REPRODUCTION AND BREEDING PATTERNS OF *ARVICANTHIS NEUMANNI* IN CENTRAL TANZANIA

BY

FURAHA PHILEMON MROSSO

A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (AGRICULTURE) OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA

2004

ABSTRACT

The population structure, reproduction and breeding patterns of the grass rat, *Arvicanthis neumanni* were investigated through Capture Mark Release (CMR) and removal trapping in Msingisi and Ihanda villages (Kilosa and Kongwa districts respectively) in Central Tanzania. Rodents in CMR grids were trapped using Sherman live traps in one 100 m x 100 m grid in each village. Animals in removal grids were captured using local traps and digging. A total of 947 animals were captured in the removal grids. A total of 49 captures and recaptures were made in the CMR grids at Msingisi belonging to 5 species in 3000 trap nights. Ninety-one captures and recaptures of rodents belonging to 5 species were made at Ihanda. The highest trap success was recorded between December and March. Three age groups, juveniles, sub adults and adults, were present in the population in most of the trapping months. However, there was a high increase in the number of juveniles and reproductively active adults two to three months after the onset of the rains (December, 2002 - May, 2003) indicating a peak in reproductive activity, between January and April. Litter size was between 5.58 ± 0.42 and 6.1 ± 0.26 in the two study sites respectively. There were no significant differences in the number of embryos implanted in the right and left horns of the uterus of pregnant females ($t_{22} = 0$, $P > 0.05$) and ($t_{36} = 1.68$, $P > 0.05$). Sex ratio of *A. neumanni* was not skewed to either males or females. Since breeding patterns are some of the requirements for sound ecological knowledge in controlling rodents, this study calls for further investigations especially on breeding patterns of *A. neumanni* in different locations for comparison with the current study.

DECLARATION

I, FURAHA PHILEMON MROSSO, do hereby declare to the Senate of Sokoine University of Agriculture that, this dissertation is my own original work and has neither been submitted or currently being submitted for a degree award in any other University.

Signature: ....

Date: ....19 · 11 · 2004....

COPYRIGHT

ACKNOWLEDGEMENTS

I wish to express my sincere thanks and gratitude to my supervisor Prof. Rhodes H. Makundi of Pest Management Centre, Sokoine University of Agriculture, for his constant assistance, encouragement and supervision of this study.

I'm greatly indebted to SUA – STAPLERAT project under the auspices of the European Union (EU) for financial support and the SUA Pest Management Centre for providing a favourable environment during the entire study period.

Many thanks are extended to the Director of SUA Pest Management Centre, Prof. Robert Machang'u and his entire staff for their constant support during the study period. I am grateful to Richard Odhiambo, for his invaluable assistance in some of ecological aspects and guidance. Dr. Apia W. Massawe and Dr. Loth S. Mulungu of SUA Pest Management Centre, greatly assisted in blowing out critics in this document.

I would like to extend my sincere thanks to Dr. Pax Jessey, Ramadhani Iddi, Clemence Pangapanga, Kevin Kessy, Omary Ali, Khalid Selemani and Dorkas Mziray of SUA Pest Management Centre for their assistance in data collection and company. In the same regard, I would like to thank the drivers; Hamisi Ng'ombe, Kassim Lutea, Claude Kisinini, Karistas Malipula and Musa Abdallah all of SUA for facilitating easy monthly communication to and from the study sites.

Special thanks goes to Msingisi village chairman Mr. Pearson Mwegalawa and Ihanda village executive officer for their logistical support.

Encouragements and moral support given by Dr. Alfred Moshi, late Mrs Dora Fidelis Myaka, my family and Cornel Massawe of ARI – Ilonga at the beginning of my study are highly appreciated.

DEDICATION

To my parents Veronica Daudi Temu and late Philemon Mchihiyo Mrosso who laid the foundation for my education and life, and to my daughters Aichi, Lily and Aika.

