Saucy 1994). Peak densities can exceed 200 ind ha^{-1} (e.g., Wieland 1973) but, in the Swiss Alps, they reach 2,000 ind ha^{-1} (Saucy 2001). In the European part of Russia, *A. amphibius* outbreaks are also known from the floodplain areas along large rivers, such as the Volga (Panteleyev 2001). However, the dynamic patterns have not yet been studied quantitatively.

Several mechanistic hypotheses have been proposed to explain population cycles in European voles. The causal factors involve genetics (e.g., Chitty 1967), maternity (Inchausti and Ginzburg 1998), population structure (Zejda 1967) interacting with seasonality (Tkadlec and Zejda 1998), dispersal (Gliwicz 1990), stress (Frank 1957), predators (Erlinge et al 1983), food (Kalela 1962, Jędrezejewski and Jędrezejewska 1996, Massey et al 2008), disease (Smith et al 2008), and landscape (Delattre et al 1992). Even though the predation hypothesis has become popular among many scientists, especially for Fennoscandian cycles, no general acceptance has been achieved (Lambin et al 2006). At least three circumstances now prevent us from settling on one universal biological explanation of population cycles: (1) we do not know whether the studied population systems at high and low latitudes in Europe belong causally to the same class; (2) the strength of any specific factor will often be dependent on other factors and we do not have enough evidence on these contingencies; and (3) we do not fully understand the interactions between density dependence and exogenous noise, and both can be considered equally important for the generation of the observed dynamics.

Plant damage during rodent outbreaks

Primary damage by rodents during outbreaks is inflicted directly, resulting in crop loss or decreased crop quality. In addition, several types of secondary damage/cost can occur, including an early return of livestock from pastures to stables; purchase of substitute fodder; weeds establish in stretches of bare soil and need to be managed; soil contaminates cut grass, leading to reduced silage quality and consequently a decrease in milk production; cost for plowing of degraded soil and loss of subsidies for "no-plow areas;" costs for new seed and replanting; infection with viral, bacterial, and fungal disease when plants are wounded; damage to cables and machinery; undermined roads and road edges; and rodent management cost. Moreover, zoonoses can be transmitted from rodent hosts to livestock, companion animals, and humans. The economic consequences of rodent-borne diseases are not well understood but there are clear negative effects from the individual scale to national economics (Bonnefoy et al 2008).

Despite the large amount of published information about the biology and ecology of small rodents in Europe (since 1950, about 2,000 articles published on cyclicity in the four species considered here), surprisingly few quantitative data are available on damage caused during outbreaks in agriculture and forestry. Since 1950, 504 articles are listed by ISI Web of Knowledge with the topic rodent damage by *Microtus arvalis*, *M. agrestis*, *Myodes glareolus*, and *Arvicola* sp. (search conducted on 12 October 2009; search terms: species name and damage). After a considerable increase in publications in the 1970s, the publication number has increased only slightly (Fig. 2). This is especially true for the two *Microtus* species despite being the most common mammals in Europe.

Rodent damage in forestry

The four rodent species considered here and a suite of other small rodents cause damage to forest trees in many parts of Europe (Bäumler 1990, Borowski 2007, Christiansen 1981, Gill 1992, Rooney and Hayden 2002). All species damage bark and stems;

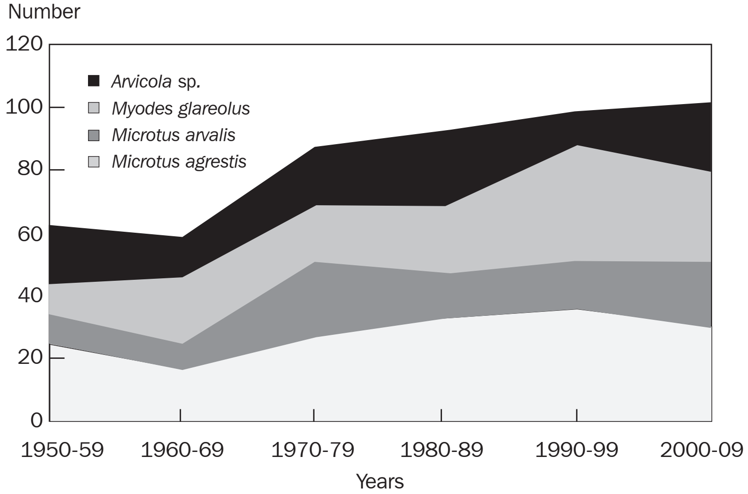

Fig. 2. Number of scientific articles relating to damage by *Microtus arvalis*, *M. agrestis*, *Myodes glareolus*, and *Arvicola* sp. published per decade in journals listed by ISI Web of Knowledge.

especially *Apodemus* sp. causes damage to roots. Damage is highly variable in space and time. In all species, damage affects more deciduous trees than coniferous trees (Commarmot 1981, Gill 1992, Hytönen and Jylha 2005). Seeds, shoots, and young trees are more at risk than trees of 5–8 years of age and older (Hansson and Zejda 1977, Ward 1993, Pigott 1985). Reforestation on land that was previously used for farming is especially prone to damage (Henttonen et al 1995, Kolb and Weisshaar 2005, Suchomel 2008). Well-developed undergrowth provides abundant shelter for rodents and increases the risk of damage to trees by field voles (Heroldova et al 2007, Hytönen and Jylha 2005), common voles (Kolb and Weisshaar 2005), and bank voles (Suchomel 2008, Davies and Pepper 1993, Ward 1993). Similarly, grasses growing in gaps caused by forest deterioration can enhance rodent damage (Borowski 2007). Rodent damage is higher in plantations versus natural re-growth (Baxter and Hansson 2001, Heroldova et al 2007, Saniga 2003) and more pronounced when little alternative food such as blueberry is available (Heroldova et al 2008). Landscape structure seems to be related to bark damage by common voles while habitat structure affects the extent of bark damage by bank voles, possibly involving snow conditions (Hansson 2002). This is in line with the finding that landscape structure matters for common vole abundance (Delattre et al 2009, Morilhat et al 2007). In addition, shading can increase damage risk (Hytönen and Jylha 2005) and native species are usually more severely damaged than exotic tree species or native species that suffer from altered environmental conditions (Baxter and Hansson 2001). Interestingly, plant genotype may also matter as some hybrids are less likely to be damaged by rodents than others (Baxter and Hansson 2001, Hallgren and Hjalten 2004).

Damage is often minor on a national scale but can be considerable locally (Baxter and Hansson 2001, Borowski 2007, Gill 1992) (Table 1). The relation between vole abundance and damage is sometimes obvious (Borowski 2007, Heroldova 2002, Davies and Pepper 1993). However, in many cases, the occurrence of damage is determined by food availability in winter, snow cover, and possibly the presence of trace elements such as iron in tree bark (Borowski 2007), which are largely independent of vole density.

Rodent damage in agriculture

Grasslands, clover, alfalfa, winter cereals, and rape are the crops most endangered by vole damage in European agriculture. In addition, significant damage can be inflicted to sugar beets and vegetables during outbreaks. In agriculture, damage by common voles to field crops is documented best. Damage is highly variable and highly correlated to rodent density. During the outbreak in 2007, vole infestation was recorded on more than 3 million ha in central Spain, which required management action on 1.3 million ha and along 179,000 km of field margins (personal communication, C. Caminero Saldaña, ITACyL, Castilla y León Government). Similarly, rodenticides were used in Germany on about 280,000 ha in that year and about 320,000 ha were treated during the previous vole outbreak in 2005 (Barten 2009).

In outbreak years, up to 80% of alfalfa primary production is consumed by common voles in Poland (Babinska-Werka 1979, Truszkowski 1982). On average,

Table 1. Examples for the extent of damage caused by small rodents in forestry.

Species	Country	Type of damage	Extent	
Multiple rodent species	UK	Seedling survival	15–40%	Max[1]
	Germany	Young trees[a]	9%	Mean[2]
	UK		40–100%*	Max[3]
	Poland	Countrywide	4%	Mean of districts[4]
	France	Several tree species	6–58%	[5]
	Czech Republic		2–20%	Range[6]
Bank vole	France	Seeds	5–10%	[7]
	Slovakia	Shoots	15–50%	Max[7]
	Czech Republic	Larch trees	47–72%	1 year[7]
	Czech Republic		2–14%	Mean of 8 years[7]
	Czech Republic	Oak seedlings	40%	Max[8]
Common vole	Germany	Oak	19%	Max of 9 years[9]
	Germany	Beech damage/loss	50–73%	Max of 9 years[9]
	Germany	Cherry damage	47%	Max of 9 years[9]
Field vole	Poland	Beech, fir	2–28%	[6]
	Germany	Beech	93%	1 year at outbreak[10]
	England	Several species	0–100%	[10]
	Switzerland	Several species	3–15%	Mean[11]
	Germany	Several species	10–90%	1 year of high abundance[12]
Water vole	Finland	Root damage	0–>50%	Range of 8-year study[13]
	Switzerland	Apple trees	10%	Mean of 3 years[14]
	Switzerland	Grassland	50%	1 year at outbreak[14]

[a]Damage after rodenticide treatment. [1]Rooney and Hayden (2002); [2]Bäumler (1990); [3]Gill (1992); [4]Borowski (2007); [5]Baubet et al. (2005); [6]Heroldova et al (2008); [7]Hansson and Zejda (1977), [8]Suchomel (2006); [9]Niemeyer and Haase (2003); [10]Niemeyer et al (1997); [11]Commarmot (1981); [12]Frank (1952); [13]Teivainen et al (1981); [14]Meylan (1974).

1.6–45.8% of alfalfa is consumed by common voles depending on the phase of the cycle. Combined with damage to other crops, about 0.2–6.4% of primary production is eaten by voles, which translates to a financial loss of 3.5% (range 0.5–16%) of farmers' income (Truszkowski 1982). Grassland can be completely destroyed (Richter 1985). In winter wheat, common vole damage begins to develop in winter by eating the green parts and continues in the growing season until the ripening stage, destroying the stand just before harvest. In 1997, the yield in many wheat fields of the Znojmo area (Czech Republic) was halved and in some fields 100% loss occurred (observation by E.T.). Field vole damage can be important, especially in Northern Europe, where 25–30% damage to stored hay can occur (Myllymäki 1977).

Losses experienced during outbreaks are hardly acceptable by farmers, especially given the multitude of associated problems that cause additional cost (purchase of substitute fodder, reseeding, weeding, plowing of degraded soil).

Financial consequences of rodent outbreaks

Most estimates of financial losses in plant production due to rodents suffer from difficulties in assessing damage and losses in a field across crops and years and separately for the relevant species. In the 1970s, a comprehensive overview of damage data was published by EPPO (Mathys 1977) based on surveys and field estimates of damage and losses. At the time, it was evident that information was available for only a few European countries about the rodent impact on crops during outbreaks in financial terms. These data suggest that, in the early 1970s, damage by field voles in Fennoscandian horticulture was about 2.93[1] million € per year, in forestry 1.1 million € per year, and in agriculture 0.4 million € per year (Mathys 1977, Myllymäki 1977). Myllymäki (1977) estimated that field voles in Europe caused economic damage of 60–119 million € from 1945 to 1977. Field vole damage to German forestry was about 5.42 million € per year (BBA 1978, Frank 1952). Damage by bank voles seemed to be lower; quantitative examples are 0.13 million € per year in Slovakian forestry in one year and 0.45 million € per year in hay production in northern Swedish agriculture (review in Hansson and Zejda 1977). Damage by water voles in German forestry and horticulture is estimated to be substantial. In reforestation, 1.41 million € per year can be lost because of water voles (Schneider 2000). A recent survey was conducted by Walther et al (2008) covering 698 ha of fruit-growing area, which represents about 13% of Germany's organic fruit cultivation. According to 75 questionnaires analyzed in the survey, damage to fruit trees (mainly apple) averages several million € per year in Germany (Walther et al 2008). Because of many uncertainties in these estimates, there is a wide range of impact assessments (3.6 to >35 million € per year). Similarly, common voles can inflict damage to apple trees of about 25 million € per year during outbreaks (Heise and Stubbe 1987). Based on production figures and the size of the vole-infested area during a common vole outbreak in Germany in 2007, about 8.5% of the wheat production area was affected by vole damage. A crop loss of 11% in this area resulted in a deficit of about 130 million € (Barten 2009). Including financial losses in other crops (grassland, fruit growing) leads to forfeited turnover of circa 700 million € in 2007 (Barten 2009, Lauenstein 2008). In the same year, a dramatic rodent outbreak caused the highest losses to cereal, potatoes, and vineyards for 10 years in Central Spain (JCYL 2008). The management cost alone was estimated at 15 million € and compensation paid by the local government to farmers was 9 million € (personal communication, C. Caminero Saldaña, ITACyL, Castilla y León Government). Recurrent and widespread damage by common voles makes this species the most serious vertebrate pest in European plant production.

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[1] National currencies converted to German marks using the interbank exchange rate of 1 January of the year of publication and the result divided by 1.98 to yield euros.

Management options during rodent outbreaks

The main management method to control rodents in agriculture and forestry is the application of rodenticides. Both acute poisons (e.g., zinc phosphide) and anticoagulants (e.g., chlorophacinone, bromadiolone) are used in Europe because they are generally effective and can be easily applied on a large scale. However, rodenticides can be a risk for nontarget species when used on a large scale during rodent outbreaks (Olea et al 2009). What active rodenticide chemicals ("actives") and formulated products are registered and what restrictions apply differs between countries. In some countries, including Germany, surface application of rodenticides in agriculture is prohibited. Instead, products have to be inserted into burrow entrances to limit access for nontarget species. This dramatically increases the management cost. In other countries, including the Czech Republic, rodenticide pellets are broadcast on the surface but the density of pellets per square meter is strictly limited. Most farmers recognize the risk associated with improper use of rodenticides and act accordingly. Failure to comply with these regulations will inflict hefty fines (up to 50,000 € in Germany). Rodenticide resistance can be a problem in managing commensal rodents in Europe (Pelz 2007) but there have been no reports on rodenticide resistance in arvicoline species. There is a general trend within the European Union to minimize the use of rodenticides. This is greatly enhanced by the lack of new "actives" and a decline of "actives" registered for use in plant protection. Therefore, farmers increasingly need to rely on alternative methods. A variety of other control methods are available for managing arvicoline rodents during and between outbreaks (Table 2). Farmers especially apply habitat manipulation (short vegetation along field margins, tillage), support of predatory birds by providing roosts and nest boxes, and fencing off particularly valuable crops (orchards).

In forestry, habitat management including clearing of undergrowth, mixed stands, and natural reforestation instead of monoculture seems to be appropriate to minimize rodent damage. Collaring seedlings and young trees with plastic tubes or wire mesh as well as the application of repellents can prevent damage. In addition, certain hybrids can be selected that are less vulnerable to rodent damage. Finally, biocontrol through encouraging predators might be an option although quantitative data on the effects in European forestry are largely lacking. Elevated predation pressure can also lead to an increase in rodent damage (Pusenius and Ostfeld 2000, further references in Table 2).

