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Ecologically based rodent management in Africa: potential and challenges

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Abstract. Rodent management in agriculture remains a major challenge in developing countries where resource-poor farmers are ill equipped to deal with pest species. It is compounded by unpredictable outbreaks, late control actions, lack of/or inadequate expert interventions, expensive rodenticides and other factors. Ecologically based rodent management (EBRM) is recommended as the way forward for rodent management in Africa. EBRM relies on understanding the ecology of pest species and formulating this knowledge into management programs. The present paper evaluates the potential for establishing EBRM in Africa and the challenges that have to be overcome to implement it. The major constraints for establishing EBRM in Africa include the absence of key studies on the taxonomy and ecology of rodents, inadequate research on EBRM, lack of knowledge by farmers on available technologies and agricultural policies that are unfavourable. The development of EBRM and its success in Asia is a strong encouragement to African scientists to develop similar management strategies for the most important pest species such as the multimammate rats, *Mastomys natalensis*. EBRM initiatives such as the Development of Ecologically Based Rodent Management for the Southern Africa Region (ECORAT) project undertook studies on e.g. rodent ecology, taxonomy, knowledge, attitude and practices and rodent–human interactions in rural agricultural communities. Through this project, EBRM interventions were introduced in Tanzania, Swaziland and Namibia to provide solutions to local rodent-pest problems. Intervention actions including community-based intensive trapping of rodents, habitat manipulation and sanitary measures demonstrated that the impacts of rodents on communities could be drastically reduced. EBRM programs in Africa must address how to change attitudes of target communities, building scientific capacity, implanting rodent-management skills by translating the developed technologies and strategies into simple understandable and easy-to-implement actions and influencing policy makers to accept the concepts and practices to be introduced. Further, we need to demonstrate that EBRM is economically feasible and sustainable and that through community participation, EBRM will become deeply rooted in those communities.

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Introduction

Rodents are of considerable economic and public-health importance because of their abundance, diversity and proliferation in all kinds of habitats, including agricultural fields, domestic and peridomestic areas and industrial infrastructure. Their impact in agriculture includes damage and losses of crops in the field and in storage and reduction of the value of crops through contamination. In public health, they are reservoirs of zoonotic diseases such as lassa fever, plague, toxoplasmosis and leptospirosis. Among the bacterial diseases, plague is the most threatening and is re-emerging in some countries in the world (WHO 2006). Rodents cause significant damage to property, including buildings, furniture, wires and clothes.

Rodents represent a significant constraint to crop production in agro-ecosystems worldwide and their management remains a major challenge to scientists, extension specialists and farmers. Rodents pose a greater threat to agricultural productivity of resource-poor farmers in Africa because of the damage and losses they cause and the high costs for their management relative to other regions in the world (Makundi *et al*. 1999). The need for sustainable rodent-pest management in Africa also arises from the fact that rodent-pest infestations are increasing as a result of changing agro-ecosystems and agronomic and land-use practices. Developing an effective and sustainable rodent-management system is viewed essential for increasing crop yields and economic benefits to farmers. Many studies in different parts of the world have indicated substantial losses of agricultural produce as a result of rodents, in particular cereals, which are the staple food for millions of people (Makundi *et al*. 1991; Singleton and Petch 1994; Boonsong *et al*. 1999; Parshad 1999; Singleton *et al*. 1999; Leirs 2003). For southern and South-east Asia alone, a conservative estimate of 5% annual loss caused by rodents amount to 16 million tonnes of rice, enough to feed 50 million people (Leirs 2003). Although there are relatively few studies that provide accurate estimates of crop losses caused by rodents in Africa, recent studies of farmer's knowledge, attitude and practices in rodent management have clearly indicated that rodents are regarded as the most serious pests in agriculture and the most difficult to control (Makundi *et al*. 2005; Meheretu *et al*. 2010). About 25 species of rodents have been recorded as pests in agriculture in Africa, causing a wide range of damage and losses in cereals, legumes, vegetables,

root crops, cotton and sugarcane (Makundi *et al*. 1999). Among the species, *Mastomys natalensis* (Muridae) is the most serious pest and is widely distributed in sub-Saharan Africa (Kingdon 1974). Since the socio-economic conditions and cropping systems are very similar in sub-Saharan Africa, the impact of this pest species is severe in many countries. Changing landscape ecology in sub-Saharan Africa as a result of clearance of woodland for agriculture has led to increasing problems with *M. natalensis* in agricultural land (Taylor 1968). At the small-scale farmer level, no new technologies have been introduced to cope with outbreaks of this pest, although there have been some important suggestions on control strategies, including regional-scale intervention following outbreak predictions (Davis *et al*. 2004), calendar-based control actions (rodenticide application) (Skonhoft *et al*. 2006) and control action (also rodenticide application) before planting and during population peaks (Sluydts 2009).

