1. Ecologically-based Management of Rodent Pests—Re-evaluating Our Approach to an Old Problem

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Abstract

Rodent pest management has gone through a period of stagnation mainly because there has been too little research effort to understand the biology, behaviour and habitat use of the species we are attempting to manage. There is a growing demand, particularly in developing countries, for rodent control strategies that either have less reliance on chemical rodenticides or can better target their use. Similar concerns exist with the control of insect and weed pests. This has led to the development of the concept of ecologically-based pest management (EBPM) which builds on the progress made with integrated pest management (IPM). We analyse this idea for rodent pests and provide examples where research on the basic biology and ecology of rodent pests has provided management strategies that are more sustainable and environmentally benign. The theme of ecologically-based rodent management (EBRM) was foremost in our minds when we invited people to contribute to this book. The other significant considerations were a focus on rodent pest management in developing countries and the importance of marrying basic and applied research on rodents. If in developing countries we can foster the importance of population ecology and an emphasis on management directed at the agro-ecosystem level, then we are confident that the next decade will see rapid advances in rodent pest management.

Keywords

Rodent management; IPM; rodent ecology; ecologically-based rodent management

Introduction

The genesis of this book was a common concern on the lack of progress in rodent pest management over the past 20 years in both developing countries and elsewhere. This has occurred despite the advent in the 1970s of sophisticated chemical rodenticides and effective strategies for their use (see Buckle 1988; Buckle and Smith 1994).

We contend that rodent pest management has gone through a period of stagnation for four primary reasons. First, there has been too great an emphasis on how to develop, use, compare and market rodenticides, with particular attention on commensal rodents in industrialised countries. In developing countries, on the other hand, the lack of a critical approach to the use of rodenticides for particular species has in some instances led to an unreasonable aversion to rodenticide use. Second, the development of rodent control strategies generally has been based on short-term experiments where immediate declines in rodent numbers were seen as a success, without much consideration of long-term consequences or ecosystem effects. Third, field studies have rarely progressed beyond alpha-level, descriptive population studies (see Krebs, Chapter 2). Fourth, the recommended management protocols have been too prescriptive. They rarely take into account the particular characteristics of the pest species or of the socioeconomic constraints of the end-users of the technology.

What has been lacking is a solid understanding of the biology, behaviour and habitat use of the respective species we are attempting to manage. Armed with such knowledge we will be able to focus on disentangling the major factors that limit the growth of pest populations. This requires experimental field studies conducted at an appropriate scale and for an appropriate length of time. Recently there has been some progress in the assessment of rodent management methods using replicated, manipulative field studies based on our understanding of the ecology of the pest species (e.g. Singleton and Chambers 1996; Brown et al. 1998; White et al. 1998; Fan et al., Chapter 13), but there is still much to be done.

In the interim, there has been a marked attrition in the number of wildlife researchers working on rodent pests. Ishwar Prakash (1988) noted this trend in his introduction to the pioneering book *Rodent Pest Management*.

> It is also felt that this work … will trigger more research effort for the benefit of mankind, … (which) it appears has dampened during the last few years.

Unfortunately, his plea did not arrest this trend.

Since 1993 there has been encouraging evidence of an increase in the number of young wildlife researchers interested in the biology and management of rodent pests in developing countries. This has been due primarily to funding support provided by the Australian Centre for International Agricultural Research in Southeast Asia, the European Union, Belgium and Denmark in eastern Africa and ORSTOM (French Scientific Research Institute for Development through Cooperation) in Western Africa. We are pleased that some of

these researchers have been able to contribute to this book.

China, through necessity, also has seen a marked increase in research effort on rodent pests. Rodent problems increased in severity in the 1980s resulting in rodent control being listed as one of the top three priorities for the national plant protection program in 1985. Since 1985, rodent control has been listed in three successive national five-year-plans (1985–1990; 1991–1995; 1996–2000). There are now approximately 100 scientists with the Chinese Academy of Sciences, Ministry of Agriculture and universities working on rodent control. Many of these are young scientists, who received their degree in biology or post-graduate qualifications in the 1990s.