In agriculture, clearing of crop margins reduces the availability of shelter and food for pest rodent populations. The same is true for grazing, although grazing intensity doesn't seem to matter for vole abundance at low stocking rates of 3–5 cattle ha^{-1} (Lauenstein 1984). Food competition between cattle and voles may affect vole abundance at higher stocking rates depending on fertilizing regimes. Intense farming practices such as plowing and harrowing can reduce the abundance and re-colonization by immigrants substantially. The same is true for flooding but this technique can be used only in certain areas such as floodplains where drainage systems are managed by farmers. In small cropped areas of <1 ha, fencing is an economically viable option. As in forestry, there are no quantitative data on the effect of increased predation (e.g., through artificial nest boxes or perches). Rodent repellents are rarely used in

Table 2. Management methods and potential methods derived from ecological studies for regulating arvicoline rodents. F = forestry; A = agriculture.

Method	System	Effect	Reference
Tree diversity	F	– abundance	Niemeyer and Haase (2003), Borowski (2007)
Grazing	A/F	– abundance	Flowerdew and Ellwood (2001), Evans et al (2006)
Biocontrol predation	F	+ damage	Pusenius and Ostfeld (2000)
Biocontrol predation	A/F	?	Rooney and Hayden (2002), Caroulle and Baubet (2005)
Habitat management	A/F	– abundance	Pusenius and Ostfeld (2000), Rooney and Hayden (2002), Jacob and Hempel (2003), Jacob (2003a, 2008)
Collars	F	– damage	Davies and Pepper (1993), Rooney and Hayden (2002)
Mowing, plowing	A	– abundance	Davies and Pepper (1993), Jacob and Halle (1999)
Rodenticide	A/F	– abundance/ damage	Zajak (1983), Morilhat et al (2007)
Repellent	F	– damage	Baxter and Hansson (2001)
Flooding	A	– abundance	Jacob (2003b)
Fencing	A	– abundance/ damage	Walther and Buchleither (2007)
Plant hybrids	F	+/– damage	Hallgren and Hjalten (2004)
Silica content	A	Effect on cyclicity	Massey et al (2008)

agriculture. As silica content seems to affect the population dynamics of voles, plant hybrids with high silica content may suffer reduced damage (further references in Table 2).

A range of potential management options can be derived from ecological studies (Table 2) but, apart from collaring tree stems, the use of rodenticides and repellents, and fencing, none of them have been tested for their economic effectiveness. Some combinations are not desirable (e.g., application of rodenticides and attracting predators for biocontrol). Other methods such as habitat management may have unwanted impacts on nontargets. In any case, it would be beneficial to have robust quantitative estimates of the benefits and costs of management options to include them singly or in combination into integrated management efforts. In agriculture and forestry, it is a major problem that rodent damage is difficult to predict temporally and spatially. Only a few attempts were made to develop predictive models for European voles (Saulich et al 1974, Myllymäki et al 1985, Spitz 1985, Sellmann 1991). A new approach based on weather parameters is promising (Jacob et al 2010). Predictions could be greatly simplified if based on weather parameters similar to forecasts of plant disease and arthropod pests. Neither farmers nor officials seem to be willing to monitor vole abundance, especially when economic and political pressure subsides a few years after an outbreak. If suitable forecasts were available, the timely use of management techniques, including targeted rodenticide application in refuges, might prevent extremely high rodent abundance and associated crop damage.

Conclusions

Rodent species cause damage in European forestry and agriculture during outbreaks, which is economically considerable at the national level. The progress made during the last decades regarding population dynamics of arvicoline rodents in Europe exceeds by far the advances regarding robust estimates of outbreak-related damage—let alone cost—in agriculture and forestry. The same is true for the development of systemwide management approaches that are ecologically benign. The damage-density relation is unknown in most cases. This shortfall is problematic for the development of benefit-cost evaluations of management techniques, which are vital for assessing economic efficiency and for convincing farmers to use certain management approaches.

The adverse effects in agriculture and forestry need to be monitored long-term similar to temporal changes in population dynamics. Data on population dynamics are available and have been used for the study of irruptive vole species. Similar to dynamics, the occurrence and extent of damage caused during outbreaks need to be better understood, but damage data are not available at sufficiently large spatial and temporal scales.

Especially the development of robust predictive models could benefit from using time series of vole abundance and damage caused by the relevant vole species. Forecast models, similar to the models developed in other parts of the world (Leirs et al 1996), would be a great advantage for the timely and targeted application of pest rodent management. Developing predictive models and optimizing management approaches will require close integration of the results of basic research with efforts to improve vole management to mitigate rodent damage during outbreaks. This would be highly beneficial as farmers and foresters alike require support in their efforts to manage the considerable effects of rodent outbreaks in Europe.

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Notes

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Rodent outbreaks in Australia: mouse plagues in cereal crops

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Mouse plagues have been a feature in cereal cropping areas in southeastern Australia for more than 100 years. Mouse plagues occur in response to a series of environmental conditions such that the population abundance increases from <1 mouse ha^{-1} to >1,000 mice ha^{-1} over a period of 12–18 months. Mouse plagues develop in response to factors such as weather, rainfall, food supply, predation, disease, and social structure. In general, each factor alone is not sufficient to generate or trigger a mouse plague, but each is necessary. High densities of mice can cause significant damage to crops, but they also have other impacts on rural communities. Research work has focused on understanding the mechanisms that lead to population increases and developing predictive models. These models can achieve 70% accuracy. A range of control options are available to farmers to manage high mouse population densities, which can be successfully implemented if farmers have some warning that high mouse population numbers are expected.

A mouse plague occurs somewhere in Australia once every four years, but on average it is likely to be one year in seven for any particular region (Singleton 1989, Redhead and Singleton 1988, Mutze 1991, Singleton et al 2005). These plagues of house mice, *Mus domesticus*, are a significant problem to agricultural areas of Australia. It has been conservatively estimated from a survey of grain-growers in Victoria and South Australia that the 1993 mouse plague cost AU$64.5 million (Caughley et al 1994). Within the wheat belt of southern and eastern Australia, a number of regions are defined by different soil types, cropping systems, and climate. Yet, each is subject to mouse plagues (Fig. 1). On the Darling Downs in southern Queensland, for example, winter and summer crops are grown on a continuous basis on self-mulching dark clay soils, whereas, on the light sandy loam soils of the Victorian Mallee, winter cereals are grown in the same paddock only once every 2–3 years. The mechanisms of plague formation in these regions differ markedly (see Singleton 1989, Cantrill 1992, Pech et al 1999). Curiously, widespread mouse plagues do not occur in Western Australia, although localized outbreaks occur (Plomley 1972, Chapman 1981). In 2003, high densities of mice were recorded for the first time in Tasmania, where they caused some damage to winter cereal crops and farmers used rodenticides to limit damage (M. Statham, personal communication).

It is generally believed that house mice were introduced to Australia with European settlers (Singleton and Redhead 1990, Redhead et al 1991). There have likely been numerous introductions to different localities around Australia and to some of

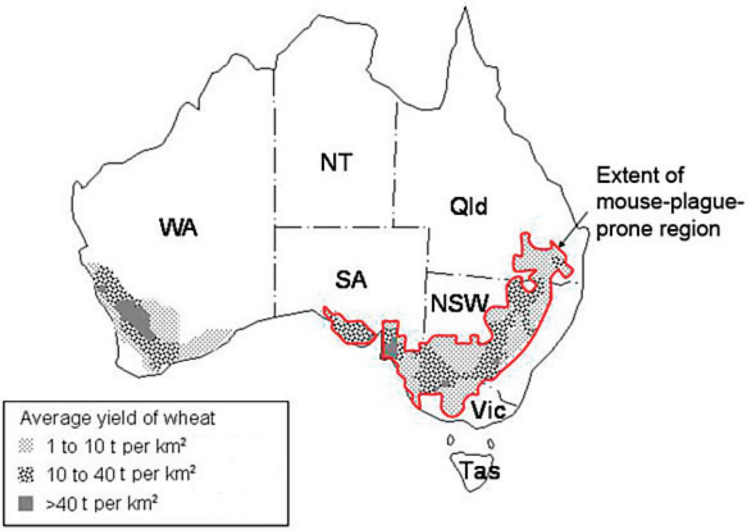

Fig. 1. Distribution of the major cereal production areas in Australia and extent of the region subject to periodic mouse plagues (enclosed by the solid line). Different levels of shading represent average yield of cereal crops (after Australian Bureau of Statistics 2003).

the offshore islands. Recent introductions of house mouse onto Thevenard Island, off the Western Australian coast, in the late 1980s have been well documented cases (Moro 2001). The house mice present in Australia would most likely have come from England, the Netherlands, or France and would therefore probably be *Mus domesticus* (= *Mus musculus domesticus*) rather than *Mus musculus musculus* (which occurs further west in Europe) (Sage et al 1993, Payseur and Nachman 2005). Domestic and feral populations of house mice have done extraordinarily well in Australia by inhabiting almost all available ecological niches. They have done particularly well in highly modified agricultural landscapes, where native rodents have faired poorly (Redhead et al 1991). There have been reports of population outbreaks in some native rodent species; however, these mostly occur after favorable climatic conditions in the arid interior of Australia (Newsome and Corbett 1975, Masters 1993, Predavec and Dickman 1994, Dickman 1999). Feral house mice have exploited the highly modified agricultural environments to occasionally reach high densities and to cause significant crop damage and losses. In Australia, mice have had the advantage of not having specific predators (although a broad range of predatory birds, mammals, and reptiles feed on mice), no small mammal competitors in the crop ecosystems, and they do not have the full suite of diseases that their forebears have back in Europe (Singleton and Redhead 1990, Tattersall et al 1994, Singleton et al 2005).

Densities of mice in nonplague years are normally <50 mice ha^{-1}, sometimes as low as <1 mouse ha^{-1}, but, at peak densities during mouse plagues, densities can exceed 1,000 mice ha^{-1} (Singleton et al 2001, 2005), a 200-fold change in density (see Korpimäki et al 2004 for discussion). The maximum density that has been estimated in crops was 2,716 mice ha^{-1} (Saunders and Robards 1983). Densities of mice can also be exceptionally high around intensive animal husbandry facilities such as piggeries during mouse plagues (Singleton et al 2007).

In southern Australia, the interval from a plague "trigger" to peak population densities is 12–18 months (Singleton 1989). However, at a macro-geographic scale, variation is high in the synchrony of outbreaks or plagues of mice in Australia. In some years, plagues occur from South Australia, through the grain belt of southern and eastern Australia, up to the Darling Downs in Queensland (a range of 1,500 km), whereas, in other years, they occur in smaller, localized areas (<50 km).

The purpose of this chapter is to review what is known of mouse plagues in Australia, what impact they have, why they develop, and what can be done to try to manage them.

The impact of mouse outbreaks on agricultural production

The crop that suffers the most from mouse plagues in Australia is wheat (Redhead and Singleton 1988, Brown and Singleton 2002). It is the main winter cereal crop grown in southern and eastern Australia, accounting for 70% of the grain export market, and it was worth US$4.2 billion in 2008-09 (www.abareconomics.com/interactive/AusWheat/ and www.abareconomics.com/interactive/08ac_march/excel/table_25a.xls, accessed 22 July 2010) (Fig. 1). Other crops that have experienced high losses during a mouse population eruption are barley, sorghum, maize, and soybeans. Pig and poultry production can also be affected severely. Caughley et al (1994) provide the most systematic assessment of the impact of a mouse plague in southern Australia.

Mice generally construct burrows in the undisturbed habitats adjacent to crops, such as along fence lines. When conditions are favorable, mice move into crops and build burrows once cover is sufficient (Singleton and Redhead 1990, Krebs et al 1995, Chambers et al 1996, 2000, Ylönen et al 2002).

Mice cause damage to crops by consuming grain and plant material. They damage crops by digging out newly planted seeds or germinating seeds (Mutze 1998, Brown et al 2003). Mouse populations generally peak in abundance at the time of sowing of winter cereals in southeastern Australia, and, during mouse plagues, farmers often have to re-sow their crops because mice have dug up the seed (Mutze 1998, Brown and Singleton 2002). Significant damage can occur at later stages of crop growth, particularly after mice begin breeding in early spring (Singleton et al 2001) and their numbers increase.

The ontogeny of house mouse outbreaks

House mouse outbreaks in Australia have been the subject of several detailed field studies and experiments that have attempted to describe and interpret the sequences of events that lead to an outbreak (Brown and Singleton 1999, Singleton et al 2005).

Figure 2 illustrates the factors that are potential causes of demographic release in house mice. We will summarize here the role each of these factors plays in generating an outbreak.

Weather

The earliest papers on outbreaks showed that drought-breaking rains were often a trigger for a mouse outbreak, but Brown and Singleton (1999) showed that there were two population states, such that in some years house mice responded rapidly to rainfall but in other years no response occurred. Good winter rainfall may thus be necessary for an outbreak to occur but it is not sufficient. By contrast, droughts are sufficient to prevent an outbreak.

Food supply

Rainfall is a surrogate for food supply in mice, and without question food is essential for mouse reproduction and survival. The puzzle, however, is that a feeding experiment on low-density populations of mice did not trigger an outbreak (Jacob et al 2007, Ylönen et al 2003). A similar experiment adding water to a summer mouse population produced no population gain (Brown et al 2008). Again, we conclude that high-quality food is necessary for an outbreak but not sufficient.

Predation

Predators can limit mouse numbers when densities are very low and when predators can aggregate in high numbers (Sinclair et al 1990) but they cannot make any headway on rapidly growing populations because the rate of increase of mice is so high (Brown and Singleton 1999). However, the risk of predation can affect body growth

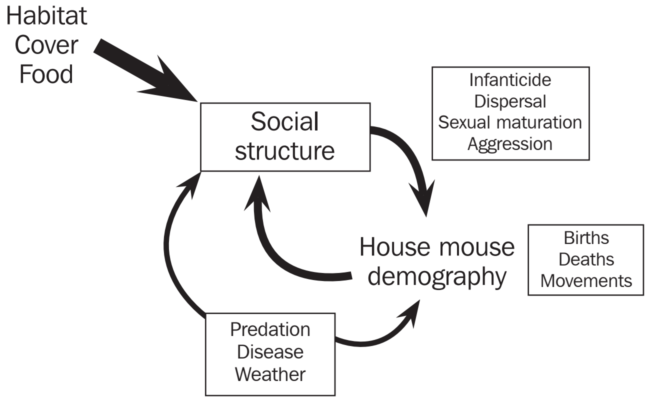

Fig. 2. Factors potentially affecting the rate of increase of house mice in south-eastern Australia. The thicker the line, the larger the likely effect of the factors (after Singleton et al 2007).

rates of mice (Arthur et al 2004), and hence their maturation. Therefore, the direct and indirect effects of predation need to be investigated at the stage of low mouse numbers, when it is most difficult to carry out such a study. Thus, predation remains an untested possibility for the phase of low density.

