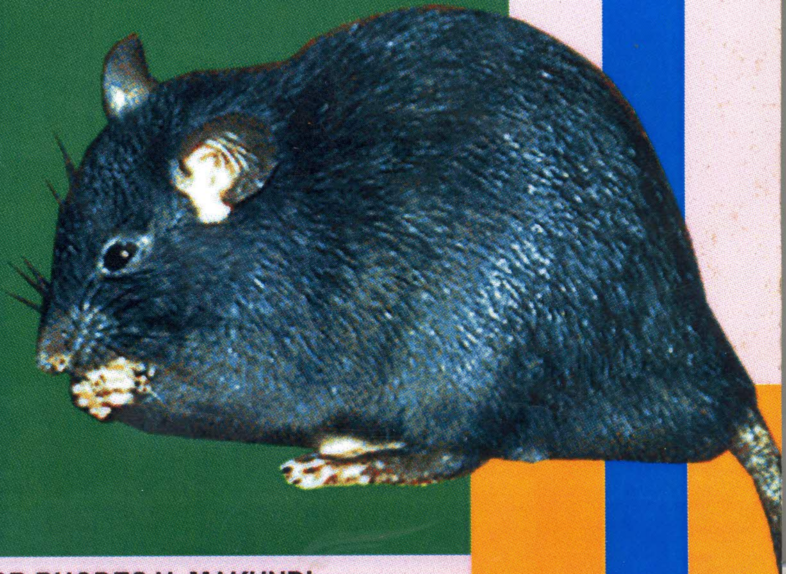
SOKOINE UNIVERSITY OF AGRICULTURE
MOROGORO, TANZANIA

PROFESSORIAL INAUGURAL LECTURE

# THE MYSTERIES OF THE RATS



**PROFESSOR RHODES H. MAKUNDI**
BSc (Zoology, Botany, Ed)(UDSM) MSc, PhD (Applied Entomology, University of Newcastle, UK)

Pest Management Centre

25th November, 2009

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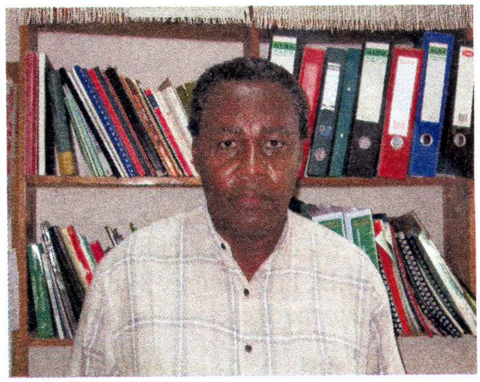
## ABOUT THE AUTHOR



**Professor Rhodes H. Makundi** was born on 24th October, 1954 at Komakundi village, Mamba Division, in Moshi Rural District, Kilimanjaro Region. He started his basic education at Komakundi Extended Primary School and Mboni Middle School between 1962 and 1968.

In 1969 he was admitted to Same Secondary School, Kilimanjaro Region, where he completed his Ordinary Level Certificate Education. He proceeded to Old Moshi Secondary School in 1973 for his advanced level secondary education. After National Service in 1975/76 he gained admission to the Faculty of Science, University of Dar es Salaam to study Zoology, Botany and Education. In 1979, Professor Rhodes H. Makundi graduated with a B.Sc. Degree from Dare s Salaam University. He briefly joined the Ministry of Education as a secondary school teacher between June 1979 and March 1980. In April 1980 he joined the Ministry of Agriculture as a Research Officer in the Plant Protection Section responsible for rodent control. In 1981 he gained a 2 year British Council Scholarship to study an MSc in Applied Entomology at the University of Newcastle upon Tyne, UK. On completing his MSc studies, Prof. Makundi returned to Tanzania and continued working with the Ministry of Agriculture as an entomologist until he joined Sokoine University of Agriculture in February 1987. He was recruited as an Assistant Research Fellow in the then Rodent Research Project under the Department of Microbiology and Parasitology in the Faculty of Veterinary Medicine. He won a scholarship from the Commonwealth to pursue Doctor of Philosophy studies in Applied Entomology in the Department of Agriculture and Environmental Sciences of the University of Newcastle, UK, in 1992 and graduated with a PhD degree in 1996. He was promoted to the position of Senior Research Fellow in 1997, Associate Research Professor in 2003 and Research Professor in 2006. He held the post of Associate Director of the SUA Pest Management Centre (SPMC) from March 2005 to August 2006 and is currently the Director of the center for the triennium September 2006 to August 2009.

Professor Rhodes Makundi has authored or co-authored more than 70 articles published in refereed international journals and book chapters. He has in addition published papers in proceedings of international and local conferences and workshops. He is the editor of a book titled *Management of Selected Crop Pests in Tanzania* published by the Tanzania Publishing House Ltd. in 2006. He has supervised 16 MSc and 4 PhD candidates. Prof Makundi is the current Chairman of the Tanzania Entomological Association. He is a member of the International Society of Zoological Sciences and The International Mammalogical (formerly Theriological) Congress.

Professor Makundi is married to Vidda-Joyce Elikana with whom he has four children, Kwame, Haika, Nsia and David†.

*†Deceased 19th January 2009 at the age of 19 years*

## ACKNOWLEDGEMENTS

I wish to acknowledge with great appreciation all the donors who have supported my research activities that led to many scientific publications. None deserves greater commendation than the SUA-VLIR programme who supported the SPMC for a period of 10 years through which the scientific output of the Centre was ranked excellent and highly commended by an External Evaluation Team appointed by the VLIR Programme. The VLIR continues to support me and the SPMC in various initiatives including the Research Initiative Programme (RIP) and the North South-South Collaboration (NSSC).

Many colleagues and benefactors deserve mention here. Prof Bukheti Kilonzo (SPMC), the late Prof. Walter Verheyen and the late Mr Ben Christian Mkondya (Ministry of Agriculture, Tanzania) have been my mentors in many ways ever since I developed a strong interest in studying rodents.

I have carried out collaborative research with many colleagues and I would like to mention only a few: Prof. Herwig Leirs, Prof Ron Verhagen, Dr Apia Massawe, Dr Loth S. Mulungu, Dr Carlo Fadda, Dr Riccardo Castiglia, Dr Paolo Colangello, Prof. Bukheti S. Kilonzo, Prof. Robert Machang'u, my graduate students, the late Prof. Walter Verheyen and the late Prof. Marco Corti. The results of our collaborative studies have been of mutual advantage. My colleagues at the Pest Management Centre and elsewhere, both technical and scientific, have made great contributions to my achievements and success. I wish to thank all of them for their contributions.

I am most grateful to the Vice Chancellor and Deputy Vice Chancellors of Sokoine University of Agriculture for the encouragement and support that enabled me to prepare and deliver this Professorial Inaugural Lecture.

I am deeply indebted to all those who in one way or another we have interacted during field and laboratories studies that led to successful scientific outputs herein contained in this Inaugural Lecture. May all be blessed.

## Foreword

Mr. Chairman,
Vice Chancellor
Deputy Vice Chancellors
Deans and Directors
Heads of Departments
Colleague Professors and All Members of the Academic Staff
Members of the Press
Distinguished Invited Guests
Ladies and Gentlemen,

I am humbled to be standing in front of this November 2009 to talk of a neglected, and yet an important group of mammals that affects every living being and animal, the rats. When I first joined the University as an Assistant Research Fellow in February 1987, it never dawned on me that one day I would become a Research Professor and possibly get the opportunity to deliver a Professorial Inaugural Lecture to the University community. Thanks to the encouragement of the University Management and the support they gave me to deliver this lecture today.

I have developed my own ideas about the rodents with regards to their ecology, approaches for their management and future direction for research, which I shall be talking about in this lecture. These ideas have shaped my research and theoretical orientation, but many ideas have also been shaped by those I have interacted with in international meetings, conferences, and locally by the colleagues that I work and collaborate with, some of whom are in this audience.

When I was growing up, I learned to hate rodents because everyone disliked them; they were all assumed to be pests and contaminants of food. Occasionally, they nipped our toes and fingers at night while asleep which caused us pain and much annoyance. Little was I told that there are only a few species that are harmful as pests, while the majority of species are harmless and some are beneficial components of ecosystems. Further, major scientific developments in biology, medicine and drugs research have been made using rats as experimental animals, which are of immense benefit to humankind. For example, the benefits and risks of hormone therapy for women, cancer studies, toxicity studies of various drugs and pesticides, dose vs body size studies for drugs and poisons, cardiovascular diseases studies, pesticides exposure studies are mostly based on rodents.

Hence, despite their role in disease pandemics and crop destruction, these animals deserve some credits for their beneficial contributions to animal communities and to human society. Therefore today, I hold very different ideas about rats. As a biologist, rats are fascinating and interesting animals to study and many discoveries are being made on their taxonomy, ecology, physiology, etc. For landscape ecologists, rats are good indicators of environmental changes. Therefore rats are very important animals in nature, whichever way you look at them. My Professorial Inaugural Lecture will focus on why rodents are mysterious creatures by exploring their biology, ecology, role in disease epidemics, crop destruction, developments in their management and beneficial aspects. Further, I shall put forward management strategies or approaches to mitigate their negative effects to our society in Tanzania.

**Abstract**

Rodents are a mysterious group of animals. They are the largest group of mammals in terms of species and in numbers. There are more than 2200 species of rodents which have been described to-date, making up 42% of the mammal species. Rodents are much more known for the losses they cause to crops, structural damage and as disease reservoirs, than for their contribution to ecosystem functioning, ecological balance and other community benefits derived from them. The multitude of problems to man due to rodents is a result of their being ubiquitous in all kinds of environments where they interact with him in a variety of ways, some of which are very harmful. The list of problems they cause is endless, and includes crop damage, household damage to clothes, damage to electrical wires which sometimes causes fires, contamination of foodstuffs with hair, urine and faeces, destruction of property, harbourage and transmission of disease pathogens which cause infections in humans and livestock, biting people, etc.

They are responsible for considerable public health problems in the world due to being reservoirs of serious zoonotic diseases. They carry viruses that cause hemorrhagic fevers, Lassa fever, Lyme diseases, etc. Among the bacterial diseases they spread, plague is the most threatening and has caused mankind great suffering and death of millions of people. Plague remains a serious threat to human kind today, and is re-emerging in many counties in Africa and Asia. The disease is subject to notification to the World Health Organization under the new International Health Regulations. In Tanzania, plague remains the most challenging rodent-borne bacterial disease due to persistent epidemics. Our focus has been to gain a better understanding of the ecology of the reservoir hosts and vectors, ecological processes in its transmission and factors involved in maintenance of the diseases in known outbreak foci. Studies also focus on zoo-geographical distribution and prevalence of other rodent borne diseases such as toxoplasmosis, leptospirosis, borelia, arenaviruses and hantaviruses.

Some species of rodents have had conflict with man ever since he settled down to cultivate the land. High densities of rodents cause severe crop damage and losses and are detrimental to the welfare of resource poor communities and the economies of many countries in sub-Saharan Africa. Despite new technologies for their control, rat population explosions have not abated and they continue to occur even in the rich economies.

Multi-disciplinary approaches to study African rodent taxonomy have made it possible to compare large series of taxa, to revise many of the genera, and to investigate rodent taxonomy on a large scale, with the discovery of new species in the process. Parallel studies have enabled us to discover some mysteries of the ecology and biology of the rodent fauna of Tanzania aimed at developing ecologically based rodent pest management.

Some species of rodents are being exploited in many ways: for medical research, a source of food for humans, disease diagnosis (e.g. tuberculosis), detection of explosives in war torn areas, etc. By discovering the many mysteries of the biology and ecology of rats, it is possible to mitigate their harmful effects on communities and exploit some of their abilities for the benefit of mankind.

# THE MYSTERIES OF THE RATS

## Introduction

Rodents are small mammals, they are diverse, mysterious in many ways, some cause tremendous economic hardships and acute health hazards to people. There are more than 2200 species of rodents which have been described to-date, making them the largest group of non-flying mammals in the animal kingdom. They make up to 42% of the mammal species. Rodents are of considerable biological and economic importance because of their abundance, diversity and proliferation on almost all continents, as well as their harmfulness on one hand and their potential beneficial use as experimental models on the other hand. They are responsible for considerable public health problems in the world as reservoirs of serious zoonotic diseases. They carry viruses that cause hemorrhagic fevers, Lassa fever, Lyme diseases, etc. Among the bacterial diseases, plague is the most threatening and has caused mankind great suffering and mortality. Plague remains a serious threat to human kind, is a re-emerging disease and is subject to notification to the World Health Organization. Several other bacterial and protozoan diseases that are harboured in rodents cause morbidity and mortality in man and domestic animals. Rodents cause significant damage property and cultivated crops. In Tanzania, population densities of rodents, such as the multimammate rats, *Mastomys natalensis,* can be very high in agricultural and fallow fields, sometimes at densities of more than 1400 rats/ha during outbreaks (Mwanjabe *et al.* 2002). Such high densities cause severe crop damage and losses and are detrimental to the welfare of resource poor communities and the economies of many countries in sub-Saharan Africa. Three species, the Norway rat, *Rattus norvegicus*, the roof rat, *Rattus rattus*, and the house mouse, *Mus musculus*, are considered *commensal* rodents, literally meaning that they "eat at the same table" as we do. Of these three, the roof rat is among the most common species in houses in Tanzania, but the multi-mammate rat, *Mastomys natalensis*, occasionally invades stores and houses under difficult conditions in the field, in particular after crops are harvested and brought to the house for storage.

Some species of rodents have had conflict with man ever since he settled down to cultivate the land, as implied in this quote "*The rate of propagation of field mice in country places, and the destruction they cause, are beyond telling*" (Aristotle 384-322 BC). The multitude of problems to man due to rodents is a result of their being ubiquitous in all kinds of environments. The list of problems is endless, and includes crop damage, household damage to clothes, damage to electrical wires which sometimes causes fires, contamination of foodstuffs with hair, urine and faeces, destruction property, harbourage and transmission of disease pathogens which cause infections in humans and livestock, biting people, killing chicks, etc. etc.

Rodents are also beneficial in ecosystems. They are a source of food for many predatory animals, and help in maintaining ecological balances in nature. They make tunnels in the ground enabling aeration, they consume a large numbers of noxious insects, weed seeds, etc.

Humans have exploited rodents in many beneficial ways. They are animals of choice for many kinds of biological and medical researches. They are hunted or reared for human food in many societies. They can be trained for various humanitarian purposes like demining, tuberculosis diagnosis, etc.

Rats have always been fascinating creatures and since everyone wants to hear a good mystery about animals, none is better than that of the rats!

There are many mysteries of rodents which are un-paralleled in any other group of mammals:

► They are ubiquitous; some follow man wherever he settles. In so doing, they interact with him in many ways, leading to property and crop damage, disease harbourage and transmission.

► they maximize breeding, growth and development when conditions are favourable, even if for a short period,

► they have highly developed senses that allow them to integrate themselves as social groups, secure food, mates and even enable them to avoid predators,

► their shape and general morphology (small size for the majority) enable them to hide in small spaces

► the majority are generalists in their food habits, a characteristic that enables them to colonize all possible habitats,

► they adapt very fast to changing environment ensuring that survival is not sacrificed,

► niche partitioning in suitable habitats ensures that available resources for co-existing species do not lead to extreme competition between them, which will have adverse effects on survival,

► behavioural avoidance of strange objects and other substances in their surrounding environment enables them to keep away from traps and poisons,

► reproductive strategies differ, but when conditions are suitable, a large litter size, fast maturation and development can ensure large turnovers over a short period, making some species major pests.

► They are highly adaptable to changes in their surroundings and respond to environmental changes in a manner unparalleled by any other group of mammals.

**Why are rodents important? Facts Sheet**

- Rodents make up about 42% of mammal species
- More than 2200 species have been described; still more are being described.
- Rodents cause tremendous economic hardship to people on a continental scale. However, less than 10% of species cause substantial impacts.
- Many species of rodent provide important "ecological services".
- They affect human health more than any other mammalian species

  ●*the Black Death (542 AD) claimed 100 million lives.*

  ●*14th Century (beginning 1347) within five years, plague killed 25 million people in Europe alone, one-third of the European population*

  ●*Plague, of which rodents are reservoirs, is a re-emerging disease globally (*Fig. 1)*:*

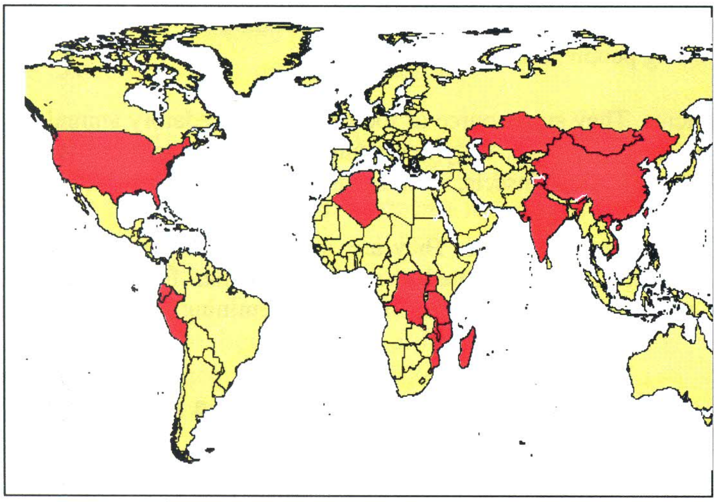


Figure 1: Human plague cases: countries that notified outbreaks of human plague to WHO, 2002-2005 (Source: WHO 2006).

