activities, we consider that the best time to practice rodent control is in May–June. Human sero-positive results against *Y. pestis* are more numerous in houses located at the edges of the villages, where sisal fences are more abundant and in houses where food is stored in bedrooms. This clearly shows that it is necessary to break the close rodent–man contact and this could be achieved by developing rat-proof buildings.

Conclusions: Needs and Perspectives

In Madagascar, the major public health problem linked to rodents is the plague. The most important reservoir is the black rat, which is also the most important pest in the fields and food stores. Along with the economic difficulties in Madagascar, rodent control is extremely difficult because it is the only country in which the black rat has displayed such successful colonisation in all habitats. In spite of the recent progress in our knowledge of the population dynamics of the black rat, there are still important gaps in their population ecology which must be filled before our fight against these rodents becomes efficient and effective. It is necessary to obtain reliable data on the population flow between habitats, due to, for example, the flooding of rice fields in the valleys and the slash-and-burn practices on the hills and at the edges of the forests. Also, we do not have enough long-term studies on the population dynamics in cultivated areas.

More needs to be done with respect to information transfer and training. For example, some rat-proofing methods are well known to farmers, but often they are poorly implemented and inefficient. In rural areas, better coordination of the activities of the health services and the plant protection services is necessary.

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22. Rodent Pest Management in East Africa—an Ecological Approach

Rhodes H. Makundi, Nicholas O. Oguge and Patrick S. Mwanjabe

Abstract

Rodents are by far the greatest vertebrate pest problem in East Africa. They are responsible for substantial damage to food and cash crops, structures and industrial and domestic property. More than 25 species of rodents have been recorded as pests in agriculture, causing a wide range of damage and losses in cereals, legumes, vegetables, root crops, cotton and sugarcane. Pest species occupy a diversity of habitats, including cultivated fields, urban environments and domestic areas. Other than being instrumental in crop damage, they are also reservoirs and carriers of zoonotic diseases, which in some areas of East Africa have claimed many victims.

The management of rodents has focused on conventional methods, mainly the use of rodenticides as a symptomatic treatment approach. These methods are supported by government, especially to contain outbreaks. However, conventional control methods have remained largely ineffective.

An ecological approach for management of rodent outbreaks is not widely practiced for lack of basic experimental data to substantiate its efficacy. Measures that are practiced on a limited scale but have a wide scope for future management of rodents in East Africa include various techniques of environmental manipulation that specifically focus on altering the suitable habitats for rodents to reduce their carrying capacity. Strategies for management of rodent populations in urban areas, in post-harvest crop systems and in response to disease outbreaks are not well developed. For the future, a more pragmatic approach is required, involving among other things, better planning of urban housing schemes, sanitation and hygienic measures; improved storage structures and practices; and ecologically focused rodent management techniques.

Recent studies on rodent ecology in East Africa have enabled the development of models to forecast outbreaks. These, when incorporated in development and implementation of control activities, may assist in alleviating the damage and losses due to rodents in the future.

Keywords

Rodents, East Africa, pest management, *Mastomys natalensis*, *Rattus rattus*, *Mus musculus*, mathematical models, ecology

INTRODUCTION

WORLDWIDE, RODENTS ARE the most important group of mammals in terms of the problems they create in agriculture, horticulture, forestry and public health. They show a wide range of adaptation, enabling them to successfully colonise and inhabit almost any type of habitat (De Graaf 1981). Rodents play an important role as reservoirs and carriers of zoonotic diseases for which some epidemics have afflicted mankind for centuries. Indeed, in Africa, some rodent-borne diseases constitute a serious burden on the human population in those areas where they are endemic (Gratz 1997).

Rodent infestations

In developing countries, the major emphasis in agriculture has been to increase crop production to feed an increasing population. In addition, demands for animal feed and raw materials for basic industrial production have led also to increased land usage, both extensively and intensively. This has created habitats that are suitable for sustaining higher densities of rodents than was previously possible. Thus, in rural communities in Africa, crop damage in the field and grain losses in storage, although not fully quantified, are undoubtedly high. These losses reduce the amount of food available to the population, and at times of food scarcity, could lead to an increase in human suffering due to malnutrition and starvation in a continent already afflicted by many natural disasters.

Some species of rodents have developed close association with human settlements. Therefore, with fast growing urbanisation in East Africa and other African countries, these species have become a serious problem in terms of public health, spoilage of foodstuffs, and material and structural damage. Unlike many developed countries, where organised and systematic rodent management strategies are already in place, lack of resources and insufficient measures for reduction of rodent populations in urban areas often compound the rodent problems in East Africa.

Post-harvest problems

The duration of grain storage at the village level lasts 3–12 months during which time rodent infestation can cause economic losses. The main purposes of on-farm storage are to provide enough food for the family through to the next harvest, to provide seed, and to sell grain when prices are favourable. Therefore, ensuring that the food and seed are kept safe is very important in view of current high demands for sufficient food for the family and to be able to sell the surplus to obtain other essentials.

Unprotected storage structures provide an abundant food source for certain species of rodents. Under such conditions, numbers can increase markedly to very high levels within a short period, leading to severe losses in the post-harvest period (Makundi et al. 1991).

Human diseases

Plague, a disease whose causal agent is *Yersinia pestis*, has been known in East Africa for many years (Roberts 1935; Davis et al.

1968; Kilonzo and Msangi 1991) and is endemic in several areas of Kenya, Tanzania and Uganda. In recent years, epidemics of plague have been experienced. The Lushoto District, Tanzania, recorded 6,599 cases and 580 deaths until December 1996 (Kilonzo et al. 1997). Similarly, the Nebbi and Arua districts in Uganda have experienced plague outbreaks in the last 10 years (B.S. Kilonzo 1998, pers. comm.). Occurrences of other human diseases involving rodents have been reported in other countries (Mills et al. 1997), but have been little studied in East Africa.

Factors influencing rodent pest outbreaks

Although many studies have been carried out to elucidate the biology of the pest species, only recently have some of the reasons for rodent population explosions become better understood. The reasons hypothesised for pest increases are biological —mainly related to the characteristics of the species themselves; ecological—ascribed to the total environment and associated climatic factors; and those related to human activities — especially agriculture, urbanisation and modifications to the natural habitats of rodents. Thus any attempt at successful rodent management in East Africa must consider all these factors.

The objective of this chapter is to review rodent pest management strategies in East Africa, namely Tanzania, Kenya and Uganda, detailing:

- rodent pest problems;
- management strategies for rodents in agriculture (including grain storage), public health and urban environments, with emphasis on ecological approaches; and
- measures with potential for future ecologically-based rodent pest management.