In this opening chapter we will set the scene with a brief overview of the magnitude of the impact of rodent pests, the concept of ecologically-based management and the aims and structure of the book.

Rodent Pests—Still a Problem

The quest to control the depredations of rodents, especially in agricultural systems, has been ongoing for thousands of years. Aristotle (384–322 BC) recounts

> The rate of propagation of field mice in country places, and the destruction that they cause, are beyond all telling.

Although the last 50 years in particular have provided good progress with rodent pest management, rural people in many countries still rank rodents in the top three of their most important pests. Of particular concern are the losses caused in developing countries where rodents are literally competing with humans for food.

A meeting on rodent pest management in Southeast Asia was held in early 1998 at the International Rice Research Institute (IRRI) in the Philippines. Reports of present-day rodent problems were presented for Australia, Cambodia, East Africa, Indonesia, Lao People's Democratic Republic (PDR), Malaysia, Philippines, Thailand and Vietnam; the accounts were impressive in their extent and impact. Rodent problems ranged from eruptive populations of mice in south-eastern Australia and rats in the uplands of Lao PDR, to the chronic problems that occur annually in the rice fields of most Southeast Asian countries.

There were two telling commentaries from the meeting in the Philippines, which place in context the impact of rodent pests in developing countries. One reported that although rodents were not the most important pre-harvest pest to Laotian farmers, they were the pest they felt they had the least control over. The other presented losses caused by rodents in Cambodia not in monetary terms but in how much rice could have been available for annual human consumption if not for rat depredations. If we apply this line of reasoning to Indonesia where rats cause annual pre-harvest losses of approximately 17%, then rats consume enough rice annually to feed more than 25 million Indonesians for a year. In countries such as Indonesia, rice provides 50–60% of the daily energy requirements for people.

In some cases, the 'official' national level of annual pre-harvest losses caused by rodents is not high. For example, 3–5% losses are reported in Malaysia (Singleton and Petch 1994) and 1–3% in the Philippines (Sumangil 1990; Wilma Cuaterno, April 1998, pers. comm.). However, when detailed

damage assessment is conducted, the damage caused by rats generally is more severe. For example, Buckle (1994b) reported a conservative loss estimate of 7.3% in the entire Penang State of Malaysia. Also, both in the Philippines and Malaysia, the patchy nature of rodent damage often results in farmers losing more than 60% of their crop, which means that rodents are still a significant national problem (Lam 1990). In other places, rodent damage may vary widely with limited damage in most years, and the most extreme losses of more than 80% of the harvest in outbreak years (e.g. Boonaphol and Schiller 1996). In countries that live at the brink of subsistence, such figures are a constant threat to food security.

This book contains detailed accounts of the magnitude and importance of the impact of rodent pests, particularly in agricultural systems. This information in itself is important because it provides a spotlight on rodent problems that generally have a lower profile than insect, weed and disease impacts on agricultural crops. The latter group of problems has a higher profile for two reasons. One is that, in developing countries, there are many entomologists, botanists and plant pathologists who are able to identify, quantify and sell the need for research, education, extension and action in their respective fields. In comparison, there are few rodent biologists; most of these have an entomological training and there is a poor infrastructure for research on rodent pests.

The second reason is that farmers have a stronger identity with rodents than other pests. Rodents are perceived as 'intelligent' pests, which learn to counter whichever control measures farmers use. Over the centuries, farmers have learned to accept the depredations caused by rats. A common response is,

> for every eight rows of rice we sow for our family, we sow two for the rats.

Unfortunately, with the increasing human population and the shortage of food in developing countries, this level of loss can no longer be tolerated.

Clearly, rodents are still an important problem, and this is without consideration of the losses they cause post-harvest, and the role they play as reservoirs for debilitating diseases of humans and their livestock.