Disease

Although diseases can be found in high-density house mouse populations, they appear to result from high contact rates and thus are an outcome of high density (Singleton et al 1993). Diseases, such as mouse parvovirus, can be inferred to be significant in precipitating the decline phase of an outbreak when densities are dropping too rapidly to suspect any other cause (Singleton et al 2000). As such, disease is probably aggravated by food shortages that start to occur after cereal crops are harvested in summer and the accumulation and circulation of different diseases through high-density populations. Thus, disease may be a contributing cause to the decline of an outbreak but the absence of disease does not appear to explain why an outbreak is triggered.

Social structure

Social interactions have the potential to affect rates of population increase through infanticide, direct aggression, and induced dispersal. In addition, social interactions affect the timing of sexual maturation in young mice (Drickamer 1984, Oli and Dobson 1999). We have no direct studies of any of these processes in wild house mouse populations, and consequently cannot draw any direct conclusions.

The best insight we have into social structure came from an elegant study by Sutherland and Singleton (2006). By monitoring the activity of individuals with event recorders in the field, they showed that house mice switch between two different social systems—an almost asocial structure at low densities and a territorial system as abundance increases. This could be a function of the relatedness of individuals and an adaptation to prevent infanticide at high mouse densities. Adult females appeared more likely than males or juveniles to make the significant social shift. The trigger for this change remains unclear and further studies are needed to determine the mechanism of this social shift.

The importance of this work by Sutherland and Singleton (2006) is that it now provides a second process in a comprehensive two-factor model to explain mouse outbreaks. Not only is a good food supply needed, provided by good rains, but the social structure of the population must also be such that it can switch to a territorial system. Without this social switch, good rainfall does not lead to a mouse outbreak. This model is in need of further testing, particularly because we have few data on both the social component of the model and the food component (e.g., are ripening and germinating seeds—White 2002—and insects critical food items in spring when an outbreak begins?). We hope that this model will give insight into the biological curio of house mouse outbreaks aptly described by Singleton et al (2005) and help lead to effective control measures to prevent crop damage.

Predictive models for mouse outbreaks

Models for outbreaks of house mice have been developed at a regional scale for New South Wales (NSW), Victoria, and South Australia, and at the local or district scale from detailed monitoring and experimental studies (Pech et al 1999). All the regional models assume that climatic factors are the primary drivers, or at least precursors, to outbreaks, whereas localized studies included factors such as soil structure (Newsome 1969a,b), food quality (Redhead et al 1985), predation (Sinclair et al 1990), refuge habitat (Singleton 1989), and crop type (Twigg and Kay 1994). The most recent models are either quantitative, that is, using the rate of increase to predict seasonal changes in abundance (Pech et al 1999), or qualitative, that is, generating estimates of the probability of occurrence of an outbreak (Kenney et al 2003, Stenseth et al 2003, Davis et al 2004), based on combinations of rainfall data and spring trapping data. Although useful models have been developed for the rate of population decline over winter and the rate of increase over summer (Stenseth et al 2003), the main shortfall with the quantitative approach is that a model for the duration of the breeding season remains elusive (Pech et al 2003). Most likely, the two-factor model described above is needed to fill this gap. The qualitative models are simple to run (Appendix A, at www.scribd.com/doc/3837203). Using data available in spring, they achieve 70% correct predictions of whether or not an outbreak will develop over the subsequent summer (Kenney et al 2003).

Given that models can be used to predict the probability of an outbreak, when should farmers intervene with preemptive control? The threshold probability for intervention depends on the balance between the costs of control and savings in reduced damage to crops (Davis et al 2004). Based on 2004 market values for crops and rodenticides, the optimal long-term strategy for farmers is to apply preemptive control when the probability of an outbreak is ≥0.3. Managers who take the risk of never applying preemptive control and highly risk-averse managers who apply control every year would be substantially worse off than risk-neutral managers who respond at this threshold. In northwest Victoria, the threshold probability corresponds to rainfall of approximately 280 mm over the period from April to October (Davis et al 2004), or more generally for southern Australia the probability of an outbreak can be estimated using the models in Appendix A (at www.scribd.com/doc/3837203).

The success and failures of management actions

A range of control strategies have been tried against mice in fields over the years. Broadly, these have included trapping, poisons, and habitat modifications.

Trapping

Traps are normally used in and around houses and storage sheds, and can also be used in the field, but, because of the high rates of re-invasion, they are rarely used. Farmers have been known to use all sorts of ingenious home-made traps or commercial traps to try to reduce mouse numbers in their fields. A classic example as used in rural

Victoria in 1917 was an intricate design of metal guard fencing to channel mice into a pit, where hundreds of thousands of mice were captured in a few nights (Fig. 3). Another type of trap used by farmers is to position a greasy bottle over the edge of a large bucket filled with water. Mice climb up onto the bottle to reach some attractive food stuck in the end of the bottle, but slip into the water and drown. The problem with all these traps is that they take a lot of effort to set them, they can catch only a small number of animals, and they are used only when numbers are already very high and damage has occurred.

Poisons

A range of registered and unregistered rodenticides have been used to try to control damage caused by mice to crops. Since the late 1990s, zinc phosphide has been registered in Australia as an in-crop rodenticide. It is commercially produced and the rodenticide is coated on the outside of sterilized wheat grains. It can be spread into growing wheat crops using a calibrated standard fertilizer spreader or applied aerially by light planes. Prior to zinc phosphide being registered, strychnine had temporary registration for use during mouse plagues. It was used heavily during the 1993-94 mouse plague in South Australia and Victoria, where 350,000 ha were baited. There was evidence that the strychnine could be taken up into the plant under certain soil conditions and this led to it being banned for broad-scale use in the field. Zinc phosphide and strychnine are “acute” rodenticides that act relatively quickly.

Fig. 3. Some 500,000 mice were captured around stores of wheat in just 4 nights during a mouse plague in northwestern Victoria, Australia, in 1917.

Zinc phosphide can reduce mouse populations by 40–98% (Mutze and Sinclair 2004, Brown 2006). However, it is often applied after damage has already occurred, and, during mouse plagues, high mouse numbers often undergo natural crashes anyway (Brown 2006). The use of zinc phosphide remains the cheapest and easiest form of broad-scale mouse control.

Second-generation anti-coagulant rodenticides such as bromadiolone and brodifacoum have been registered in some states for use around the perimeter of crops but not in-crop.

Habitat modification

A range of farm management/cultural practices have been tested in Australia to reduce the impact of mice on crops. These practices include mowing margins of crops, harrowing, plowing, grazing, application of herbicides, and provision of alternative low-value food at the periphery of high-value crops at key times. Two field studies were conducted to test the effectiveness of some of these practices. The first was conducted in Victoria and showed that reducing the amount of grasses and weeds in noncrop habitats subsequently reduced the number of mice in adjacent crops (Brown et al 1998). The second experiment was conducted in irrigated crops in NSW and showed that, by applying a combination of practices, including spraying weeds and grazing by sheep, a significant reduction occurred in grass biomass, which subsequently reduced mouse abundance (Brown et al 2004). Yields of winter cereals and rice were 40% higher after treatment. The recommendations from this experiment are provided in Table 1.

Another practice that has been tested was to sow wheat crops deeper. A field experiment demonstrated that fewer mouse holes were observed when wheat was planted at 50 and 70 mm compared with a sowing depth of 30 mm (Brown et al 2003).

Fertility control

An alternative approach to lethal control is to reduce the recruitment of young mice into the population by affecting the fertility of adult females. A review of approaches to fertility control for small mammals is presented elsewhere in this volume (Singleton et al). For house mice, there has been a large research effort to develop fertility control of female mice using immunoncontraception (Chambers et al 1999). The objective was to sterilize female mice using a mouse reproductive protein that generated an immune response, such that the antibodies blocked development of the egg in the ovary or inhibited its fertilization in the reproductive tract. This reproductive antigen was to be delivered using a mouse-specific disseminating virus (Tyndale-Biscoe 1991, Shellam 1994, Tyndale-Biscoe and Hinds 2007). Proof of concept was achieved in laboratory colonies of house mice using a recombinant murine cytomegalovirus (MCMV) that expressed the egg coat protein, mouse zona pellucida 3 (ZP3). All infected mice became infertile for periods greater than 250 days (Lloyd et al 2003). However, the method was never field-tested because, in wild mice, raised under laboratory conditions, transmission of the recombinant virus to naïve mice was very poor (Redwood et al 2007). Although some public concerns were raised regarding the release of such a

Table 1. List of recommended farming practices to reduce the impact of mice in the irrigated summer cropping area of southern New South Wales (modified from Brown et al 2004).

Action	Level of action	Timing of action	Other benefits	Practicality	Priority	Likelihood of success
Summer crop						
Cultivate early	Routine	May-September, before winter	*Heliothis* control	High	High	Medium
Control weeds/remove food and cover/spray	Routine	Twice (spray) early and follow up	Control disease, reduce soil seed bank, farm hygiene	Medium	High	High
Winter crop						
Presowing stubble management—burn	If numbers high	Depends on weather	Rubbish removal	Medium	Medium	High
Presowing stubble management—incorporate	Routine	As early as possible	Breakdown of nutrients	Medium	Medium	High
Control weeds	Routine	Before spring	Control disease, reduce soil seed bank, farm hygiene	Medium	Medium	High
Sow deeper	Not a priority	At sowing	Clean up and bait rather than adjust rate or depth	Low	Low	Low
Increase sowing rate	Not a priority	At sowing	As above	Low	Low	Medium
Monitor mice	Routine	Presowing	See mouse activity	Low	High	High
Perimeter bait	If numbers high	Pre- or at sowing	–	Low	High	Medium
Rice crop						
Stubble management—slash early	Routine	Soon after harvest	Weed control	Low	Low	Medium
Stubble management—graze	Routine	Soon after harvest	Weed control	Medium	Low	High
Stubble management—burn early	?	After harvest	Weed control	Medium	Low	High
Stubble management—burn later	?	Following spring	Weed control	Medium	Low	Medium
Manage channels and banks	Routine	Ongoing	Control disease, reduce soil seed bank, farm hygiene	Low	High	High
Bait stations	If numbers high	Before breeding season	–	Low	Medium	Medium
Other actions						
Sow early (all crops—on time)	Routine	Depends on rainfall	–	Low	Low	Low
Harvest cleanly (all crops)	Routine	At harvest	Economic gains	Low	High	High
Remove and reduce cover around sheds, silos	Routine	Continuous	Keeps farm clean	Low	Medium	High
Monitor for signs of mouse activity	Routine	Key times (early spring and autumn)	–	Low	High	High
Clean up grain spills (silos, field bins)	Routine	Sowing and harvest	Economic gains	Low	High	High
Mouse-proof houses, grain, stock feed storages	If numbers high	Continuous	Initial high cost	Low	Medium	Medium
Bait key habitats using bait stations	If numbers high	Before spring	–	Low	High	High

genetically modified organism (Fisher et al 2007), if funding becomes available in the future, the potential of this recombinant MCMV as a nondisseminating oral product could be assessed or a different virus vector could be developed.

Lessons learned

Over the last 30 years, we have made significant progress toward understanding the population dynamics of feral house mice and the factors that contribute to house mouse outbreaks and mouse plagues. Mouse plagues develop in response to factors such as weather, rainfall, food supply, predation, disease, and social structure. In general, each factor alone is not sufficient to generate or trigger a mouse outbreak or mouse plague, but each, in combination, is necessary.

Detailed knowledge about breeding dynamics and the relationship with mouse population dynamics and food supply and rainfall has been critical in understanding mouse population rates of increase and in developing models to predict outbreaks.

A range of management options are available to farmers; however, given the irregular nature of mouse plagues, it is hard to get farmers to implement preemptive management. Monitoring of mouse populations in key areas is needed to be able to adequately predict where and when outbreaks of mice will occur. However, monitoring over large areas requires a large investment in training and resources.

There needs to be a nationally coordinated approach to monitoring mouse populations so that action can be taken before mouse numbers have reached levels that lead to crop damage. However, few people with relevant skills remain in state or national government agencies. Effort is required to build and maintain this capacity; otherwise, large areas of crops will suffer significant mouse damage and inappropriate forms of management will be applied. For example, during a recent outbreak of mice, farmers were given advice from a state government department to mix insecticide baits for mice. This led to significant nontarget deaths of grain-feeding birds and secondary poisoning impacts. This should not occur when a registered product is commercially available and it is relatively cheap to administer.

Outbreaks of house mouse populations also occur in New Zealand, where work on mice has been done in substantially unmodified ecosystems. The focus in New Zealand is managing mouse populations to protect native fauna. The population increases in mice in New Zealand beech forests are small compared with the mouse plagues of Australia (see Ruscoe and Pech, this volume). The main lesson to learn from the comparison of outbreaks of mouse populations in Australia and New Zealand is that mice have an impressive physiological plasticity that enables them to extend their breeding season or to breed at different times of the year in response to pulses of food supply.

Conclusions

We have made good progress in understanding the mechanisms that generate outbreaks of mouse populations in Australia, and in developing predictive models that provide sufficient time for farmers to implement ecologically based management practices in southern Australia. However, the grain industry or state governments need to instigate appropriate surveillance and population monitoring so that the models become operational.

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Rodent outbreaks in New Zealand

Wendy A. Ruscoe and Roger P. Pech

Rodent outbreaks in New Zealand are strongly driven by resource (food) availability irrespective of the ecosystem. The irregular masting by native southern beech (*Nothofagus* spp.) and rimu (*Dacrydium cupressinum*) trees causes interannual fluctuations in invasive rodents, primarily house mice (*Mus musculus*) and kiore (*Rattus exulans*) in the rare places they occur. Nonsynchronous masting of forest trees precedes increases in ship rat (*R. rattus*) populations in mixed forests, although these increases are more regular and less intense. In this chapter, we describe the resource drivers of these population irruptions and summarize the conservation impacts caused by the periodic irruptions of rodents in native forests.

Keywords: New Zealand, black rat, house mice, beech masts

New Zealand is one of the few countries that, prior to human occupation, lacked terrestrial mammals (except two species of bat). It now has four rodent species, all invasive. The first introductions were kiore (*Rattus exulans*, the Pacific or Polynesian rat) with Maori settlers approximately 800 years ago (Wilmshurst and Higham 2004). Kiore were hunted, trapped, and perhaps kept by some Maori as a source of protein, but they also caused losses to sweet potato crops (Best 1942). These wild rats spread throughout the country and Maori knew that kiore became especially abundant in native forests following a year of plentiful seed (Best 1942). Storehouses mounted on poles to protect food and belongings also suggest that kiore were considered a pest (Atkinson and Towns 2005). For 500 years, they were the sole ground-dwelling terrestrial mammal, apart from humans, dogs, and the short-tailed bat.