Countries with plague

- *In Africa, plague remains a disease of major public health importance. More than 90 % of all cases are now notified by African countries (WHO 2006).*
- *Permanent plague foci exist in the Americas among native rodent and flea populations in Peru, Ecuador, Brazil, Bolivia and the United States (WHO 2006).*
- *In 1994, a large plague outbreak struck the cities of Surat and Beed in India, killing 54 of the 876 reported cases. Total loss of revenue due to this outbreak (due in particular to tourism losses) was estimated at 3 billion USD (WHO 2006).*
- *The Central-Asian region contains active plague foci The lethality is up to 70% because of the unavailability of treatment in remote areas and the low density of health structures. In China, plague foci are distributed in 19 provinces and autonomous regions (WHO 2006).*
- *Several other zoonotic diseases involve rodents as reservoir hosts: The number of Lassa virus infections per year in West Africa is estimated at 100,000 to 300,000, with approximately 5,000 deaths (WHO 2005).*
- *The rodent-borne hemorrhagic fever viruses in the Arenaviridae and Bunyaviridae are widely distributed on most continents where rodents occur.*
- *Diseases such as leptospirosis, toxoplasmois, borelia, lyme fever, etc. affect many people and often are not properly diagnosed.*
- *In Tanzania, 7000 plague cases in Lushoto District in 1980-2003, with a mortality rate of 10%; in 2007and 2008 plague outbreaks occurred in Mbulu Distict, with more than 100 cases and 17 deaths.*

Rodents cause high losses of crops as shown in the following examples

- *In Tanzania, rodent damage on average 15% of maize in the fields* (Makundi *et al.* 1991), *corresponding to 400,000 tonnes (that could feed 2.3 million people for a whole year; and a financial loss of US$ 40 million) (Leirs 2003).*
- *In Indonesia, annual losses of rice are 10-20% (Singleton and Perch 1994); Malaysia 2-5%(Singleton and Perch 1994); Vietnam >10% (Singleton et al. 1999); Thailand 6-7%(Boonsong et al 1999); Bangladesh 6-7% (Parshad 1999).*
- *For South and southeast Asia alone, a conservative estimate of 5% loss alone amount to 16 million tonnes of rice, enough to feed 50 million people (Leirs 2003; Riceweb 2002).*
- *Rodents contaminate million food, destroy electrical wiring resulting into fires, destroy cloths, domestic appliances, etc. costing millions of dollars.*

**Species diversity, taxonomy**

Species diversity refers to the number and distribution of species in one location. Rodents show a very high genetic diversity, which is attributed to high rate of chromosomal mutation (Corti 2002). For rodents therefore, a diversity of genetic characteristics has led to the evolution of many species, more than any other group of mammals. The genetic diversity among the rodents plays a huge role in the survival and adaptability of species. For example, when a species' environment changes, slight gene variations are necessary for it to adapt and survive. Rodents are some of the most important small mammals contributing to ecosystem species diversity. They interact extensively with their environment (physical, chemical and biotic) with complex effects on other organisms (plants and animals) on spatial and temporal scales (Dickman, 1999). Their community structure and species richness are related to variables such as habitat structure, rainfall, productivity, etc. (Avenant 2000; 2003). The rapid changes in natural ecosystems are not only a major threat to small mammal diversity in Tanzania, but lead to increasing dominancy of some opportunistic species in agricultural land (Makundi *et al.* 1999; Makundi *et al.* 2005a).

*Which species are we dealing with?*
In the last 50 years, we have seen the development of new approaches such as cytogenetics, genetics, molecular genetics and morphometrics which first separately, and later combined into multi-disciplinary approach to study African rodent taxonomy. Using these approaches, it has been possible to compare large series of taxa, to revise many of the genera, and to investigate rodent taxonomy on a large scale.
Morphometrics, cytogenetic and molecular analyses have been conducted on rodents from Tanzania for accurate identification of species. Both taxonomy and zoogeographical distribution of rodent species in Tanzania have been conducted; some of the important studies aiming at identification and refining the systematic of rodent species in Tanzania. Zoogeographical distribution has covered some of the following taxa: *Acomys*, *Gerbilliscus*, *Saccostomus*, *Arvicanthis* and *Lophuromys*. However, there are many more taxa that require attention now and in future.

Examples:

***(i) Zoogeographical distribution of Acomys***

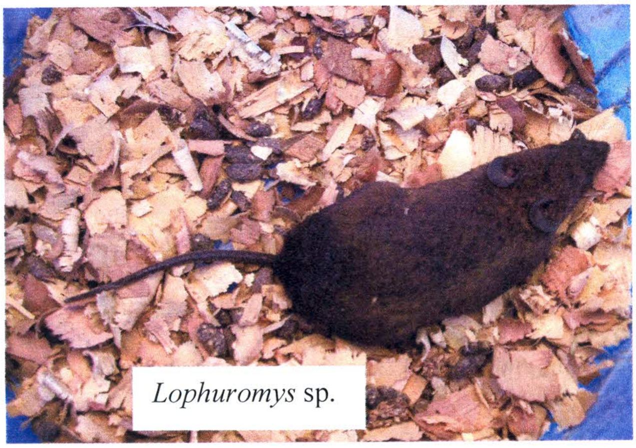
In a 1999 expedition of the Maasai Steppe, we reported 3 different karyotypes for the spiny mouse, *Acomys* spp. in this part of Tanzania, that corresponded to *Acomys spinosissimus*, *A. ignitus* and *A. wilsoni*. In later expeditions we were able to show that *A. spinosissimus* occurred further south in Chunya and in central Tanzania (Tabora, Zoissa and Matongolo. *Acomys selousi* was found in Dakawa, Morogoro, while *Acomys wilsoni* was found in Jipe and Ngasumet (Fadda *et al.* 2001).

***(ii) Saccostomus spp. and Gerbilliscus spp.***

We have identified species complex in several other genera including *Gerbilliscus* and *Saccostomus*. (Fadda *et al.* 2001; Corti *et al.* 2005).

***(iii) Lophuromys species complex***

*Lophuromys flavopunctaus* in Tanzania was thought to be a single species, but it has been recently described as a complex consisting of 4 different species, namely: *Lophuromys machangui*, *L. makundii*, *L. sabunii* and *L. kilonzoi* (Verheyen *et al.* 2007)



*Lophuromys* sp.

*(iv) Chromosomal and molecular characterization of Aethomys*

*Aethomys* is a common and widespread rodent genus in the savannas and grasslands of Africa. Its systematic and taxonomy are still unclear. However, through chromosomal and molecular characterization, we have found out that our collections from Kisiwani (Pare), Lwami, Zoissa (Kongwa) Ngasumet, Idodi, Tabora and Chunya are all *A. chrysophylus*. Further, through cytogenetics and genetics analyses we have shown a genetic divergence between *A. kaiseri* (which occurs in South Africa) and *A. chrysophylus* which occurs on a wide geographical range (cf. Chunya in South west, Tabora in western, Morogoro in Eastern/Central, and Pare in northern Tanzania) (Castiglia *et al*. 2003) .

The high diversity and species complex is attributed to frequent mutations in the Rodentia (Corti et al. 2005). There are still many other species to be described, some among those we already know, but whose taxonomy has to be refined. For example *Dasmys sua* (named after Sokoine University of Agriculture) was described recently and is found in habitats surrounding the Mindu Dam in Morogoro (Verheyen *et al*. 2004). While we are making long and expensive expeditions for the purpose of finding new species in the country, we also have to look closely into the systematic of already identified species, particularly because cytogenetics and genetic analyses offer more opportunities for refining their taxonomy.

Fig 2. Diversity of species both at local and geographical scales in Tanzania

With discoveries of the new species, there is need for follow up studies on their ecology, pest and reservoir status of crops and diseases, respectively.

***Importance of the taxonomic studies:***

- A better understanding of the diversity of species occurring in Tanzania
- An understanding of the taxonomy of species that cause crop damage and those which are disease reservoirs
- Development of integrated rodent pest management strategies and ecologically based pest management requires an accurate species identification

**Breeding and population dynamics**

Populations of all living organisms change in numbers temporally and spatially. These changes are related to inherent characteristics of the organism, the environment surrounding them and their interactions with other organisms of the same or different species. Rodents are no exception to these population changes. In fact among the mammals, rodent population fluctuations are more dramatic and violent than any other mammal species. Rodents show amazing characteristics related to their reproduction and breeding patterns, recruitment and development. The population dynamics of rodents in the tropics is strongly influenced by climatic conditions. They show remarkable reproductive capacities. For example, under ideal conditions, a single pregnant rat could theoretically breed several hundred rats in a year, were all of her progeny to survive and breed normally.

Food plays an important role in the breeding, development and survival of rodents. The importance of food on demographic parameters of rodents cannot be overemphasized, in particular its influence on reproduction and population dynamics. Rodents switch diets in response to seasonal changes, which may lead to population regulation. Our studies show that *M. natalensis* during the wet season feed more on seeds, arthropods and grasses (Odhiambo *et al.* 2008a). Maize seeds become the most preferred if they are available in the field at sowing. In the Chunya valley in southwestern Tanzania for example, all individuals had a maize rich diet in the maize fields when maize was most available, indicating a dietary shift from other food resources to maize (Odhiambo *et al.* 2008). This seasonal switch in food selection indicates a survival strategy in this species determined by seasonality.

No other mammals are so strongly influenced by climatic factors in their breeding patterns as are rodents. In the tropics, rainfall appears to be of prime importance for breeding, recruitment and survival of many species of rodents. Since rainfall is seasonal, populations of many species of rodents also show strong seasonality in breeding patterns. Take the case of *Mastomys natalensis.*

- ▶ Distinct breeding and non breeding seasons is evident in the species
- ▶ When rainfall patterns are favourable, early breeding occurs
- ▶ The breeding season becomes extended with longer duration of the rains
- ▶ They cease to breed when unfavourable conditions set in (e.g. beginning of the dry period), and under extreme stressful conditions (e.g. lack of food) they reabsorb the fetus instead of aborting.

*Importance of seasonal breeding*

- ▶ It ensures that the young are born in the most favourable conditions (availability of primary resources is assured), and therefore greater survival of offspring
- ▶ Development is faster (e.g. for *M. natalensis*, young may complete development and start breeding in the same season of birth)
- ▶ Less competition between individuals of the same or different species due to abundance of resources.

***Population dynamics***

Population dynamics, reproduction, growth and survival of *M. natalensis* in Tanzania are linked to the rainfall patterns and its abundance. When the conditions are favourable, for example during the wet season, both males and females exhibit typical breeding conditions in their genitalia (males become scrotal; females have perforated vagina) (Fig. 3) and pregnancy rate increases. Population density increases occur rapidly due to fast breeding, growth and development and recruitment of new individuals into the population. Studies in different localities in Tanzania show that rainfall influences the patterns of population dynamics (Fig 4). These patterns are also influenced by other factors including the predation and competition between individuals of the same or different species.

The accumulated knowledge on the population dynamics of some species is of interest for agricultural pest management purposes and for understanding disease dynamics where rodents are the reservoir hosts. Population dynamics is not static and therefore, population numbers keep on changing both spatially and temporally, sometimes driven by human made factors. With this in mind, our studies have remained focussed on how an understanding of the dynamic changes can be used to develop ecologically-based rodent pest management (Makundi *et al.* 1999). Spatial and temporal patterns in the distribution of species and their abundance are receiving serious attention in Tanzania (Leirs 1992; Telford 1989; Makundi *et al.* 2005a, 2007a, 2007b Leirs *et al.* 1997, Odhiambo *et al.* 2008b, Mulungu *et al.* 2008). Cross site comparisons of diversity and population dynamics of seemingly similar or different habitats can provide knowledge which can be used for ecological management of problematic pest species (Fig. 4). Such studies have often shown variations in the temporal and spatial dynamics of certain species even at the small scale level (Massawe *et al.* 2005).

*Effect of stable environment*

Some species show relatively stable fluctuations, without explosive rise and fall in density, which is an indication of relatively stable environment (Fig 5). In the Magamba Forest in Lushoto District, northeast Tanzania, three species, namely *Lophuromys kilonzoi*, *Praomys delectorum* and *Grammomys dolichurus* maintain low populations densities, where as in neighbouring fields, the population of *M. natalensis* reach explosion levels. These studies have shown drastic rise and declines of the multimammate rats, *M. natalensis*, where densities reached >200 rodents/ha (Fig. 6) (Makundi *et al.* 2005a) compared to the low densities (<25 animals/ha) of the three species commonly found in the forest. In agro-forestry habitats in Magamba village, the population of *M. natalensis* was much lower than in the savanna like habitats of Manolo village (Figs. 6&7). It is obvious that the forest offers more predictable conditions compared to the unstable habitats of the surrounding cultivated fields. Since variations between dry and wet seasons are not very much pronounced in montane rain forests, the primary productivity on which rodents depend is assumed not to fluctuate to extremes in between seasons. In ecological terms such species will be regarded to be k-strategists, whereas species like *M. natalensis* approach the de facto definition of r-strategists.

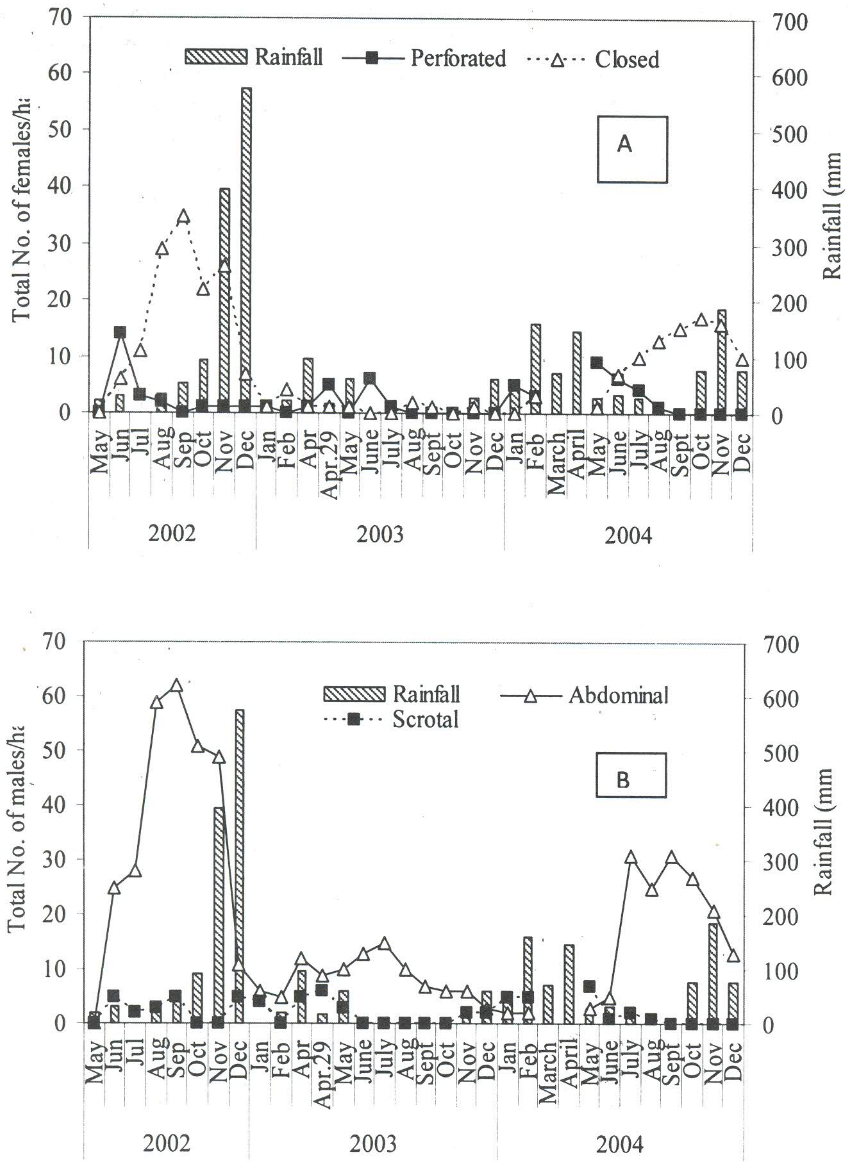



Fig 3. Breeding conditions of *M. natalensis* at Manolo, Shume, Lushoto (Makundi *et al.* 2007)