Rodent Pests

Although serious arthropod pests sometimes afflict the East African countries, rodents are by far the greatest vertebrate pest problem in agriculture and public health (Fiedler 1994). They are responsible for substantial damage to food and cash crops and play an important role as reservoirs and carriers of zoonotic diseases (Fiedler 1994; Gratz 1997; Mills et al. 1997). Several species of rodents are pests, ranging from the medium-sized multimammate rat (*Mastomys natalensis* Smith) to the giant rat (*Cricetomys gambianus* Waterhouse) and the crested porcupine (*Hystrix cristata* Thomas). Some of the pest species are found specifically in certain geographical and environmental conditions, while others are widely distributed. For example, *Rattus norvegicus* (Barkenhout) is restricted to coastal sea-ports and is not found inland (Mwanjabe 1989; Fiedler 1994), the house mouse (*Mus musculus* L.) is found mostly in urban areas and in some village dwellings (Delany 1975; Fiedler 1994) and *Rhabdomys pumilio* (Sparman) is commonly found in grasslands lying at high elevations (Hubbard 1972). However, the house/roof rat (*Rattus rattus* L.), the multimammate rat (*M. natalensis*) and the Nile rat (*Arvicanthis niloticus* Desmarest), are widely distributed over East Africa (Kingdon 1974).

More than 25 species of rodents have been recorded as pests in agriculture, causing a wide range of damage and losses in many crop types, including cereals, legumes, vegetables, root crops, cotton and sugarcane (e.g. Hubbard 1972; Fiedler 1994). In Kenya, about 10 species of rodents have been recorded as the most important pests (N.O. Oguge 1998, unpublished report). Most of the serious rodent problems in East Africa are caused by species belonging to the family Muridae. They occupy a diversity of habitats, including cultivated fields where crop damage occurs. Other than being instrumental in crop damage, they also spread diseases, which in some areas of East Africa have caused many deaths (Gratz 1997).

Some species cause damage in some areas or in certain crops but not in others. Among the factors that possibly influence the occurrence and severity of rodent attack are the following.

Farming practices

These affect the nature of the habitat, shelter and population density of rodents. Thus where small farms—typical of peasant farming in East Africa—are interspersed with fallow land, serious damage of the crops occurs mainly at the edges of fields (Taylor 1968). The fallow lands also provide suitable ground for shelter and breeding while grass and weed seeds are supplementary food for rodents (Mwanjabe 1993). The introduction of some crops to certain areas has been associated with persistent rodent outbreaks. For example, in the Lake Rukwa Valley, Tanzania, the opening up of bush and forest for cotton and maize farming is presumed to have precipitated the rodent outbreaks in the mid 1960s and 1970s (Mkondya 1975).

Changes in climatic factors

The influence of climatic factors, especially rainfall patterns, on rodent populations in East Africa are well-documented (Chapman et al. 1959; Taylor and Green, 1976; Telford 1989; Leirs 1992, 1995). The timing and duration of rainfall affects the vegetation, which is the main source of food for rodents. The availability of abundant and nutritious food is a crucial factor for rodent reproduction and survival. Rainfall, therefore, is the most likely proximate influence on the breeding season in some localities (Neal 1977), with most of the young born when nutritious food is plentiful (Field 1975; Neal 1984).

The intrinsic characteristics of the pest species

Some pest species are able to exploit large differences in environmental conditions, even within small geographical areas, leading to rapid breeding, increase in abundance and consequently, severe crop damage. Certain species breed prolifically under favourable conditions, making it possible for outbreaks to occur. For example, *M. natalensis* is the main species causing severe damage to cereals and cotton in many areas in East Africa. This species is able to live in diverse climatic and geographic circumstances and therefore is found widely distributed in fallow and cultivated land where it thrives primarily on wild plants and crops, respectively (Kingdon 1974; De Graaf 1981). It has a wide habitat tolerance and adaptability, which makes it the first invader of cultivated land (Taylor and Green 1976; De Graaf 1981). Prolific breeding and rapid succession are additional characteristics which make this species a serious agricultural pest (Leirs 1992, 1995; Leirs et al. 1993). It has been observed that this species might be present in low numbers in a particular area and then rapidly increase, often associated with ripening cereals (Taylor and Green 1976). Further, studies on its distribution have shown that it occurs in habitats ranging from grasslands to areas with rainfall of up to 1,800 mm annually (De Graaf 1981). The distribution of *M. natalensis* in habitats which are heterogeneous in many aspects and its occurrence in some areas also inhabited by other species suggests that it must encounter inter-specific competition (Taylor and Green 1976; K.D. Taylor 1976, unpublished report). The fact that high densities of this species occur relative to others, clearly indicates that *M. natalensis* is capable of taking advantage of prevailing conditions to dominate both natural and man-altered habitats such as cultivated farm land.

Three rodent species are responsible for most post-harvest crop damage. *R. rattus* and *M. musculus* inhabit houses and storage structures, whereas *M. natalensis* moves from the fields to frequently invade rural storage structures. *R. rattus* is ubiquitous in both cities and villages, whereas *M. natalensis* is a semi-synanthropic rodent found only in the peripheries of both cities and large villages (Mwanjabe 1989).

Crop Damage and Losses

Serious outbreaks of *M. natalensis* in Tanzania were recorded as early as the 1930s (Harris 1937), and in subsequent years in various parts of the country (Chapman et al. 1959; Mkondya 1977; Mwanjabe 1990). During the 1997/1998 cropping season, rodent outbreaks were reported in several regions in Tanzania and resulted in widespread crop damage (Rodent Control Centre, Morogoro, Tanzania – unpublished rodent monitoring and control reports, 1998). In Kenya, severe damage in wheat farms was recorded in 1962 and attributed to *A. niloticus*, *M. natalensis*, and *R. pumilio* (Taylor 1968). Pre-harvest losses are common also as a result of attack by ground squirrels, *Xerus erythropus* (Key 1990a).

Rodent damage to cereals manifests itself in four ways:

- removal of planted seeds, which necessitates purchase of new seed and replanting;
- attack on the vegetative (growing) stage;
- damage to mature crops before harvest; and
- extensive damage and contamination (via urine, droppings, hairs, disease organisms) of grain in village storage granaries.