Seasonal outbreaks of *M. natalensis* in Morogoro Tanzania may cause damage, reaching 80–100% in maize fields at the sowing and seedling stages (Mwanjabe and Leirs 1997). The average annual loss of maize is ~15% (Makundi *et al*. 1991), which corresponds to losses of 400 000 t. This amount could feed 2.3 million people for a whole year (Leirs 2003). The sugarcane rat, *Thryonomys* sp., and *Lemniscomys striatus* also cause damage to crops in fields, whereas *Rattus rattus* is a primary pest species feeding on stored food supplies and causing damage to stored goods in granaries (Drazo *et al*. 2008). Cassava and other tuber crops often experience severe damage caused by rodents in eastern and southern Africa (Makundi *et al*. 1991; Bekele *et al*. 2003; Sichilima *et al*. 2003). Maize and rice are the most vulnerable to rodent damage during the heading stage in central Africa (Drazo *et al*. 2008). Farmers in Africa have continued to rely on rodenticides to control rodent outbreaks. However, problems of supply, poisoning of non-target organisms and increasing costs for their purchase and application are some of the shortcomings associated with this strategy (Makundi *et al*. 1999). Rodent-control campaigns using rodenticides can achieve only short periods of population suppression because the remaining animals compensate with better survival and better breeding performance (Singleton *et al*. 1999). Experiences elsewhere have shown that reliance on rodenticides is not sustainable and there have been shifts to integrated approaches and ecologically based strategies (Singleton *et al*. 1999). Traditional methods for rodent control in Africa cannot cope with outbreaks (Makundi *et al*. 1999). Therefore, alternative rodent-management strategies are required. Knowledge of the ecology of rodent-pest species and its application in ecologically based rodent management in Africa is currently viewed as cost-beneficial in the long-term and is also a sustainable approach (Makundi *et al*. 1999; Belmain *et al*. 2008).

In this article, we examine the potential for ecologically based rodent management in Africa as an alternative to traditional and conventional approaches to reduce the impact of rodents on crops. Further, we discuss the challenges that have to be addressed and recent initiatives to implement EBRM in Africa.

Ecologically based rodent management

Ecologically based rodent management (EBRM) whose primary aim is to provide effective and economic management of rodent pests is regarded as the most rational strategy for the future (Singleton *et al*. 1999). EBRM is essentially an integration of rodent-management methods that relies strongly on understanding of the population biology, social behaviour, taxonomy and community ecology of rodents, with additional emphasis to include end users early in the development of the management strategies (Singleton *et al*. 2004). EBRM further aims at developing environmentally benign management programs that focus not simply on killing animals but on preventing their eruptions and otherwise reducing their impact on crop yields (Singleton *et al*. 2007). Recent studies in Indonesia involving large replicated field trials have shown that EBRM had some effects on rodent population structure, which reduced the mean level of crop damage and led to higher rice production (Jacobs *et al*. 2010).

Africa has critical problems of rodent infestations in agro-ecosystems, which are compounded by lack of effective rodent-management strategies. Although the management of rodents in ecological perspectives was proposed many years ago as a way forward for Africa, no such programs were established (Makundi *et al*. 1999; Sicard *et al*. 1999). Most of the successful EBRM programs have been implemented in Asia where the cropping and farming systems are different from those in Africa. Also different are the target rodent species, their biology and ecology. Social and cultural systems in Asia are also different from those of farming communities in Africa. These are important variables that influence the way farmers perceive and conduct rodent management in their fields. According to Singleton *et al*. (2004), EBRM requires management systems to be developed for specific species under specific production systems. In Asia, rice is the principal staple and commercial crop which rodent management aims at protecting. It has been shown, for example, that Indonesian villages that practised EBRM increased rice yields by 6% and rodent-control costs were significantly reduced (Singleton *et al*. 2004). In many parts of Africa with serious rodent problems, maize is one of the most vulnerable crops because of rodent depredation. The rodent population characteristics, crop damage and loss variables, socio-economic conditions of the farmers and the nature of the farming systems in Africa will define how the EBRM is developed and made functional in specific places and for specific crops or cropping systems.

The development of EBRM to manage the rice-field rats, *Rattus argentiventer*, in Asia (Singleton *et al*. 1999, 2004; Brown *et al*. 2006) is a strong encouragement to African scientists to develop management strategies for rodent-pest species such as e.g. the multimammate rats, *M. natalensis*, grass rats, *Arvicanthis* spp., *Rhabdomys pumilio* (Makundi *et al*. 1999), *Thryonomys* sp. and *Lemniscomys striatus* (Drazo *et al*. 2008). EBRM in Africa must address variables such as the complexity of the agricultural systems, socio-cultural differences of different communities and variables of climate and landscape. Researchers must understand the key components that influence the rodent-pest severity, including the biology and characteristics of the pest population and how these interact with the agro-ecosystem.

Potential of EBRM in Africa

The potential for establishing EBRM in Africa can be assessed in different ways, including the following:

(1) The fact that the majority of farmers are resource poor and cannot afford to invest in pesticides. The currently unfavourable cost (of rodenticides and their application) – benefit ratio makes EBRM a welcome alternative for farmers. This has been demonstrated in Asia where EBRM programs helped increase crop yields and reduced rodenticide usage (Singleton *et al*. 2004).
(2) The magnitude of losses and food insecurity is huge in many countries because of the ineffectiveness of traditional and conventional practices to manage rodent pests (Makundi *et al*. 1991, 2005; Leirs 2003; Meheretu *et al*. 2010) and therefore EBRM will be viewed as an alternative to reduce these losses.
(3) A workable rodent-management system that lowers future risks of rodents developing resistance to rodenticides and ineffectiveness as a result of factors such as e.g. poor formulation of bait and rising costs, will be easily acceptable.
(4) Small-holder farmers in Africa view rodents as difficult pests to control primarily because of lack of effective management strategies (Makundi *et al*. 2005; Meheretu *et al*. 2010). Introduction of EBRM will enable them to solve a persistent pest problem.