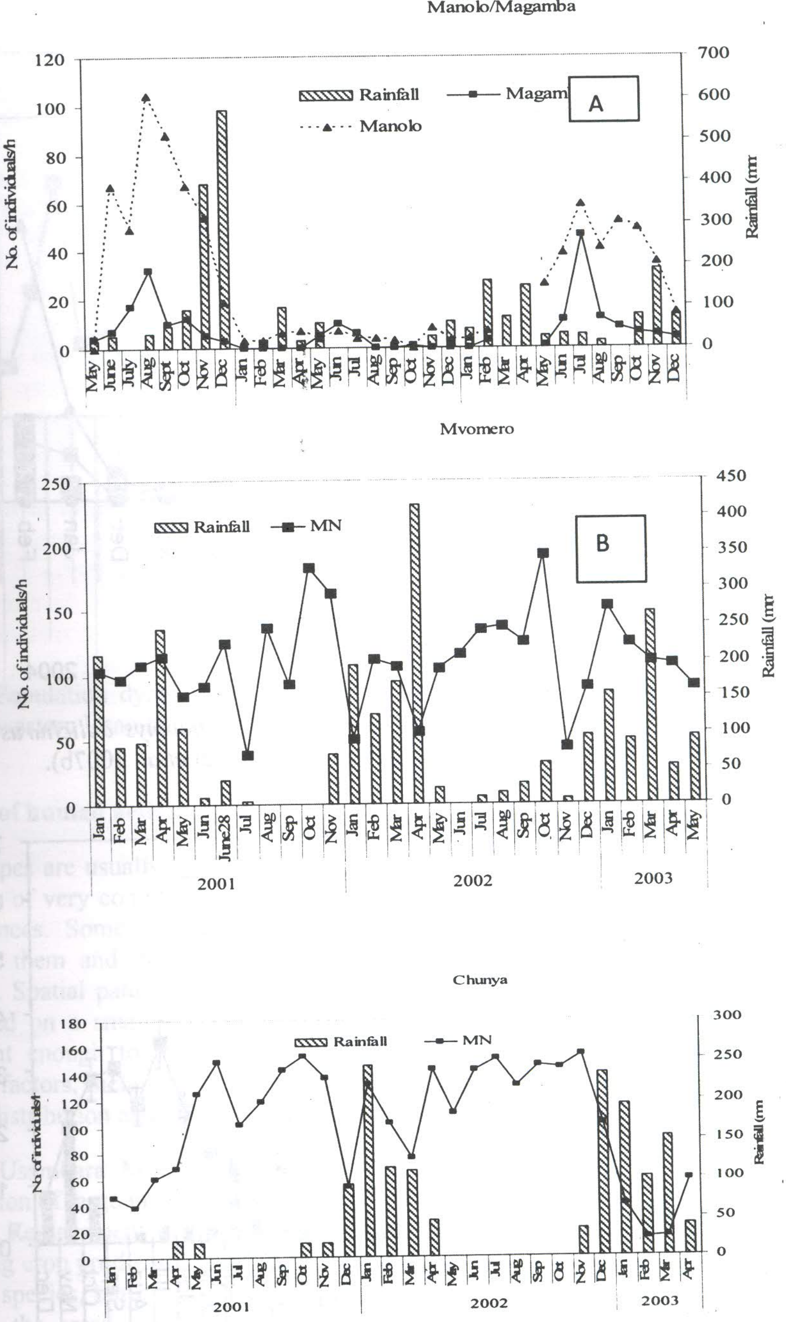



Fig 4. Population dynamics of *M. natalensis* in Lushoto, Mvomero and Chunya (Tanzania) (Makundi *et al.* 2007)

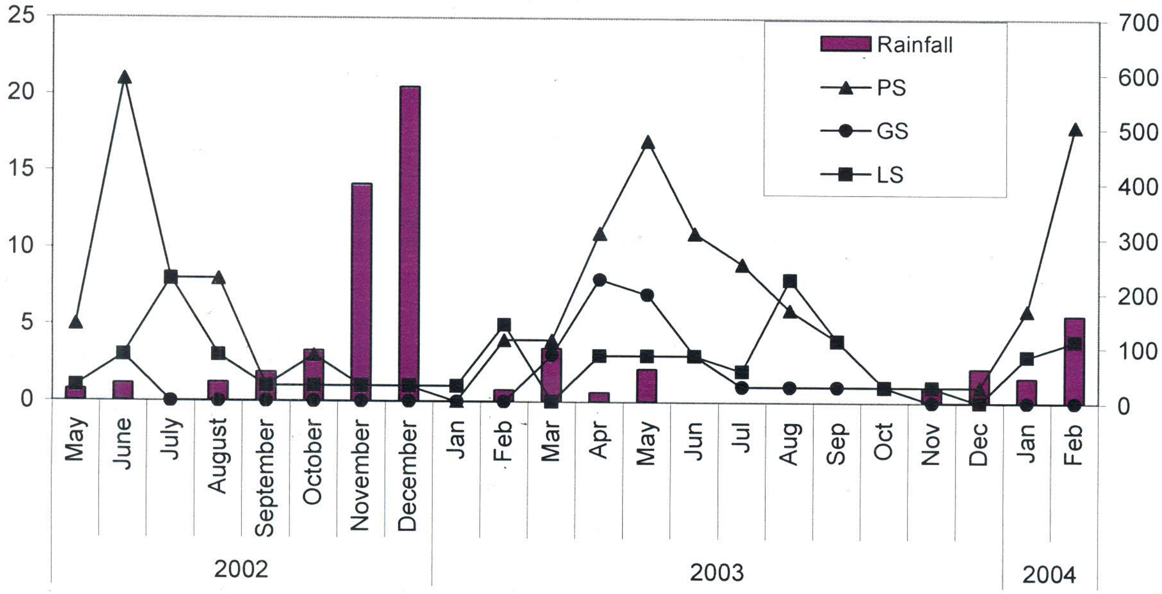



Fig. 5. Population dynamics of *Lophuromys kilonzoi* (LS), *Grammomys dolichurus* (GS) and *Praomys delectorum* in Magamba Forest, Lushoto District (Makundi *et al.* 2007b).

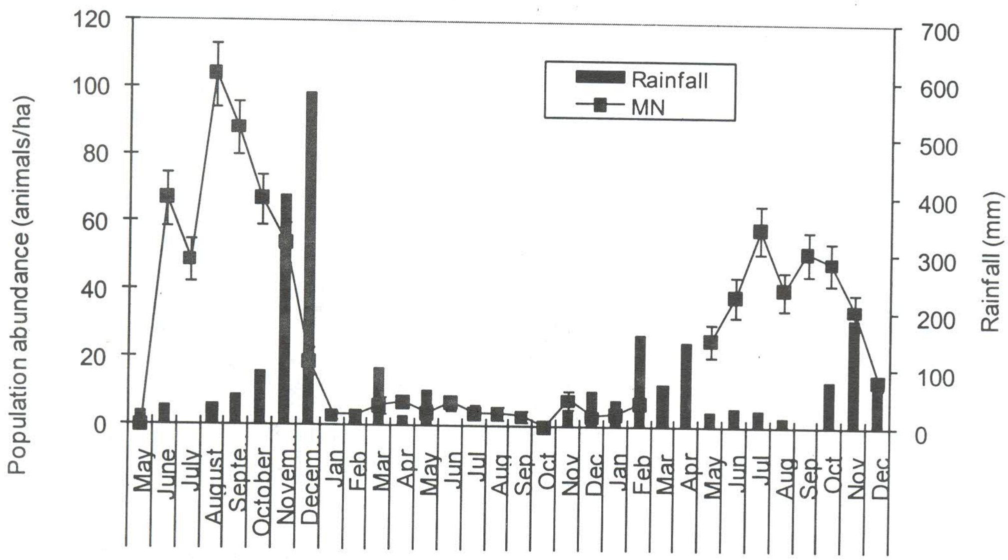



Figure 6. Population dynamics of *Mastomys natalensis* (MN) in a fallow land at Manolo in the Western Usambara Mountains

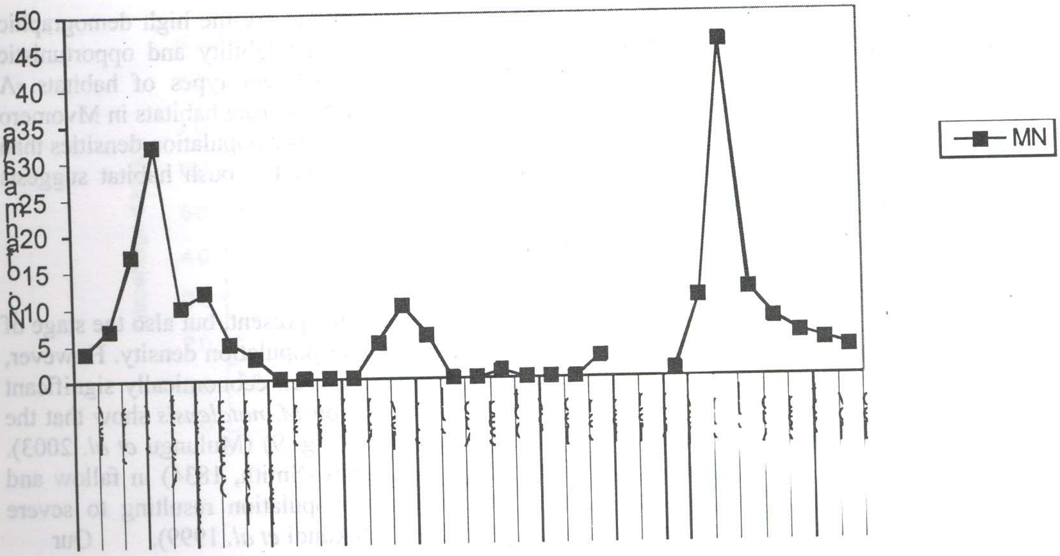



Fig. 7. Population dynamics of *Mastomys natalensis* in agro-forestry habitat in the Magamba village, western Usambara Mountains.

**Impact of human activities**

Landscapes are usually organized in certain spatial patterns called "mosaics". The patterns may be made of very complex or simplified habitats which are subject to natural and human caused disturbances. Some disturbances may produce more complex spatial patterns or they may simplify them and therefore affect the organisms living in them or the dynamic ecological patterns. Spatial patterns of distribution and abundance of rodents refer to how the species are organized on a small or geographical scale. On a small spatial scale, some factors may be sufficient enough to influence the diversity and population abundance (Steen *et al.* 1996). Several factors, including primary productivity and vegetation density have been shown to affect spatial distribution and habitat selection of rodents (Ims *et al.* 1993).

In the Usambara Mountains, north-east Tanzania, increasing human population has led to destruction of large proportions of natural forests, which directly threatens the existence of native species. Replacement of the natural forest by exotic tree plantations and other human activities including crop production, lead to modifications and fragmentation of suitable habitats for native rodents species, but could also create ideal conditions for colonization by opportunistic species. Further, the creation of agro-forestry zones in the western Usambara Mountains has altered natural habitats, which directly affects among other parameters, species distribution and abundance (Makundi *et al.* 2003). Apart from limiting the spatial distribution of rodents, these activities lower the survival of native species, and in the case of the Magamba Forest Reserve in north-east Tanzania, it has led to invasion by two opportunistic rodent species, the multimammate rats, *Mastomys natalensis*, and the grass rats, *Arvicanthis nairobae* in areas hitherto unsuitable for their habitation (Makundi *et al.* 2003).

Among the factors which make some species of rodents problematic are the high demographic outputs, their ability to adapt to changing landscapes/resources availability and opportunistic habits. Fig 8 shows how *M. natalensis* has adapted to two different types of habitats. A comparison of the population densities of *M. natalensis* in two neighbouring habitats in Mvomero District (Fig. 8) shows that the fields under maize cultivation had higher population densities than the bushy habitat. The low population density of *M. natalensis* in the bush habitat suggests resource scarcity (marginal) for maintenance of high populations.

***The rodent density crop damage relationship***

Crop damage and losses are related to the number of pest organisms present, but also the stage of growth of the crop. Maize damage and losses are related to rodent population density. However, there has to be a threshold population of the pest which will cause an economically significant damage/loss, above which intervention is necessary. Our studies on *M. natalensis* show that the threshold population during maize sowing is actually quite low (Fig. 9) (Mulungu *et al.* 2003). Erratic and periodic population explosion of *Mastomys natalensis* (Smith, 1834) in fallow and agricultural fields enables the species to reach the threshold population resulting to severe damage to crops almost on annual basis (Makundi *et al.* 1991, Makundi *et al.* 1999). Our studies on population density–crop damage relationships (Fig. 9) aimed at developing pest management strategies which are cost effective, non-disruptive to the environment and other species and ecologically friendly. The relationship between rodent population density and crop losses is fundamentally important in two ways: (i) it provides us with information on the threshold population size that causes economic damage to the crop (ii) it enables us to establish precisely the most appropriate timing of control measures.

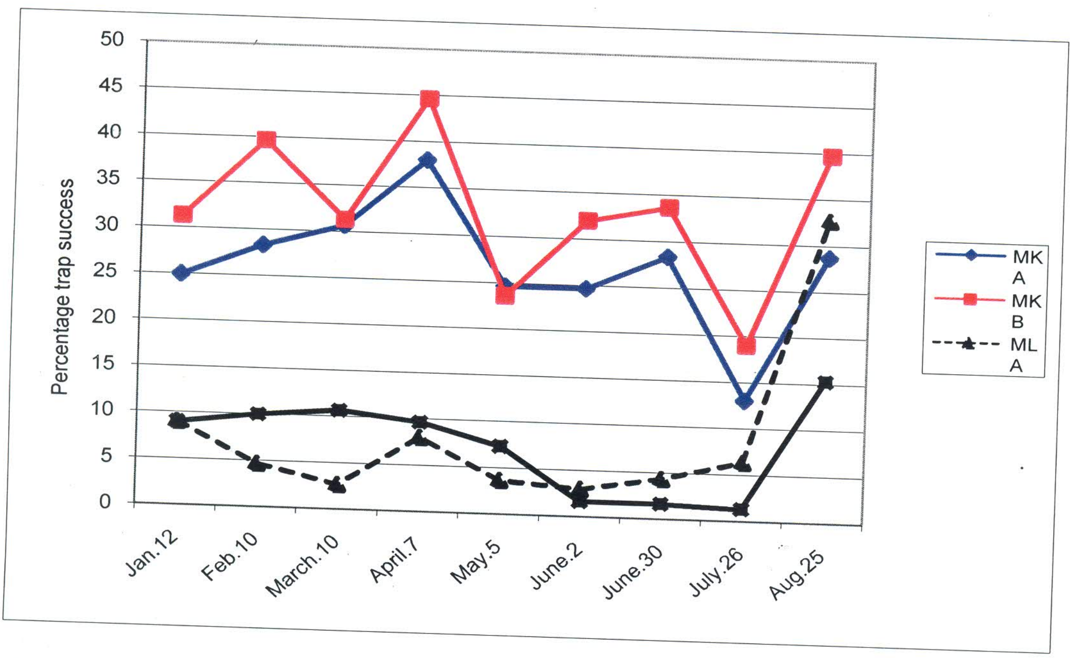



Fig 8. Variations in population abundance of *Mastomys natalensis* in four fields during the cropping season in 2002 in Mvomero, Morogoro, Eastern Tanzania (MKA and MKB are crop fields).