TABLE OF CONTENTS

ABSTRACT.......... ii

DECLARATION.......... iii

COPYRIGHT.......... iv

ACKNOWLEDGEMENTS.......... v

DEDICATION.......... vii

TABLE OF CONTENTS.......... viii

LIST OF TABLES.......... xii

LIST OF FIGURES.......... xiii

LIST OF PLATES.......... xv

LIST OF APPENDICES.......... xvi

LIST OF ABBREVIATIONS.......... xvii

CHAPTER ONE.......... 1

1.0 INTRODUCTION.......... 1

CHAPTER TWO.......... 5

2.0 LITERATURE REVIEW.......... 5

2.1 The genus *Arvicanthis* 5

2.2 Distribution of *Arvicanthis* species in Africa.......... 8

2.3 Distribution of *Arvicanthis* species in Tanzania.......... 9

2.4 Ecology and behaviour of *Arvicanthis* spp.......... 10

2.5 Morphology measurements and maturation.......... 11

2.6 Crop damage caused by the grass rats, *Arvicanthis* spp.................... 12

2.7 Reproduction and breeding patterns.................................... 13

2.7.1 Influence of rainfall on reproduction and breeding patterns.......... 13

2.7.2 Sex ratio.. 19

2.7.3 Litter size.. 19

2.8 Population structure.. 20

2.8.1 Age determination.. 20

CHAPTER THREE.. 22

3.0 MATERIAL AND METHODS.. 22

3.1 Study areas... 22

3.1.1 Location... 22

3.1.2 Climate.. 24

3.1.3 Land use... 24

3.2 Experiment layout and design.. 25

3.2.1 Trapping techniques.. 25

3.2.1.1 Capture-Mark-Release trapping.................................... 25

3.2.1.2 Removal trapping 26

3.2.2 Handling of the animals.. 27

3.2.2.1 Handling of animals from the CMR trapping......................... 27

3.2.2.2 Handling of animals from the removal trapping..................... 27

3.3 Data collection.. 27

3.3.1 Data collected from CMR grids.. 27

3.3.2 Data collected from the removal trapping................................ 28

3.4 Data handling and processing.. 30

3.5 Data analysis.. 31

CHAPTER FOUR... 32

4.0 RESULTS AND DISCUSSION... 32

4.1 Habitat of *A. neumanni* in the study areas................................. 32

4.2 Population dynamics and trap success from the CMR study................ 34

4.3 Morphology measurements and body weight of *A. neumanni* 37

4.4 Age population structure of *A. neumanni* in Msingisi and Ihanda villages.. 41

4.5 Reproduction and breeding season of *A. neumanni* at Msingisi and Ihanda villages.. 44

4.5.1 sex ratios.. 44

4.5.2 Changes in reproductive conditions of males and females of A. *neumanni* 46

4.5.3 Variations in testes size of adult *A. neumanni* (males with scrotal testes.. 50

4.5.4 Litter size and implantation 52

4.5.4.1 litter size.. 52

4.5.4.2 Implantation.. 53

CHAPTER FIVE.. 54

5.0 CONCLUSIONS AND RECOMMENDATIONS.. 54

5.1 CONCLUSIONS.. 54

5.2 RECOMMENDATIONS.. 55

6.0 REFERENCES.. 56

7.0 APPENDICES.. 68

LIST OF TABLES

Table **Page**

Table 1: *Arvicanthis* species.. 7

Table 2: Species captured in Msingisi and Ihanda villages......................... 35

Table 3: Sex ratio of *A. neumanni* at Msingisi during the study period............45

Table 4: Sex ratio of *A. neumanni* at Ihanda during the study period............. .45

Table 5: Litter size of female *A. neumanni* in Msingisi and Ihanda villages...... 52

Table 6: Number of embryos implanted in the right and left horns of the pregnant *A. neumanni* females in Msingisi and Ihanda villages..........53

LIST OF FIGURES

Figure		Page
Figure 1:	A map of Africa showing distribution of *Arvicanthis* spp	9
Figure 2:	A map showing location of study villages	23
Figure 3:	Schematic map of the CMR grid used in Ihanda and Msingisi villages	25
Figure 4:	Trap success of rodent species from the Msingisi grid	36
Figure 5:	Trap success of rodent species from the Ihanda grid	36
Figure 6a:	Body weight variations of adult *A. neumanni* males and females in Msingisi village	38
Figure 6b:	Body weight variations of subadult *A. neumanni* males and females in Msingisi village	39
Figure 7a:	Body weight variations of adult *A. neumanni* males and females in Ihanda village	39
Figure 7b:	Body weight variations of subadult *A. neumanni* males and females in Ihanda village	40
Figure 8:	Distribution of adults, subadults and juveniles of *A. neumanni* males in Msingisi village	42
Figure 9:	Distribution of adults, subadults and juveniles of *A. neumanni* females in Msingisi village	42
Figure 10:	Distribution of adults, subadults and juveniles of *A. neumanni* males in Ihanda village	43