Challenges facing the introduction of EBRM in Africa

The major constraints for establishing EBRM in Africa include the following:

(1) Lack of national institutions mandated to develop and deliver the EBRM technologies to stakeholders. Such bodies exist for other important pests such as armyworms, locusts and *Quelea quelea* birds. In some countries in Africa, EBRM technologies have been developed through the support of short-term research projects. The costs for establishing and maintaining permanent institutions responsible for EBRM will be far outweighed by the benefits that could be realised by reducing rodent damage to crops. In Tanzania, for example, losses amounting up to $42 million could be averted annually if an effective EBRM program is introduced to protect maize crop from rodent depredation (Leirs 2003).
(2) Inadequate or non existence of research that addresses EBRM in many African countries. EBRM is a new concept and in Africa, it has not been widely publicised beyond academic circles. In many countries in Africa, researchers are still debating integrated pest management (IPM).
(3) Lack of economic analysis that can help policy makers and farmers make proper decisions on pest-management strategies that will provide the best benefits in the agricultural system where rodents are a problem. Lessons from South-east Asia show that EBRM requires strong sociological and economic components (Singleton *et al*. 2004).
(4) Lack of knowledge by farmers for proper adoption of technologies on EBRM. The developed rodent-management programs need to be publicised and understood, and in addition, farmers need to know how the introduced technologies will change their socio-economic status and general welfare.
(5) Lack of proper agricultural and/or pest management policies that focus on establishing, coordinating and implementing EBRM. Agricultural policies may have a significant effect on development and adoption of EBRM. The policies may affect funding for rodent management, research and extension. Pest-management policies, if they exist, may be biased towards funding of certain rodent-management strategies (e.g. purchase and application of rodenticides) which may not encourage and support the development of ecologically based rodent management.
(6) Lack of/or insufficient studies to develop or evaluate strategies for management of key rodent-pest species in agriculture. Required studies include rodent behaviour, population dynamics (breeding patterns, factors regulating densities, spatial and temporal density changes), establishing the rodent density–crop damage relationship and threshold population size that causes significant crop losses (Mulungu *et al*. 2003); the influence of farming practices on distribution and abundance of rodents (Massawe *et al*. 2003, 2005). Singleton *et al*. (2004) emphasised the need to identify the source and sink for dispersal of rodents, with particular attention paid to adjoining habitats that may be the source of recolonisation after control campaigns. This is of great relevance because most farming systems in Africa are a mosaic made up of cultivated fields interspersed with fallow land.
(7) Despite the fact that rodent pests are recognised as a chronic problem in some crops or some agro-ecosystems, there are few researchers in Africa who are involved in studies such as e.g. of rodent taxonomy, ecology and rodent management. Fewer resources are allocated for these kinds of studies by African governments and donor organisations than those allocated to funding of contemporary issues such as malaria and HIV.

Understanding the taxonomy of the pest species

Ecologically based management of rodent-pest species relies strongly on knowing their taxonomy (Corti *et al*. 2005). A proper identification of species is required, and sometimes, refining the taxonomy of the already known species is mandatory. However, the exercise is slow and sometimes haphazard, particularly without good financing in Africa. Taxonomic studies should also focus on rodent species diversity to be able to categorise the pest species, non-pest species and beneficial species (Makundi *et al*. 2010). It is also possible that some species are potential pests depending on the crops being cultivated. Changes in the cropping system or concentrating rodent-management activities on the dominant pest species could elevate some minor species to pest status. Therefore, in an EBRM program the management practices should address these species in a locality, district or country. However, it should also be noted that there is hardly a single strategy that could be adopted on a wide area because of the changing ecology of the pest species brought about by environmental variables, spatial variations in landscape ecology and species diversity.

In the past few years, some progress has been made in refining the taxonomy of several rodent taxa in East Africa. Some studies were conducted in 2001–2003, aiming at understanding the taxonomy and ecology of pest species in East and southern Africa (Corti *et al*. 2005). The taxonomy of

several groups, including *Gerbilliscus*, *Aethomys*, *Acomys*, *Arvicanthis*, *Saccostomus* and *Lophuromys*, has been refined (Fadda *et al*. 1999; Castiglia *et al*. 2003; Corti *et al*. 2005). In more recent studies, combined molecular and morphological approaches enabled identification to species level of rodents from Tanzania, Swaziland and Namibia (The Natural Resources Institute 2010). These studies are a good foundation for establishing EBRM in East and southern Africa. Similar initiatives have been carried out in Sub-Saharan West Africa (Sicard *et al*. 1999).

Ecological studies

EBRM programs in Africa should aim at integrating management strategies that are applied at key periods on the basis of an understanding of the biology and ecology of the pest species and the cropping system. Studies of rodent ecology that will form the basis for an area-wide rodent management in Africa are currently few and fragmented. Pioneering studies have been carried out in East Africa (e.g. Leirs 1992; Leirs *et al*. 1996; Mwanjabe and Leirs 1997; Makundi *et al*. 1999, 2010; Ojwang and Oguge 2003), southern Africa (Sichilima *et al*. 2003; von Maltitz *et al*. 2003) and West Africa (Sicard *et al*. 1999). Modelling populations of key pest species such as the multimammate rats is important in conducting EBRM in Africa (Sluydts *et al*. 2007, 2009). These studies were carried out in recognition that farming and rodents are isolated and that farming and land-use practices have a great influence on the status of certain species of rodents as pests in agriculture (Massawe *et al*. 2003; Mulungu *et al*. 2005). A community's understanding of the linkage between farming or cropping system and other land-use practices and the pest status of rodents is important for successful introduction of management strategies.

Ecological management of pest species should aim at reducing key resources such as food and nesting sites at critical times of the year through habitat modification (e.g. reducing fallow patches surrounding cultivated fields) (Makundi *et al*. 1999), tactical strategies to reduce population size by implementing specific actions such as community-based intensive trapping (Belmain *et al*. 2003, 2008), establishing threshold populations that cause economic damage to the crop (Mulungu *et al*. 2003), identification of critical times when control actions are most appropriate (Stenseth *et al*. 2003), predicting the occurrence of outbreaks and giving an early warning to the community (Leirs *et al*. 1996; Mwanjabe and Leirs 1997; Makundi *et al*. 1999).