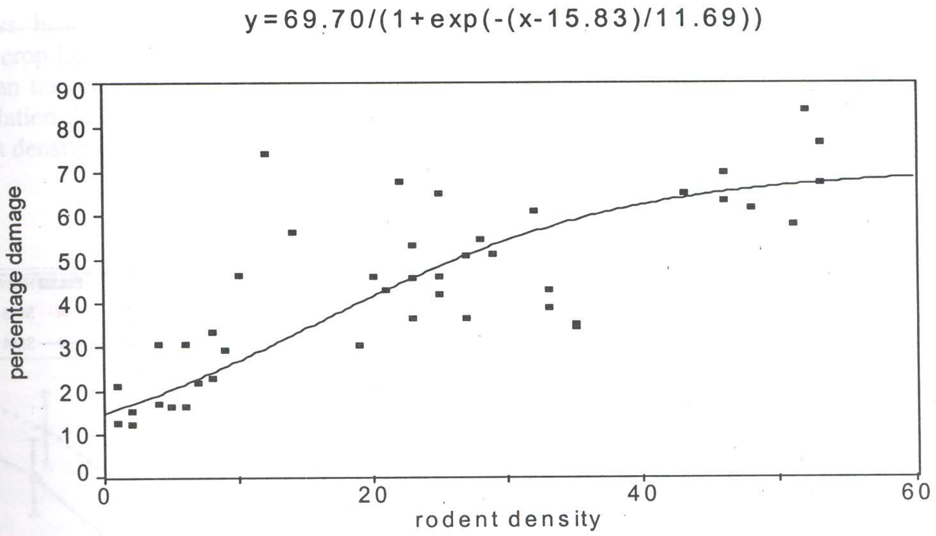
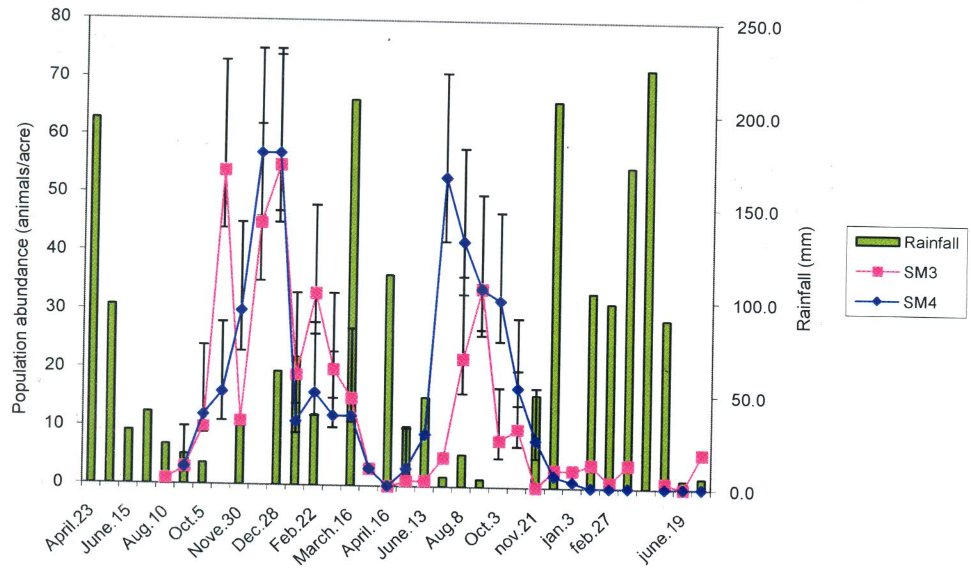



Fig. 9. Relationship between rodent density and maize damage (Mulungu *et al*. 2003)

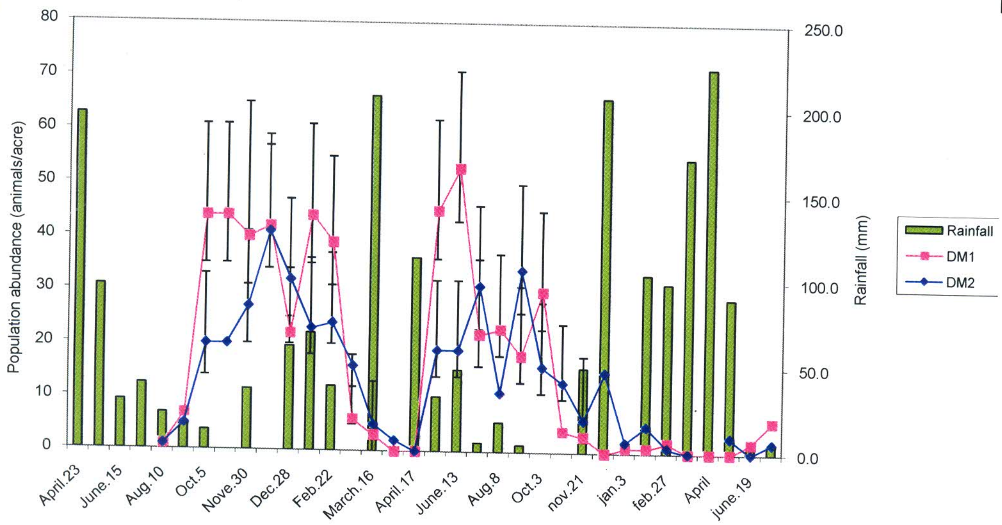
The rodent density-crop damage relationship above shows that at sowing of maize, >50% of the damage occurs when the rodent density is 30-40 animals/ha.

**Land use influences rodent populations: Land use patterns vs rodent ecology**

Different land use patterns influence rodent abundance. Our studies have shown that farming practices and land use patterns influence the population ecology of rodents (Maasawe *et al*. 2003) (Fig. 10). The major question is, however, which population processes are affected? Could it be recruitment, survival, breeding, dispersal, etc.? Each of these parameters needs to be assessed experimentally for each of the pest species.




(a) Rodent population abundance in Slash and burn mono-crop field




(b) Rodent population abundance in tractor-ploughed mono-crop fields

**Fig 10: Effect of land management and farming practices on rodent populations (Massawe *et al.* 2007)**

Fig. 10 shows how land preparation methods and cropping systems influence population abundance in crop fields. Slash and burn practices increase recruitment of new individuals in the population than tractor ploughing. The same practices influence recruitment of new individuals into the population during the growing period (Fig 11). Invariably, cropping systems also affect the population density of rodents in the field (Fig 12).

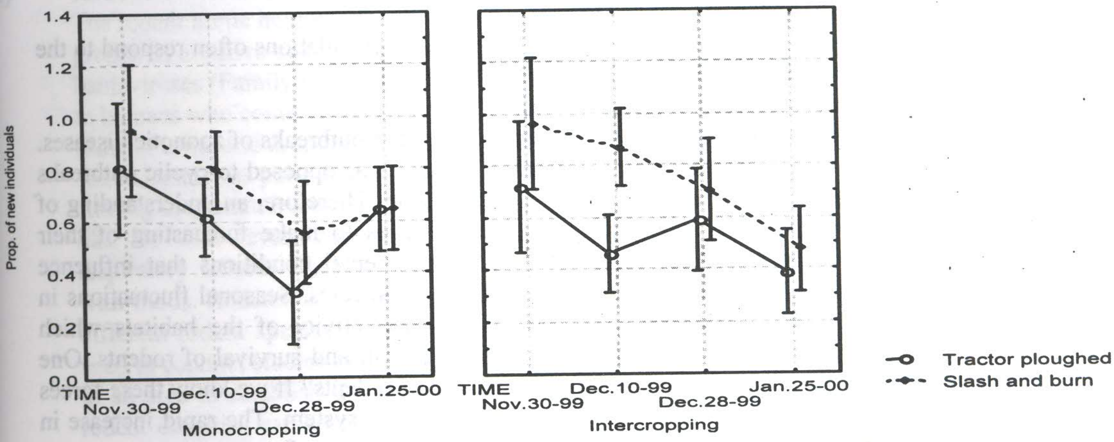



Fig. 11. Recruitment of new individuals at different time intervals during growing season of maize in the different treatments in the 1999 short rainy season ($P \leq 0.05$) (Massawe *et al.* 2007).

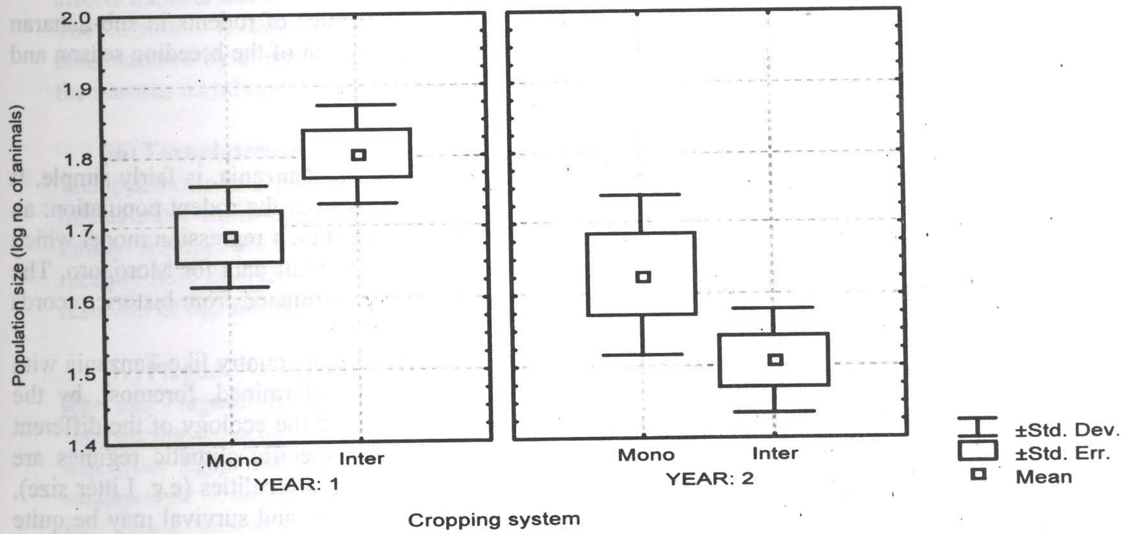



Fig 12: Rodent population densities in different cropping systems ($p < 0.05$). (Massawe *et al.* 2007).

***The mystery of outbreaks and their prediction***

Outbreaks or population explosions refer to unusual occurrences of large numbers of rodents in one season or in some years. Outbreaks of rodents have certain characteristics:

- Outbreaks occur in some species and not others
- They sometimes occur sporadically, often as a surprise to the community; or occur in certain areas regularly, and sometimes do not show a recognizable pattern
- Some years have outbreaks, some are without
- They occur in certain seasons
- Certain conditions are associated with outbreaks: rodent populations often respond to the timing, duration and amount of rainfall.

Outbreaks of rodents are associated with severe crop losses and/or outbreaks of zoonotic diseases. In sub-Saharan Africa, outbreaks of rodents are usually irregular as opposed to cyclic outbreaks which occur in temperate climates after a known period of time. Therefore, an understanding of the mechanisms that influence these populations can enable us to make forecasting of their occurrences. Irregular outbreaks occur under certain environmental conditions that influence some aspects of the biology and demographic processes of the species. Seasonal fluctuations in population abundance reflect seasonal differences in the productivity of the habitats which directly or indirectly influence breeding and reproduction, growth and survival of rodents. One major question is what forces drive the population dynamics of rodents? If we know these forces we could predict outbreaks and therefore create an early warning system. The rapid increase in abundance of rodents from low numbers to an outbreak depends on three factors:

(i) the population density at the start of the breeding season,
(ii) the rate of increase over the breeding season,
(iii) the duration of the breeding season.

Rainfall is one of the major factors influencing population dynamics of rodents in sub-Saharan Africa through its influence on the initiation of breeding, the duration of the breeding season and survival of offspring.

*An outbreak prediction model*

The model for predicting outbreaks of *M. natalensis* in Morogoro, Tanzania, is fairly simple. It relies on a single factor only, rainfall and two kinds of responses from the rodent population: an outbreak or no outbreak (Leirs *et al.* 1996). The prediction is based on a regression model which requires a comparison of the actual rainfall data with the usual rainfall data for Morogoro. The relationship between the likelihood of an outbreak and rainfall is estimated from historic records and forms the basis for a forecasting system.

However, this kind of forecasting creates certain problems for a large country like Tanzania with different agro-ecological zones. The agro-ecological zones are determined, foremost, by the rainfall patterns. This, therefore, suggest that in order to understand the ecology of the different species of rodents, studies based in these localities with their specific climatic regimes are necessary. Certain parameters of the species may be common across localities (e.g. Litter size), but other important parameters such as number of litters per season, and survival may be quite different. Unimodal rainfall patterns may influence the same rodent species quite differently from a bimodal rainfall pattern.

**The public health importance of rodents:**

Rodents and their parasites are known to be involved in the transmission of plague, Lyme disease, salmonella, typhus, leptospirosis, toxoplasmosis, borelia, food poisoning, Lassa fever, and hantaviruses.

*Mysterious disease outbreaks involving rodents*

(i) **Rodent-borne Hemorrhagic fevers**

The rodent borne hemorrhagic fevers are mysterious infectious diseases caused by two distinct groups of negative-stranded RNA viruses, namely the Arenaviruses (Family Arenaviridae) and hantaviruses (Family Bunyaviridae). Hantaviruses are carried by rodents and can be transmitted to humans who come into contact with infected rodents or who inhale the infected dust from the rodents' urine and droppings. In humans, the virus causes a potentially fatal respiratory illness called hantavirus pulmonary syndrome (HPS).

Among the hantaviruses, Lassa virus is highly pathogenic to humans. Hantavirus infections starts like flu with fever, coughing, and chills. Other strains of hantaviruses cause kidney and respiratory failures. However, the victims of this disease die a painful death, their lungs filling with fluids. Rodents are the primary carrier of hantaviruses. Each hantavirus appears to "prefer" different rodent species. To understand the nature of hantaviruses transmission to humans, we need to conduct studies on their prevalence and demographic analysis of rodent species occurring in an area to establish the correlation between rodent densities and hantavirus infection. Since rodent densities are correlated to precipitation, these factors need to be investigated since the probability of human-rodent contact usually rises with increasing rodent densities, resulting in an increase in virus transmission.

**(ii) Leptospirosis**

Leptospirosis is a bacterial zoonotic disease caused by spirochaetes of the genus *Leptospira* that affects humans and a wide range of animals, including mammals, birds, amphibians, and reptiles. The infection is commonly transmitted to humans by allowing fresh water that has been contaminated by animal urine to come in contact with unhealed breaks in the skin, eyes or with the mucous membranes.

**(iii) Toxoplasmosis**

Toxoplasmosis is a parasitic disease caused by the protozoan *Toxoplasma gondii*. The parasite infects most warm-blooded animals, including humans, but the primary host is the felid (cat) family. Animals are infected by eating infected meat, by ingestion of faeces of a cat that has itself recently been infected, or by transmission from mother to fetus. Cats have been shown as a major reservoir of this infection.

(iv) **Plague**

***Rats and Plague: Mystery of the Black Death - Ancient mysteries***

*"Appearing miraculously in 542 A.D., the Black Death claimed 100 million lives. Winding its way from Egypt through Asia Minor and into Europe, the devastation lasted 52 years and disappeared as mysteriously as it arrived".* In: Ancient Mysteries: *http://www.cduniverse.com/productinfo.asp?pid=6930251. Visited on 22 September 2008.*

*"No one knows exactly why, but in the late 1320s or early 1330s, bubonic plague broke out in China's Gobi desert. Spread by flea-infested rats, it didn't take long for the disease to reach Europe. In October of 1347, a Genoese ship fleet returning from the Black Sea - a key trade link with China, landed in Messina, Sicily. Most of those on board were already dead, and the ships were ordered out of harbor. But it was too late. The town was soon overcome with pestilence, and*

*from there, the disease quickly spread north along trade routes -- through Italy and across the European continent. By the following spring, it had reached as far north as England, and within five years, it had killed 25 million people -- one-third of the European population" (http://www.pbs.org/wnet/secrets/previous_seasons/case_plague/index.html visited on 22 September 2008).*

***Plague: causative agent and pandemics***

*Yersinia pestis* causes plague, a re-emerging zoonotic disease globally (WHO Report 2006) transmitted to humans through flea bites and typically characterized by the appearance of a tender and swollen lymph node, the bubo. Plague has had devastating effects on human population throughout history. Three pandemics (pandemic: from the Latin *pandemus*, meaning *"of all the people", an epidemic over an especially wide geographical area; universal*) have been attributed to plague in the last 1,500 years. *Yersinia pestis* has been subdivided into three biovars on the basis of their abilities to ferment glycerol and to reduce nitrate. Based on their current geographic niche and on historical records that indicate the geographic origin of the pandemics, researchers have postulated that each biovar caused a specific pandemic (Perry and Fetherston 1997; Wren 2003). Biovar *Antiqua*, from East Africa, may have descended from bacteria that caused the first pandemic, whereas *Medievalis*, from central Asia, may have descended from the bacteria that caused the second pandemic. Bacteria linked to the third pandemic are all of the *Orientalis* biovar (Wren 2003).

***Personal interest in plague***

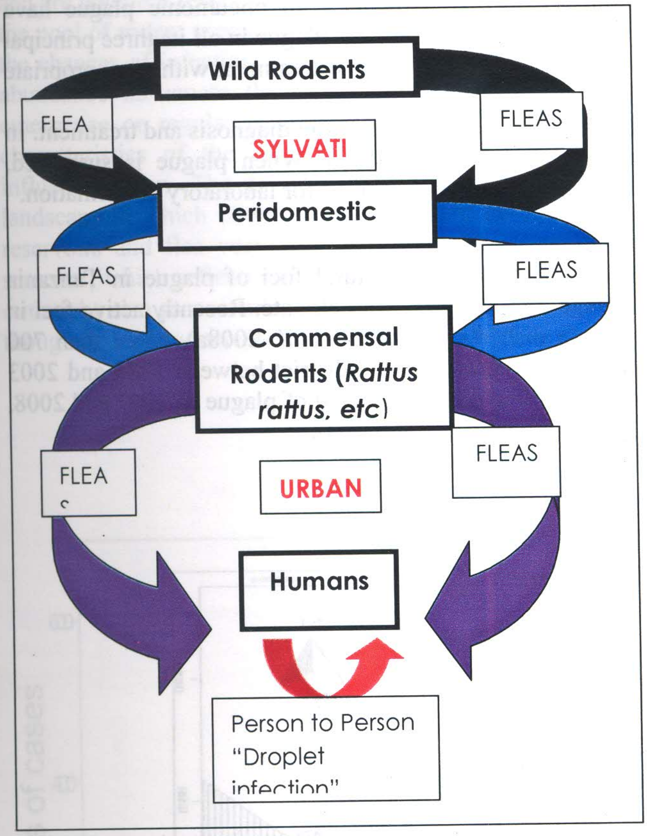
My interest in plague started about 20 years ago, when Prof Kilonzo introduced me to the subject. I developed a special interest in the ecology of the diseases in relation to its epidemiology. To date, with colleagues at the SPMC and abroad, together with the Ministry of Health and Social Welfare, we have endeavoured to solve the mystery of plague in Tanzania in order to reduce the suffering of people in the epidemic foci.