In the late 18th century, European settlers brought with them the Norway rat (*Rattus norvegicus*; the brown, sewer, or water rat), which were pests on ships. These quickly spread through the early settlements and into the native forests and by the mid-1800s were common throughout both the North and South Island (Fig. 1). In the following few years, both ship rats (*Rattus rattus*, black or roof rats) and house mice (*Mus musculus/domesticus*) were accidental stowaways on ships to New Zealand and quickly invaded many New Zealand ecosystems. By the late 1800s, Norway rats were becoming scarce, possibly because of predation by introduced stoats (*Mustela erminea*) and other mustelids that were released in large numbers in 1884, or competition with the invading ship rats and house mice (Innes 2005a). Rodents are more likely to persist on islands that are stoat-free than on islands with stoats (Taylor 1984), which supports the predation hypothesis. Although two or three of the rodent species can co-exist, competitive exclusion is another likely mechanism because nowhere in the

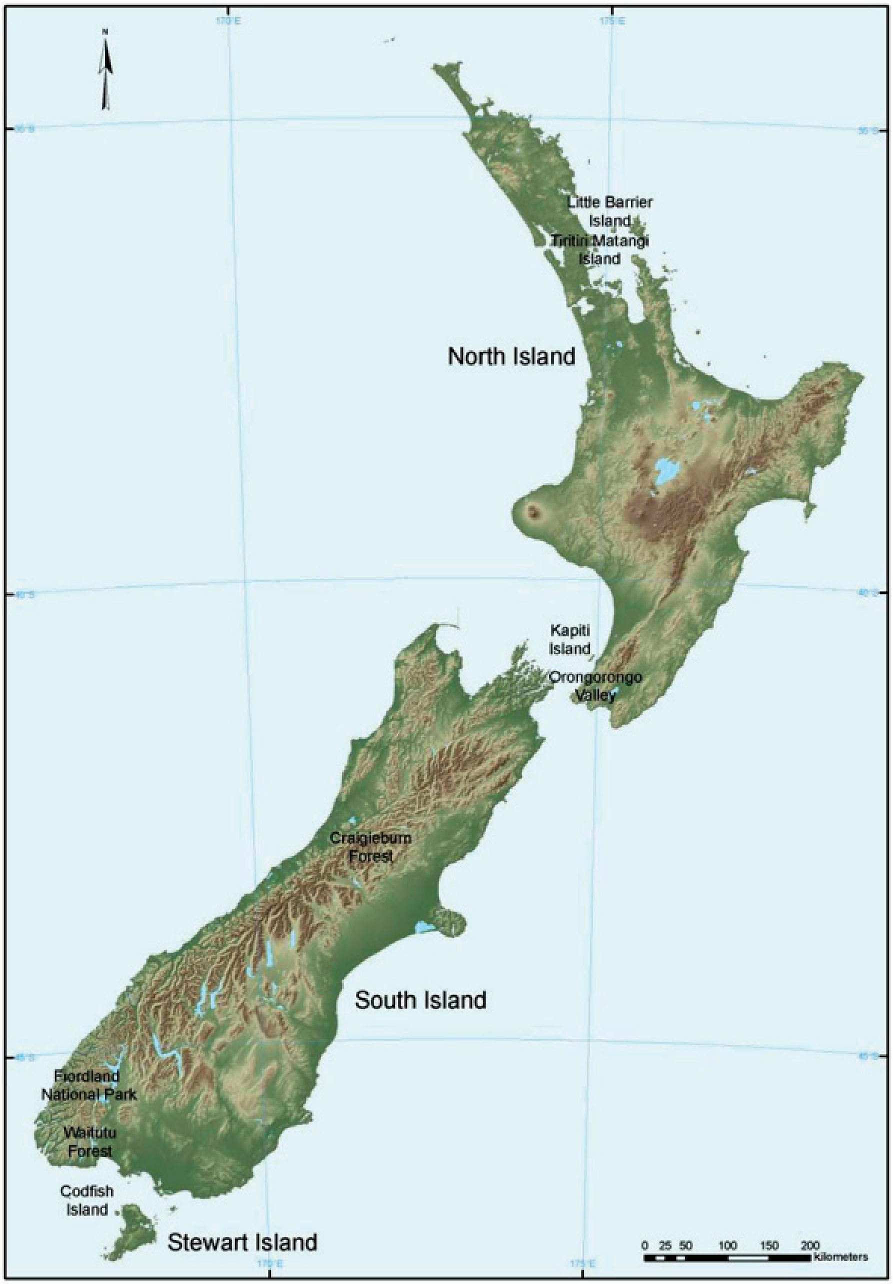

Fig. 1. Map of New Zealand with islands and place names mentioned.

New Zealand region do all four species of rodent live together, as on warmer Pacific Islands (Innes 2005a, b).

Kiore had disappeared from most of the North and South Islands of New Zealand by 1900. Small isolated populations persist in Fiordland National Park and Waitutu Forest in the southwestern corner of the South Island but, other than that, kiore are now restricted to offshore islands (Ruscoe 2004). Likewise, Norway rats are now commonly associated with cities, settlements, and waterways and are rarely found in natural ecosystems (Innes et al 2001). Ship rats and house mice are common in nearly all habitat types, and continue to pose a significant conservation threat to New Zealand native biota.

Ecosystems with sporadic input of resources

Native beech (*Nothofagus* spp.) dominates a large proportion of the forested areas of New Zealand, especially in the South Island. Beech trees flower and seed heavily at irregular intervals, termed "masting," in a pattern similar to rattada events (Sections 1 and 2, this volume). Between these heavy seed years, individual trees may produce some seed or none at all. At Craigieburn Forest, Canterbury, South Island, the annual crop of mountain beech (*N. solandri cliffortioides*) seed varies between 0 and 12,000 seeds m^{-2} (Richardson et al 2005). Nonsynchronous masting of tree species in mixed forest results in more consistent net primary productivity than in beech forest. Also in grasslands, seed production varies between synchronous masting approximately every 3–5 years by native tussock (*Chionochloa* spp.) in alpine areas (Schauber et al 2002) and annual seeding by grasses (mostly nonnative) in lower-altitude and agricultural areas. For many New Zealand ecosystems, the large between-year variation in flower and seed production leads to high temporal variation in rates of increase of a variety of native and exotic animals, especially rodents. Consequently, much effort has been put into researching trophic cascades generated by masting and the consequences of irruptive rodent populations for the conservation of native species.

House mice

Wodzicki (1950) and Riney et al (1959) were the first ecologists to document the correlation between high numbers of house mice and unusually heavy beech seeding. During years with low beech seedfall, house-mouse population densities are generally low; they increase slightly over summer to autumn/winter peaks (King 1982, Murphy 1992), and then usually decrease with cooler temperatures, food shortages, and cessation of breeding. In contrast, during high-seedfall years, mouse populations continue increasing through winter, leading to peak numbers, up to 50 mice ha^{-1} (Ruscoe et al 2003), in late winter or in the following spring or summer (Fitzgerald et al 1996, Choquenot and Ruscoe 2000, Ruscoe et al 2003).

The mechanism driving the response of mouse populations to beech seedfall is the sudden increase in food: flowers, seed, and invertebrates (Fitzgerald et al 1996, Alley et al 2001, Ruscoe et al 2005). Based on a 25-year data set (1972-96) from the Orongorongo Valley in the southern North Island (Fig. 2), the rates of change of house-mouse populations between autumn (the season in which most beech seed falls) and winter, and between winter and spring, were positively related to seedfall and negatively related to mouse density (Choquenot and Ruscoe 2000). Rates of change between spring and summer, and between summer and autumn, were related to mouse density alone. Plausible density-dependent mechanisms include social factors, intraspecific competition for available food, predation, and/or the effects of disease or parasites. There is mounting evidence, however, that ship-rat numbers may limit mouse abundance in beech forests where they are sympatric (Innes et al 1995, Choquenot and Ruscoe 2000, Ruscoe et al 2003). Also, Innes et al (1995) showed that when rats were removed, mouse numbers increased faster than would be possible by *in situ* breeding, suggesting that there may be a behavioral as well as a numerical response by mice to the removal of rats.

In beech forest, predation on mice by stoats is likely to have the greatest impact in postmast years. Stoats respond numerically to mouse population increases associated with high-seedfall years (King 1983, O'Donnell et al 1996), whereas mouse populations respond quickly to seed availability, and the timing of stoat reproduction is set by changes in daylength, regardless of food supply in autumn and winter (King 1980). Stoats can produce only one litter in spring (around October), and an increase in food supply leads to a reduction in intrauterine and nestling mortality, followed by a population increase (King 2002). In years when mice are abundant, juveniles make up 80–90% of the stoat population in January and February, whereas, in low-mouse

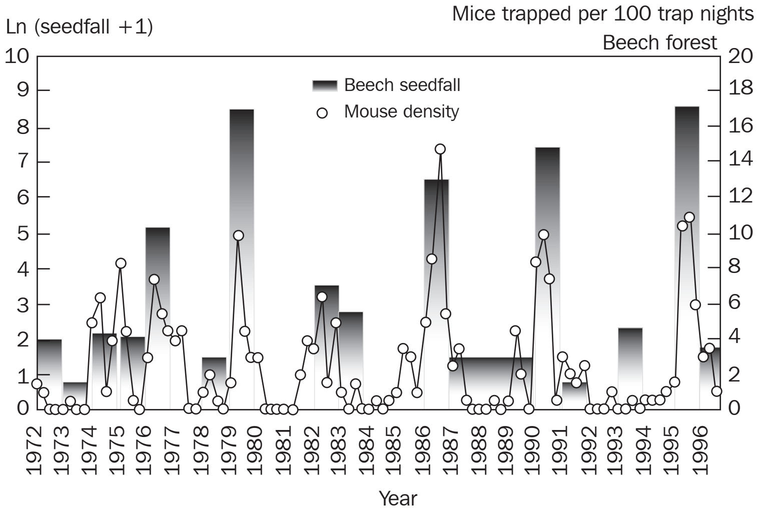

Fig. 2. House-mouse numbers in New Zealand's Orongorongo Valley, 1972-96, and beech seedfall (log scale) over the same time period. (Data from Choquenot and Ruscoe 2000.)

years, juveniles make up <10% of the stoat population in summer (Murphy and Dowding 1994, Powell and King 1997, King 2002). Mice can be important prey for stoats (King 1983), but, when occurrence in the diet is converted to kill rates, it is apparent that the impact of predation is unlikely to be significant during years with high mouse densities (Jones et al 2010, personal communication). In most years, stoats do not appear to regulate mouse population growth rate in beech forests (Ruscoe et al 2003). This is not surprising, as stoats defend large home ranges (70–250 ha), which prevents the buildup of high stoat numbers relative to mouse numbers (Murphy and Dowding 1994). There is greater potential for predator regulation immediately after a mast year. At this time, mouse populations have declined due to food shortage (Blackwell et al 2001, Ruscoe et al 2003), resulting in low mouse density and a relatively high density of stoats (Fig. 3).

Kiore

Kiore are no longer considered a pest on the main islands of New Zealand as they have highly restricted distributions. Kiore persist on offshore islands but, since 1984, eradication campaigns have reduced the number of kiore-infested islands from 61 to 26 (Atkinson and Towns 2005).

Seasonal variation in the density of kiore in New Zealand results from a regular pulse of births over the summer. On Tiritiri Matangi Island, availability of grass seed caused a strong seasonal pattern in breeding and population fluctuations (Moller

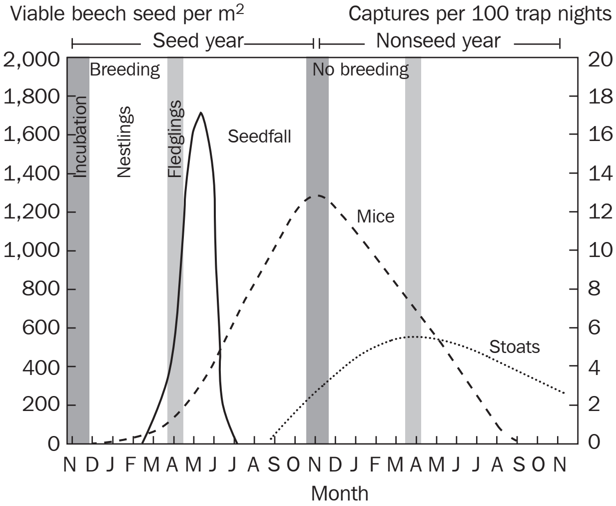

Fig. 3. A conceptual model illustrating the timing of kaka breeding, and the response of the mouse and stoat populations to beech seedfall. Reprinted from Wilson et al (1998), with permission from Elsevier.

1977, Nicholas 1982). Prior to their eradication in 1993, densities reached as high as 100–170 kiore ha^{-1} in grassland and 70–80 kiore ha^{-1} in forested parts of the island. In contrast, population fluctuations are far more modest and densities much lower on completely forested islands around Tiritiri Matangi Island (Craig 1986) and are relatively stable on Kapiti and Stewart islands (Atkinson and Towns 2005). In tropical Pacific croplands or on simple atoll systems, kiore diet is predominantly vegetarian, with animal remains never constituting more than 8% by volume (Atkinson and Towns 2005). In New Zealand, animal matter (invertebrates, lizards, and birds) can constitute a much higher component of the diet, up to 90% (Bunn and Craig 1989). Given the importance of animal matter in the diet, kiore have probably been responsible for both local and total extinctions of some species of flightless beetles and weevils, giant weta (*Deinacrida* spp.), land snails, frogs, lizards, tuatara (*Sphenodon punctatus punctatus*), small sea birds, and bats (Atkinson and Towns 2005).

Ship rats

Ship rats are by far the most widely distributed rat in New Zealand. They occur on the three main islands and have been present on up to 49 offshore and outlying smaller islands (Innes 2005b). All ship rats have been karyotyped as the Oceanic form ($2n = 38$), with no Asian form ($2n = 42$) being found (Yosida et al 1974), indicating invasion from the Pacific Islands. They are now present in virtually all habitat types, including urban areas, farms, and beech forest following heavy seeding events (Dilks et al 2003), but most commonly in diverse lowland podocarp-hardwood forests, where they are ubiquitous (Innes 2005b). Seasonal breeding of ship rats causes corresponding seasonal changes in density, from low numbers in spring and early summer to a peak usually in autumn/winter. Heavy seeding of hinau (*Elaeocarpus dentatus*), pigeonwood (*Hedycarya arborea*), rimu (*Dacrydium cuppressinum*), and beech have all preceded extended breeding seasons, indicating the key role food supply plays in initiating population increases (Daniel 1978, Blackwell et al 2003, Dilks et al 2003). Ship rats occur at much higher densities in lowland podocarp-hardwood forests (up to 14 rats ha^{-1}; Ruscoe et al 2009) than in beech forest (up to 4.6 rats ha^{-1}; Ruscoe, personal observations), where they are not as numerous as house mice and do not respond to seedfall to the same extent.

It is not clear whether predators (stoats, feral cats (*Felis catus*)) can regulate ship-rat populations. Some studies showed no difference in the population size and dynamics of ship rats in areas where predators were controlled vs. noncontrolled areas (Blackwell et al 2003, Ruscoe et al 2009); however, there have been reports of much higher ship-rat populations following control of stoats (I. Flux, unpublished). Population models suggest that predators cannot prevent an irruption of ship rats in New Zealand forests, but may be able to delay the start of an irruption or hasten its decline (Blackwell et al 2001, Ruscoe et al 2003). Recent research has revealed that, in the absence of possums, ship rats reach higher densities than in the presence of possums, presumably via competitive release (Ruscoe et al 2009).