IPM, Rodenticides and Ecologically-based Management

Integrated pest management (IPM) is simply the integration of a range of management practices that together provide more effective management of a pest species than if they are used separately. IPM was developed with the aim of promoting methods for managing insect pests and plant diseases that were least disruptive to the ecology of agricultural systems (Smith and van den Bosch 1967).

Ecologically-based pest management

In 1996, a review of pest management of insects and weeds by the Board on Agriculture of the National Research Council (NRC) of the United States of America, highlighted that the practice of IPM has generally not been consistent with the underlying philosophy of IPM. They contend that there has been too much focus on pest scouting and precise application of pesticides. They argue that there is a need to refocus objectives from pest control to pest

management and this requires greater emphasis on ecological research and a systems approach (National Research Council 1996). This extension and refocusing of the ecological aspects of IPM led the NRC to develop a concept termed 'ecologically-based pest management' (EBPM). The fundamental goals of EBPM are threefold. One is to minimise adverse effects on non-target species and the environment. The second is to develop an approach that is economic for end-users, particularly farmers, in both the developed and developing world. The third is to establish an approach that is durable.

The development of IPM for rodents has followed a similar path to IPM for insects. The primary foci have been the development of simple monitoring systems to decide whether or not to instigate a baiting campaign, and the development of effective patterns of use for particular rodenticides. Generally, the focus in rodent control has been mostly to achieve a visible increase in mortality, without appropriate attention to other demographic processes or ecological compensation mechanisms. There have been attempts to develop rodent IPM based on an understanding of the habitat use and population dynamics of rodent pests (see Wood and Liau 1984 a,b; Redhead and Singleton 1989; Whisson 1996; Brown et al. 1998; White et al. 1998) or the use of biological control (e.g. Lenton 1980; Singleton and Chambers 1996), but with the possible exception of *Rattus tiomanicus* in oil palm plantations (Wood and Liau 1984a,b), these have not been adopted successfully over a large area. The progress of rodent IPM in Southeast Asia and Australia has been reviewed by Singleton (1997).

Also, biological control needs to be viewed in the context of ecologically-based management of pests because often it is limited in its specificity and efficacy. This is supported by a review of one of the success stories of biological control, the weevil — *Cyrtobagous salviniae*, for controlling the floating fern salvinia (*Salvinia molesta*). Following its establishment in South Asia in 1939, salvinia was spread by man to Southeast Asia and Australasia. It severely disrupts the lives of people by forming dense mats a metre thick, choking slow moving waterways, rice fields and lakes (see Thomas and Room 1986 for details). Efforts to develop biological control were thwarted initially because the fern was incorrectly identified, resulting in the testing of the wrong herbivores. In 1978, salvinia was found in Brazil where it is relatively rare. Field studies identified three potential herbivores and one of these, *C. salviniae*, was released into a lake in northern Queensland and destroyed 30,000 t of salvinia within a year (Room et al. 1981).

When tested in other waterways the weevil was not a success. Subsequently, a combination of ecological and laboratory studies revealed that, if the level of nitrogen was too low in the fern, the weevil population declined. Nitrogen was added to waterways which increased the weevil population, until it eventually reached a critical density at which the damage it caused to the plant resulted in a sufficient increase in nitrogen in the plant itself for the weevil population to be self-sustaining (Room 1990). This was an unexpected result because higher levels of nitrogen generally make weed problems worse. The salvinia story highlights how taxonomic and

ecological research provided a strong basis for a successful systems approach for pest management.