Further, the role of predators in EBRM should not be underestimated. Natural predators of rodents include small carnivores (e.g. weasels, stoats, mongooses, cats and ferret), birds-of-prey (e.g. buzzards, kites and owls) and reptiles such as snakes and monitors lizards. However, the impact of predation on rodent populations varies depending on the type of predator and the size of the rodent population. Predators cannot control rodent populations effectively when they are at peak levels (Wodzicki 1973). However, predators can be introduced or attracted in the fields to increase the predation pressure on rodents. For example, birds-of-prey can be attracted by setting up perches and nest-boxes in the fields on a community basis rather than on one farm only. Integrated control, including effective trapping, predation and other preventive measures implemented in the context of EBRM, may significantly reduce rodent populations. During the implementation of the STAPLERAT Project in East Africa in 2000–2003, local communities in Tanzania and Kenya had a highly negative reaction to owls; however, involving the farmers in the program and explaining the aims of installing nest-boxes and benefits of owls made the farmers view owls positively. Studies in South Africa indicated that using owls to control gerbil (*Gerbilliscus afra*) damage in wheat farms in the Western Cape Province was twice as effective as using poison, and much less expensive in the long term (Potter 2004).

The selection of techniques shall depend on available ecological information, nature of the agronomic system, environmental awareness and socio-economic considerations that need to be investigated before EBRM implementation.

Hypotheses testing in an EBRM context

To establish workable EBRM strategies in Africa, we need to define our goals so that appropriate hypotheses are tested to provide more basic and applied information on rodent ecology, behaviour and habitat utilisation of the many species of rodents that can be found in an area. We also need to know how intricately the ecology of the pest species is linked to the existing rodent-management practices and how they affect rodent populations and whether these could be improved for greater impact in reducing the depredation of crops by rodents.

The need to define the ecologically based rodent-management hypotheses that can be tested in the field, and whose outcome can provide us with practical solutions appropriate to a particular community, is paramount. Experimental work based on relevant hypotheses that aim at providing ecological information for implementing rodent management in the EBRM context is needed.

In some areas, however, some key pests such as *M. natalensis* may have already been studied in detail and therefore the required ecological information can form the basis for EBRM. However, the minor or occasional rodent pests may also require much attention. For example, studies in Vietnam showed that when *Rattus argentiventer* was suppressed through trapping, *R. losea* emerged in greater abundance (Brown *et al*. 2003). This further illustrates the intricate and delicate associations between species, which need to be well understood in EBRM context to ensure that control of one species does not create a new pest problem.

Other studies may focus on the need to establish the threshold population above which most damage is caused. In Tanzania, for example, the threshold population size that causes economically significant crop damage was established for maize at the sowing stage (Mulungu *et al*. 2003). The established relationship is fundamentally important in the following two ways: (1) it provides us with information on the minimum population size that causes economic damage to the crop and (2) it enables us to establish precisely the most appropriate timing of control measures.

Community participation in ecologically based rodent management

One major lesson of EBRM from South-east Asia is the emphasis to involve and include end-users early in the development of

management strategies (Singleton *et al*. 2004). For ecologically based rodent management to function, the farming communities must carry out coordinated actions because individual efforts have little impact on rodent populations. Rodents quickly colonise areas from which they were exterminated by poison or other means of control (Krebs 1966). Community rodent-pest control could be a first step towards ecologically based rodent-pest management in Africa. In many countries in Africa, management of rodents is currently on individual farm or household basis, each farmer applying their own strategies (e.g. trapping and poisoning) (Makundi *et al*. 1999). Involving the community in rodent management is a major challenge that addresses the problem of e.g. organisation, cultural and social differences, training and financing. Knowledge, attitude and practice (KAP) studies have been an important component of EBRM in South-east Asia (Sang *et al*. 2003; Sudarmaji *et al*. 2003; Tuan *et al*. 2003). In Africa, trans-country surveys by means of KAP studies should be carried out to enable us to understand the knowledge limits of those individuals we want to assist in rodent management. Understanding how much they know, what tools they actually use and how effective they are for rodent management is important in the pre-EBRM implementation. Few studies have been conducted to show the knowledge, attitude and practices in rodent management in Africa. In studies carried out in Tanzania and Ethiopia by Makundi *et al*. (2005) and in Ethiopia by Meheretu *et al*. (2010), it was clearly shown that farmers considered rodents in their fields a major pest problem and ranked them higher than insects, diseases and birds.

A successful EBRM program will require community participation in the whole process of its establishment. In South-east Asia, for example, EBRM methods were identified through farmer consultations on the basis of their cropping calendar and the biological knowledge of rodent populations accumulated from field studies (Singleton *et al*. 2004). Because it is envisaged that new technologies will be developed and adopted in EBRM program, farmer's perceptions on their technical effectiveness and feasibility in terms of economic profitability, social acceptability and cultural suitability must be assessed (Palis *et al*. 2003). Resource-poor farmers in Africa also require low-cost technologies for rodent management that will enable them to maximise production without hiking the production costs. For example, management methods involving trapping and environmental management have been emphasised as an appropriate approach in an EBRM context (von Maltitz *et al*. 2003; Belmain *et al*. 2008). The few studies conducted in Africa (Makundi *et al*. 2005; Meheretu *et al*. 2010) suggest that farmers generally lack effective strategies and technologies to manage rodents in their fields. It is also important to know whether the farmers are interested to know more and whether the problem we want to address is viewed as serious from their point of view and not from the researcher's point of view. It is also necessary to fill the knowledge gap by means of e.g. seminars and farmer field schools.