The emphasis on increasing agricultural production by expanding the acreage under crop has certainly created more suitable habitats for rodents, with a subsequent increase in population numbers and crop damage in areas where such problems were previously unknown. It is also apparent that some crops are more prone to attack than others, with the small-grain cereals (rice and wheat) being more susceptible to rodent damage than maize during the growing stage (A.W. Massawe 1998, pers. comm.). The time of planting also affects crop damage since in many areas in East Africa, sowing and crop growth coincides with increasing rodent populations, especially of

M. natalensis (Taylor and Green 1976; Telford 1989; Mwanjabe and Sirima 1993). Studies in some areas of East Africa have also shown that the occurrence of high rainfall during the short rainy season initiates aseasonal breeding resulting in high densities of *M. natalensis* at the beginning of the main rainy season (Leirs 1992; Leirs et al. 1989, 1996). This coincides with the time of planting seeds which are removed by rodents, followed by their attack on emerging seedlings.

Recent quantitative information on economic losses due to rodents is generally lacking in East Africa. However, earlier reports (Taylor 1968) indicated 20% damage to maize plantations, 34–100% loss of young wheat in some fields and 34% loss of barley after outbreaks of rodents in Western Kenya. Key (1990a,b) found an average of 9.7% of planted seeds and seedlings and 5.4% of maize cobs damaged by striped squirrels (*X. erythropus*) in southern Kenya. Some reports in Kenya have indicated that most of the pre-harvest damage in maize and wheat occurs between planting and germination, with a final loss of 2–10% (N.O. Oguge 1998, unpublished data). In Tanzania, rodent damage to field crops is widespread although rodent outbreaks tend to be sporadic. Rodent outbreaks occur in some areas for one or a few seasons and cause widespread losses, but these losses have not been properly assessed and quantified. In one study, it was shown that about 6% of the seedlings were devoured during the planting season, but the final crop losses or damage were not available (J.T. Christensen 1984, unpublished data). Some districts experience rodent attack on crops after planting, during crop growth and during storage, increasing the level of losses significantly (Makundi et al. 1991). Studies conducted in Chunya District, Lake Rukwa Valley, Tanzania, indicated 10% damage of maize seedlings, resulting in a 9.9% crop loss at harvest (Myllymäki 1989, Denmark–Tanzania Rodent Control Project, Final Report, unpublished). Mwanjabe and Leirs (1997) observed crop damage of 40–80% in Morogoro and Chunya districts but the final crop loss levels were not provided.

In Uganda, striped squirrels were reported to be digging up forestry nursery seeds, and attacking cotton bolls, bean pods and sweet potato (Kingdon 1974).

Reliable estimates of food storage losses are unavailable since critical assessments have not been conducted in any of the countries in the region. However, rodents are exceptionally wasteful feeders and therefore, they spoil more food than they actually consume (Hall 1970).

Rodent Pest Management Strategies Used in the Past

Traditional rodent control strategies in East Africa have evolved over a long time and were probably most suited to managing low-density rodent populations. Thus, in areas where there have been persistent rodent pest problems, a variety of techniques have evolved. In other areas (e.g. Lushoto, north-eastern Tanzania), there are virtually no traditional rodent control techniques, indicating that rodent problems in such areas are relatively new (R.H. Makundi, personal observation).

Some methods that were used in the past were selected to solve localised rodent problems in certain areas. These included the following.

Bounty schemes

These were organised to control rodents, especially in plague outbreak areas. In Kilimanjaro region, Tanzania, Lurz (1913) reported a bounty scheme to control rodents in the 1912 plague outbreak. The scheme was introduced also to the Rukwa Valley in Tanzania to control rodent outbreaks in the late 1960s (Mkondya 1975). The bounty schemes were not sustainable for two main reasons—(i) financial resources were scarce and (ii) they made villagers less responsible for rodent control in the absence of payment. In addition, villagers viewed bounty schemes as an economic activity and, therefore, those who participated in killing rodents were not interested in altering the conditions that enabled rodents to multiply. This resulted in bounty schemes being successful in reducing numbers of rodents temporarily, but did not change the carrying capacity of suitable habitats for rodents within the villages.

Burning of houses and vegetation

This was practiced in plague outbreak areas, in which the dwellings of the victims were burnt down while villagers with sticks and clubs killed escaping rodents (Kilonzo 1984). This approach was probably effective where inhabitants built shelters which were simple and temporary and where there was shifting cultivation and a semi-nomadic life. This technique probably targeted *R. rattus*, which mainly inhabits human dwellings, but not the other species that are also reservoirs of plague. The burning of vegetation was based on the assumption that burnt land was freed from rodent infestation. However, it has limited use in management of rodents in agriculture over a whole season since it is now clearly understood that some of the major pest species invade regenerating vegetation after fire (De Graaf 1981). Also, this technique did not consider the dispersal capacity of the different rodent species.

Trapping

A large proportion of the rural population in East Africa has made use of different, locally produced traps to control rodents. These have enabled the reduction of rodent numbers in some localities (Lund 1977; Kilonzo 1984).

Poisoning

Harris (1937) reported successful control of rodent outbreaks in maize and cotton fields in the early 1930s in Tanzania by using barium carbonate mixed with maize and sorghum meals. In the 1970s, widespread baiting with warfarin and zinc phosphide was used to control rodent outbreaks in Tanzania (Mkondya 1975, 1977; Fiedler 1994). Government intervention, in the form of free supplies of rodenticide and distribution and supervision of bait application, enabled the reduction of crop losses. However, with poor extension services in most villages in rural East Africa, this management strategy has often failed to be implemented at the appropriate time to reduce populations of rodents to uneconomic levels. It follows that management of rodents by poisoning in the past was not based on good knowledge of their population dynamics, which is essential if there is to be a strong impact.

Current Rodent Management Strategies

Use and choice of rodenticides

The use of rodenticides to control rodent outbreaks is not widely practiced on an individual farm basis. In Tanzania, the government has organised control campaigns since the mid 1970s, but in areas where major outbreaks do not occur, farmers do not feel the need to control rodents.

Success in the use of rodenticides — whether acute poisons or anticoagulants — has been influenced by three factors, as outlined below:

- Availability of the required rodenticides, often influenced by available funds for their purchase.
- Acceptability of bait formulations to rodents, often influenced by palatability under field conditions. The availability of other food resources for rodents in the field may determine the level of bait consumption. In Tanzania, a highly acceptable bait formulation of bromadiolone, targeted against *M. natalensis*, was developed in 1988 (A. Myllymäki 1989, unpublished report).
- The timing of bait application. This is critical for alleviating damage. One hypothesis that has not been widely tested under different agro-climatic and agro-ecological conditions, is that rodents should be effectively controlled during the season when the population is low and before animals start breeding, to prevent them from reaching harmful levels at the time of planting through to harvesting. However, with small farm holdings, which can be easily re-colonised, prophylactic treatment when the population is low may produce less than expected results, especially for those species which breed prolifically (Myllymäki 1987).