***The plague cycle***

The natural reservoirs of plague are wild rodents. The risk of human infection increase when plague penetrates populations of domestic rodents, particularly rats of the genus *Rattus*. The disease can remain enzootic, whereby it remains circulating among rodent species. However for some reasons, people get infected due to interaction between rodents and humans in houses and in the fields (Fig. 13). Human infection usually is acquired through the bites of infected rodent fleas and has an incubation period of 1-6 days. Plague also can be contracted from handling infected animals, especially rodents, lagomorphs (e.g., rabbits or hares), and domestic cats, or through close contact with patients with pneumonic plague (person-to-person transmission).

*Clinical forms*

The principal forms of plague are bubonic, septicaemic, and pneumonic. All of these forms can be accompanied by fever and systemic manifestations of gram-negative sepsis. Bubonic plague is distinguished by the presence of a bubo (i.e., one or more enlarged, tender, regional lymph nodes) (Fig. 14).




The plague cycle in the affected villages in Mbulu and Lushoto typically resembles the Urban Plague Cycle because of the way the villages were established (houses are close to each other, more or less like urban streets, with commensal rodents moving across households, spreading the disease

Fig. 13: The plague cycle: Lushoto and Mbulu foci

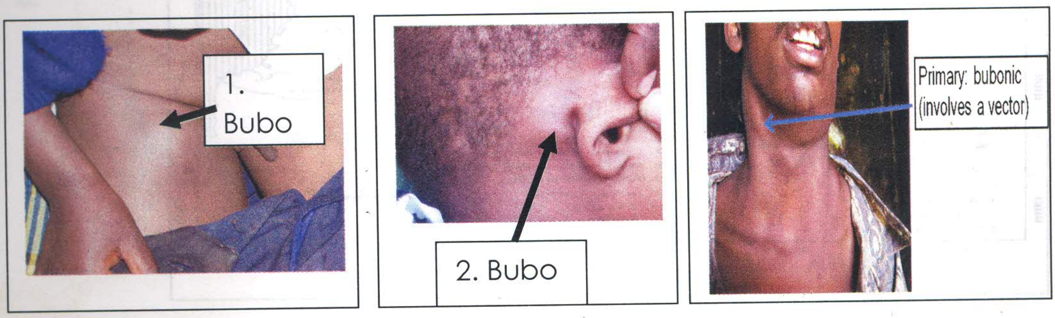



Fig. 14. Primary bubonic plague manifestations in lymph node (Pictures 1&2 by Makundi R.H.).



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Patients with septicaemic plague often have prominent gastrointestinal symptoms, including nausea, vomiting, diarrhea, and abdominal pain, and patients with pneumonic plague have dyspnea, chest pain, and a cough that can produce bloody sputum. Plague in all its three principal forms (bubonic, septicaemic and pulmonary or pneumonic) kills if treatment with an appropriate antibiotic is delayed.

In Tanzania, nearly all fatal plague cases are associated with delays in diagnosis and treatment. In its early stages, plague is treatable with appropriate antibiotics. When plague is suspected, antibiotic treatment should be initiated immediately and not delayed for laboratory confirmation.

***Plague in Tanzania: epidemiology and ecology***

Plague is endemic in Tanzania as shown in Fig. 15. The natural foci of plague in Tanzania include mountainous areas with good average rainfall and a mild climate. Recently active foci in Tanzania are in Lushoto, Mbulu and Karatu districts (Makundi *et al.* 2008a). More than 700 people died in Lushoto out of about 7000 cases reported in the district between 1986 and 2003 (Davis *et al.* 2006) (Fig. 16). In Mbulu District, 9 and 7 people died of plague in 2007 and 2008, respectively (Makundi 2007; Makundi 2008 ~ Unpublished Reports).

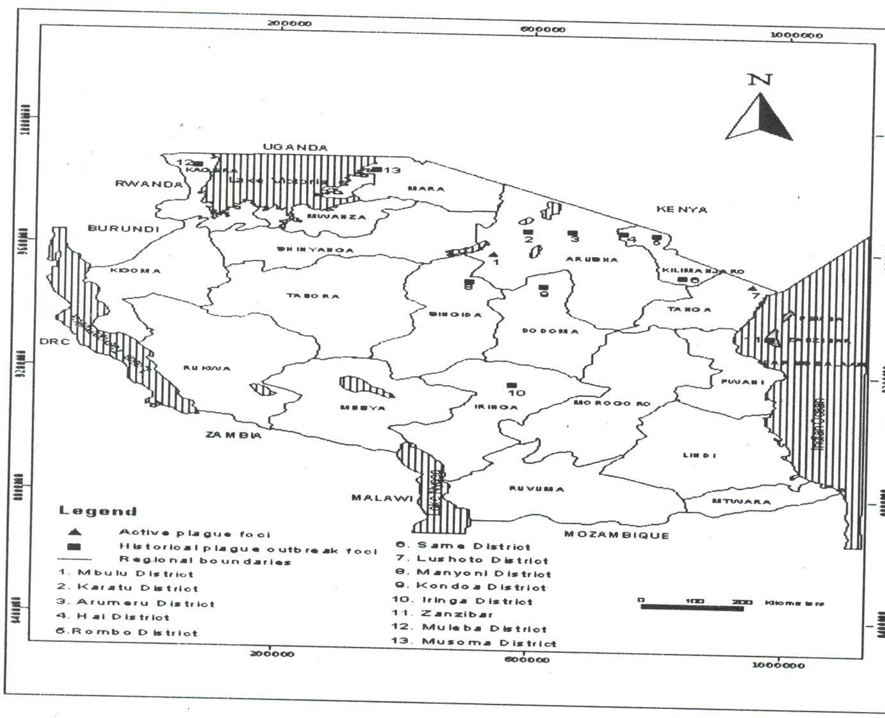



Figure 15: Active and historical plague outbreaks localities in Tanzania

In the active plague foci in Tanzania, several species of rodents are involved in the plague cycle, and are potential reservoirs. In all the plague outbreak foci in Tanzania, there is a great variety of the pool of rodent species which are potential reservoirs (Makundi *et al.* 2008a), which increases the chances of infection in the rodent and human population. The vector and rodent population abundance influences the dynamics of infection by the plague bacteria. Therefore, the re-emergence or regular outbreaks of plague in an area will be determined by the ecological characteristics of the reservoir and vector populations and the external environment that influences them. The primary natural foci of plague are connected with particular types of landscape in which climatic conditions are favourable for a high and stable number of rodent reservoirs and flea vectors of *Y. pestis*. Plague outbreaks in the active foci in Tanzania are seasonal, which reflects the seasonality of the host reservoirs species (rodents) and vectors, but outbreaks also show marked inter-annual variations in human cases (Fig. 16). A climatic effect is thought to lead to increased reproduction and survival rates among rodents and fleas.

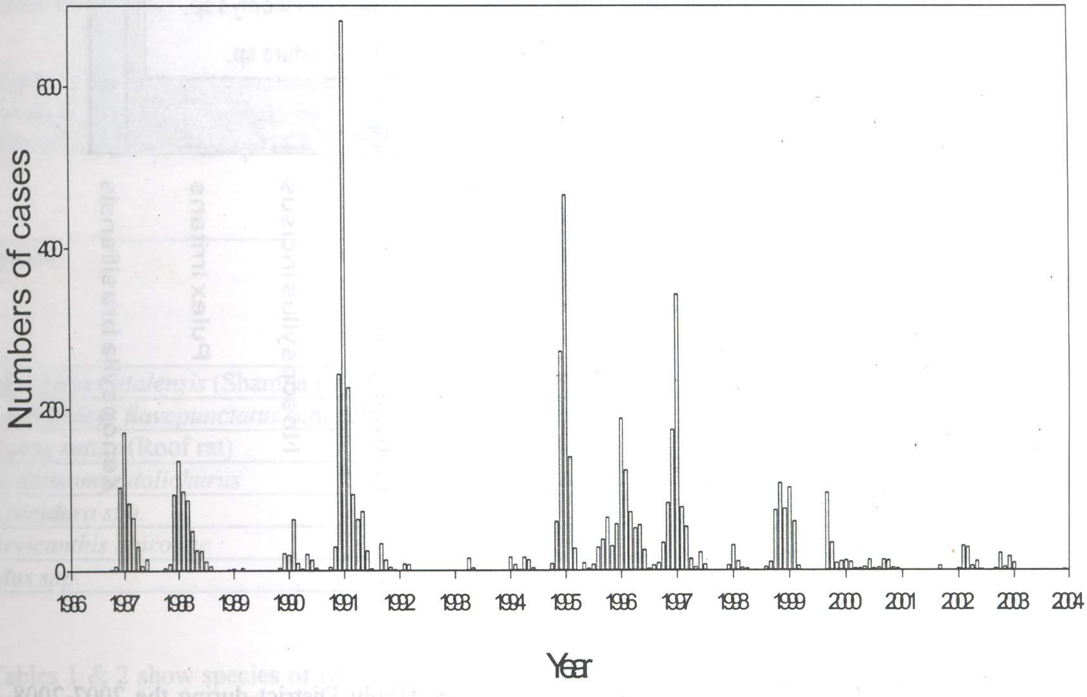



Fig. 16. Inter annual plague prevalence in Lushoto District, Tanzania (Davis *et al. 2006*)

The species of rodents and fleas which are involved in the plague cycle are diverse (Fig. 17), but there are some common species between localities. However, this does not tell us much about how people interact with these species leading to infection. Neither are we certain of which species of rodents maintain the innoculum during non-outbreak season and the efficiency of the different vector species to transmit the disease.

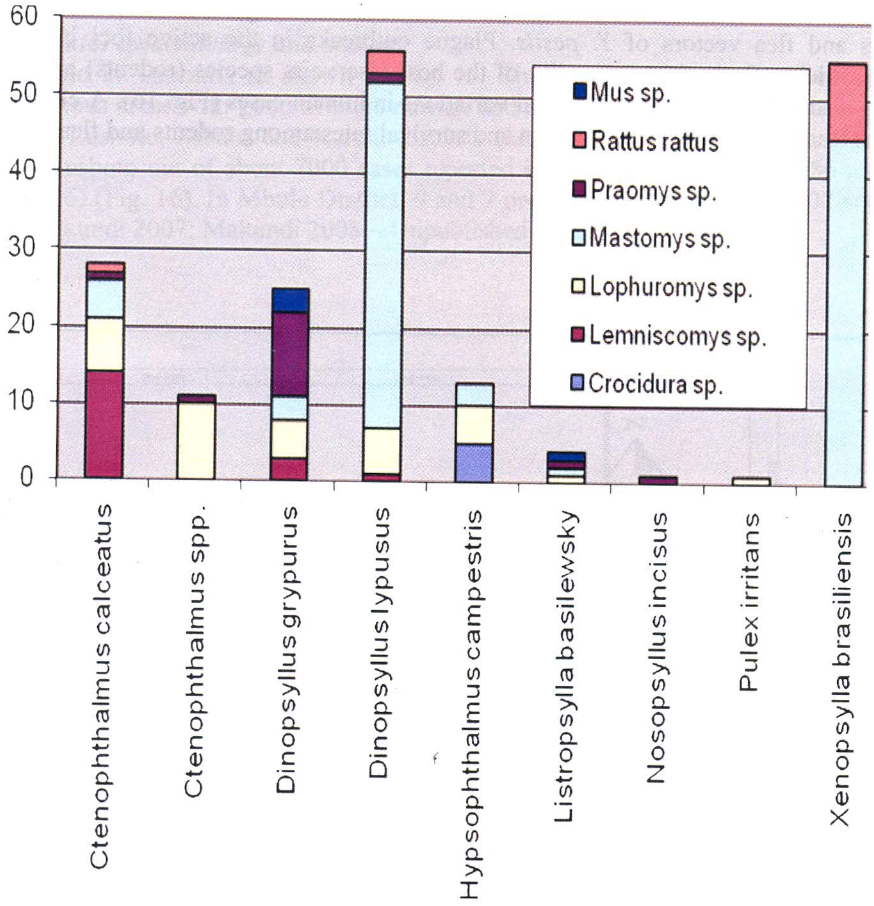



Fig. 17. Diversity of fleas found on rodents in Mbulu District during the 2007-2008 plague outbreaks

Table 1: Rodent and insectivores species composition and presence of specific antibodies against *Yersinia pestis* F1 antigen in deforested area under crop cultivation and human residences in Mbulu District, Tanzania in March 2007 (Makundi *et al.* 2008a).

| **Species** | **Total no of Sera** | **No positive specific antibodies)** | **Percent Positive for antibodies against *Yersinia pestis*** |
|---|---|---|---|
| *Mastomys natalensis* | 21 | 13 | 61.9 |
| *Lophuromys flavopunctatus* | 11 | 9 | 81.8 |
| *Rattus rattus* | 15 | 7 | 46.7 |
| *Praomys delectorum* | 4 | 1 | 25.0 |
| *Leminiscomys striatus* | 3 | 1 | 33.3 |
| *Graphiurus spp.* | 2 | 1 | 50.0 |
| *Crocidura spp.* | 5 | 3 | 60.0 |
| *Mus minutoides.* | 1 | 1 | - |

Table 2: Rodent and insectivores species composition and presence of specific antibodies against *Yersinia pestis* F1 antigen in Lushoto District, Western Usambara Mountains, Tanzania in November 2007 (Makundi 2007- Unpublished Report)

| **Species** | **Total no of Sera** | **No positive specific antibodies)** | **Percent Positive for antibodies against *Yersinia pestis*** |
|---|---|---|---|
| *Mastomys natalensis* (Shamba rat) | 48 | 33 | 68.8 |
| *Lophuromys flavopunctatus* (chocolate rat) | 4 | 1 | 25.0 |
| *Rattus rattus* (Roof rat) | 18 | 1 | 5.6 |
| *Grammomys dolichurus* | 13 | 6 | 46.1 |
| *Crocidura spp.* | 1 | 0 | - |
| *Arvicanthis nairobae* | 2 | 0 | - |
| *Mus spp.* | 1 | 0 | - |

Tables 1 & 2 show species of rodents and insectivores which were found positive for plague by ELISA in Lushoto and Mbulu plague outbreak foci. This clearly shows a diverse group of species of rodents and insectivores that are potential reservoirs of the disease (Makundi *et al.* 2008a). The major factor contributing to the appearance of plague in human populations is increased contact between humans and rodents in the outbreak foci. This can be caused either by encroachment of human activity into rodent habitats or by movement of rodents into areas of human activity due to anthropological or environmental disturbances. Exposures to plague possibly occur in the fields, but the peridomestic environment is most certainly where most infections occur. Peridomestic rodents, which interact with wild rodents, bring infected rodent fleas into the home and these are suspected as a potential source of human infections. Pigs in Mbulu district were found to be plague positive, but their role in the plague cycle is unknown. In both Lushoto and Mbulu Districts, there is intensive farming which has intruded into the natural habitats where wild rodents carrying *Y. pestis* are found. However, the role of the different rodent species in the epidemiology of plague in Tanzania is not known. Some species are reservoirs and can maintain the disease without any symptoms of ill-health, but other species are killed by the infection. High mortality of susceptible rodents is observed before the disease occurs in the human population. This was observed in Mbulu District during the 2007 plague outbreak (Makundi *et al.* 2008a). Other rodents may act as "amplifier" host species of the diseases and therefore serve as temporary reservoirs because they pick the bacteria which multiply in them. These are passed on to other species of rodents in the enzootic cycle of the diseases. Several species of fleas are potential vectors of the diseases in active plague foci (Fig. 17). However, the vectorial capacity of these species is unknown. Microhabitats characteristics are important in determining the suitability of some habitats for the survival of fleas (Laudisoit *et al.* 2007). One common factor in all the active plague foci in Tanzania is the abundance of the human flea, *Pulex irritans* in houses and the presence of the roof rat, *Rattus rattus*. The human flea is regarded as poor vector of *Yersinia pestis*, but there are no reasons for not implicating it in plague transmission in Tanzania.

**Plague Management**

The biological events that lead to plague outbreaks are dynamic: these include changes in the reservoirs and vectors numbers, changing infection levels in animal reservoirs, different levels of rodent-fleas-human interactions, rodent movements and interactions between them, etc. This dynamic system needs to be monitored throughout the year and results must be included into an adaptive plague management programme. In the course of plague management in Lushoto and Mbulu Districts, an adaptive plague management model was developed and successfully tested. The model is shown in Fig. 18.

**Plague today, tomorrow and forever?**

Are there dangers of persistent plague outbreaks in the world? The conditions for plague epidemics in rural and urban areas are very conducive particularly in the less developed countries. The following are some of the contributing factors:

- Rapid urbanization has led to congestion of people in townships and cities with increasing inability to remove and destroy organic garbage creates conducive conditions for rodent breeding and increases in their abundance.
- Landscape changes have altered the ecological conditions which favour rodent population increases and contact between rodents and humans
- Efficient transportation could increase the spread and distribution of plague locally and between countries
- Unhygienic living conditions and rural poverty could enhance rodent and fleas infestation and therefore contribute to plague outbreaks.