Change of attitudes and implanting rodent-management skills

A successful EBRM poses another major challenge that it must bring about some change in attitude and practices among the farmers. Farmers may have been used to practice rodent control in a particular way. For example, storage structures with no rat-guards are prone to rodent infestation and severe post-harvest losses (Makundi *et al*. 2007). To introduce rat-guards in these structures appears simple, but certain modifications may be required, including raising them from the floor to a certain height and building them outdoors. Whereas these modified storage structures are an important component of EBRM in Africa, this change may not be easily accepted in some communities because outdoor storage is much more prone to theft and pilferage (Makundi *et al*. 2007).

EBRM programs for African farmers should implant the necessary skills and knowledge so as to increase their ability to manage rodents by applying the recommended strategies. The successful EBRM programs in countries such as Vietnam and Indonesia have clearly shown high levels of farmer participation in the experimental phase (testing of control options), which increased the adoption rates of the developed technologies in the final phase of implementation (Brown *et al*. 2003; Singleton *et al*. 2004). Therefore, in implementing EBRM in Africa, we should be able to demonstrate the following:

(1) Rodent pests can be sustainably managed through the alternative approaches that we want to introduce. However, we also need to emphasise that rodenticide use can be a component of EBRM when used sensibly, safely at key times and key habitats in a community effort.
(2) It is economically feasible and less expensive to implement relative to the conventional approaches, e.g. the use of poisons. Even if the benefit–cost ratio of EBRM and conventional approaches are similar, we may need to show that the environmental benefits of EBRM could be higher than those of conventional methods.
(3) Through participatory research and community actions such as intensive trapping (Belmain *et al*. 2008), it is possible to control rodents and reduce their impact on crops and public health.

EBRM initiatives in Africa

There have been some initiatives to establish rodent-management systems based on the EBRM concept in South Africa (von Maltitz *et al*. 2003), Sub-Saharan West Africa (Sicard *et al*. 1999), East Africa (Leirs *et al*. 1996; Mwanjabe and Leirs 1997; Makundi *et al*. 1999; Leirs 2003; Odhiambo and Oguge 2003) and southern Africa through the Development of Ecologically Based Rodent Management for the Southern Africa Region (ECORAT) project (http://www.nri.org/projects/ecorat/, accessed 10 July 2010). In Tanzania, an early warning system for rodent outbreaks was developed on the basis of an outbreak prediction model (Leirs *et al*. 1996; Mwanjabe and Leirs 1997). Rodent-outbreak prediction models allow the different actors in rodent-pest management to implement the recommended strategies to prevent population build-up to damaging levels. Farmers and extension staff are able to monitor rodent populations in the field and in cases where the likelihood of an outbreak is predicted, control measures could be implemented. Where early predictions are made, ecologically relevant strategies could be more effective in reducing the impact of rodent outbreaks. In southern Africa, the ECORAT project emphasised understanding of species diversity

(Table 1), breeding patterns, population dynamics, habitat utilisation and disease potential.

Community-based intensive trapping in southern Africa

Intensive trapping aims at reducing rodent populations to very low numbers by removing them faster than their rate of breeding and immigration (Belmain *et al*. 2003, 2008). In southern Africa, intensive trapping was combined with other measures, including making grain stores rodent-proof, clearing rubbish in houses and peri-domestic areas and reducing fallow and bush in areas surrounding the home, to minimise rodent impacts. Intensive trapping of rodents was identified as an ecologically based strategy that was relevant for African villages and reduced rodent infestations significantly in the households in Namibia, Swaziland and Tanzania (Belmain *et al*. 2008)

Publicising EBRM

At the ground level where we want to introduce EBRM, we need to be more aggressive in publicising the concept and showing the opportunities in EBRM *v.* the conventional approaches for rodent management, the failures in the past or anticipated failures and constraints (e.g. resistance, costs), the limitation of available resources to control rodents using the conventional approaches, and how a good understanding of the ecology of the pest can be used to manage them.

The availability of scientific information does not necessarily imply that the problem of rodents in the field is solved. We need to identify further the management actions that could be implemented by the farmers. These have to be translated into simple messages that can be adopted and applied by the farmers in a community participatory approach. Another major challenge in the publicity of EBRM is to ensure that policy makers or their advisers accept this non-conventional approach to rodent-pest management. Therefore, the information that is generated through research has to be channelled to the appropriate organs for delivery to the farmers. A good extension service could be a solution to this challenge if there are good links with the policy makers, although institutions that are conducting the research can also link up with farmers.

EBRM should aim at building capacity at all levels, including universities and research institutions, to enable them to develop the tools for EBRM, including the knowledge on ecology of the local rodent species.

Table 1. Rodent species diversity in Tanzania, Namibia and Swaziland

Tanzania (10 species)	Namibia (6 species)	Swaziland (5 species)
Acomys spinossismus	*Aethomys chrysophilus*	*Dendromus mystacalis*
Aethoms chrysophilus	*Aethomys mamaquensis*	*Mus minutoides*
Arvicanthis neumanni	*Mastomys natalensis*	*Lemniscomys rosalia*
Graphiurus murinus	*Saccostomus campestris*	*Mastomys natalensis*
Lemniscomys zebra	*Gerbilliscus leucogaster*	*Rattus tanezumi*
Lemniscomys rosalia	*Mus indutus*	
Mus minutoides		
Mastomys natalensis		
Rattus rattus		
Gerbilliscus vicina		

Conclusions

There cannot be a ‘quick fix’ in establishing EBRM in Africa and the journey to a fully fledged working systems could be long, involving accurate identification of the pest species, accumulating knowledge on their ecology, behaviour and habitat utilisation, experimenting on rodent-management options, formulating and implementing the most effective management strategies, changing attitudes, getting communities to work as a single unit with the same purpose, training and communicating.

EBRM systems are evolving slowly and therefore the potential for a functional EBRM in Africa is strong. However, there are many challenges that must be addressed progressively. Already some progress is being made to implement EBRM in some countries in Africa, on the basis of some focused studies made in the past few years.