Rodenticides have commonly been used for symptomatic treatment to reduce damage when rodent populations are already high. This necessitates the application of large amounts of rodenticides. If knowledge of rodent population dynamics is available, this could be used to suggest appropriate timing of prophylactic treatment to alleviate the damage caused in rodent outbreaks.

Zinc phosphide has been most commonly used for controlling rodent outbreaks in Tanzania. In Kenya, it accounts for over 80% of all rodenticides used in rodent pest management (N.O. Oguge 1998, unpublished data). The choice of zinc phosphide by farmers with little disposable income is based on low cost and a reasonably quick effect relative to anticoagulants, but even this rodenticide is not easily available to most farmers. In the 1998 rodent outbreaks in various regions (e.g. Tanga, Pwani and Morogoro) in Tanzania, zinc phosphide was widely used because the Ministry of Agriculture supplied it to farmers free (P.S. Mwanjabe 1998, pers. comm.). Poor extension services also affect the use of rodenticides (A.W. Massawe 1998, pers. comm.).

Physical measures

Physical measures are used widely to control rodents in East Africa. The measures commonly practiced by farmers include trapping, digging and flooding burrows

(*Tachyoryctes* spp., *Tatera* spp.), exclusion and hunting (*Hystrix* spp., *C. gambianus* and *Thryonomys* spp.).

There are many different types of traps used to capture rodents in different areas within East Africa, but basically they are of two main designs: kill and live-traps. Traps are widely used to control rodents within houses, storage structures and in crop fields. Trapping methods are generally popular among peasant farmers who lack other resources for rodent pest management, and in few places are used to capture rats to supplement the diet. For rodent control to be highly successful where there is crop damage or threat of disease, use of traps has to be combined with other control methods such as environmental sanitation, proper storage of food, and when necessary, application of rodenticides (K.D. Taylor 1976, unpublished report). When rodenticides are available, trapping is a less favoured method because it is labour intensive and is less effective in controlling outbreaks. However, pitfall traps, especially those which also combine drowning in tins or buckets half filled with water, have been claimed by farmers to be effective during times of rodent outbreaks.

Exclusion by rat proofing of the storage house or structure is recognised as an effective method to reduce post-harvest losses in rural communities (Hall 1970). The practice of storing grain in the ceiling or stores built within traditional houses, usually with walls constructed with mud, is common in East Africa. The structural nature of the houses makes it difficult to protect the grain from rodent damage because an effective barrier between the commodity and rodents cannot be created. Improving storage structures, therefore, will be the most appropriate long-term strategy to reduce rodent damage to crops during storage. This should entail, first, raising the basement of the structure to one metre above ground level and, secondly, incorporating a sleeve or a band of sheet metal that makes the surface too slippery for rodents to traverse when fitted closely to the slit. Further, rodents can be kept away by the removal of vegetation around the vicinity of the storage structure, maintaining the stores in a good state of repair and ensuring the surrounds have minimal food residues and other rubbish on which rodents feed. Although rodent proofing of outdoor storage structures is very effective in excluding synanthropic rodents, it has not been adopted by many rural communities.

Exclusion using rodent proof containers, such as steel drums and clay pots, is common in rural areas. These are used for storage of seed and smaller quantities of grain. The containers provide adequate protection against *M. musculus* and *R. rattus* for stored grain in the household.

Environmental manipulation

Habitat manipulation has been encouraged in a few places in East Africa. It assumes that shelter and food are the main factors affecting rodent numbers in any given habitat. This approach also focuses on the fact that rodents are extremely dependent on shelter for survival. For numbers to increase conditions must be favourable for breeding and survival of the young to reproductive stage (K.D. Taylor 1976, unpublished report). Disruptions of the environment, caused by harvesting and ploughing, lead to a decrease in the shelter available for rodents and possibly expose them to predators and reduce their population density. For example, Taylor and Green (1976) noted that in Kitale, Kenya, arable fields were unstable habitats for rodents. In Tanzania, Leirs et al. (1997) observed a rapid decrease in rodent abundance immediately after ploughing and planting but densities increased again after a few days. It has been suggested that in some parts of East Africa, the destruction of the natural environment has displaced many predators of rodents, while the new conditions created are favourable for high rodent population density (K.D. Taylor 1976, unpublished report).

Environmental manipulation as a rodent control strategy in East Africa has not been very successful because it has not been extensive enough or incorporated as a component of the small holder farming system. In order for this strategy to benefit many farmers it must not be confined to a few individual fields, as is currently the case.

Where environmental manipulation has been carried out, it has included one or more of the following practices.

Grazing, regular bush clearing and grass cutting

Areas that are regularly cleared of bushes or that support grazing usually have a lower carrying capacity for rodent populations (Green and Taylor 1975), however pasture land that is not grazed regularly can support high populations of rodents, especially granivorous species (*A. niloticus, R. pumilio, M. natalensis and Otomys angoniensis*). Green and Taylor (1975) found that cover was an important population regulating factor for these species in Kenya and that when cover was removed it resulted in depletion of rodent populations. The population density of *A. niloticus* is markedly affected by regular cutting of vegetation, which reduces suitable habitats for this species (Green and Taylor 1975). Observations in the plague outbreak villages of Lushoto District, Northeast Tanzania, showed that clearance of bushes, especially of the perennial *Rumex usambarensis*, removed pockets of *A. niloticus* populations near houses (R.H. Makundi, personal observation). It also has been suggested that the population of *A. niloticus* in Kampala, Uganda, dropped considerably because the municipal council was continuously cutting grass around the city (De Graaf 1981).

Grazing in the fields immediately after harvest and in the fallow land between farms might help to destroy vegetation cover and remove food sources for rodents. This practice is common in many areas in East Africa, although the common purpose is not to control rodents, but to make use of the stubble and crop remains as animal feed during the dry season. However, there is a delicate balance between vegetation cover and soil erosion. The risks of soil erosion due to overgrazing must always be considered in using this approach.

Regular weeding has been reported to affect rodent population density in cultivated fields. For example, Mwanjabe (1993) reported that clean, weeded farms were less severely attacked and sustained lower rodent populations throughout the year than unweeded farms in Chunya District. A potential widespread management strategy could be the application of herbicides to control weeds over a large area but the economic and environmental implications do not allow this method to be implemented on a wide scale.

Agricultural practices and land management strategies

In East Africa, the rains are seasonal with one or two rain seasons in a year. This also determines the cropping patterns, with intensive agricultural practices being found where the rainfall is well distributed over the year. Over a vast area the farming system is composed of small farms that are 0.5–2 ha, forming a mosaic of fallow land interspersed with cultivated areas, which is ideal for maintaining large rodent numbers that invade crop fields. In these areas, rodent management strategies require changes in land practices, producing less fallow patches that are a refuge for rodents and from where invasion of crops occurs. To reduce the damage to crops by rodents, cropping needs to be synchronised over a large area.