Despite the above, some developments have been made, which could reduce the occurrence of epidemics. These include:

- Availability of antibiotics for plague treatment. In Tanzania, free treatment is provided during plague epidemics
- Better housing in some sections of the society ensures less serious rodent and flea infestation
- Information flow and better understanding of the plague cycle (knowledge on reservoirs, vectors, rodent and flea management practices and strategies, etc. Plague is now subject to reporting and quarantine under the New International Health Regulations, 2007)

• Better organizations for plague control and prevention (at the national and international levels i.e. WHO)

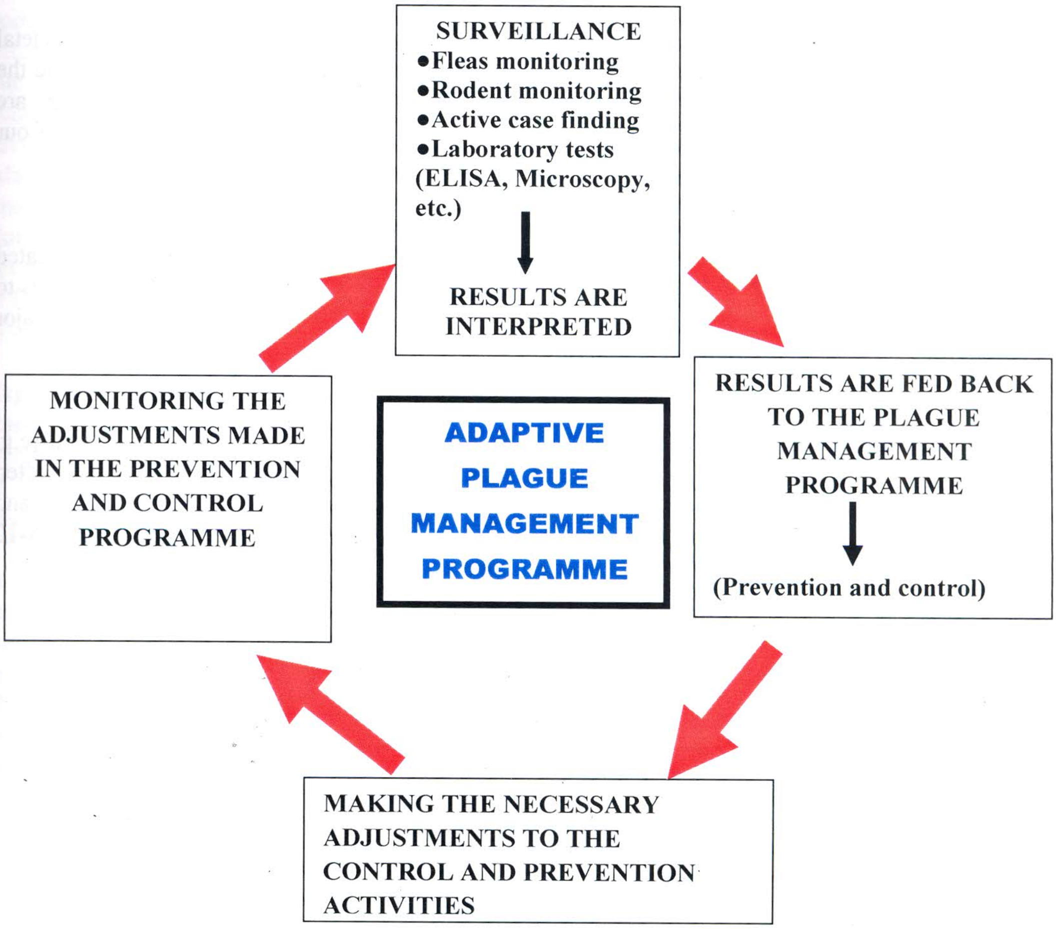



Fig. 18. An adaptive plague management approach for Tanzania

**Beneficial aspects of rodents**

***Ecosystem balance***

Rodents contribute to ecosystem functioning in many ways, although these are not easily noticed and are not appreciated by the ordinary observer:

• They enable nutrient cycling
• They feed on many noxious organisms some of which could be harmful
• They are prey to many other mammals (civets, cats, mongooses, lions, etc.), birds (owls, eagles, etc.) reptiles (snakes, etc.) and therefore enable maintenance of ecological/ecosystem balance

### *Medical research*

Many medical studies are based on rodents. They include the benefits and risks of hormone therapy for women, cancer studies, toxicity studies of various drugs, dose vs body size studies for drugs and poisons, cardiovascular diseases studies, pesticides exposure studies, etc.

### *Environmental changes: Ecological studies*

Long-term ecological research on rodents has immeasurable environmental and societal benefits. Long-term data on the ecology of rodents can help scientists to quickly determine the cause of disease outbreaks and how to prevent their spread. Such ecological studies are imperative to enabling decision makers to make informed choices concerning the health of our society and environment.

### *Cloning: potential benefits for human medicine and agriculture*

Rodent cells have been widely used for determining gene function, as they can be manipulated to "knock out" or up-regulate genes or to introduce foreign genes. Genetic engineering studies to produce transgenic animals and for gene therapy, which are based on rodents, have major implications for human medicine and agriculture.

### *Source of meat for humans*

Many communities feed on rodents as a meat source. In some countries in West Africa (e.g. Ghana and Benin), families rear cane rats for meat in the household and for sale and is often more expensive than beef (Fig. 19). Although several species are taken for meat, cane rats and giant pouched African rats fetch the highest prices in local markets in West Africa, at US$ 8-10 and 2-10 per kg, respectively (Assogbagjo *et al.* 2003).

(Picture by Makundi R.H., 2007)

Fig. 19: Cane rats (*Ndezi* in Swahili) (*Tryonomys swinderianus*) being reared in captivity for meat supply in a household and for sale in Benin, West Africa

***Exploiting rodent abilities: the function of smell (abilities to be conditioned)***

Mammals have certain abilities which when properly exploited could benefit man in various ways. The dog for example has many abilities which have been very useful to human kind e.g. as guide and rescue animals, landmine detection, etc. Rats and mice also have a good sense of smell. They mark pathways with urine and use their sense of smell to recognize the odors emanating from their surroundings, from food sources, etc. The sense of smell serves the rat in many ways: Olfactory cues are important for signaling the social and sexual status of individuals of a species. The detection of such cues is a key step in regulating behaviors such as mating and aggression. Many species rely heavily on their sense of smell to locate food, detect predators or other dangers, navigate, and communicate societal information. Olfaction plays a role in mate choice, mother–infant recognition and signaling between members of a group. Humans have a reduced reliance on smell relative to rodents, but the ability to smell is still an important function in our lives. Humans may not depend on olfaction for survival to the same extent as rodents, but we nevertheless use olfaction extensively to gather information on our surroundings, from the smell of food stuffs to detect whether they are still safe to eat, and the smell of your choice of deodorant to impress your spouse or girl friend.

**Exploitation of the sense of smell of rodents**

***Rats as Biosensors***:

The SUA-APOPO project has pioneered research geared at exploiting the strong sensory abilities of rodents to detect land mines buried in the ground and tuberculosis in human sputum. The excellent smell capabilities of the pouched African giant rats (*Cricetomys gambianus*) to detect TNT in land mines and the *Mycobacterium tuberculosis* (TB) in human sputum has been the core of this research. *Mycobacterium tuberculosis* and the disease tuberculosis, have seriously plagued mankind for centuries. Land mines and TB are a serious problem in Africa, in particular in the war torn zones in central Africa. In the former Portuguese colonies of Angola and Mozambique, land mines continue to claim many lives many years after the wars ended.

*HeroRats* are trained pouched African giant rats which have been conditioned to detect TNT, which they are able to do even at very low concentrations, and with very high accuracy. The rats are conditioned to detect TNT or tuberculosis through a system similar to classical conditioning by positive reinforcement. The rats are rewarded by being given food upon positive recognition of the scent of TNT or tuberculosis.

**Rodent Pest Management**

***Rodent pest management expectations and the real world***

In a normal ecological balance, it would be expected that natural forces will keep the populations of rats under check and therefore, outbreaks of devastating populations will be rare. However, rat population outbreaks in Tanzania are more frequent than would be expected (Mwanjabe 2002). In addition, the normal practices for restraining rodent populations do not seem to function in the expected way:

- The cat fails to bring rodent populations in the house and peridomestic areas under control
- The applied poison is ineffective due to one or more reasons
- The other predators (owls, snakes, mongooses, etc) do not increase in numbers at a rate capable of consuming more prey as they become available.

• Rodent pests have a strong capacity to recover rapidly from imposed reductions in abundance (i.e. Due to trapping or application of poison). Demographic responses include rodent population compensating through high recruitment of young and high immigration into areas where the population was knocked down by poison or other measures (Fig. 20).

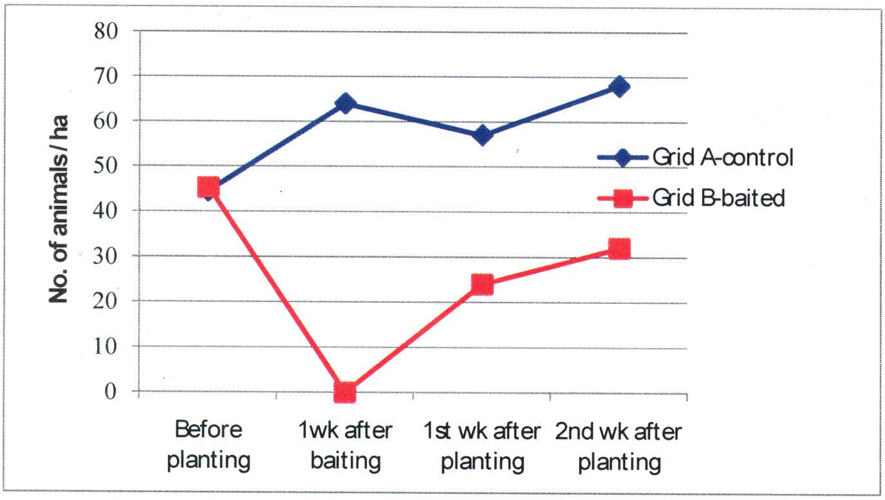



Fig 20: Effect of rodent control (single application of the anti-coagulant, bromadiolone bait) on population of *Mastomys natalensis* during the seedling stage of maize in Morogoro, Tanzania (Makundi R.H. ~STAPLERAT Project Scientific Report 2003)

***Farmers concerns and the expert approach to rodent pest management***

Farmers are concerned with the damage and losses caused by rodents, while health officers and the community at large worry about the diseases which can be transmitted from rodents to humans and domestic animals. Indeed many farmers think rodents are too clever for them, and therefore accept the damage as being inevitable. In south-east Asia for example, farmers have frequently stated "*for every eight rows of rice we sow for our family, we sow two for the rats*" (Quotation from South East Asia). This shows some level of resignation and it implies that rodents are difficult to control. Management of rodent pests has never been an easy task. People have tried all possible measure to reduce the impact of rodents as pests, including wishful thinking (Leirs 2003) as illustrated in the Pied Piper of Hamelin (*Quote*):

*"Please your honours"* said he, *"I am able,*
*"By means of a secret charm, to draw*
*"All creatures living beneath the sun,*
*"That creep or swim or fly or run,*
*"After me so as you never saw!*
*"And I chiefly use my charm,*
*"On creatures that do people harm,*
*"The mole and toad and newt and viper,*
*"And people call me the Pied Piper"*

(R. Browning 1888 - *The Pied Piper of Hamelin*) (Source: Leirs 2003).

Rodent management poses many challenges for which solutions are not always at hand. However, when faced with a rodent pest problem, anything that may mitigate the problem has been accepted even if the desired outcome was not achieved. Charles Elton, the prominent Professor of Ecology at Oxford University, who was among the most influential ecologists of the twentieth century, understood the problem of rodent pest management when he stated (*Quote*) (Elton 1942).

Charles Elton 1900-1991

*"The affair runs always along a similar course. Voles multiply. Destruction reigns. There is dismay, followed by outcry, and demands to Authority. Authority remembers its experts and appoints some: they ought to know. The experts advise a Cure. The Cure can be almost anything: golden mice, holy water from Mecca, a Government Commission, a culture of bacteria, poison, prayers denunciatory or tactful, a new god, a trap, a Pied Piper. The Cures have only one thing in common: with a little patience they always work ... (but) they have never been known to prevent the next outbreak.*

***Managing rodents in domestic areas***

In the household, people are concerned with infestation by commensal rodents. Their management can focus on the following:

- Identification of the rodent species causing the damage, its shelter, habits and density.
- Sanitation and environmental modifications to remove sources of food and harborage.
- Trapping to rapidly reduce rodent populations.
- Poisoning, using rodenticide baits to ensure that those not trapped are killed by the poison
- Exclusion to keep rodents out of buildings, food stores or other structures.
- Monitoring continuously to assess the effectiveness of the rodent control program and rapidly deal with any new infestations.

***Farmer's attitudes, knowledge and practices***

In the past, we investigated farmer's attitudes, knowledge and practices in Ethiopia and Tanzania in order to establish the difficulties and opportunities for rodent pest management and found out that socio-economic conditions and culture of farmers influence the rodent pest management practices used (Makundi *et al.* 2005b). Rodent pest management is also influenced by the farmer's knowledge on variables affecting crop damage, the level of crop susceptibility, the rodent pest population during the most susceptible crop stage and how much farmers are prepared to control the pests (Makundi *et al.* 2005b). Farmers are quite knowledgeable about rodent pest problems (Figs. 21 & 22). However, in many situations, farmers have few effective technologies that can be used to reduce the impact of rodents on their crops. This makes farmers to rank rodents as number one pest, probably because they are least able to control them compared to the other pests.

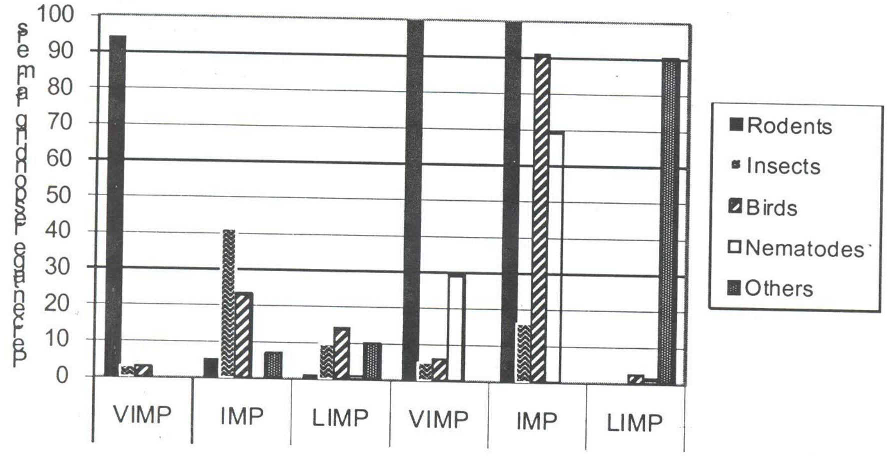



Fig.21. Ranking of the importance of pests in different crops in Tanzania and Ethiopia (VIMP = Very Important; IMP = Important; LIMP = Least Important)(N=120 - Tanzania; N = 180-- Ethiopia) (Makundi *et al.* 2005b)

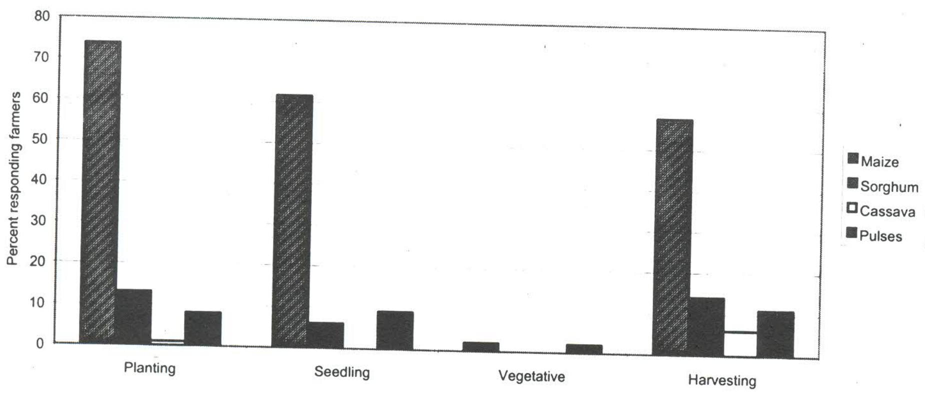



Fig. 22: Ranking of rodent damage to crops at different crop growth stages in Tanzania (Makundi *et al.* 2005b)

***Managing rodents in the field***

Ecological factors, ascribed to the total environment and associated climatic factors, characteristics of the rodent species and human activities, especially those leading to modifications of natural habitats, have been blamed for increasing rodent pest problems in Tanzania (Makundi *et al.* 1999). The management of rodents in Tanzania 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.

**Rat catcher's approach: Bounty schemes vs community based intensive trapping**

*Bounty schemes*

These were organized to control rodents, especially in plague outbreak areas. In Kilimanjaro region, Tanzania, Lurz (1913) reported a bounty scheme to control rodents during 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 (Makundi *et al.* 1999).

*Community based intensive trapping*

This is a new rodent control approach, particularly for management of commensal rodents in houses and peridomestic areas. The community is organized into groups, and each group simultaneously conducts trapping for a certain period (7 days), and thereafter continues to monitor rat activities in the houses. The community based intensive trapping approach is being tried in Berega, Kilosa District, Tanzania and has already shown that the number of rodents infesting houses is substantially reduced, which also leads to reduced rodent-human interactions.