Ecologically-based rodent management

For rodents, an ecological basis for control was suggested many years ago (Hansson and Nilsson 1975; see also Redhead and Singleton 1988) but the implementation of those early ideas has been largely overlooked. One success was the eradication of coypu (*Myocastor coypus*), an introduced rodent pest, in Britain in the 1980s. After several decades of unsuccessful control, a new strategy was developed based on a long-term population dynamics study and biological simulations. A complete solution of the problem was obtained in less than six years through integrating knowledge about the animal's biology and behaviour with a well-organised control scheme with attractive incentives for trappers (Gosling and Baker 1989). There are other good examples in the rodent literature which illustrate the importance of ecological, taxonomic and behavioural studies for developing effective strategies for managing rodent pests. We provide some further examples later in this chapter, with more detailed case studies provided in the ensuing chapters (Macdonald et al., Chapter 3; Leung et al., Chapter 14).

The advantages of viewing biological control of rodents as part of an integrated ecologically-based approach to rodent management rather than a single panacea for control has been reviewed by Singleton and Brown (1999). For simplicity, we propose that this strategy be termed 'ecologically-based rodent management' (EBRM). The contributions by Pech et al. (Chapter 4) and Hinds et al. (Chapter 10) further portray the advantage of having a strong ecological understanding of the biology of both the rodent pest and the disease agent when developing techniques for biological control. In this instance, the focus is on developing fertility control of house mice. Without a multi-disciplinary approach, the requisite knowledge of reproductive biology, social behaviour patterns and population dynamics of the wild house mouse could not be consolidated to allow full development of a product which can then be tested for efficacy.

Rodenticide-based control strategies have a clear need for a good biological basis to build upon. Toxicity of active ingredients and bait palatability are obvious factors which have been studied under laboratory conditions for many decades (see e.g. Buckle 1994a; Johnson and Prescott 1994). Less common, but equally important, is a proper understanding of how poisons can be delivered. For example, rodenticides in Hawaiian macadamia orchards were commonly distributed by broadcasting on the ground. Recently, population and behavioural studies of the black rat, *Rattus rattus*, revealed that those rats which damage the nuts forage only in the trees. This information led to placement of bait stations in trees leading to more efficient use of rodenticides for controlling damage (Tobin et al. 1997).

In China, chemical rodenticides, mostly anticoagulants, are still the routine weapons for controlling rodents in farmland and grassland. However, such rodent control campaigns in the absence of a sound ecological knowledge of the pest species

have generally only achieved short periods (6–9 months) of respite from the ravages of the rodents. In the rice fields of southern China the effects have been even shorter (Huang and Feng 1998). Indeed, many studies (Liang 1982; Liang et al. 1984; Zhang 1996; Huang and Feng 1998; Qi et al. 1998) have shown that the response of rodent populations after chemical control is non-linear. Killing some individuals may reduce the population numbers initially, but the remaining animals compensate with better survival and better breeding performance. For example, following an 88% reduction in a population of the Mongolian gerbil (*Meriones unguiculatus*), the body mass at first pregnancy was reduced from 58 g to 35–50 g (Wang et al. 1998).

In Malaysia, populations of the Malayan wood rat (*R. tiomanicus*) also showed a rapid population response after control, with a full recovery in population density occurring over 12–18 months. In this case, knowledge of the population dynamics and factors limiting population growth resulted in an effective management program of rats in oil palm plantations. Management consisted of an intensive baiting campaign followed by recurrent placement of baits every six months (see Wood and Liau 1984a).

Re-invasion is another factor resulting in populations returning quickly to pre-control densities (e.g. Guruprasad 1992). This is particularly a problem in developing countries where farmers often manage their own rodent problems on small plots of land (0.25–2 ha) at different times to their neighbours. The land use patterns on these small holdings also generally result in a patchy landscape. We therefore need ecological studies to examine the relative demographic importance of each patch and the timing and rates of movements by rats between patches (Singleton and Petch 1994). This metapopulation approach to rodent control is achieving more attention (see Smith 1994), but appropriate field studies of the spatial dynamics of rodent populations in agro-ecosystems in developing countries (e.g. Leirs et al. 1997b) are few.