Ship rats are omnivorous generalists. The main animal foods are arthropods, particularly weta (*Hemideina* spp.), but also spiders, stick insects (Phasmatodea), moths, and cicadas (Hemiptera: Cicadidae). Other prey items that are of conservation significance are native snails, slugs, birds, and lizards (Whitaker 1978).

Conservation impacts of rodents

Prior to human settlement, the New Zealand fauna included avian, reptilian, and invertebrate consumers of seed, insectivorous birds and reptiles, and hawks and owls that preyed upon smaller birds, reptiles, and invertebrates. Introductions of mustelids, cats, and rodents added new predator-prey interactions to New Zealand ecosystems.

Most impacts of kiore on New Zealand fauna and flora occurred prior to European colonization and are not well documented. Evidence that kiore caused local extinctions or permanent reductions of native species has come from studies comparing the fauna of kiore-infested and kiore-free islands and by monitoring changes following eradication of kiore on islands. Several species of terrestrial invertebrates (land snails, weta, cockroaches, earwigs, spiders, and beetles), lizards (skinks and geckos), and the endemic tuatara have all increased in abundance following removal of kiore from off-shore. Kiore not only compete with tuatara for invertebrate prey but also directly affect tuatara populations by predation of eggs and juveniles (Tyrrell et al 2000). Also, kiore have had a major impact on small burrow-nesting birds, Pycroft's and Cook's petrels (*Pterodroma* spp.), and the little shearwater (*Puffinus assimilis*), causing up to 90% of nest failures (Pierce 1998). Chicks of the kakapo (*Strigops habroptila*), an endemic flightless parrot, have been reported killed by kiore within days of hatching on Little Barrier and Codfish islands (D.V. Merton, unpub. data).

Native ground-dwelling and particularly hole-nesting birds are particularly susceptible to predation by rats and stoats because these species are arboreal and the native species have evolved few predator-avoidance behaviors. The mohua (*Mohoua ochrocephala*) is a small passerine that was once present in most forest habitats over much of South Island and Stewart Island, but began to decline noticeably around the 1890s and is now present in only 25% of its former range (O'Donnell 1996). The ranges of the native parrots, kakariki (*Cyanoramphus auriceps*) and kaka (*Nestor meridionalis*), have also contracted and predation by rats and stoats but also human-induced habitat modification are thought responsible. Even in large intact forests, populations of all three avian species have declined to such low levels that further local extinctions are possible. Mohua, kaka, and kakariki nest in tree hollows up to 20 m from the ground. Both ship rats and stoats are able climbers, and can access a large proportion of nests. Because the nesting holes have only one entrance, incubating females cannot escape, and are taken along with the eggs or chicks (Dilks et al 2003) (Fig. 4). Following years of high mouse abundance, stoat numbers may increase fivefold, resulting in increased predation on native bird populations (King 1983). This is in contrast to the Northern Hemisphere, where good years for rodents often relieve the predation pressure of stoats on birds (King 1980).

Fig. 4. Photo of ship rats eating chick. D. Mudge, Nga Manu.

The extent to which beech masting is sufficient to satiate both native and exotic seed predators will determine whether house mice pose a real competitive threat to birds and other native granivores. Recent research has shown that the introduced possum (*Trichosurus vulpecula*) also consumes large amounts of green seed in tree canopies (Sweetapple 2003). In prehuman New Zealand, only birds and invertebrates consumed beech seed, but today rodents and possums place additional predation pressure on seeds. This seed removal (Ruscoe et al 2005), in addition to the effects of other exotic herbivores (deer (*Cervus* spp.), pigs (*Sus scrofa*), and goats (*Capra hircus*)), will determine the long-term impacts of invasive mammals on beech forest dynamics. Mice are also known to eat weta (Miller and Miller 1995, Fitzgerald et al 1996). If they significantly deplete weta populations, then they may pose a direct threat to these native invertebrates as well as competing with native insectivores, for example, the native owl (*Ninox novaeseelandiae*) (Haw et al 2001).

Although it is difficult to isolate the impacts of each rodent species, the spread of ship rats on the North Island was more or less coincident with declines of the bell bird (*Anthornis melanura*), robin (*Petroica australis*), stitchbird (*Notiomystis cincta*), saddleback (*Philesturnus carunculatus*), and thrush (*Turnagra capensis*). On the South Island, declines of the mohua, South Island kokako (*Callaeas cinerea cinerea*), and parakeets (*Cyanoramphus novaezealandiae* and *C. auriceps*) all occurred during the period when ship rats were spreading. When ship rats reached Big South Cape Island, off Stewart Island, they precipitated the decline of five native bird species and the extinction of a further four species (Bell 1978).

Management

The immediate major conservation threat in the beech forest system is the effect of predation on native biota, particularly forest birds. Although house mice could be the primary cause of high predator abundance in this system, current conservation management in southern New Zealand involves intensive predator trapping in years following a high seedfall. For example, stoat trapping has occurred in the Eglinton Valley for the last 15 years. However, in this valley, ship-rat numbers have increased in high-seedfall years (1999, 2000) to beyond numbers attained prior to stoat trapping. Concern is growing that this is a result of stoat trapping relieving predation pressure on rats. Whether this increase in rat numbers is due to the predator trapping or is the result of an increase in the frequency of beech masting events (Richardson et al 2005) is unknown, but highlights the need to understand species interactions and the importance of managing house mice, ship rats, and stoats collectively.

Ship rats are considered the most pervasive and devastating agents of change and efforts to control them have increased markedly in the last two decades, mostly using brodifacoum (a second-generation anticoagulant) or when co-targeted with possums using aerially distributed sodium monofluoroacetate (1080). However, because of the high reproductive rate of rats, control needs to be done a lot more frequently than when targeting rats instead of possums. Brodifacoum is a persistent and mobile toxin (Eason et al 2002) and is now used only by the New Zealand Department of Conservation for island eradications and not for repeated control operations. Ship rats have been eradicated from nine New Zealand offshore islands but remain on at least 26 others (Innes 2005b).

Concluding remarks

Outbreaks in New Zealand, irrespective of the ecosystem, are strongly driven by resource (food) availability. Annual seeding by nonnative grasses on islands causes large seasonal fluctuations in kiore. In contrast, the irregular masting by southern beech (*Nothofagus* spp.) and rimu (*Dacrydium cupressinum*) trees causes interannual fluctuations in kiore on the mainland. Nonsynchronous masting of forest trees precedes ship-rat population increases in mixed forests though these increases are more regular and less intense as rats have a variety of seed species to use; at least some seed is available most years. The most dramatic irruptions occur in house-mouse populations with the irregular heavy mast events in both beech forest and (to a lesser extent) alpine grasslands. The decadal-level increase in the frequency of moderate to high beech seedfall years has been attributed to recent climate change (Richardson et al 2005). If this trend continues, the result is likely to be more frequent high rodent populations leading to higher sustained populations of predators, primarily mustelids.

Although many impacts of rats on both native flora and fauna have been documented, the specific impacts of house mice (apart from driving predator populations) are unknown. House mice are implicated in the extinction of some native invertebrates and lizards from islands, though evidence is lacking. Increased numbers of invertebrates have been trapped following mouse eradication campaigns (Ruscoe and Murphy 2005), but this may not restore the community to premouse composition. Although research into the impact of mice on forest regeneration via seed predation is currently under way (Wilson et al 2007, 2010), the direct impact of mice on invertebrate and lizard communities remains largely unquantified. Managers undertaking control of ship rats and top predators face large house-mouse populations and are unsure of the potential adverse environmental consequences. Quantifying the direct impacts on native biota remains a gap in current knowledge.

Generally, eradications of rodents in New Zealand and throughout the Pacific have been attempted, often successfully, on islands where re-invasion can be prevented. Second-generation anti-coagulants are commonly used and applied aerially. This limits their use to islands with no susceptible nontarget species or where the loss of other species is considered acceptable. Another by-product of island eradications has been increased appreciation of the consequences of "mesopredator release." Mesopredator release occurs when removal of a top predator leads to a numerical increase in a secondary predator, which then causes damage to a shared prey species. For example, the eradication of cats on Little Barrier Island (New Zealand) led to increased predation on Cook's petrel (*Pterodroma cookii*) by kiore (Rayner et al 2007), which in turn had to be eradicated. Ecological release (incorporating mesopredator release and competitive release) was also documented in New Zealand when the eradication of Norway rats from Mokoia Island was followed by greatly increased densities of house mice (Simberloff 2002). Various forms of ecological release are being increasingly recognized as a consequence of the effects of pest control campaigns (Blackwell et al 2006). The lack of species-specific rodent control technology and community concerns about broad-scale application of toxins prevent the aerial delivery of rodenticides on the New Zealand mainland. These remain two of the biggest challenges to cost-effective, wide-scale rodent management in New Zealand.

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Rodent outbreaks in North America

Gary Witmer and Gilbert Proulx

Fluctuations in rodent population densities in North America are a reality. Our understanding of the factors causing such fluctuations is incomplete; therefore, it is important to monitor populations to increase our understanding of natural wildlife communities so as to avoid substantial damage to agriculture, forestry, and urban infrastructures, and to prevent rodent-borne disease transmission to humans. There is a need to establish integrated pest management programs in which monitoring, preventive cultural practices, and various control methods (mechanical, physical, biological, and chemical) are strategically coordinated to maintain rodent population densities at acceptable pest levels.

Keywords: agriculture, damage, land use, management, North America, outbreaks, rodents

North America has more than 400 species of rodents (Hall 1981). They are found in all ecoregions, from high arctic tundra to forests, prairies, and arid deserts. They inhabit subterranean, terrestrial, arboreal, and aquatic habitats. Most of these species do not cause significant problems for humans. However, many rodents have adapted to and taken advantage of human environments, and are considered pests in urban settings, agriculture, and forestry. Rodent populations can reach high densities, often considered outbreaks, under diverse environmental conditions. Also, many species have cyclic fluctuations related to various biological factors. Whether or not all these high densities qualify as “outbreaks” and “cyclic-high” peaks, such fluctuations in rodent numbers result in significant conflicts with humans (Marsh 1988, Hygnstrom et al 1994). In this chapter, we argue that many rodent species experience population outbreaks with similar characteristics and effects on natural and anthropogenic environments.

High rodent densities reported in North America

Rodents are characterized by high intrinsic rates of increase (Batzli 1999). When they have the required food, water, and cover to survive and reproduce, they thrive; when these resources are in short supply, animals either emigrate or die (Tobin and Fall 2004). Greater reproduction and immigration may lead to population increases and peaks (Miller 1946, Proulx 1997). All rodent populations, independent of their size, life history, and habitat, can fluctuate in numbers. Table 1 shows some examples of high densities for various rodent species reported in North America. Many of these species occupy agricultural fields under some conditions.

Table 1. Some high rodent densities reported in North America and average characteristics of those rodent species. Compiled from Banfield (1974), Feldhamer et al (2003), Hygnstrom et al (1994), and Marsh (1988).

Species	Body mass (g)	Lifespan (years)	Litters per year	Litter size	High density ha^{-1}	Cyclic populations (yes/no)	Primary habitats	Additional references
Brown lemming (*Lemmus sibiricus*)	100	1	1–3	4–9	320	Yes	Tundra	Pitelka and Batzli (1993)
Voles (*Microtus* spp.)	65	1	1–5	3–6		Yes	Grassland	Beck et al (1958), Boonstra and Krebs (1978), Murray (1965)
Ground squirrels (*Spermophilus* spp.)	500	4–5	1	4–9	330	Yes?	Grassland	Proulx (2010), Rickart (1988)
Muskrat (*Ondatra zibethicus*)	1,100	2–3	2–3	4–8	100	Yes	Marsh, wetlands	Errington (1954)
Deer mice (*Peromyscus* spp.)	30	<1	2–4	3–5	100	No	Many habitats	Sullivan and Krebs (1981), Vessey and Vessey (2007), Hoffman (1955)
Pocket gophers (*Thomomys* spp.)	250	1–3	1–2	3–6	153	No	Forest, grassland	Witmer and Engeman (2007), Aldous (1957), Proulx (1997)
Cotton rats (*Sigmodon* spp.)	200	<1	2–6	5–7	373	No	Grassland	Hawthorne (1994)
Rice rats (*Oryzomys* spp.)	80	<1	5–6	2–5	50	No	Marsh, grassland	Smith and Vrieze (1979)
Grey squirrel (*Sciuris carolinensis*)	800	3–4	2	3	50	No	Forest	Jackson (1961)
Nutria[a] (*Myocastor coypu*)	5,400	2–3	2–3	4–5	138	No?	Marsh, wetlands	Wentz (1971)
Norway rat[a] (*Rattus norvegicus*)	450	1	4–6	6–12	150	No?	Urban/suburban	S. Stopak (USDA, pers. comm.), Brooks and Barnes (1972), Colvin and Kaukeinen (2008), Proulx, unpubl. data
House mouse[a] (*Mus musculus*)	30	1	5–10	5–6	500	No?	Urban/suburban	Pearson (1963)

[a] Introduced to the U.S.

For the most part, population fluctuations are irregular. But, the fluctuations of some populations are more regular than one would expect by chance. These are commonly called cycles (Smith 1974). The two most common intervals between oscillations are 3 to 4 years, typified by lemmings (Stenseth 1999, Wilson et al 1999) and voles (Krebs 1996, Ylonen et al 2003), and 6 to 10 years, typified by muskrats (McLeod 1950, Errington 1954, Butler 1962) and ground squirrels (Erlien and Tester 1984, Byrom et al 2000). However, there is no clear distinction between small mammal populations that are cyclic and those that fluctuate irregularly (Hansson and Henttonen 1985, Taitt and Krebs 1985). Within the same habitat or region, rodent populations often irrupt and reach numbers that are manyfold those of "normal" densities (Table 2).

Table 2. Temporal fluctuations in the density of rodents from a single population.

Species	Densities ha^{-1}		References
	General range	High	
Columbian ground squirrel (*Spermophilus columbianus*)	10–30	43–78	Dobson and Kjelgaard (1985)
Fox squirrel (*Sciurus niger*)	0.05	2.1–5.1	Brown and Yeager (1945)
Northern pocket gopher (*Thomomys talpoides*)	47	183	Hansen (1960)
Muskrat (*Ondatra zibethicus*)	20–40	>80	Lynch et al (1947), Errington (1963)
Voles (*Microtus* spp.)	0	427	Myers and Krebs (1974), Taitt and Krebs (1985)
Mountain beaver (*Aplodontia rufa*)	<1	15–20	Hooven (1977)

Factors associated with rodent outbreaks in North America

Many factors can cause high densities or outbreaks of rodent populations in North America. Some are density-independent (abiotic), for example, weather, and others are density-dependent (biotic), for example, predation. Some factors act synergistically (e.g., loss of cover and increased predation), while others may be interrelated (e.g., frequent precipitations and forage increase). Although a variety of factors may be responsible for population fluctuations, weather, food, social interactions, and predation are often identified as the main causes.