*Cultural practices*

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 (*Arvicanthis spp., R. pumilio, M. natalensis and Otomys angoniensis*). 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. nairobae* populations near houses (R.H. Makundi, Pers. Obs.). 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 un-weeded farms in Chunya District. The farming system in Tanzania 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 use practices, producing less fallow patches that are a refuge for rodents and from where invasion of crops occurs. Cropping schemes need to be synchronized over a large area to reduce the damage by rodents.

*Poisoning*

The use of rodenticides to control rodent outbreaks is not widely practiced on an individual farm basis (Makundi *et al.* 1999). 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 (Makundi *et al.* 1999).

▶Availability of the required rodenticides: this is often influenced by availability of funds for their purchase.

▶Acceptability of bait formulations to rodents: it is often influenced by palatability under field conditions.

►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 populations are low, before animals start breeding.

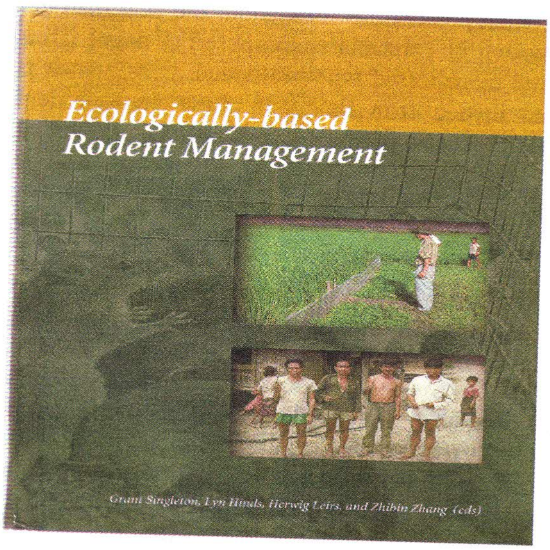
Zinc phosphide is most commonly used for controlling rodent outbreaks in Tanzania. The choice of Zinc phosphide by farmers with little disposable income is based on low cost and a reasonably quick effect relative to anticoagulants, but even this rodenticide is not easily available to most farmers. If knowledge of rodent population dynamics is available, this could be used to suggest appropriate timing of prophylactic treatment to alleviate the damage caused during rodent outbreaks (Makundi *et al.* 1999).

*Virus vectored immuno-contraception*

Fertility control of house mouse populations through immuno-contraception (Chambers *et al.* 1999) involves sterilization of rodents by an immuno-contraceptive antigen (a reproductive protein) that generates an immune response, with antibodies in the female host blocking fertilization. Immuno-contraceptive approaches are highly species-specific. A major biological challenge for developing and disseminating virally-vectored immune-contraception agent for rodents is whether the modified virus has a sufficiently high transmission rate under field conditions (Arthur *et al.* 2005). Although fertility control of rodent pests through immuno-contraception is still some way off, it is a potential approach to managing rodent species with large output of young for which we experience frequent outbreaks.

**Ecologically-based rodent management**

In 1999, I was among a group of world leading scientists involved in research on rodents who met in Beijing, China, to discuss the concept of "Ecologically-based Rodent Management". Each of us contributed a chapter to the first book ever published on ecologically based rodent pest management. My contribution (co-authored by the late Patrick Mwanjabe and Prof. Nick Oguge from Kenya) was a chapter titled "*Rodent Pest management in East Africa: An ecological Approach*", which lays down the fundamental principles for establishing a management system of rodents based on an understanding of their ecology in East Africa (Makundi *et al.* 1999).




**Makundi, R.H,** Oguge, N.O. and Mwanjabe, P.S. (1999) Rodent Pest Management in East Africa – An Ecological Approach. Pp. 460 – 476. In: Singleton, G., Hinds, L. Leirs, H., and Zhang, Z. (Eds.). *Ecologically-based Rodent Management*. Australian Center For International Agricultural Research, Canberra, Australia. 494 p.

Ecologically-based rodent management is an alternative approach to managing rodent pest populations in agricultural systems. It aims at combining a variety of control measures with timing targeted at key periods based on an understanding of the biology and ecology the pest species. A strong ecological understanding of the target species is required, focusing at a farming systems level. 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 minimizing surrounding cultivated fields, tactical strategies to reduce population size at specific times of the year and in specific habitats). Additional strategies include reduction of vegetation in refuge habitats of rodents, encouraging biological control (attraction of birds of prey such as owls) and the use of rodenticides at key times in key habitats. The selection of techniques depends on available ecological information, agronomy, environmental awareness and socio-cultural considerations that need to be investigated before application.

Ecologically-based rodent management realizes that management of rodents must focus on individual species and not on rodent communities. Ecological management of rodents has to be species specific. This approach to rodent management requires a good understanding about the rodent species, their behaviour, breeding potential and patterns, population dynamics and habitat utilization in a specific locality. In Tanzania, knowledge on rodent ecology is building up slowly, and may take a long time before we are able to fully integrate this knowledge into ecologically based rodent pest management system for the whole country.

Measures that are practiced on a limited scale but have a wide scope for future management of rodents in Tanzania 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.

Understanding the population dynamics, breeding patterns of the individual species is most important (examples: Figs. 23 & 24). Currently our studies in Berega, Kilosa District aim at developing ecologically based rodent pest management.

**Urban rodent pest infestation**

Rodent infestation in urban areas poses a great risk to public health in Tanzania and, therefore, their control is most important. In the city of Dar es Salaam, >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 other urban areas such as Morogoro (Lyimo, 1993). The unhygienic environment infested with rodents is ideal for transmission of zoonotic diseases to man and domestic animals. Factors that are responsible for high urban infestations by rodents and potential management strategies are summarized in Table 3.

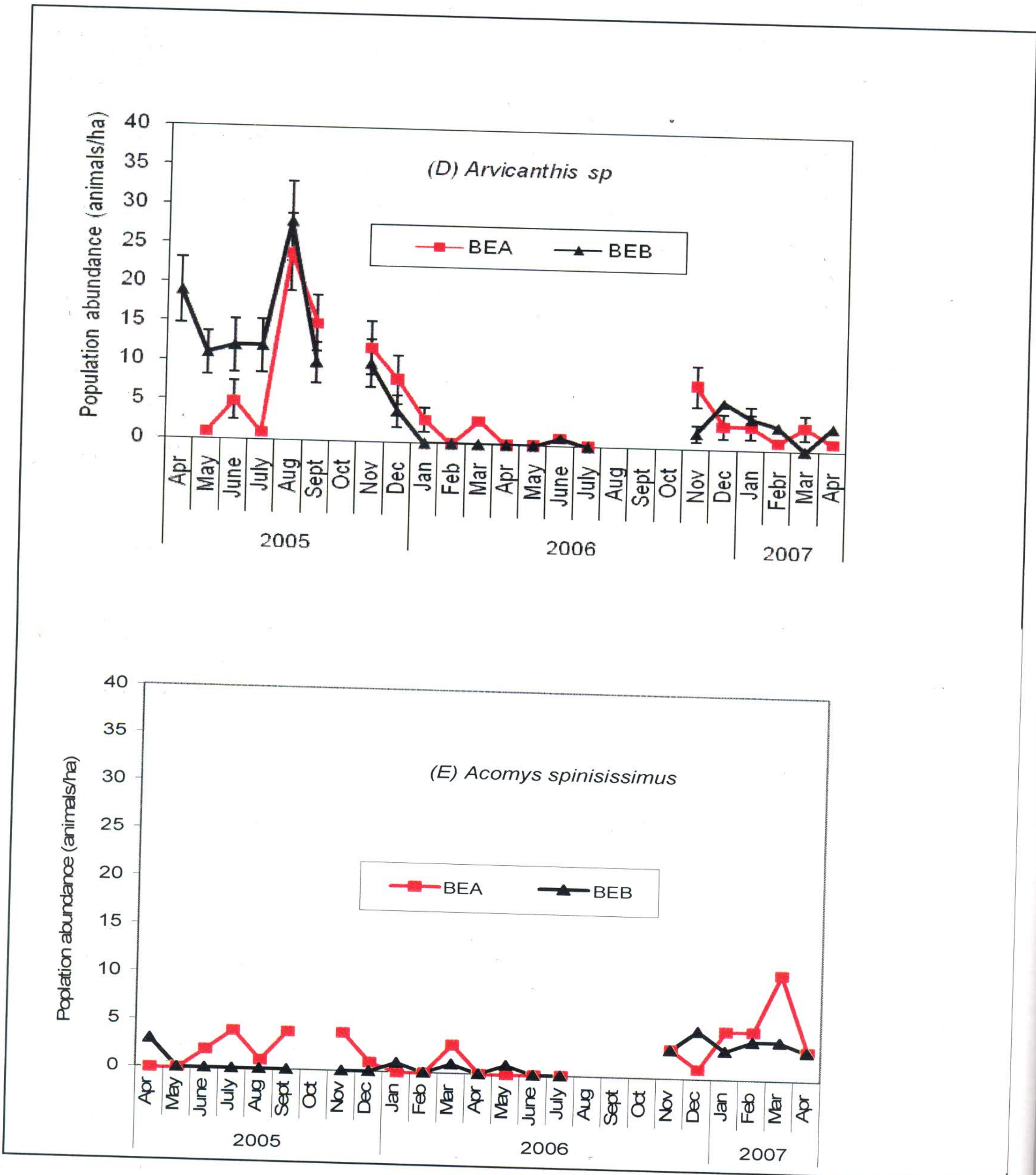



Fig. 24. Population density changes over time, *Arvicanthis neumanni* and *Acomys spinosissimus* in Berega, Kilosa District

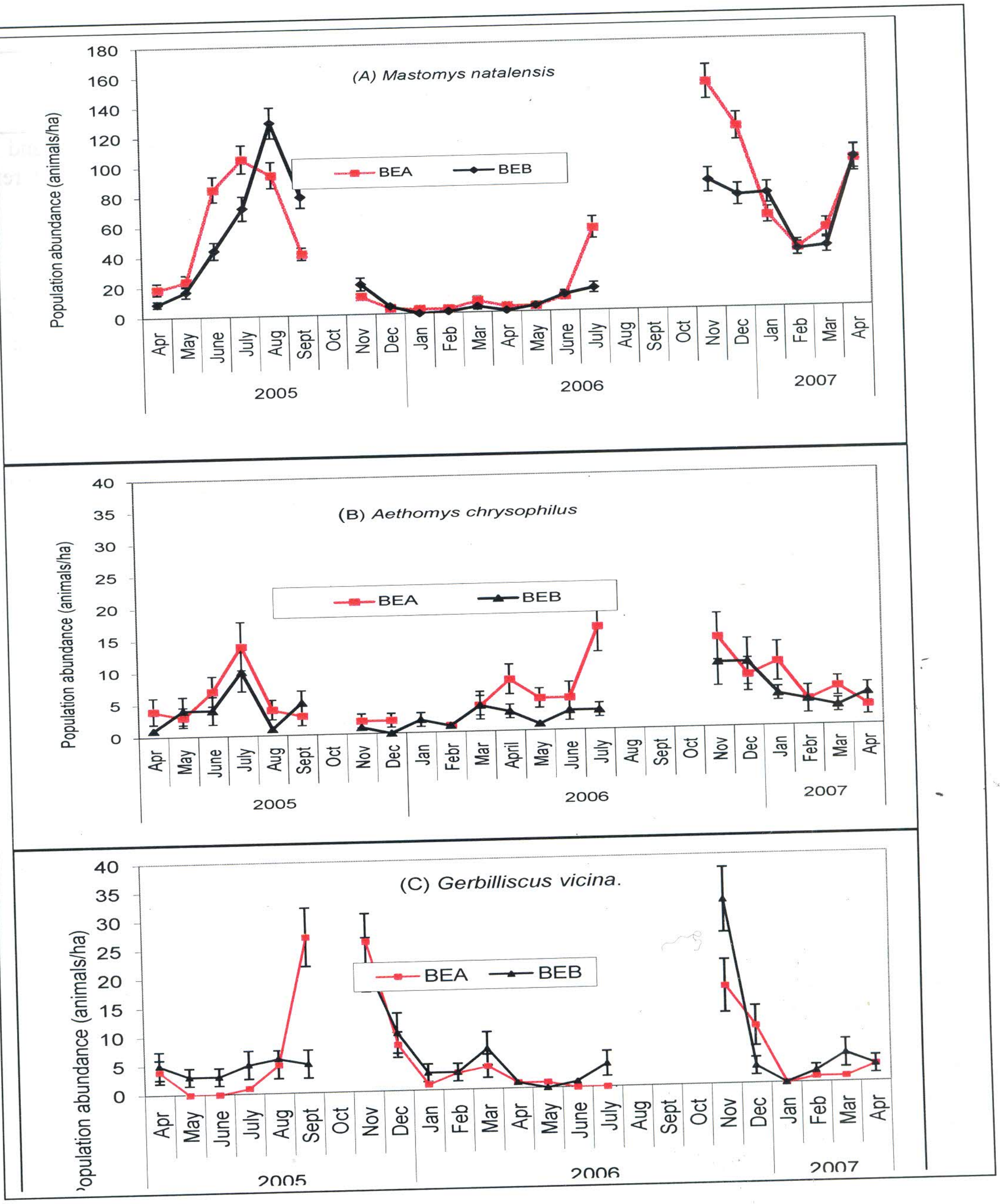



Fig. 23. Population density changes over time, *Mastomys natalensis*, *Aethomys chrysophilus* and *Gerbilliscus vicina* in Berega, Kilosa District

Table 3. Factors responsible for high urban infestations by rodents and strategies for their management (Makundi *et al.* 1999).

| **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 |
| 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. | •Controlled and systematic rodenticide application. •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. | Public health education, especially on the potential for disease outbreaks involving rodents and methods of rodent control at household and community levels. |

**Rodent pest management in Tanzania: future strategies**

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 to allow forecasting of outbreaks and provide an early warning for 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 and facilitating timely availability of rodenticides to farmers when required;

► 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;

► creating and ecological databases for rodent species and developing integrated pest management and/or ecologically based pest management systems for the pest species.

► encouraging farmers to control rodents on a community approach on routine basis, rather than depending on external (e.g. government) intervention. A community-based rodent pest management is an effective approach (Fig. 25)

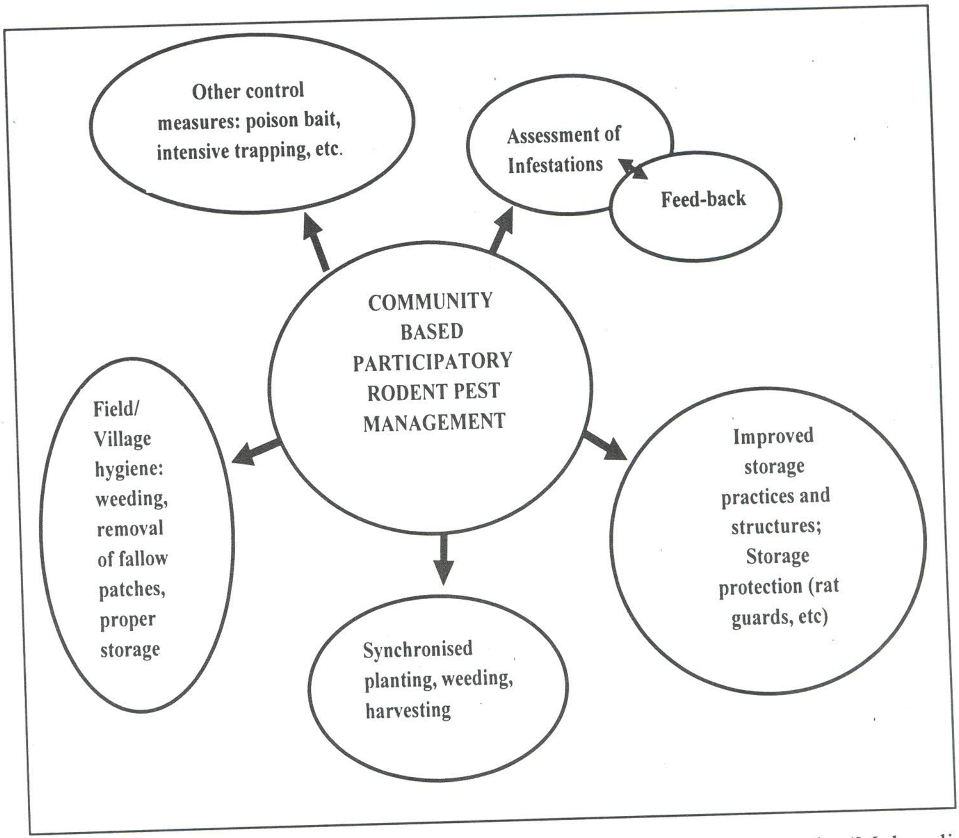



Fig 25: Participatory community based rodent pest management approach (Makundi R.H. Unpublished)

It is neither effective nor practical in terms of rodent population reduction for farmers to engage on rodent pest management on separate and individual basis.