Ethology in rodent pest management

The development of resistance by rodent pest species to first and second generation anticoagulants explicitly necessitated an integrated approach to rodent management, where use of one poison type was complemented or alternated with the use of other poison types, physical control methods, exclusion, or other control measures (Greaves 1994). Here again, more attention was paid to short-term, and indeed often urgently needed, quick solutions like changing to a stronger poison. Much less effort has been directed towards preventing the development of, or containing the geographical distribution of, resistance. So-called 'behavioural resistance', where rodents refuse to eat the poisonous baits, poses other challenges. In the Birmingham restaurant area, house mice were impossible to control until detailed studies revealed that they had difficulties in digesting starch and were therefore unlikely to eat grain-based baits; changing to fish baits solved the problem quickly (Humphries et al. 1996).

The Chinese zokor (*Myospalax fontanieri*) provides another practical example of the importance of understanding rodent behaviour in developing effective management. In the farmland of Northwest Loess Plateau, the zokor, which lives

underground, shows a cautious response to chemical baits. Less than 70% of a zokor population can be killed by using the best possible baiting technique for this species: setting baits in their underground tunnels (Zou et al. 1998). Further improvement in this kill rate depends on a better understanding of the behavioural aspects of feeding for this species, particularly in overcoming its neophobic response to baits (Zhang and Wan 1997) or perhaps whether they show social learning of food preferences (see Galef 1994; Berdoy 1994 for reviews).

A good ecological basis to management strategies can help to provide excellent rodent damage control without interfering with rodent demography. Wood mice (*Apodemus sylvaticus*) in Germany can be lured away from sugar beet seeds during the short period after sowing when they are prone to rodent damage by providing an attractive, unpoisoned alternative food in the periphery of the fields (Pelz 1989). As all the above examples show, however, solutions are often specific and require a detailed knowledge of the biology, ecology and behaviour of the pest species. Obtaining such knowledge is a laborious yet rewarding task that will allow the development of new damage control strategies.

Further examples of the benefits of combining knowledge of the ecology and ethology of rodent species for developing better integrated control are provided by Santini (1994) for three European species of rodents in agriculture and forestry, and Buckle et al. (1997) for the Malayan wood rat in oil palm plantations.

Re-emergence of Population Ecology of Rodent Pests

The current book builds on the strong ecological theme that emerged at an international workshop on rodent biology and integrated pest management in Africa, held in Morogoro, Tanzania, in 1996 (for published proceedings see Belgian Journal of Zoology Volume 127, Supplement). Africa is an economically poor continent and control strategies which rely primarily on rodenticides are unrealistic. This has sparked interest in a more integrated ecological approach to rodent pest management. One of the conclusions of the workshop was, however, that such strategies cannot materialise without the availability of population data from long-term studies (more than three years) (Leirs 1997). In West Africa, much information was collected by Hubert and co-workers in the 1970s (e.g. Hubert 1982), while in East Africa it is only in the past few years that long-term ecological studies have begun to provide insights into the main factors driving rodent population dynamics (Leirs et al. 1996, 1997a). Building on these insights, the focus has now switched to experimental field studies.

The workshop in Morogoro formulated recommendations, many of which are relevant to the present book (Leirs 1997a). The key recommendations are as follows:

- The taxonomy of many pest rodents must be clarified so that control actions can target the correct species.
- Life-history studies and physiological comparisons between these species are imperative.

- Experimental ecological studies, properly designed with appropriate controls, must be set up to evaluate management strategies and, in the first place, test our hypotheses (or, rather, unsubstantiated beliefs) about rodent population dynamics.

- Poisons in this framework are not considered as something to avoid, but as only one of the possible approaches which should be used more effectively and integrated with other approaches.