Weather. The two most commonly measured forms of biological response to climate change are adjustments in species' geographical distributions and in timing of activity (Parmesan et al 2000, Parmesan and Yohe 2003). Extremes of temperature have a direct impact on the distribution of kangaroo rats (*Dipodomys* spp.), some species not being able to maintain their body temperatures in cold weather, and others being overly sensitive to high temperatures (Dawson 1955, Gaby 1972).

Abundant rainfall, especially after a period of drought, can result in a flush of vegetation growth. Rodent populations can respond quickly to the improved forage and cover provided in these situations. Abundant rainfall when combined with a mild winter and a warm spring can lead to high reproduction and survival in some species of rodents. Such conditions have led to house-mouse outbreaks in California (Pearson 1963) and vole outbreaks in Oregon (Beck et al 1958). Tomich (1986) noted similar house mouse outbreaks in Hawaii and Singleton et al (2007) noted similar responses in house mouse populations in Australia so the phenomenon appears to occur worldwide, especially in mild climate (subtropical, Mediterranean) areas. Weather events (mild temperatures and abundant precipitation) can lead to abundant acorn crops (i.e., mast production) a year or two later, resulting in dramatic increases in mice and vole populations (Schnurr et al. 2002, Clotfelter et al. 2007). Oceanic weather events (El Niño Southern Oscillation) can cause increased precipitation that results in increases in rodent populations for the reasons previously discussed (Hjelle and Glass 2000, Rodriguez-Moran et al 1998, Glass et al 2000).

Drought impacts on vegetation growth may affect the composition of rodent communities. Rodents often respond to decreased vegetation height with reduced movements and increased risk sensitivity in their feeding behavior (Jacob 2008), and their productivity may be affected. Conversely, low vegetation height may attract rodents that monitor the movements of their con-specifics and predators. Population outbreaks of Richardson's ground squirrel in grasslands and pastures with low vegetation in southern Saskatchewan were the result of a widespread drought (Proulx 2010).

Food. When rodents have access to high quality and/or quantity of food, the percent of the population in reproductive condition may increase (Reichman and Van De Graaf 1975), yearlings may breed earlier than usual (Lair 1985), the proportion of females weaning a litter augments (Karels and Boonstra 2000), and litter size may increase considerably (Table 3).

Predation. Where predators are abundant, and particularly where they have coevolved with the prey species, density-dependent or delayed density-dependent predation will either prevent outbreaks or generate cycles (Klemola et al 2003). In the Canadian tundra, predation mortality was sufficient to prevent summer population growth of noncyclic lemming populations (Reid et al 1995) and may have been sufficient to regulate cyclic lemming populations (Wilson et al 1999).

Predators may be considered specialists or generalists and they may respond in a numerical or functional way to fluctuations in prey abundance. Generalist predators are believed to stabilize prey numbers, whereas specialist predators should cause fluctuations in numbers (Andersson and Erlinge 1977). For example, ferruginous hawks (*Buteo regalis*) are specialist predators feeding almost exclusively on Richardson's ground squirrels (Lokemoen and Duebbert 1976, Schmutz et al 1980). Least weasels (*Mustela nivalis*) and short-tailed weasels (*M. ermine*) are vole specialists (Simms

Table 3. Effect of food quality and/or supply on the litter size of rodent populations.

Species	Number of young per litter[a]		References
	Lower food quality or supply	Higher food quality or supply	
Northern pocket gopher (*Thomomys talpoides*)	3–5 (native grass lands)	5–7 (alfalfa fields)	Hansen (1960), Hansen and Ward (1966), Andersen (1978), Proulx (2002)
Pine vole (*Microtus pinetorum*)	1.6 (abandoned orchard)	2.0 (managed orchard)	Cengel et al (1978)
Belding's ground squirrel (*Spermophilus beldingi*)	3.6	4.1 (supple mental feeding)	Trombulak (1991)

[a] Statistically significant differences between litter sizes.

1979, Korpimäki et al 1991). Long-tailed weasels (*M. frenata*) may become specialist predators of Richardson's ground squirrels from April to July, when adults and juveniles are active above ground, but thereafter switch to other prey (Proulx et al 2010). In other regions, they may systematically investigate fields to find and kill northern pocket gopher (Proulx 2005a). Thus, some predators of small mammals can change from being specialists to being generalists in a seasonal and regional fashion (Korpimäki and Krebs 1996).

Multiple factors. Despite intensive research efforts, ecologists still disagree about what causes population cycles (Korpimäki et al 2004, Krebs 1996, Ylonen et al 2003). Researchers have suggested the cycles are related to resource limitation (Ford and Pitelka 1984, Hornfeldt et al 1986), predation pressures (Korpimäki et al 1991, Korpimaki and Norrdahl 1998), vegetation cover (Birney et al 1976), density-dependent season length (Smith at al 2006), breeding performance (Mihok et al 1985), defense mechanisms from food plants (Massey et al 2008), disease outbreaks (Wolff and Edge 2003), and the body condition of individuals in a population (Agrell et al 1992), but perhaps not to stress hormone levels (Boonstra and Boag 1992). Lambin et al (2006) suggested that the reasons for cycles likely differ by geographic region, and multiple reasons should be considered.

Urban settings and land-use practices

Environmental conditions (e.g., food supplies, low predator numbers, cover, etc.) that are associated with rodent population fluctuations are often identified in urban settings, agricultural land, and forest operations. We briefly discuss such environments because these are the areas where significant conflicts with humans can occur.

Urban settings. Commensal species of rats and mice commonly occur in urban settings in North America as in other urban areas of the world. Occasionally, they reach high densities. Millions of commensal rats may live in the larger cities (Corrigan 2001). Recently, Colvin and Kaukeinen (2008) ranked the major cities of the U.S. for their rodent risk. A number of human-caused factors make the urban setting very supportive of commensal rodent populations, and populations are maintained at low densities if continuous management actions are taken, typically with the use of rodenticides.

In many situations, urban settings inadvertently provide the basic needs of commensal rodents: food, harborage (cover), water, and a relatively predator-free environment (with the occasional exception of pets and feral cats). The urban environment also provides a relatively stable thermal environment year-round. Food comes from a variety of sources: stored foods, pet food, food spillage, and wastes. Harborage or cover comes from the many interstitial spaces in buildings, burrowing under foundations, outbuildings, sewer systems, debris piles, and other areas. Water is available from kitchens and bathrooms, leakage inside and outside of buildings, intentional or unintentional catchment devices, yard watering, pools and ponds, pet water bowls, and other sources.

Proper sanitation and exclusion integrated with inspection and management activities are all important elements of keeping urban rodent populations at low levels so that significant damage or disease hazards are not issues of concern. Specific recommendations and comprehensive municipal programs were presented by Colvin and Jackson (1999), Corrigan (2001), and Colvin and Kaukeinen (2008). Colvin and Kaukeinen (2008) described the development and use of an environmental management system (EMS) to reduce the risk of rodent infestations in urban settings. The EMS system included

- Have a solid policy and legal basis
- Assess risks and associated mitigation
- Establish specific objectives and targets
- Plan and organize necessary resources (personnel, budget, equipment)
- Acquire and train competent personnel
- Implement and monitor management actions
- Document all aspects of the EMS
- Assess EMS effectiveness with audits and reviews

Agricultural production. Farms and ranches can support large populations of commensal rodents in and around buildings for the same reasons described above for urban settings. Beyond this, however, are factors involved with the creation and maintenance of agroecosystems that can be very supportive of rodent populations. No-till agriculture can conserve soil and water resources, but provides good habitat (food and cover) for rodents (Witmer et al 2007). The grassy edges or fallow fields surrounding crop fields provide refugia for rodents, which can then take advantage of crop fields once they grow to stages that produce abundant forage and cover. Additionally, certain crops provide better conditions and resources for rodents: corn fields support more rodents than soybean fields (Witmer et al 2007, Witmer and Fantinato 2003), and alfalfa fields provide pocket gophers with higher quality food supplies than do native grasslands (Proulx 2002, 2005b). Poor grassland management and overgrazing create favorable living conditions for ground squirrels (Proulx 2010).

In some settings (e.g., agricultural areas and airports), predators are controlled or excluded for various reasons, which can result in abundant rodent populations (Kim et al 2007, Witmer and Fantinato 2003). These predator populations would otherwise dampen rodent population outbreaks (Andersson and Erlinge 1977, Baker and Brooks 1982).

Forestry operations. Clearcut logging (removal of entire forest canopy) generally results in a large response in growth by understory vegetation. This provides abundant ground cover and nutritious forage for rodents (as well as rabbits and ungulates) that take advantage of the situation. These herbivores can cause substantial damage to reforestation efforts, especially when nursery-raised, fast-growing seedlings are planted. Sullivan and Krebs (1981) documented outbreaks of deer mice (*Peromyscus* spp.) after logging, and Witmer and Engeman (2007) noted increases of pocket gophers after logging. In years of peak populations of meadow vole (*Microtus pennsylvanicus*), Buckner (1972) reported young stands of Scotch pine being completely girdled.

Rodent problems in North America

The types and levels of damage associated with high rodent population densities have been discussed by Marsh (1988) and Witmer et al (1995). Commensal rodents, for example, Norway rats, roof rats (*Rattus rattus*), Polynesian rats (also called Kiore, *R. exulans*), and house mice, cotton rats and rice rats, ground squirrels, pocket gophers, voles, and sometimes lemmings all may cause losses to crops and pasture and rangeland forage. Many of these species will also cause significant damage to orchards and young forest plantations. Deer mice are mainly seed-eaters and can adversely affect reforestation efforts. Rats and mice cause physical damage to structures and wiring when they move into buildings. Tree squirrels cause damage to electrical wiring and transformers (causing power outages), and to structures and wiring when they move into building attics. Muskrats and nutria (*Myocastor coypus*) damage marsh vegetation, dikes and levees, and nearby crops. Beaver (*Castor canadensis*) damage includes flooding of roads and pastures, cutting and eating crops and ornamental plants, damaging fish ponds by plugging overflow pipes, and flooding of forested areas (Baker and Hill 2003). Once introduced to islands, commensal rodents have also caused significant damage to endemic flora and fauna, including the extinction of numerous species (Howald et al 2007).

High rodent population densities can result in increased cases of rodent-borne disease (e.g., hantavirus) transmission to humans (Hjelle and Glass 2000, Rodriguez-Moran et al 1998, Glass et al 2000), and in increased plague outbreaks (Stapp et al 2009). Ground squirrels are reservoirs of hantavirus and several zoonotic diseases, including leptospirosis, tularemia, and plague. Water-borne tularemia is a zoonotic disease occurring in beavers and muskrats. For an overview of the many diseases carried, and potentially transmitted, by rodents, see Meerburg et al (2009).

Case history: Richardson's ground squirrels in Canada

The range of Richardson's ground squirrel (*Spermophilus richardsonii*) includes the southern prairies of Canada and extends south into the prairie region of the north-central United States. The animals are buffy-gray and average 36 cm in total length, with a mass of 450 g. They produce one litter of 6–8 young per year and live to 3–4 years. They live in colonies and build and occupy elaborate burrow systems. They feed on a variety of natural green vegetation and seeds, but also various crops. The Richardson's ground squirrel is second in prominence only to the grasshopper in the rogue's gallery of agricultural pests in the Canadian plains. Reliable and comprehensive data are scarce, but it is certain that this rodent did severe damage to crops over large areas of the Canadian prairies in the last century, and generations of farmers waged battles to control this species (Banfield 1974).

In 2000-01, western and central Canadian prairies experienced a severe drought with warm winter and low precipitation (Liu et al 2004). As Richardson's ground squirrels prefer to establish their burrow systems in fields with shorter vegetation and good visibility (Yensen and Sherman 2003), dry weather and depressed plant growth created ideal conditions for a population outbreak (Proulx 2010), with densities often exceeding 40 animals ha^{-1} in spring (Proulx et al 2010). An increase in cattle numbers in the late 1990s (Statistics Canada 2001) because of a valuable market, and a huge livestock oversupply due to import restrictions on live ruminant animals and meat products from Canada caused by the discovery of bovine spongiform encephalopathy (mad cow disease) in 2003 (Mitura and Di Piétro 2004), led to overgrazing and persistence of favorable environmental conditions for ground squirrels (Proulx 2010). Although there was an obvious lack of effective control methods available to farmers at the beginning of the population outbreak (Proulx 2010), the adoption and misuse of a variety of poison baits during the 2000s (e.g., strychnine baits spread on surface, alteration of registered baits with other toxicants and attractants, excessive use of anticoagulants in poor bait station designs, etc.) resulted in an increase in moribund and poisoned ground squirrels and nontarget animals on the surface, and the subsequent poisoning of predators that further contributed to a lack of effective control of ground-squirrel populations (Proulx 2010). The Richardson's ground squirrel population outbreak was therefore due to an agricultural drought and poor grassland management following socioeconomic changes, and the depletion of predator populations (Proulx 2010).

The control of Richardson's ground squirrel populations requires a long-term management program, integrating sustainable grassland management techniques with an effective conservation of mammalian and avian predators, and the sensible use of effective rodenticides. The success of such a multifaceted management program will depend on the establishment of an effective education program, the institution of incentive programs for better management of grassland ecosystems, and the implementation and enforcement of rules to better monitor the production and distribution of effective poisons, and minimize their excessive use (Proulx 2010).

Case history: voles in Washington State

Voles occur over a large part of North America (Witmer et al 2009). These animals are grayish brown, and average 15–16 cm in length, with a mass of 40–50 g. They produce 1–5 litters of 3–6 young per year, but live only about a year. They build and occupy simple burrow systems with many openings. They feed on a variety of natural green vegetation and seeds, but also various crops. They are active year-round and feed on tubers and roots during the winter. When densities are high, they cause substantial damage to agriculture (Witmer and VerCauteren 2001). In no-till agricultural crop fields in the state of Washington, montane voles (*Microtus montanus*) and long-tailed voles (*M. longicaudus*) are the main damaging species.

Vole studies began at the Palouse Conservation Farm because of the damage being sustained in experimental no-till crop fields. Unfortunately, the land management practices used in no-till agriculture to conserve water and soil (no annual tillage, no burning, and leaving plant stubble) all benefit small rodent populations (Witmer and VerCauteren 1991). Initially, rodent population densities were high, with as many as 70 captures overnight in 10 by 10-m grids of 100 Sherman live traps (Witmer, unpublished data). As much as a 15% loss of pea plants occurred over winter (Witmer et al 2007). This can happen because voles remain active all winter under snow cover. A food habits study revealed that the voles were feeding mainly on grain crops (barley and wheat) as well as pea plants (Witmer et al 2007). It was clear that vole populations abandoned fields after harvest and that the surrounding fallow fields provided refugia for survivors and a source population that could later reinvade fields once crops were growing again.

Experimental population and damage control methods were started (Witmer et al 2007), but, unfortunately, the vole population crashed of its own accord so the study results were equivocal. Metal barriers extending about 38 cm above and below ground did not prevent rodent access to crops. Zinc phosphide–treated grain reduced populations, but they rebounded within a year. This suggests that rodenticide baiting would need to be a long-term vole management requirement to keep populations below significant damage thresholds.