***Storage***

The impact of rodents on food security and health in rural areas in Tanzania is severe. Farmers face considerable storage problems as a result of rodent pests which have to be overcome to achieve sustainable food security and maximization crop surpluses for future sale. Rodenticides do not provide the ultimate solutions to the rat problems because they are expensive, are not readily available, and can cause human health problems in the environment. Rodents can also develop bait shyness, which will compound the rodent infestation problems. Knowledge on crop storage technology can be properly utilized for the control of rats in rural areas and was the case of our pilot programmes in Handeni, Mvomero and Iringa Rural districts (Makundi *et al* 2008b – In Press) (Fig. 26). The most effective means of controlling rodents in storage systems improve storage structures with adequate rodent proofing and practicing good store management.

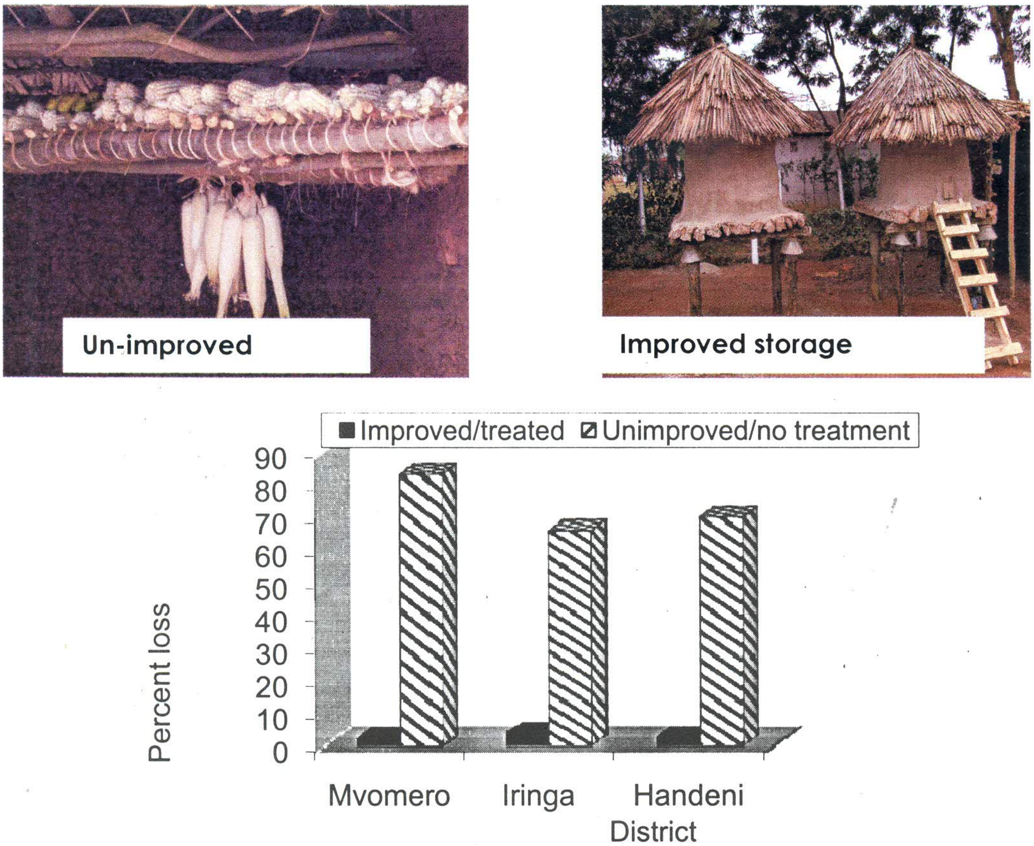



**Fig. 26. Maize losses due to insects and rodents in improved and un-improved storage**

**Where to from here? The future of rodent research**

*(i) Rodent-borne zoonoses research.*

*(a) Rodent borne zoonoses*

There are more than 60 diseases in which rodents are involved as reservoirs. Among the common are plague, toxoplasmosis. *Leptospirosis*, *Borelia* and hemorrhagic fevers. Rodent-borne diseases such as the hemorrhagic fevers, though recently recognized and of much focal public health importance, do not have arthropod vectors. Climatic conditions and agro-ecological patterns could all play a part in disease outbreak since they influence rodent population density. With increasing human population, which leads to pressure on natural habitats (for farmland, pasture, settlements, etc), there is an obvious increase in the risks of human infections due to the proximity of rodents to humans and the resultant rodent-human interactions. Studies in Lushoto and Mbulu districts, where there have been frequent outbreaks of plague, suggest that many factors including the diversity of habitats, diversity of rodent species which are reservoirs, the vector (fleas) diversity and spatio-temporal patterns of distribution and abundance of reservoirs and vectors of *Yersinia pestis* contribute to the disease outbreaks. With increasing population of rodents in man altered landscapes, we are likely to see more epizootics in the rodent populations and increases of human infections of rodent borne zoonoses. There are close associations between environmental conditions such as rainfall, rodent population dynamics and prevalence of zoonotic diseases in the reservoir population and the risk to human infection. Therefore future studies should aim at understanding the dynamics of infectious agents (bacteria, viruses, protozoa, etc) in their natural reservoir hosts from ecological and epidemiological perspectives.

***(b) Plague ecology vs climate change***

Climate has an important influence on plague, via effects on rodents, fleas and the causative agent. Climate change may therefore contribute to the disease's future emergence. Climate change could lead to emergence of plague in non-traditional foci due to its influence on the plague vectors in various ways. We anticipate that, for rodents, climate change will affect their population abundance. However, whatever the long term consequences of climate change, rodent pest numbers will undoubtedly continue to fluctuate from season-to-season, depending on the particular combination of weather conditions that occurs each year. The patterns of plague epidemics (both spatial and temporal) will change with previously unsuitable areas of dense human population becoming suitable for disease transmission. Where these fluctuations have higher peaks, it will lead to more severe crop damage, more serious disease infections and expansion of areas under infection. Some predictions can be made: For example, increased and extended precipitation in some areas may lead to greater availability of primary resources, of which species such as *M. natalensis* will take advantage to breed faster, develop quickly and increase in numbers to outbreaks proportions. Therefore, more frequent outbreaks will be expected. For diseases such as plague, there is need to refine our surveillance systems, including use of Geographic Information Systems (GIS) technologies to understand how environmental changes are linked to plague transmission. We also need to explore the potential of molecular epidemiology of plague in order to establish which strains cause the human infections. Future monitoring of rodent populations will allow us to predict the disease trends, its changing ecology and epidemiology on large geographical scale, which is of great importance for prevention and control.

***(ii) Refining and improvement of management strategies for rodents***

(a) Ecologically based rodent pest management

A better understanding of the ecology of rodents in different ecological zones of Tanzania will allow us to use the knowledge of the ecology of pest species to develop sustainable management strategies. We need to refine our prediction models to fit different environmental conditions and increase our ability to provide an early warning to farmers on impending rodent outbreaks

(b) Investigate further how predators could augment control strategies already being applied
(c) Experimentation on management options for rodent pests (barrier crops, cultural approaches, management of land use practices, etc.).

*(v) Further exploitation of the abilities of rodents*

The ability of rodents as bio-sensors could be exploited further in the following fields of national interest.

**(a) Drug and illegal arms transfer detection**

Rats show much promise in bio-sensor detection technology due to their highly developed sense of smell. Since bio-sensing depends on vapor detection (vapors being emitted by the target substance you want to detect), the same principle applied to bio-sensing of landmines could be further developed for detection of drugs and ammunition which are being illegally trafficked across common borders of neighbouring countries. This could be built into the peace and security initiatives between the countries.

**(b) Rescue services**

*Camerats* (Rat backpack with miniature camera, wireless transmitter, sound communication package and data storage device) could be very useful to detect individuals caught up and trapped collapsed buildings during man-made or natural disasters (e.g. earthquakes). The major advantage is their small size which allows them to enter small crevice where other animals like dogs cannot reach. The excellent response shown by the rats as bio-sensors for TNT and TB, clearly indicates that their potential exploitation is unlimited so far as technological advances are incorporated in their training and handling.

***(vi) Better understanding of the ecology of rodents***

Future studies should investigate the population and community ecology of rodent species in different geographical areas, the effect of landscape ecology on species distribution and dynamics and rodent-human interactions in areas of high zooonotic disease infection risks. In view of the size of the country, and the fact that rodents comprise the largest group of mammals, the need for understanding the diversity of species and their zoogeographical distribution and ecology is imperative. Ecologically-based rodent pest management is only possible when the ecology of the species we are dealing with is known.

***(vii) Taxonomy***

New methods for taxonomic studies (karyotype and molecular genetics) can help in refining the species complexes in Tanzania. The following areas of taxonomy need further attention:

- Refining the taxonomy of certain groups, or the already identified species, particularly due to the occurrence of species complex noted in some taxa.
- Collections in un-explored areas particularly in central and western Tanzania (the Singida-Tabora - Kigoma - Sumbawanga Axis, the Rift Valley, certain pockets of Highlands, the Udzungwa). Also expeditions should be made to cover the geographical gaps in some of our collections.
- Applying karyotype and molecular techniques to learn more about the species we are dealing with, particularly where some morphological variations are observed in the same species. Making morphological and molecular comparisons is necessary, particularly where some morphological observations seem to be different from the expected (e.g. *Acomys* with an un-usual sex chromosomes) (Castiglia *et al.* 2007).

In all these studies, it is important to make a phylogentic analysis of the different taxa and the zoogeographical distribution of the species.

## National strategies for rodent management, control and prevention of plague

### 1. Rodent management

*(a) Commensal rodents*

(i) Provide information to communities in rural and urban areas to understand the economic and health importance of rodents and enable them to effectively manage rodent pest problems.

(ii) Communication of health hazards related to rodent infestations and food contamination.

(iii) Introduce community based rodent pest management in households and surrounding peri-domestic areas.

*(b) Field rodents: national strategies for rodent pest management*

(i) Strengthen the generation of appropriate, cost-effective and sustainable rodent pest management technologies and strategies for small-scale farming communities in Tanzania

(ii) Develop a national system for forecasting and early warning of impending rodent outbreaks

(iii) Establish a system for improved delivery of knowledge and tools to farmers for field rodent pest management aiming at improving livelihood in rural communities.

(iv) Enhance community based rodent pest management

**2. Rodent borne zoonotic diseases: control and prevention of plague**

Plague is currently the most important rodent-borne zoonotic disease which is subject to notification to the World Health Organization under the New International Health Regulations, which aim at reducing the risk of international spread. In Tanzania, the epidemiological patterns of plague outbreaks are not well known. Neither do we have much knowledge on how an epidemic builds up in the reservoir population culminating into transmission and spread in the human population. Therefore a national integrated plague surveillance, prevention and management is necessary. The following are proposed in order to put in place a national strategy for plague prevention and control in Tanzania.

(i) Active and continuous surveillance of vectors and reservoirs of plague in endemic foci in Tanzania. Improved surveillance could help detecting when and where outbreaks may happen and appropriately mobilise resources in advance.

(ii) Introducing a rapid diagnostic test (RDT) for plague for use in case-identification in Tanzania. The diagnosis of plague is based on clinical signs and symptoms but a late diagnosis is one of the major causes of human death and spread of the disease. Therefore we need a rapid screening test that is reliable, accurate, affordable and acceptable to patients as well as health workers (Makundi *et al.* 2007~Unpublished report).

(iii) Establish an epidemiological database of plague endemic areas in Tanzania. Plague remains an epidemiological threat, a disease of major public health importance in Tanzania and subject to the International Health Regulation. Plague has been known in Tanzania for many years, the earliest authenticated cases were recorded over 100 years ago. Despite this long history, we lack a full understanding of its epidemiology in Tanzania, which makes plague management less efficient and its prevention difficult.

(iv) Provision of health education, communicating plague prevention and management education and matters related to behavioral change in communities living in plague endemic areas. Different communities may show different responses to plague outbreaks which positively or negatively affect the delivery of control measures. The association of plague with rodents may lead to stigmas related to the quality of housekeeping and hygiene standards. Plague may also be associated with witchcraft, affecting people's understanding of the disease transmission and their choices for treatment. We generally lack understanding of social-cultural variables that influence prevention and control of plague in different communities

(v) Applied Research on Plague:

*(b) Field rodents: national strategies for rodent pest management*

(i) Strengthen the generation of appropriate, cost-effective and sustainable rodent pest management technologies and strategies for small-scale farming communities in Tanzania

(ii) Develop a national system for forecasting and early warning of impending rodent outbreaks

(iii) Establish a system for improved delivery of knowledge and tools to farmers for field rodent pest management aiming at improving livelihood in rural communities.

(iv) Enhance community based rodent pest management

**2. Rodent borne zoonotic diseases: control and prevention of plague**

Plague is currently the most important rodent-borne zoonotic disease which is subject to notification to the World Health Organization under the New International Health Regulations, which aim at reducing the risk of international spread. In Tanzania, the epidemiological patterns of plague outbreaks are not well known. Neither do we have much knowledge on how an epidemic builds up in the reservoir population culminating into transmission and spread in the human population. Therefore a national integrated plague surveillance, prevention and management is necessary. The following are proposed in order to put in place a national strategy for plague prevention and control in Tanzania.

(i) Active and continuous surveillance of vectors and reservoirs of plague in endemic foci in Tanzania. Improved surveillance could help detecting when and where outbreaks may happen and appropriately mobilise resources in advance.

(ii) Introducing a rapid diagnostic test (RDT) for plague for use in case-identification in Tanzania. The diagnosis of plague is based on clinical signs and symptoms but a late diagnosis is one of the major causes of human death and spread of the disease. Therefore we need a rapid screening test that is reliable, accurate, affordable and acceptable to patients as well as health workers (Makundi *et al.* 2007~Unpublished report).

(iii) Establish an epidemiological database of plague endemic areas in Tanzania. Plague remains an epidemiological threat, a disease of major public health importance in Tanzania and subject to the International Health Regulation. Plague has been known in Tanzania for many years, the earliest authenticated cases were recorded over 100 years ago. Despite this long history, we lack a full understanding of its epidemiology in Tanzania, which makes plague management less efficient and its prevention difficult.

(iv) Provision of health education, communicating plague prevention and management education and matters related to behavioral change in communities living in plague endemic areas. Different communities may show different responses to plague outbreaks which positively or negatively affect the delivery of control measures. The association of plague with rodents may lead to stigmas related to the quality of housekeeping and hygiene standards. Plague may also be associated with witchcraft, affecting people's understanding of the disease transmission and their choices for treatment. We generally lack understanding of social-cultural variables that influence prevention and control of plague in different communities

(v) Applied Research on Plague:

- Conduct studies on the ecology and maintenance of plague in its natural foci and applying this knowledge for plague prevention and control. Plague endemic areas in Tanzania are diverse in their geography, climate and ecology which are also reflected in the diversity and ecology of plague reservoirs and vectors. The lack of ecological information on plague reservoirs and vectors hampers our efforts to predict and manage plague outbreaks effectively.

- Identification of areas at greatest risk for human plague outbreaks in Tanzania through Geographic Information System (GIS) and remote sensing

- Use mathematical modeling to improve our understanding of spatiotemporal variations in human plague risks and epizootic activity.

**Conclusions**

Despite the fact rodents have plagued man for thousands of years, they are still a problem today and will continue to be troublesome for many years to come. Rodents shall continue to be an important mammalian group affecting human welfare in the spheres of crop losses and public health. With changing landscape ecology brought about by increasing demand for agricultural land and pasture for animals, a greater interaction between people and rats will bring about more conflicts between them.

Existing strategies for management of rodent pests are least effective to mitigate the high losses of crops being experienced in Tanzania, and therefore there is an urgent need to develop alternative strategies in particular those based on understanding the processes that control and regulate population explosions. Ecologically based rodent pest management strategies offer some promise for future management of rodents in Tanzania, but suffer the inadequacy of ecological information about the pest species, which is a pre-requisite for a successful implementation of this strategy.

Low hygienic levels and public health systems that are below acceptable world standards may lead to transmission of rodent-borne zoonoses which may spread faster in our communities leading to high morbidity and mortality. Plague remains the most threatening of these epidemics. We know very little about the epidemiological patterns, the reservoirs other than the involvement of rodents in its spread and ecological patterns that lead to build up of an epidemic. A national integrated plague surveillance, prevention and management system is required in Tanzania. Provision of health education, communicating plague prevention and management education and matters related to behavioral change in communities living in plague endemic areas is mandatory. Since plague is now subject to reporting and quarantine under the New International Health Regulations (2007), Tanzania should put in place a system for the surveillance of the diseases to ensure all cases are promptly diagnosed, confirmed and reported to the World Health Organization, which will, on the basis of these reports, provide the necessary assistance for control and prevention of epidemics.

The rodent fauna of Tanzania is very diverse, but we know very little about its taxonomy, zoogeographical distribution and ecology. There is a great demand to conduct studies on rodent taxonomy using new approaches such as karyotype and molecular genetics. The ecological studies conducted in Tanzania are few and fragmented. The need for better understanding of community ecology of rodents and how this is related to the prevalence and distribution of zoonotic agents (hantaviruses, arenaviruses, toxoplasmas, leptospira, etc) for which rodents are reservoirs is highly desired in order be able to safeguard public health.

Some species of rodents could potentially be beneficial to mankind if their abilities are properly investigated and exploited as has been shown for the giant African pouched rats in land mine detection and tuberculosis diagnosis.

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