In general there is no common approach to land management that is aimed at reducing rodent damage to crops in East Africa. Encouragement of large block farms and clearing of headlands reduces the density of rodents considerably. Taylor (1968) noted that large, mechanically cultivated monocultures were often not highly infested with rodents, but these are not common at the small holder farmer level.

Other practices like efficient harvesting of cereals and cotton are recommended in most rodent outbreak areas in Tanzania (Mkondya 1977) to reduce the available food resources for rodents.

Many farmers burn their fields in the aftermath of the harvest or immediately before planting. This probably changes the habitat for a short duration, but most likely it has no detrimental effect on the future population size of rodents because burnt areas soon have new vegetation and are reinvaded rapidly by pest species from other areas. For example, Green and Taylor (1975) reported an increased catch of *M. natalensis* following burning in some areas in Kenya. Presumably, more grass seed becomes available on the ground after fires, which probably explains why rodents are attracted to burnt areas.

In many parts of East Africa, the harvesting time coincides with the beginning of the dry season. It is common for farmers to leave the crop in the fields, a form of temporary storage, for extended periods to allow further drying before threshing. This practice is common for cereals, especially maize, sorghum and millet. A crop left in the field for extended periods is predisposed to severe attack by rodents. Among the practices that are encouraged are early harvesting and storage of the crops in improved, rodent-proofed cribs constructed for the dual purpose of storage and in-storage drying to reduce both rodent and insect damage of crops.

Rodent Management and Public Health

Rodent infestation in urban areas

Rodent infestation in urban areas poses a great risk to public health in East Africa and, therefore, their control is most important. In the city of Dar es Salaam, Tanzania, >70% of households were reported to be infested with commensal rodents (*R. rattus*, *R. norvegicus* and *M. musculus*), with highest infestations in commercial premises dealing with food handling and processing (Rongo

1993). Studies carried out in the city of Nairobi, Kenya, similarly showed that there was a serious rodent infestation problem, both indoors and outdoors, that required immediate control activity (Njenga et al. 1993). These problems are also widespread in small urban areas as pointed out by Lyimo (1993) for Morogoro municipality in Tanzania. The unhygienic environment infested with rodents is ideal for transmission of zoonotic diseases to man and domestic animals.

The factors that are responsible for high urban infestations by rodents and potential management strategies are summarised in Table 1.

Control of rodents in response to plague outbreaks

The management of plague in East Africa requires an understanding of the ecological, social and cultural factors which have led to persistence of the disease for many decades, as well as why the conventional approaches to plague control have been ineffective in some areas. Ecological factors that contribute towards the spread and persistence of plague in Lushoto District, Tanzania, and possibly other plague outbreak foci in East Africa may be divided into biotic and abiotic factors (Table 2).

Rodent Outbreak Forecasting and Management

Rainfall and the nature of agricultural activities have a significant effect on the severity of rodent outbreaks. This is particularly well understood for *M. natalensis* which have breeding seasons that are strongly influenced by the pattern of rainfall (Chapman et al. 1959; Taylor 1968; Telford 1989; Leirs 1992; Leirs et al. 1997). Studies in Tanzania (Telford 1989; Leirs 1992) have indicated that *M.natalensis* normally starts breeding towards the peak of the long rains in areas where there are two rain seasons (usually long and short rain seasons) in a year. However, when the short season rains are high and extended, animals survive better and extend their breeding season, mainly due to an abundance of food and shelter (Leirs et al. 1996; Mwanjabe and Leirs 1997). This extended reproduction results in high recruitment at the beginning of the following breeding season before the long rain season. Therefore rodent outbreaks will be experienced at the time of planting and in subsequent crop growth stages, resulting in crop losses. The key factor in this model is the amount of rain and the duration of the short rains season. This indicates that early warning systems based on rainfall data could be developed to enable farmers to prevent crop damage and losses. In Tanzania, such a system was developed towards the end of 1996 (Mwanjabe and Leirs 1997). In order for such a system to function, the rain patterns must be well understood and there must be a reliable surveillance of rodent population levels. Using this model, the possible organisation of rodent management activities in East Africa is shown in Figure 1. With this management strategy in place it should be possible to control outbreaks of *M. natalensis* before crop damage occurs. The suggested organisation of rodent management strategies in East Africa assumes that the respective Ministries or Departments will provide the necessary information and logistics to enable farmers to control the outbreaks.

Table 1.
Factors responsible for high urban infestations by rodents and strategies for their management.

Factors responsible for high rodent infestations	Management strategies
Lack of efficient collection and proper disposal of refuse, which creates an abundant supply of food for rodents.	Improved sanitation of both residential and commercial premises through efficient refuse and garbage collection and their proper disposal.
Lack of well-planned housing schemes creates suitable shelter and breeding grounds for rodents in human dwellings.	Proper planning of residential and commercial areas to reduce potential rodent-attractive habitats.
Lack of long-term rodent management strategies that are centrally coordinated and implemented.	Incorporating rodent proofing in the construction of dwellings, warehouses and food storage structures.
Tolerance of rodent infestation by the public and lack of awareness of rodent control measures.	Controlled and systematic rodenticide application.
	Public health education, especially on the potential for disease outbreaks involving rodents and methods of rodent control at household and community levels.

Table 2.
Ecological factors contributing towards the spread and persistence of plague in Lushoto District, Tanzania.

Biotic factors	Abiotic factors
Abundance of fleas infesting rodents and houses, with high prevalence of species which are known to be highly infective. These include *Xenopsylla cheopis*, *X. brasiliensis*, *Ctenocephalides felis*, *Pulex iritans*, *Dinopsyllus lypusus*, *Nosopsylla* spp. and *Leptopsylla aethopica* (Njunwa et al. 1989; Makundi and Kilonzo 1994).	Changes that have occurred after deforestation and opening the land for agricultural development (R.W. Bell 1963, unpublished report) have contributed to colonisation by savanna species of rodents, mainly *M. natalensis* and *Arvicanthis* spp. which are reservoirs of plague.
Presence of plague reservoirs, mainly rodents. These species are *Mastomys natalensis*, *Rattus rattus*, *Arvicanthis* spp., *Grammomys* spp., *Lophuromys favopunctatus* and *Praomys* spp. *Tatera* spp., *Rhabdomys pumilio*, *Lemniscomys* spp., *Otomys* spp. and *Aethomys* spp. also have been found to be reservoirs of the disease in other areas of East Africa (Davis et al. 1968).	The mild temperature and moist conditions (October –March) enable a drastic increase in abundance and prevalence of flea vectors, which coincide with increasing numbers of rodents and plague victims (Njunwa et al. 1989; Makundi and Kilonzo 1994).
High human population pressure increases interaction between people, wild and commensal rodents and fleas.	