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Notes

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Rodent outbreaks in sub-Saharan Africa

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Rodent outbreaks are a major concern for agriculture in Africa, especially in drier areas. In this chapter, we describe the phenomenon, the species involved, and the hypotheses that exist to explain it. The population dynamics seem to be best explained by a link with rainfall through bottom-up processes. We review recent work and describe, using the example of Tanzania, how an understanding of rodent population ecology helps to develop prediction and simulation models that can assist in decision making about control strategies.

In sub-Saharan Africa, cereal crops are plagued by a number of eruptive animal pests that cause enormous harvest losses during outbreak years, while being absent or at least less conspicuous in other years. Among insects, the desert locust (*Schistocerca gregaria*) and the African armyworm (larvae of a migratory moth) (*Spodoptera exempta*) are prime examples. Among vertebrates are the red-billed quelea (*Quelea quelea*) and several related species, and obviously there are also rodents. During rodent outbreak years in eastern Africa, locally, more than 80% of the potential harvest may be lost (e.g., Mwanjabe et al 2002), but even in nonoutbreak periods rodents cause chronic damage to crops (Fiedler 1988b, Makundi et al 2005).

Rodent pest outbreaks have been recorded in Africa since the early 19th century (Fiedler 1988a). However, of the almost 400 existing rodent species on the African continent, only about 5% are known to cause damage to agricultural crops (Makundi et al 1999). *Mastomys* and *Arvicanthis* species are most frequently involved in population irruptions, and they are considered the dominant vertebrate pest species in sub-Saharan Africa (Table 1). Broad-scale management of these rodents tends to rely on rodenticides. Ecologically based rodent management (EBRM) techniques (Singleton et al 1999) are still rare in sub-Saharan Africa, although there has been a considerable increase in the knowledge of the involved species' ecology during the last two decades (see below).

In this chapter, we will provide a brief overview of rodent outbreaks on the African continent. Although our overview is not exhaustive, we will use it to illustrate the different hypotheses proposed to explain nationwide outbreaks. We point out some of the work that has been done since an earlier review on rodent outbreaks in Africa (Leirs 1999). We focus on different models that were developed and how these are currently applied by different actors, using the situation in Tanzania as an example.

Table 1. Reported outbreaks of the genus *Mastomys* on the African continent over an 80-year period. Updated after Fiedler (1988a), Leirs (1995), Leirs et al (1996), and previously unpublished data collected during the Staplerat project. Abbreviated species names: *An, Arvicanthis* sp.; *Gl, Gerbilliscus leucogaster*; *Gg, Gerbillus* sp.; *Me, Mastomys erythroleucus*; *Mh, Mastomys huberti*; *Mn, Mastomys natalensis*; *Rp, Rhabdomys pumilio*; *Tg, Taterillus gracilis*.

Years	Country	Species	References
1925-26	Tanzania	*Mn*	Harris (1937)
1930-31	Tanzania	*Mn*	Harris (1937)
1936	Tanzania	*Mn*	Kingdon (1974)
1951-52	Kenya, Tanzania	*Mn, An*	Heisch et al (1953), Taylor (1968)
1955-56	Tanzania, Uganda	*Mn, An*	Chapman et al (1959)
1961	South Africa	*M* sp.	Malherbe (1963)
1962-63	Kenya, Sudan, Tanzania, Nigeria[a]	*Mn, An, Rp*	Taylor (1968), Brei (1981)
1963	South Africa	*Gg.*	Hey (1974)
1966	Zambia	*Mn*	Sheppe (1972)
1966-69	Botswana, South Africa	*Mn, Gl*	Smithers (1971)
1967	Zimbabwe	*Mn*	Choate (1975)
1968	Kenya, Tanzania	*An*	Mkondya (1977), Staplerat report
1969	Sudan	*Mn, An*	Hopf et al (1976)
1971	Tanzania	*Mn*	Kingdon (1974)
1970-72	Nigeria	*Mn, An*	Brei (1981)
1975	Tanzania, Zimbabwe	*Mn*	Choate (1975), Mkondya (1977), Fiedler (1985)
1975-76[b]	Mali, Mauritania, Niger, Nigeria, Senegal, Sudan	*Mn, An, Mh, Me, Tg, Gg*	Poulet (1980), Brei (1981), Hubert and Adam (1985)
1977	Tanzania	*Mn, An?*	Mkondya (1977)
1977-78	Kenya	*An, Mn*	Akiev (1982), Darlington (1984)
1978	Somalia	*Mn*	Barre (1978)
1979	Zambia	*Mn*	Staplerat report
1979-80	Senegal	*Me, Tg*	Hubert and Adam (1985)
1983-84	Tanzania	*Mn*	Telford (1989), SUAPMC[c]
1984-85	Zambia	*Mn*	Staplerat report
1986	Kenya	*Me*	Staplerat report
1986-87	Chad, Sudan	*An, Mn*	Fiedler (1988b)
1987	Tanzania	*Mn*	Leirs (1995), SUAPMC[c]
1989	Tanzania, Zambia, Kenya	*Mn, Me*	Mwanjabe (1990), Mwanjabe et al (2002), Staplerat report
1991	Zambia	*Mn*	Staplerat report
1998	Tanzania, Zambia	*Mn*	SUAPMC[c], Staplerat report
2001	Tanzania, Zambia	*Mn*	SUAPMC[c], Staplerat report
2005	Tanzania	*Mn*	SUAPMC[c]

[a] Reported as rodent outbreak south of Lake Chad in northern Nigeria in the early 1960s.

[b] A major rodent outbreak occurred throughout the Sahel region during this time period.

[c] Unpublished data, SUA Pest Management Center, Morogoro, Tanzania.

Rodent outbreaks in sub-Saharan Africa

Different rodent species living in different ecosystems cause significant problems to agriculture in Africa. Some species have a clear tendency to be more r-selected and reach outbreak abundance now and then. Others tend to be more K-selected and, although less prone to outbreaks, they often have greater body mass and eat more of the crop per capita. The latter group can be responsible for considerable damage locally but with little interannual variation. They include the large cane rats (*Thryonomys* spp.) that can be problematic in sugar cane or rice plantations. In this chapter, we will focus on species that display drastic variations in population numbers between years.

Population outbreaks of rodents in Africa seem to be limited to just a few species, mainly species belonging to the murine genera *Mastomys* (multimammate mice) and *Arvicanthis* (grass mice), except in the Sahel region, where several gerbil species can be involved as well (see Table 1). Both genera are endemic to Africa. *Mastomys* is the most common genus of rodents (and probably of mammals) in Africa, and currently comprises eight species (Wilson and Reeder 2005). It is widespread in Africa south of the Sahara. The most important species for agriculture or public health are *M. natalensis* (occurring over most of the continent), *M. huberti* (in West Africa), *M. erythroleucus* (from Senegal to Ethiopia, and south to Cameroon and eastern Democratic Republic of Congo), *M. coucha* (inland in South Africa), and *M. awashensis* (in Ethiopia). Most species are difficult to recognize externally and often chromosomal or molecular identification is needed (Granjon et al 1997, Lecompte et al 2005). In studies that did not use such identification techniques, animals have not always been assigned to the correct species. This occasionally leads to confusing knowledge on the biology of these rodents. Other confusion may stem from the older inclusion of multimammate rats in the genus *Praomys* (used in some papers up to 1990) or problems with species names (Granjon et al 1997). The taxonomy of the genus *Arvicanthis* as well still requires considerable attention, but currently seven species are recognized, which all occur in the northern half of the continent (Wilson and Reeder 2005). The species of both genera live mainly in grasslands and wooded savanna, cultivated areas, and, particularly for *Mastomys* sp., in human dwellings or stores (Kingdon 1974).

The ecology of the genus *Mastomys* has been studied intensively during the past two decades, in different regions of Africa (e.g., Duplantier and Granjon 1988, Leirs 1995, Bekele and Leirs 1997, Monadjem 1998, Mohr et al 2003, Mahlaba and Perrin 2003, Vibe-Petersen et al 2006, Massawe et al 2007, Crespin et al 2008, Sluydts et al 2009). Crucial for their outbreak capacity is the substantial reproductive potential, which is characterized by the large number of mammae (8 to 12 pairs) they possess; hence, their common name of multimammate mice. Under favorable conditions, litter sizes can reach 27 young (Duplantier et al 1996) with fecundity rates up to 68 young per adult female (Leirs et al 1993).

Importantly, changes in population numbers of African rodent pests seem to be regulated primarily by bottom-up processes (Leirs et al 1993, 1997a). An abundant amount of rainfall, especially early or late in the season, being one of the key factors that drive primary production, is hypothesized to cause outbreaks of multimammate mice (Leirs et al 1996). Some studies hypothesized important effects of predators or disease on *Mastomys* sp. population dynamics (Hubert and Adam 1983, Fiedler 1988b, Granjon and Traore 2007, Crespin et al 2008), but experiments in Tanzania could not indicate significant effects on rodent abundance (van Gulck et al 1998, Vibe-Petersen et al 2006). Interestingly, however, increased predator presence changed the rodents' behavior and this in turn reduced damage in maize fields (Mohr et al 2003). In a comparative analysis between *Phyllotis darwini* from Chile (also an eruptive rodent species) and *Mastomys natalensis* from Tanzania, we found that the population dynamics of the South American rodent was very sensitive to differences in survival in some seasons, whereas, in multimammate mice, variations in recruitment were the most important (Lima et al 2003).

What is an outbreak?

In the 1960s, outbreaks were reported from Sudan all the way down into South Africa (Table 1). In the 1970s, the whole West African Sahel region was plagued by several rodent population irruptions (Poulet 1980, Hubert and Adam 1985). In 1989, a widespread outbreak of the multimammate mouse was reported in the Lindi region in Tanzania. Rodent densities were estimated to reach 1,400 rats per hectare, causing a yield loss of 48% in maize fields. As a consequence of this outbreak, the Tanzanian government had to supply food to residents threatened by famine (Mwanjabe et al 2002). Other outbreaks were geographically fairly limited, but were often reported only in the gray literature or in ecological studies for which the field work accidentally co-occurred with such an event (Leirs et al 1996).

Most historical reports on rodent problems are of a descriptive nature and they often lack detailed information on the magnitude of the rodent outbreak and the amount of crop damage caused. Vagueness of the term "outbreak" used throughout the literature is illustrated for example in Hubert and Adam (1985), where the authors indicated that the 1975-76 outbreak was a "large outbreak," while the 1979-80 one was "less marked." Between 1925 and 2005, 16 outbreaks were reported in Tanzania alone. In addition, the Rodent Control Center (RCC) of the Ministry of Agriculture in Tanzania undertook extensive field campaigns applying rodenticides in 16 out of 22 years from 1983 to 2004. In some years, just over 400 ha were treated with rodenticides, while in other years campaigns spread over 60,000 ha (Fig. 1).

In general, a rodent population outbreak could be defined as a sudden rise in population density that goes beyond the normally observed density fluctuations in the population. Such a definition is vague and not really useful for practical purposes. Defining an outbreak is a difficult task and in general will depend on the place, the rodent species, and a certain viewpoint people take when experiencing or working with high rodent numbers. Population ecologists are inclined to define a rodent outbreak by a threshold rodent density (e.g., Singleton et al 2005). A farmer, however, may speak of an outbreak when he or she experiences rodents invading the individual crop field. An agricultural planner regionally or nationally may consider high rodent numbers

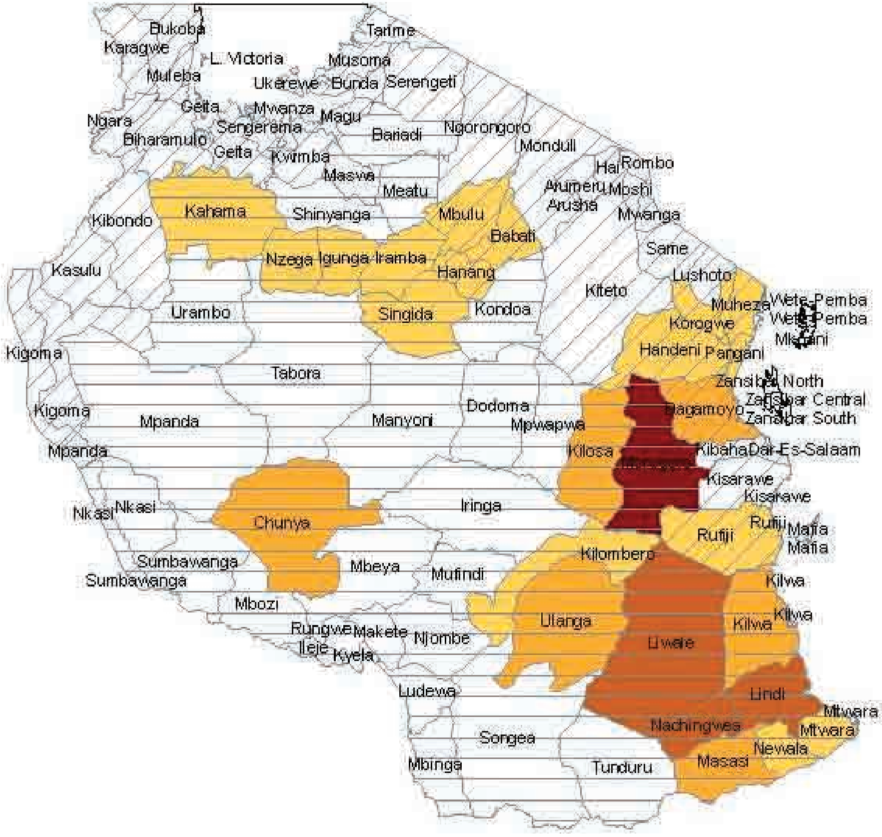

Fig. 1. Frequency of interventions made by the RCC in Tanzania in response to reported rodent problems between the early 1980s and 2000 (data, personal communication from Patrick Mwanjabe, Rodent Control Center, Morogoro, Tanzania). The darker the zone, the more interventions that were made. Horizontal lines indicate places with a unimodal rainfall pattern (one cropping season) and sloping lines have a bimodal rainfall pattern (usually two cropping seasons).

an outbreak if assistance for rodent control is requested over a large area, if harvest losses become economically significant, or if food security in an area is threatened.

In Australia, in most years, house mice occur at such low densities that they are even hard to trap. From above 50 mice per hectare, Australian scientists speak of a rodent outbreak, between 200 and 800 they call a minor plague, and above 800 a major plague. The categories are accompanied by comments on economic losses. A minor plague is accompanied by damage spreading over several hundred square kilometers, while for a major plague this extends to thousands of square kilometers (Singleton et al 2005). In Africa, the separation between “normal” densities and outbreaks is less dichotomous. In a population of *M. natalensis* in Morogoro, Tanzania, densities fluctuate seasonally between approximately 20 and 300 animals per ha, but during outbreak years this may surpass 1,000 animals per ha (Telford 1989, Leirs 1995). The peak density in a year may be less relevant than the density at the time when crops are most vulnerable. For example, Mulungu et al (2002) found that, during the planting season, even a rodent density of 40 multimammate mice per ha could lead to the destruction of 80% of maize seedlings. A clear cut-off value for rodent outbreaks in Africa has never been formulated although it has been implicitly assumed when formulating outbreak models, whether they are conceptual or statistical. For example, a logistic regression was used to describe the relation between rainfall and outbreaks in Tanzania (Leirs et al 1996). Indeed, in order to develop predictive models and test hypotheses, it is of prime importance that years with the presence or absence of an outbreak be correctly identified.