Figure 11: Distribution of adults, subadults and juveniles of *A.neumanni* females in Ihanda village..43

Figure 12a: Monthly changes in reproductive conditions of *A. neumanni* males at Msingisi village..48

Figure 12b: Monthly changes in reproductive conditions of *A. neumanni* females at Msingisi village..48

Figure 13a: Monthly changes in reproductive conditions of *A. neumanni* males At Ihanda village..49

Figure 13b: Monthly changes in reproductive conditions of *A. neumanni* females at Ihanda village..49

Figure 14: Monthly variation in testes size of sexually active *A. neumanni* in Msingisi village..51

Figure 15: Monthly variation of testes size of sexually active *A. neumanni* in Ihanda village..51

LIST OF PLATES

Plate 1: CMR grid sites...26

Plate 2: Measuring of ear length...29

Plate 3: Measuring testes length...29

Plate 4: Measuring of body weight...29

Plate 5: Measuring of hind feet length...29

Plate 6: *Arvicanthis neumanni* male with scrotal testes...29

Plate 7: Thorny shrub areas (one of habitats of *A. neumanni* in the study areas)...33

Plate 8: Grass areas along roads (one of habitats of *A. neumanni* in the study areas) with a *Swadi* trap...33

LIST OF APPENDICES

Appendix **Page**

1. Pictures showing four trap types used in the study...............................68
2. Rainfall data obtained from Makambini, Gairo Morogoro (for Msingisi village) and Mlali Dodoma (for Ihanda village), October 2002 – September, 2003 69
3. Schematic presentation of toe clipping code..70

LIST OF ABBREVIATIONS

ACIAR	=	Australian Centre for International Agricultural Research
^{0}C	=	Degrees Celsius
CMR	=	Capture-Mark-Release
df	=	Degrees of freedom
E	=	East
EU	=	European Union
g	=	Gramme
ha	=	Hectare
HBL	=	Head body length
m.a.s.l.	=	Metres above sea level
Max.	=	Maximum
Min.	=	Minimum
mm	=	Millimetre
PCR	=	Polymerase Chain Reaction
SD	=	Standard deviation
SE	=	Standard error
Spp.	=	Species (Plural)
SUA	=	Sokoine University of Agriculture
USA	=	United States of America
>	=	Greater than
#	=	Number

%	=	Percent
6-MBOA	=	6-methoxy-2-benzoxazololinone
χ^2	=	Chi-square
±	=	Plus or minus

CHAPTER ONE

1.0 INTRODUCTION

Increasing food production is a major challenge, particularly in the developing countries due to increasing population. In Tanzania, poor soils and drought, which affect food production, are further aggravated by the presence of pre and post-harvest pests (Makundi *et al.*, 1999).

One of the factors contributing to low food production are pests, particularly rodents at pre and post harvest crop stages (Taylor, 1968; Leirs, 1992; Oguge *et al*, 1997; Leung *et al.*, 1999; Nils *et al*, 2001; Mulungu, 2003). The extent of rodent damage on crops, for example maize in Tanzania, vary from negligible to over 80% depending on location and growing season (Mulungu *et al.*, 2003). Regional reports from Lindi in Tanzania showed that yield loss due to rodents was 85,108 tonnes (i.e. 71,236 for cereal and 13,872 for pulse crops) in 1989/90 (Mwanjabe *et al.*, 2002). Makundi *et al.* (1991) reported 5 – 15% annual losses of maize due to rodents in Tanzania. In Tanzania, rats have been shown to consume 40 – 80 % of the planted maize seeds (Mwanjabe and Leirs, 1997). In countries that live at the brink of subsistence, such figures are a threat to food security. The majority of farmers in Tanzania are small holders, who own fields of 0.5 – 2 ha per household. These fields are usually isolated plots surrounded by bushes and fallow land (Mwanjabe, 1993), which creates good environment for rodent harbourage and infestation of crops.