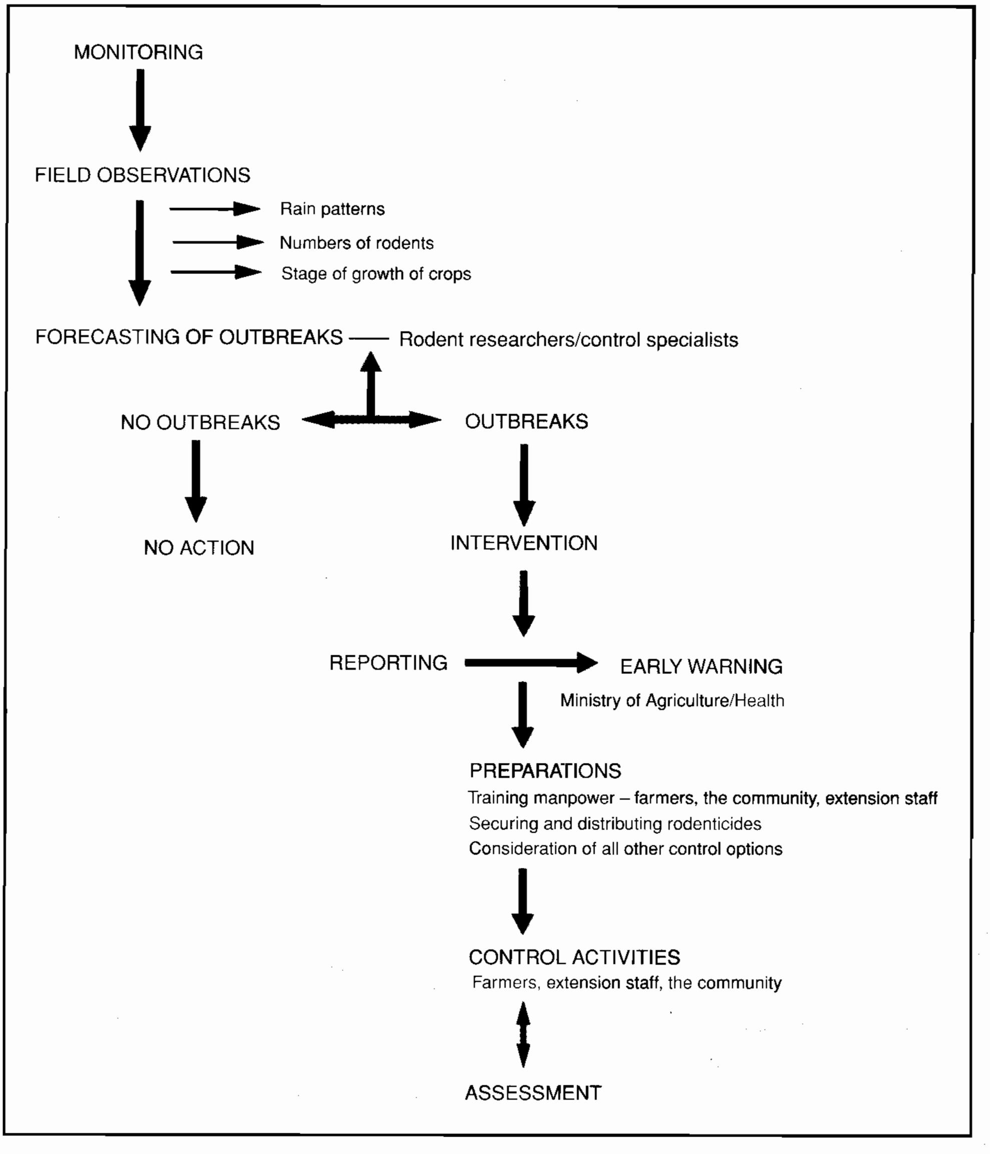

Figure 1.
Organisational model for management of rodent outbreaks for Eastern Africa (based on models produced by Leirs et al. 1996 and Mwanjabe and Leirs 1997).

Future Rodent Management Strategies in East Africa

Success of future rodent management requires integration of control approaches in a manner that will reduce the risks of severe outbreaks and their consequences both in the agricultural and public health sectors. The approaches required include:

- monitoring of rain patterns and rodent densities in the field;
- forecasting of outbreaks to enable necessary measures to be taken to reduce their effects;
- efficient inspection of premises and monitoring of populations to determine the presence and density of rodents before and after implementation of control measures;
- rodent exclusion, especially in food storage structures, and where possible, residential and commercial premises;
- improved sanitation, both in rural and urban areas;
- application of rodenticides to reduce population levels either by symptomatic or prophylactic treatments;
- training of rodent control personnel, especially those who are involved directly in the extension service, and raising community awareness on rodent pest problems and measures for their control;
- facilitating timely availability of rodenticides to farmers when required; and
- encouraging farmers themselves to control rodents on a routine basis, rather than depending on external (e.g. government) intervention.

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23. Ecologically-based Rodent Management in Developing Countries: Where to Now?

Herwig Leirs, Grant R. Singleton and Lyn A. Hinds

Abstract

This book has catalogued the impacts of rodents at an international scale and establishes that sustainable and ecologically-compatible management of rodent pests should be of equal importance to that of insect and weed pest management. Ecologically-based rodent management (EBRM) is a holistic approach to rodent management, but must be understood at all levels—by decision-makers, extension staff, scientists and the end-users. Inevitably more basic and strategic research will be required before appropriate strategies for EBRM are developed, and different constraints will apply in different situations when considering its implementation. Clearly EBRM must be finely targeted to specific agro-ecosystems and pest species. New technologies, conventional and biotechnological, will be developed over the next decades. Of critical importance will be full assessment of these before their adoption and widespread implementation. Training of the next generation of scientists and managers is also an essential element of EBRM because the solution to rodent management problems is complex and must be considered as a long term problem requiring continuing development and application.

Keywords

Ecologically-based rodent management, rodent pests, training, developing countries

Introduction

THIS BOOK HAS achieved, for a subset of developing countries, an audit of the status of rodents as pests in the 1990s. In this chapter we consider the progress of 'ecologically-based rodent management' (EBRM) in developing countries through drawing on the contributions provided from Asia (eight chapters, six countries) and Africa (four chapters, three regions). We will focus primarily on management, training and research issues.