What causes rodent outbreaks in Africa?

Rodent outbreaks have been reported in a variety of places in Africa, but, even since the beginning of the 20th century, they were associated with rainfall patterns. Several authors have proposed different mutually nonexclusive hypotheses to provide an explanation for the observed phenomena. About ten years ago, a review was published on the different models that existed to explain rodent outbreaks in Africa (Leirs 1999) and since then no new major insights have been developed, so we repeat only the major existing ideas here. Taylor and Green (1976) and Hubert and Adam (1985) proposed that a prolongation of the rainy season could generate excess food and cover, allowing for better survival and/or reproduction of rodents. This in turn could lead to irruptive population behavior, especially after a period of low density. Fiedler (1988b) suggested that, in more arid countries in Africa, consecutive dry years would result in a decrease in size of the rodent population, and of its competitors and predators. When the rains return, those who are able to respond most quickly, typically the r-selected species, could generate enormous population growth rates. A different scenario highlighted the importance of unusual timing of rainfall in places with a bimodal rainfall pattern (Leirs et al 1996). When rainfall during the first peak of the rainy season is abundant, rodents can start breeding before the main breeding season. The new recruits grow fast and are able to participate in the main breeding season. Therefore, mice from two generations breed in the same reproductive season, resulting in an exponential increase in the population. The mechanisms and demographic processes underlying this scenario have been documented in Tanzania (Leirs et al 1990, 1993a, Firquet et al 1996). Several projects attempted to investigate whether the same scenario applies to other regions in eastern and southern Africa, but conclusions remain elusive mainly due to the absence of outbreaks in the study periods (unpublished reports of the STAPLERAT and RATZOOMAN projects, available from www.nri.org/projects/ratzooman/publications.htm).

In Africa, outbreaks of rodent populations seem to originate locally, and suggestions in older literature that they are the results of mass migrations over distances of many kilometers (e.g., Harris 1937) are not supported by actual observations. No-table exceptions to this, however, are localities where periodic flooding events cause rodents to aggregate on higher ground and then reach very high densities there. This is the case in, for example, the Zambian floodplains (Sheppe 1972) or the inner delta of the Niger River in central Mali (Granjon et al 2005, Crespin et al 2008). This is not to say that movements of rodents are not important for rodent pest problems in other parts of Africa: short-distance daily movements were observed between grassland and crop fields in Tanzania (Leirs et al 1997b) and *M. natalensis* were seen to move into houses after harvest time in a Lassa-fever endemic region in Guinea, West Africa (Fichet-Calvet et al 2007).

How can an outbreak be predicted?

Given the stochastic nature of precipitation, if variation in rainfall distribution over time is the major underlying trigger for rodent outbreaks in Africa, then long-term forecasting of outbreaks seems to be impossible. However, the delay between unusual rainfall events and the effects on the rodent population does allow for predictions that span one agricultural season. This may be sufficient time to enable farmers to implement preventive management actions. A logistic regression model was built for rodent outbreaks in Tanzania using historical reports of outbreaks over a 30-year period (1947-77) (Leirs et al 1996). The model uses cumulative rainfall over the months December-January in Tabora, Central Tanzania (corresponding to the early start of the wet season and thus important for the initialization of the reproductive season in *M. natalensis*), as the explanatory variable and the occurrence of an outbreak (yes or no) as the dependent variable. It is remarkable that this model performs so well with rainfall from a single locality in predicting outbreaks throughout the country, because Tanzania has two different wet-season regimes: a bimodal pattern in the northern part and along much of the coast, and a unimodal pattern in the center and south of the country. As it seems, the early rains in Central Tanzania provide a good indication of early precipitation in the rest of the country. Indeed, although total amount of rainfall is difficult to predict, the timing of the onset of the major rainy season is more correlated over the whole of East Africa (Camberlin et al 2009). Still, outbreaks do not always occur throughout the country.

The logistic regression model allows an estimate of the likelihood of a rodent outbreak approximately 6 months in advance, if local rainfall data are available. This likelihood can then be used as a basis to decide whether or not to start preparations for rodent control actions. Initiating such actions only when the probability for an outbreak is high incurs the risk that an outbreak will occur anyhow although one is not prepared; initiating actions at too low a probability will incur expenses that may turn out to be unnecessary. Davis et al (2004) showed how one can make a decision that maximizes the economic benefit, if one takes into account the cost of the damage caused during an outbreak, the expenses for control actions, and the mitigation effect of the control actions on the damage. They calculated that, for Tanzania, using a specific set of costing parameters, there is a threshold of 366 mm of cumulative rainfall in December-January. Of course, decisions may be influenced also by political and societal considerations, other than just the economic cost. A predictive tool like this is useful for agricultural planners or pest control authorities at local and regional levels. Of course, it does require information on local precipitation. The Tanzanian Ministry of Agriculture's Rodent Control Center recently set up a system with pluviometers in each district where rodent outbreaks are known to occur now and then. An alternative approach may be to use remote-sensing information to estimate rainfall, for example, based on greenness of vegetation (Martiny et al 2010), a system that has also been developed to predict rainfall-related infectious diseases (Anyamba et al 2010).

Although regression models as described above are good for forecasting, they provide no possibilities for assessing the efficacy of control actions or evaluating what-if scenarios. In contrast, mechanistic models that describe what is happening in a rodent population, rather than when it is happening, have a poor real-life predictive value because of the stochasticity in the environment, but they are very useful for simulation exercises (Leirs 1999). Stenseth et al (2001) used the population dynamics model for *M. natalensis* from Morogoro (Leirs et al 1997a) to simulate what the effects would be on the rodent population of different timing of rodenticide applications. Skonhoft et al (2006) extended this to a bio-economic model by including data on the cost of rodenticide application, the value of the harvested crop, and the cost of agricultural inputs such as field preparation, planting material, and fertilizer. The optimal strategies from a bio-economic perspective turned out to be quite different from the ones that were considered the best ones in a purely population dynamics approach. Interestingly, it was also noted that the more economical strategies may differ between low-input (subsistence farmers) and high-input farms (large commercial farms).

Conclusions

Population outbreaks of rodents occur in different regions in Africa and seem to be initiated bottom-up, linked to precipitation. This makes outbreaks predictable at least some months in advance, without the need for continuous biological monitoring. Understanding also the mechanisms underlying the population dynamics of rodents allows for the development of simulation and decision models, including also economic components. However, the pest rodent story in Africa involves several species embedded in a broad and variable landscape with highly variable densities, with some species causing damage even in nonoutbreak years. A more detailed reporting scheme for both minor and major outbreaks would be most useful to better understand the spatial and temporal patterns of this problem in Africa.

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Notes

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Appendix 1.
Recipes for rodent culinary delights

Compiled by Grant Singleton

In many places in Asia and Africa, rodent meat provides an important protein supplement to the diet of people. In some instances, rat meat is imbedded in the culture of societies. For example, in southern Vietnam, some weddings are not complete unless there is a plate of rat meat at each table of the wedding reception. The rat meat signifies fertility, an important symbol for the newlyweds. In 2002, Khiem et al (2003) conducted a market study of meat from field rats in the Mekong Delta in southern Vietnam. They identified five trade routes in six southern provinces of Vietnam. Two of the major markets for the meat were Can Tho and Ho Chi Minh City. However, throughout the Mekong, rat meat appears on the menu of restaurants (Fig. 1). They estimated the annual trade in rat meat to be 3,300–3,600 t of live rats. From personal observation of this trade, at least 90% of the rats are *Rattus argentiventer*. The mean weight of an adult *R. argentiventer* is around 125 g (Brown and Tuan 2005); therefore, more than 25 million rats entered the rat meat market in that year.

In this section, we provide a selection of recipes for preparing rodent meat. Rodents are potential carriers of more than 60 human diseases, so good hygiene needs to be practiced when preparing the rats for cooking. Also, we recommend that the rat meat be well cooked before it is consumed, and one never consumes rats that typically occur in cities, such as the Norway rat, *Rattus norvegicus*. With those words of caution, we now invite you to enter a world of unusual culinary delights. With the recipes that follow, I am sure that you will be more than tempted to try one of these dishes the next time you see rodent meat on the menu in a restaurant during your travels in Asia or Africa. Bon appétit!

Fig. 1. Rat meat was featured at this restaurant in An Giang Province in southern Vietnam in November 2008. The translation is "New dish (*moi*); roasted nhum rat Peking style" (nhum = the name of a rather big rat, *Bandicota* species).

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Fried rat meat (Myanmar)
(Kywatha Kyaw)

Provided by Nyo Me Htwe

Ingredients

1.5 kg	Roasting rat meat
2	Medium onions
3 cloves	Garlic
1 teaspoon	Finely grated fresh turmeric
1 stalk	Lemon grass
3 tablespoons	Peanut oil
1 1/2 teaspoons	Salt
1 teaspoon	Ground turmeric
1/2 teaspoon	Chilli powder

- Cut rat meat into bite-sized pieces
- Peel and roughly chop onions and put into blender container with garlic, turmeric, and sliced lemon grass
- Heat the peanut oil in an 8- to 12-quart pan or Dutch oven
- Add the blended ingredients, salt, and chilli powder
- Cook on medium heat, stirring occasionally, until the onions are limp but not browned, for about 20 minutes
- Add the rat meat pieces and stir to coat them with the onions and spices
- Fry over medium heat, stirring well with a wooden spoon
- At this stage, they will begin to stick to the pan; so, keep stirring
- Add the rat pieces, turning them well in the mixture so that they are coated evenly
- Cook, turning every 5 minutes, until the rat meat is tender and the skin is crisp
- Serve with white rice

Savannakhet roulette (Lao PDR)

JOHN SCHILLER

Ingredients (to serve 4 people):

1 kg (or 5 medium-sized field rats)		Rat meat
2–4	local variety	Medium onions
2	stalks	Lemon grass
1	teaspoon	Salt
2	cloves	Chilli
1 1/2	cups	Sticky rice
		Vegetable oil; banana leaves

- Quickly burn off the fur
- Remove the intestines and other internal organs
- Skin the rat
- Brush outer layer with vegetable oil and sprinkle salt
- Finely chop the onions and garlic; grind the lemon grass
- Wrap in banana leaf and steam for 2 hours
- Add chilli, lemon grass, and onion

Ready to serve with sticky rice

Champassak delight (Lao PDR)

Ingredients (to serve 4 people):

8 medium-sized “forest rats”	Rat meat
1 teaspoon	Salt
2 cloves	Chilli
	Vegetable oil
1 liter	Rice whiskey

- Soak rat in hot water to remove the hair
- Remove the intestines and internal organs
- Brush meat with vegetable oil and sprinkle salt
- Finely chop the garlic and add
- Barbeque the meat—best if medium to well done—and sprinkle rice whiskey as meat cooks
- Add mimosa or local greens as a garnish
- Partake of the barbequed meat with copious quantities of rice whiskey

Mekong special—Riz au rat (Vietnam)

Ingredients

8 medium-sized “spring field rats”
2 cloves

Rat meat
Chilli
Fish oil

- Soak rice for 1 hour
- Remove intestines and other internal organs
- Skin the rat
- Steam the rat meat
- Finely chop the garlic
- Pound together the rice, rat meat, chilli, and fish sauce
- Heat until rice is ready for consumption

Masakan “Tikus Bumbu RW”

Provided by a colleague of Djafar Baco
(dish from Manado, North Sulawesi, Indonesia)

Ingredients

5 rats	
2 ounces	Small chilli (*rica*)
± 5 grams (2 internodes)	Ginger
15 blades	Onion stem (*rampa-rampa*)
1 bundle (2.5 cm diameter)	Basil leaf
3 upper internodes	Citronella stem
3 leaves	Atsiri leaf
12–15 leaves	Citrus leaf
10 fruits	Citrus juice (*jeruk nipis*)
0.5 liter	Coconut oil
Add for taste	Salt
5–6 cloves	Garlic

Prepare the rat meat

- Burn the hair of the rat; after the body is clear of hair, burn again until oil seeps out
- Before cooking, roast first and dice the body of the rat
- Cut the rat into 1 to 6 pieces (depends on size)
- Soak in *jeruk nipis* (orange juice) for 15 minutes
- Fry the rat until it is half-cooked

Prepare the spices and other additives

- Prepare the spices separately with coconut oil (1–4 tablespoons); cook over a gentle flame
- Chop the garlic until it is brownish and dice the onion stem; add both to the cooking meat
- Mash the ginger and then add
- Finely cut the basil leaf; cut the citronella blade into 3–4-cm lengths and add these plus the citrus leaves

Final preparation

- After the spice and other mix becomes pale (2–3 minutes), add the half-cooked rat and add half a glass of water and then cover the simmering mixture for 2–3 minutes
- After that, add salt accordingly and stir
- After the water and oil have evaporated, the dish is ready to be served

Contribution from Zambezia, Mozambique

For more details on how to catch the rats and photos of the catching and cooking process, visit http://mozi-ing.blogspot.com/search?updated-min=2010-01-01T00%3A00%3A00-08%3A00&updated-max=2011-01-01T00%3A00%3A00-08%3A00&max-results=50.

Capture the rats from fields. Keep the bodies in a pile and count them only at the end. To do otherwise is bad luck. Boil the rats in a pot and then stack the rats on skewers to dry over a hot fire. These dried/roasted rats can be stored on the skewer for several days. When you feel a craving for rat, just throw a few in an earthen pot with some salt and water, bring to a boil, and then eat with your *chima* (thick cassava porridge)—hair, feet, tripe, and all.

Editor's note: Zambezians eat the intestines, fur, and most everything; generally all that remains are the teeth and tail.

Food to keep rats away from your rice fields

This came up when M.A. Quilloy was involved in focus group discussions with farmers in Infanta, Quezon, Philippines. It is an indigenous way of dealing with rats visiting the rice fields, diverting their attention and appetite.

Ingredients (to feed 50 rats)

10–15 fresh coconuts	Grated coconut meat (any amount)
2 kg	*Penuche*—a sweet Filipino delicacy made from sugar cane (a class of muscovado sugar)
1 liter	Coconut milk

The following should be prepared in the middle of the rice fields:

- Mix all ingredients together and boil
- Stir constantly until crumbling consistency is attained
- Scatter the cooked product

  The aroma of sweet-smelling coconut cooking and the sweet taste attract the rats. This food is cooked for the rats as a “special” food for them, in time when they visit the rice field. The rats end up eating the prepared delicacy instead of the rice stalks or grains.