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References

Bekele, A., Leirs, H., and Verhagen, R. (2003). Composition of rodents and damage on maize farms at Ziway, Ethiopia. In ‘Rats, Mice and People: Rodent Biology and Management’. (Eds G. R. Singleton, L. A. Hinds, C. J. Krebs and D. M. Spratt.). pp. 262–263. (Australian Centre for International Agricultural Research: Canberra.)

Belmain, S. R., Meyer, A. N., Timbrine, R., and Penicela, L. (2003). Managing rodent pests in households and food stores through intensive trapping. In ‘Rats, Mice and People: Rodent Biology and Management’. (Eds G. R. Singleton, L. A. Hinds, C. J. Krebs and D. M. Spratt.) pp. 440–445. (Australian Centre for International Agricultural Research: Canberra.)

Belmain, S. R., Dlamini, N., Eiseb, S., Kirsten, F., Mahlaba, T., Makundi, R., Malebane, P., von Maltitz, E., Massawe, A., Monadjem, A., Mulungu, L., Siwiya, E., Taylor, P., and Tutjavi, V. (2008). The ECORAT Project: Developing Ecologically-Based Rodent Management for the Southern Africa Region. *International Pest Control* **50**, 136–138.

Boonsong, P., Hongnark, S., Suasa-ard, K., Khoprasrt, Y., Promkerd, P., Hamarit, G., Nookarn, P., and Jäkel, T. (1999). Rodent management in Thailand. In ‘Ecologically-based Rodent Management’. (Eds G. Singleton, L. Hinds, H. Leirs and Z. Zhang.) pp. 338–357. (Australian Centre for International Agricultural Research: Canberra.)

Brown, P., Tuan, N. P., Singleton, G. R., Tuat, N. P., Tan, T. Q., and Hoa, L. T. (2003). Impact of village level rodent control practices on rodent populations and rice crop in Vietnam. In ‘Rats, Mice and People: Rodent Biology and Management’. (Eds G. R. Singleton, L. A. Hinds, C. J. Krebs and D. M. Spratt.) pp. 196–202. (Australian Centre for International Agricultural Research: Canberra.)

Brown, P. R., Tuan, N. P., Singleton, G. R., Ha, P. T. T., Hoa, P. T., Hue, D. T., Tan, T. Q., Tuat, N. V., Jacob, J., and Muller, W. J. (2006). Ecologically-based management of rodents in the real world: application to a mixed agro-ecosystem in Vietnam. *Ecological Applications* **16**, 2000–2010. doi:10.1890/1051-0761(2006)016[2000:EBMORI]2.0.CO;2

Castiglia, R., Corti, M., Colangelo, P., Annesi, F., Cataglia, E., Verheyen, W., Sichilima, A., and Makundi, R. (2003). Chromosomal and molecular characterization of *Aethomys kaiseri* from Zambia and *Aethomys chrysophilus* from Tanzania (Rodentia: Muridae). *Hereditas* **139**, 81–89. doi:10.1111/j.1601-5223.2003.01763.x

Corti, M., Castiglia, R., Colangelo, P., Capanna, E., Beolchini, F., Bekele, A., Oguge, N., Makundi, R. H., Sichilima, A., and Leirs, H. (2005). Cytogenetics of rodent species from Ethiopia, Kenya, Tanzania and Zambia. *Belgian Journal of Zoology* **135**(Suppl.), 197–216.

Davis, S. A., Leirs, H., Perch, R., Zhang, Z. B., and Stenseth, N. C. (2004). On the economic benefit of predicting rodent outbreaks in agricultural systems. *Crop Protection* **23**, 305–314. doi:10.1016/j.cropro.2003.09.002

Drazo, N. A., Kennis, J., Leirs, H., and Migimiru, D. A. (2008). Farmer survey in the hinterland of Kisangani (Democratic Republic of Congo) on rodent crop damage and rodent control techniques used. *Mammalia* **72**, 192–197. doi:10.1515/MAMM.2008.034

Fadda, C., Castiglia, R., Colangelo, P., Corti, M., Machangu, R., Makundi, R., Scanzani, A., Tesha, P., Verheyen, W., and Cappana, E. (1999). The rodent fauna of Tanzania: a cytotaxonomic report from the Maasai Steppe. *Rend Accademia Lincei Zoologia* **12**, 29–49.

Jacobs, J., Sudarmaji, Singleton, G. R., Rahmini, Herawati, N. A., and Brown, P. (2010). Ecologically based management of rodents in lowland irrigated rice fields in Indonesia. *Wildlife Research* **37**, 418–427.

Kingdon, J. (1974). 'East African Mammals – An Atlas of Evolution in Africa. Vol. IIB (Hares and Rodents).' (Academic Press: London.)

Krebs, C. J. (1966). Demographic changes in fluctuating populations of *Microtus californicus. Ecological Monographs* **36**, 239–273. doi:10.2307/1942418

Leirs, H. (1992). Population ecology of *Mastomys natalensis* (Smith 1834) multimammate rats: possible implications for rodent control in Africa. Ph.D. Thesis, University of Antwerp, Belgium.

Leirs, H. (2003). Management of rodents in crops: the pied piper and his orchestra. In 'Rats, Mice and People: Rodent Biology and Management'. (Eds G. R. Singleton, L. A. Hinds, C. J. Krebs and D. M. Spratt.) pp. 183–190. (Australian Centre for International Agricultural Research: Canberra.)

Leirs, H., Verhagen, R., Verheyen, W., Mwanjabe, P., and Mbise, T. (1996). Forecasting rodent outbreaks in Africa: an ecological basis for *Mastomys* control in Tanzania. *Journal of Applied Ecology* **33**, 937–943. doi:10.2307/2404675

Makundi, R. H., Mbise, T. J., and Kilonzo, B. S. (1991). Observations on the role of rodents in crop losses in Tanzania and control strategies. *Beitrage zur Tropischen Landwirtschaft und Veterinarmedizin* **29**, 465–474.