Establishing a Profile for Ecologically-based Rodent Management

The importance of the impact of rodents is a common theme which has emerged from the chapters contributed from developing countries. This recognition is felt commonly to be overdue. The breadth of information coalesced in this book is immense—for example, in Indonesia, the depredations of rodents are equivalent to the amount of rice required to provide 25 million people 65% of their annual dietary requirements, while the impacts of rodents are increasing in Lao People's Democratic Republic (agriculture), Madagascar (conservation), Tanzania (agriculture and health) and Vietnam (agriculture). We hope that this cataloguing of impacts at an international scale will assist in establishing that sustainable and ecologically compatible management of rodent pests requires equivalent stature to that of insect and weed pest management.

The inclusion of research on rodent pests in the current national 5-year plan in China (see Chapters 12 and 13) and the recent development of a national rodent pest laboratory in Indonesia (see Chapter 14), indicates that the impacts of rodent pests are beginning to gain appropriate status. In both these countries there is strong recognition for the need to develop and apply EBRM. These programs need to be progressed so that they become flagships for EBRM in developing countries.

A common message to emerge from those developing countries which have embraced EBRM, is that basic studies of the taxonomy, ecology and population dynamics of the target rodents are required before management strategies can be developed and implemented (see Chapters 15, 18, 21 and 22). The difficulty of convincing governments in developing countries of the need for basic research cannot be underestimated; these countries have major rodent problems today, whilst the food demands of society are intensifying, leading to increasing pressure on biologists to deliver immediate solutions.

Moving Beyond Mortality Control

Traditionally, rodent control has focused on numbers of rodents. An intuitive and simple response to high rodent numbers became generally accepted: if there are too many rats, then kill some. Methods for doing this killing have been developed over thousands of years and vary from simple hunting to use of sophisticated chemical compounds. This minimalist approach to rodent damage management is often successful, but it is not sustainable. Indeed, population size is the result of several processes—not only mortality, but also natality, immigration and emigration. Focusing only on mortality neglects the other demographic processes and possible interactions. It is a strategy which concentrates on 'reparation' of the problem, rather than prevention. The holistic approach, which we have termed 'ecologically-based rodent management' (Chapter 1; see also Singleton and Brown 1999), at least provides for some optimism that more sustainable and persistent strategies can be developed and that rodent damage is not an insoluble problem.

The chapters on rodent pests in developing countries indicated a plethora of pre- and post-harvest problems in rural areas and storage and disease problems in both rural and urban areas. Several chapters also provided examples on how aspects of demography other than just mortality could become important elements in the management of rodent damage (e.g. Chapters 1, 10, 14 and 20). Another persuasive message to emerge from the contributions by authors from developing countries is that there is a strong will by their governments to adopt more ecologically-based rodent management. However, despite a wide interest in more integrated approaches of rodent control (see, for example, in Prakash 1988; Buckle and Smith 1994), the development and implementation of the principles of what we now call EBRM have been slow and difficult. The reasons and constraints for this are many, and may differ between situations. We discuss the most important of them here.

Constraints on Developing and Implementing EBRM

Basic biological knowledge

The complex biology and behaviour of rodents is probably the main reason why integrated pest management in rodent control has not evolved as fast as that for insect or weed control. For many rodent species, even for the common pest species, knowledge of their population ecology is far from adequate. In some instances even the taxonomy of the rodent pests is not well defined (see Chapters 15 and 18). Although a farmer may not care which species is destroying his crop, management strategies based on ecological characteristics require knowledge on which species are present, their habitat use, breeding patterns and population dynamics.

Sometimes, taxonomic differences are of paramount importance to a rodent problem. For example, within the African genus *Mastomys*, there are two morphologically similar species that can be recognised only by the number of chromosomes. One of them, *Mastomys natalensis*, is resistant to, and a reservoir for, the plague (*Yersinia pestis*), while the other, *Mastomys coucha*, is very susceptible to the plague (Isaacson et al. 1981). Knowing which species are present in an urban or semi-urban environment has major implications for management strategies, especially when resources are limited, as is the case in most eastern African rural communities.

Krebs (Chapter 2) claims that it is now time to move on from descriptive studies of rodent pests to experimental work. This unfortunately is only true for a few pest species in African and Asian countries where sufficient knowledge is available. The case studies presented in this book on the population ecology of rodent species from China, Indonesia, Malaysia, Mali, Tanzania and Thailand indicate examples of where an experimental approach would be timely. In most instances, however, more basic research is required. Information at community or landscape level is even more scarce, but vital for investigations on such issues as the potential for biological control using predators.

The development of specialised techniques like immunocontraception requires a detailed knowledge of the reproductive physiology of the target species and a thorough understanding of its population ecology (Chapter 10). In developing countries, such a broad knowledge base is available for just a few species of rodent pests.

This shortage of biological knowledge often reflects a limited understanding of its importance by funding organisations, the low number of interested and adequately trained scientists, and the poor economic situation of many of the countries that we discuss here. Added to this is the reality that most of the research underpinning EBRM in developing countries has to be done in situ, where scientists are often working in isolation from international colleagues because of language problems, poor communication infrastructure and/or international political issues.

Ownership of rodent problems

In many countries, national rodent control programs or services have been established, often for good reasons (e.g. Madagascar, see Chapter 21). Yet, however well meant or successful, some of these programs contribute to a perception that rodent control is not the farmers' responsibility but the government's and, at best, farmers should participate in control actions directed by government technicians. Moreover, rodent problems are often considered to be a fact of life and a common view held by farmers is that nothing can be done about them. As a result, there is often not a strong commitment by farmers and other end-users in applying strategies that may require a long-term involvement.

Few governments in developing or developed countries are involved in early tactical management of rodent pests. Instead, governments generally only become involved when problems suddenly reach a level at which emergency actions are required. After this 'crisis management', rodent pests generally again fall back to the bottom of the political agenda. If farmers take a lead from how governments handle rodent pests, then it makes it harder to convince farmers that they need to adopt early tactical control rather than crisis management. Unfortunately, this happens at all levels, be it local, regional, national or international funding agencies.

An ecologically-based approach also requires an acceptance that activities in one place may have a dampening effect on rodent populations in another place. For example, EBRM may recommend changes in land management or in irrigation schemes where the individual who applies the actions is not always the one (or the only one) who will benefit. Socioeconomic, cultural or political aspects may then dominate the development of EBRM strategies (Singleton and Petch 1994; see Chapters 8 and 14).