The development of the concept of EBPM is important, because it builds on the solid foundations developed by IPM. In effect, EBPM is refocusing IPM towards understanding the population biology of the pest and the agro-ecosystem in which it lives. From the viewpoint of a population ecologist, one wonders what all the fuss is about; EBPM is self-evident. However, when one moves into applied wildlife management, especially of rodents, then the need to sell a concept such as ecologically-based management of rodent pests becomes a reality (Singleton and Brown 1999). Unfortunately, too often there is a divide between practitioners, who are more concerned with the details of how to apply specific control technologies, and wildlife researchers who focus on understanding the theory and the context of the problem (Sinclair 1991). We have provided a mix of pure (Section 1 and parts of 2) and applied (Sections 2 and 3) rodent biology in this book in an attempt to bridge this divide.

Aims and Structure of the Book

This book has four broad aims:

- to raise the profile of the importance of basic research for developing effective, applied management of rodent pests;

- to argue the need for an ecologically-based approach to rodent pest management;

- to raise the profile of rodent pest management in developing countries; and

- to spark interest in prospective students in a challenging but rewarding field of endeavour.

The book begins with a section on theory and current paradigms of rodent biology and management.

This section includes contributions from leading small mammal ecologists. Krebs (Chapter 2) provides a thought-provoking paper on the different phases of small mammal ecology and concomitant shifts in research paradigms. Macdonald and coworkers (Chapter 3) present the results of a series of novel studies used to disentangle the interesting social behaviour of Norway rats. Dickman (Chapter 5) examines, at the ecosystem level, the positive role rodents play as 'ecosystem engineers' through their impact on the chemical and structural attributes of the environment. Mills in his chapter on arenaviruses and hantaviruses (Chapter 6), and Pech and his coworkers through their synthesis of models for predicting mouse plagues in Australia (Chapter 4), both provide a different perspective of the need for strongly focused population studies of rodents.

One common theme is addressed by all authors—the importance of basic research for developing effective management of rodents.

The second section covers broad methods of management—rodenticides, physical control and biological control. This section provides overviews on the state-of-the-art technologies for fertility control (Chambers et al., Chapter 10), chemical control (Buckle, Chapter 7) and the control of rodent pests in urban environments (Colvin and Jackson, Chapter 11). Reviews are provided also on physical methods of control, particularly in rice agro-ecosystems in developing countries (Singleton and coworkers, Chapter 8) and on the ecological management of Brandt's vole in the grassland of Inner Mongolia (Zhong and coworkers, Chapter 9). The common theme for this section is ecologically-based pest management.

In a conscious effort to ensure the book is relevant to developing countries, regional case studies of rodent problems and the progress with associated research are provided for Asia and Africa in Section 3. This section has contributions from selected countries edited by G.R. Singleton and Z. Zhang (Asia—contributions from China, Indonesia, Lao PDR, Thailand and Vietnam) and H. Leirs (Africa—contributions from Burkina Faso, Kenya, Madagascar, Mali and Tanzania). The information on the biology and management of rodent pests in developing countries, and the infrastructure for research and extension, varies considerably. In some countries, such as Cambodia and Lao PDR, the problem is only just being defined and it is still not known which species cause the major problems in the different agro-ecosystems (see contribution by Schiller et al., Chapter 18). The contributions in this section comprise a mix of biological studies aimed directly at management, and general overviews of rodent problems and how they are currently being managed in various developing countries.

In seeking contributions for this book we were heartened by the enthusiasm that it generated from researchers across the spectrum of pure and applied research. We received no 'knock backs' from contributors we targeted. Indeed, we had to limit the contributions that were on offer. What pleasantly surprised us was the strong interest by 'pure' scientists in hoping their work would not only be of heuristic value. They were keen for their findings to be accessible to researchers in developing countries because they felt their research could make a significant contribution to tackling the problem of rodent pests in these regions. So perhaps Denis Chitty is indeed correct in stating "pure and applied science differ mainly in aims, not methods". If this book acts as a catalyst for pure and applied scientists to work together towards a common aim of reducing the impact of rodent pests in agricultural ecosystems of developed and developing countries, then we will be more than satisfied with our toil.

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Section 1

Basic Research —
the Foundation for Sound Management

Pure and applied science differ mainly in aims, not methods

Chitty 1996

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