Makundi, R. H., Oguge, N. O., and Mwanjabe, P. S. (1999). Rodent pest management in East Africa – an ecological approach. In 'Ecologically-based Rodent Management'. (Eds G. Singleton, L. Hinds, H. Leirs and Z. Zhang.) pp. 460–476. (Australian Centre For International Agricultural Research: Canberra.)

Makundi, R. H., Bekele, A., Leirs, H., Massawe, A. W., Rwamugira, W., and Mulungu, L. S. (2005). Farmer's perceptions of rodents as crop pests: knowledge, attitudes, and practices in rodent pest management in Tanzania and Ethiopia. *Belgian Journal of Zoology* **135**(Suppl.), 153–157.

Makundi, R. H., Misangu, R. N., Reuben, S. O. W. M., Kilonzo, B. S., Mwatawala, M., Sikira, A., Lyimo, H., and Maumba, M. (2007). Reduction of crop losses through improved storage for food security at village level in Tanzania. In 'Proceedings of the First Annual PANTIL Research Workshop: Transforming Livelihoods of Small Scale Farmers: Contribution of Agricultural and Natural Resources Research'. (Eds L. D. B. Kinabo and W. S. Abeli.) pp. 174–179. (Sokoine University of Agriculture: Morogoro, Tanzania.)

Makundi, R. H., Massawe, A. W., Mulungu, L. S., and Katakweba, A. (2010). Diversity and population dynamics of rodents in farm-fallow mosaic fields in central Tanzania. *African Journal of Ecology* **48**, 313–320. doi:10.1111/j.1365-2028.2009.01109.x

Massawe, A. W., Leirs, H., Rwamugira, W. P., and Makundi, R. H. (2003). Effect of land preparation methods on spatial distribution of rodents in crop fields. In 'Rats, Mice and People: Rodent Biology and Management'. (Eds. G. R. Singleton, L. A. Hinds, C. J. Krebs and D. M. Spratt.) pp. 229–232. (Australian Centre for International Agricultural Research: Canberra.)

Massawe, A. W., Rwamugira, W., Leirs, H., Makundi, R. H., and Mulungu, L. S. (2005). Influence of land preparation methods and vegetation cover on population abundance of *Mastomys natalensis* in Morogoro, Tanzania. *Belgian Journal of Zoology* **135**(Suppl.), 187–190.

Meheretu, Y., Welegerima, K., Deckers, S., Raes, D., Makundi, R., and Leirs, H. (2010). Farmers' perspectives of rodent damage and management from the highlands of Tigray, northern Ethiopia. *Crop Protection* **29**, 532–539.

Mulungu, L. S., Makundi, R. H., Leirs, H., Massawe, A. W., Vibe-Petersen, S., and Stenseth, N. C. (2003). The rodent-density-damage function in maize fields at an early growth stage. In 'Rats, Mice and People: Rodent Biology and Management'. (Eds G. R. Singleton, L. A. Hinds, C. J. Krebs and D. M. Spratt.) pp. 301–303. (Australian Centre for International Agricultural Research: Canberra.)

Mulungu, L. S., Makundi, R. H., Leirs, H., Massawe, A. W., Machang'u, R. S., and Ngowo, V. (2005). Spatial patterns and distribution of rodent damage in maize fields in Tanzania. *Belgian Journal of Zoology* **135**(Suppl.), 183–185.

Mwanjabe, P. S., and Leirs, H. (1997). An early warning system for IPM-based rodent control in smallholder farming systems in Tanzania. *Belgian Journal of Zoology* **127**, 49–58.

Odhiambo, C. O., and Oguge, N. O. (2003). Patterns of rodent pest distribution in a maize cropping system in the Kenyan Rift Valley. In 'Rats, Mice and People: Rodent Biology and Management'. (Eds G. R. Singleton, L. A. Hinds, C. J. Krebs and D. M. Spratt.) pp. 217–219. (Australian Centre for International Agricultural Research: Canberra.)

Ojwang, D. O., and Oguge, N. O. (2003). Testing a biological control programme for rodent management in a maize cropping system in Kenya. In 'Rats, Mice and People: Rodent Biology and Management'. (Eds. G. R. Singleton, L. A. Hinds, C. J. Krebs and D. M. Spratt.) pp. 251–253. (Australian Centre for International Agricultural Research: Canberra.)

Palis, F. G., Morin, S., Van Chien, H., and Chi, T. N. (2003). Socio-cultural and economic assessment of community trap–barrier system adoption in southern Vietnam. In 'Rats, Mice and People: Rodent Biology and Management'. (Eds G. R. Singleton, L. A. Hinds, C. J. Krebs and D. M. Spratt.) pp. 422–425. (Australian Centre for International Agricultural Research: Canberra.)

Parshad, V. R. (1999). Rodent control in India. *Integrated Pest Management Reviews* **4**, 97–126. doi:10.1023/A:1009622109901

Potter, L. (2004). Raptors for rodent control: Is the Barn Owl a viable control agent for pest rodents on South African farmlands? M.Sc. Thesis, University of Cape Town, South Africa.

Sang, P. M., Huan, N. H., Escalada, M. M., and Heong, K. L. (2003). Farmer's beliefs and practices in rat management in the Mekong Delta, Vietnam. In 'Rats, Mice and People: Rodent Biology and Management'. (Eds G. R. Singleton, L. A. Hinds, C. J. Krebs and D. M. Spratt.) pp. 426–430. (Australian Centre for International Agricultural Research: Canberra.)