Access to information

EBRM is, by necessity, targeted to specific agro-ecosystems and pest species. Solutions are rarely generic; they cannot simply be transplanted between places. Therefore, large information campaigns cannot be set up easily. On top of that, the rather complex message of EBRM has to compete with straightforward techniques of pesticide application. Promotion of the latter is nearly always driven by commercial objectives, and therefore often is better organised and has more financial support.

Where national authorities have a large influence on rodent control strategies, they will search for national solutions. These will not always take into account the specific local conditions that are important in EBRM.

Investment capital

Finally, it should be noted that most EBRM strategies are, by definition, aiming for long-term results. In countries such as Indonesia, Tanzania and Vietnam, most farmers are risk-aversive, low-capital entrepreneurs. Thus, many will not invest in solutions which immediately are more expensive, even though they may pay off in the long run. Therefore, EBRM ideally should only be marginally more expensive to implement than existing practices, even if these practices are less effective and more expensive than EBRM in the long term.

Maintaining the Momentum for Ecologically-based Rodent Management

Training the next generation of scientists

Although we have discussed a number of factors which are likely to constrain the development and implementation of EBRM, the most basic and important of them is the lack of biological knowledge. Fortunately, there is a growing interest among zoologists and wildlife managers to spend the time and energy on understanding the population biology of rodent pests. Many authors of chapters in this book stand proof of that. In order to secure this development, particularly in developing countries, there is an urgent need for more ecologists. Young population ecologists and wildlife managers need to be educated at academic levels (M.Sc., Ph.D.) with a strong emphasis on pure science, but in the context of applied, strategic research. Far too often there has been a wide gap between basic and applied research, leading to technologists providing incremental improvements on methods that are part of a classical but unimaginative template, while pure scientists conduct their research and gather new insights outside agricultural systems. Today, we have a need for scientists and managers to be adept in both fields. The chapters in Section 1 of this book are by scientists who have a major focus on basic research but are aware that their research in ethology (see Chapters 2 and 3), modelling (Chapter 4), ecosystem dynamics (Chapter 5) and epidemiology (Chapter 6) could make important contributions to the management of rodent pests. However, the findings of their research need to be readily accessible to field practitioners. Often this is not the case and we are pleased that they were willing to use this book as one forum to bridge this communication gap.

Once young scientists have been trained formally, they require the opportunity to conduct strategic research. In an EBRM context this would consist of basic biological research under the field conditions where rodents cause problems. This kind of research will not quickly provide new techniques and solutions meaning that long term funding has to be secured.

Also, the results of strategic research need to be transferred to practitioners. This technical transfer should focus on new EBRM methods that have been tested under field conditions in replicated, experimental studies conducted on an appropriate scale. It is very important that at this stage, the science can be integrated with particular socio-economic systems. Investigating socio-cultural aspects and consequences of EBRM strategies, as well as economic cost–benefit ratios, is essential.

Short-term thinking for long-term problems

EBRM requires a long-term approach, both in development and in application. Much effort will be needed to convince policy-makers of this. On the other hand, the impacts of rodent pests will not abate until we have developed appropriate EBRM-techniques. Therefore, there will be continued pressure for urgent, short-term solutions, particularly in developing countries. Consequently, EBRM proponents must be prepared to develop interim management practices, even though they are unlikely to be sustainable. An example of this is the work of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Rodent Research Group. The focus of this group is EBRM (Singleton 1997; Singleton and Brown 1999) and long term research (> 5 years) is progressing to develop strategies for EBRM. Mouse plagues have occurred in the past few years whilst this research has been in progress. To help combat these outbreaks, research effort has been deflected periodically to help develop broad-scale aerial application of rodenticides (Brown et al. 1997; Brown and Singleton 1998). This balance of research focus has meant that farmers see the research outputs of the group as relevant to their needs, and this has maintained their interest in the ongoing research on EBRM.

Maintaining credibility with farmers and other end-users

Ecologically-based rodent management will rarely provide spectacular quantities of dead rodents. Indeed, the concept of EBRM is to maintain rodent densities below levels that cause significant economic losses to agricultural produce or significant health problems. On the other hand, as discussed above, EBRM will require investments in material or labour. For these reasons, farmers may be sceptical about applying such methods. Therefore, a major challenge is to convince farmers of the benefits of EBRM.

An equally large challenge is to ensure that new methods are only promoted when they have proven their value. There is a risk that enthusiastic scientists, managers of scientists, impatient funding organisations or politicians may promote strategies that are not yet well tested but that are popular, politically correct or attract research funds. If these strategies are less effective than announced, the loss of credibility would make it difficult to later convince end-users to adopt an improved version. A topical example in Southeast Asia is the trap–barrier system plus trap crop. This method has good potential to be the cornerstone for developing EBRM in rice ecosystems, but a number of possible weaknesses have been identified (see Chapter 8). This management system is being strongly promoted by some government agencies in the region, yet its performance has not been assessed at the village level, nor do we know whether any of the potential weaknesses are sufficiently major to require some modification of this simple technology (Singleton et al. 1998).

Incorporating and integrating different strategies

As a holistic approach, EBRM will rarely focus on one single element in the rodent's biology. Management strategies will therefore implicate different techniques and methods. Some may be slight modifications of existing technologies, others may be more innovative. The challenge will be to find a balance, ensuring that focusing too much on one technique does not compromise the benefits of an EBRM approach. For example, the argument that immunocontraception of house mice, *Mus domesticus*, if successful, needs to be integrated into an EBPM context (Chambers et al. 1997; Chapter 10) is a good example of the type of thinking that is required.

Concluding Comments

The re-emergence of the importance of population ecology and an emphasis on management directed at the agro-ecosystem level raises hopes that rodent pest management will begin to match the progress made by entomologists and botanists in controlling insect and weed pests. We are confident that the next decade will see rapid advances in ecologically-based rodent pest management. The development of this strategy will be driven not only by a new generation of wildlife managers who will have stronger training in the theory and practice of population ecology and ecosystem management, but also by the imperative to produce 'clean and green' produce for domestic and export markets. Therefore, by necessity, we will have to develop more environmentally benign and sustainable methods for rodent pest management, reducing our sole reliance on rodenticides as killing agents.

Ecologically-based rodent management provides the necessary platform for designing management strategies which are environmentally safe. The combined contributions to this book indicate strongly that reasonable progress towards the development of EBRM requires good cross fertilisation between basic and applied research on rodent pests, plus the ability to apply the fruits of this union in a meaningful socio-economic context. In developing countries in particular, advances in EBRM could translate to significant improvement in the human condition. If this book can influence the basic and applied rodent biologists of today and tomorrow to contribute towards this outcome then we will be well satisfied.

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