Sicard, B., Diarra, W., and Cooper, H. M. (1999). Ecophysiology and chronobiology applied to rodent pest management in semi-arid agricultural systems in Sub-Saharan West Africa. In 'Ecologically-based Rodent Management'. (Eds G. Singleton, L. Hinds, H. Leirs and Z. Zhang.) pp. 409–440. (Australian Centre for International Agricultural Research: Canberra.)

Sichilima, A. M., Zulu, M. S., and Leirs, H. (2003). The effects of *Tephrosia vogelii* and land preparation methods on mole rat activity in cassava fields. In 'Rats, Mice and People: Rodent Biology and Management'. (Eds G. R. Singleton, L. A. Hinds, C. J. Krebs and D. M. Spratt.) pp. 254–255. (Australian Centre for International Agricultural Research: Canberra.)

Singleton, G. R., and Petch, D. A. (1994). A review of the biology and management of rodent pests in Southeast Asia. Australian Centre for Agricultural Research Technical Report No. 30, Canberra.

Singleton, G. R., Hinds, L. A., Leirs, H., and Zang, Z. (Eds) (1999). 'Ecologically-based Management of Rodent Pests.' ACIAR Monograph No. 59. (Australian Centre for International Agricultural Research: Canberra.)

Singleton, G. R., Brown, P., and Jacob, J. (2004). Ecologically-based rodent management: its effectiveness in cropping systems in South-east Asia. *NJAS Wageningen Journal of Life Sciences* **52**, 163–171. doi:10.1016/S1573-5214(04)80011-3

Singleton, G. R., Brown, P. R., Jacob, J., Aplin, K. P., and Sudarmaji, (2007). Unwanted and unintended effects of culling: a case for ecologically-based rodent management. *Integrative Zoology* **2**, 247–259. doi:10.1111/j.1749-4877.2007.00067.x

Skonhoft, A., Leirs, H., Andreassen, H. P., Mulungu, L. S. A., and Stenseth, N. C. (2006). The bioeconomics of controlling an African rodent pest species. *Environment and Development Economics* **11**, 453–475. doi:10.1017/S1355770X06003044

Sluydts, V. (2009). A bio-economic model for rodent control in Africa: a regional solution for a local problem? Ph.D. Thesis. University of Antwerp, Belgium.

Sluydts, V., Crespin, L., Davis, S., Lima, M., and Leirs, H. (2007). Survival and maturation rates of the African rodent, *Mastomys natalensis*: density dependence and rainfall. *Integrative Zoology* **2**, 220–232. doi:10.1111/j.1749-4877.2007.00065.x

Sluydts, V., Davis, S., Mercelis, S., and Leirs, H. (2009). Comparison of multimammate mouse (*Mastomys natalensis*) demography in monoculture and mosaic agricultural habitat: implication for pest management. *Crop Protection* **28**, 647–654. doi:10.1016/j.cropro.2009.03.018

Stenseth, N. C., Leirs, H., Skonhoft, A., Davis, S. A., Pech, R. P., Andreassen, H. P., Singleton, G. R., Lima, M., Machangu, R. S., Makundi, R. H., Zhang, Z., Brown, P. R., Shi, D., and Wan, X. (2003). Mice, rats, and people: the bio-economics of agricultural rodent pests. *Frontiers in Ecology and the Environment* **1**, 367–375. doi:10.1890/1540-9295(2003)001[0367:MRAPTB]2.0.CO;2

Sudarmaji, Singleton, G. R., Herawati, N. A., Djatiharti, A., and Rahmini (2003). Farmers' perceptions and practices in rat management in West Java, Indonesia. In 'Rats, Mice and People: Rodent Biology and Management'. (Eds G. R. Singleton, L. A. Hinds, C. J. Krebs and D. M. Spratt.) pp. 389–394. (Australian Centre for International Agricultural Research: Canberra.)

Taylor, K. D. (1968). An outbreak of rats in agricultural areas of Kenya in 1962. *East African Agricultural and Forestry Journal* **34**, 66–77.

The Natural Resources Institute (2010). 'ECORAT (Development of Ecologically-Based Rodent Management for the Southern Africa Region) Project.' Available at http://www.nri.org/projects/ecorat/ [verified October 2010].

Tuan, N. P., Williams, S. J., Brown, P. R., Singleton, G. R., Tan, Q. T., Hue, D. T., Ha, P. T. T., and Hoa, P. T. (2003). Farmers' perceptions and practices in rat management in Vinh Phuc province, northern Vietnam. In 'Rats, Mice and People: Rodent Biology and Management'. (Eds G. R. Singleton, L. A. Hinds, C. J. Krebs and D. M. Spratt.) pp. 339–402. (Australian Centre for International Agricultural Research: Canberra.)

von Maltitz, E. F., Kirsten, F., Malebana, P. S., Belmain, S. R., Sandmann, E. R. I. C., Lundall-Magnuson, E., Mosala, M., Hlangwani, K. F., Mavasa, M. R., Mugogovhali, T. V., Nyamande, T. P., Ramugond, R., Randel, R., Stathers, T. E., and Kleih, U. K. (2003). Developing a rodent management strategy for South Africa's Limpopo province. In 'Rats, Mice and People: Rodent Biology and Management'. (Eds G. R. Singleton, L. A. Hinds, C. J. Krebs and D. M. Spratt.) pp. 418–421. (Australian Centre for International Agricultural Research: Canberra.)

Wodzicki, K. (1973). Prospects for biological control of rodent populations. *Bulletin of the World Health Organisation* **48**, 461–467.

World Health Organization (2006). Inter-regional meeting on prevention and control of plague. Antananarivo, Madagascar, 1–11 April 2006. WHO/HSE/EPR/2008.3, Geneva.