Mastomys natalensis and *Arvicanthis niloticus* are some of the commonest rodent species found in Tanzania (Kilonzo, 1976, 1984). Massawe (2003) reported the multimammate rat (*Mastomys natalensis*), Nile rat (*Arvicanthis niloticus*), house mouse (*Mus musculus*) and striped grass rat (*Lemniscomys* sp) to be some of the rodent pests of crops in Tanzania. *Mastomys natalensis* is the most serious field rodent pest in Tanzania (Leirs, 1992; Mwanjabe, 1993; Fiedler, 1994; Mulungu, 2003; Massawe, 2003). Reproduction and breeding patterns of *M. natalensis* are well studied in east Africa. The annual pattern of breeding of *M. natalesnsis* is linked to the rain patterns (Workneh, 2003; Leirs, 1992; Telford, 1989). Highest mean number of embryos was recorded towards the end of the rainy season and beginning of the dry season. Telford (1989) and Leirs (1992) found strictly seasonal breeding in *M. natalensis* in Morogoro, Tanzania, which was also linked to rainfall. They suggested that, unusual rainfall might cause seasonal breeding resulting in higher densities. Leirs (1992) and Massawe (2003) noted that breeding of *M. natalensis* started soon after the onset of heavy long rains in March and was continuous well into the dry season.

Arvicanthis spp is well adapted physiologically and ecologically for continuous breeding (Neal, 1981). However, Neal (1981) also reported that immature males and adult females in western Uganda began to mature or increase their reproductive activity the month after the start of rains and peaked two to three months after the start of the rains. This supports Delany and Happold (1979) that reproductive activity in tropical rodents has conventionally been related to rainfall, and that, in this region rain is the most important factor accounting for seasonal variations in primary productivity. Taylor and Green (1976) found cessation of breeding in *Arvicanthis* spp around the middle of the dry season and they did not begin again until two to three months after the start of the rains. Kingdon (1974) reported that one facet of *Arvicanthis* spp success seems to lie in their ability to recoup in numbers after the annual dry season depletion and the high number of 4 – 6 young per litter. Many studies on rodents in Tanzania have focused mainly on *M. natalensis.* Cheeseman and Delany (1978) noted steady expansion of research into ecology of rodents in the grasslands of tropical Africa. However, in the case of *Arvicanthis* spp and particularly *Arvicanthis neumanni*, only little has been done in Tanzania. Some works on other *Arvicanthis* species have been done in Tanzania, for example, Senzota (1982) conducted studies on habitats and food habits of *A. niloticus* in Serengeti National Park.

Studies on reproduction and breeding patterns of *Arvicanthis neumanni* in central Tanzania are lacking; *Arvicanthis neumanni* is one of the common rodent species in this area. Therefore, this study aimed at advancing our knowledge on reproduction and breeding patterns of *A. neumanni* in central Tanzania. The knowledge would help in developing sustainable rodent pest management based on ecological principles.

General objective was:

To understand the population structure and reproduction patterns of the grass rat, *Arvicanthis neumanni,* in central Tanzania.

The specific objectives were:

(i) To understand the population structure of *Arvicanthis neumanni* in Kilosa and Kongwa districts, Tanzania.

(ii) To establish the breeding season (s) of *A. neumanni* in Kilosa and Kongwa districts.

(iii) To establish the litter size of *A. neumanni* during the breeding season.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The genus *Arvicanthis*

The genus *Arvicanthis* belongs to the Family Muridae (true rats and mice) (Parker, 1983). Their rather harsh grizzled coat and smooth incisors distinguish *Arvicanthis* from other rodents (Kingdon, 1974). These rats are essentially grass loving, and presence of piles of cut grass and well-established routes in fields indicate their presence (Kingdon, 1974). They do not normally venture into concrete or brick buildings but do enter grass huts and grass stores (Parker, 1983). *Arvicanthis* (Lesson 1842) (Rodentia: Muridae) is a widespread genus of herbivorous rats ranging from Egypt, Sudan and throughout all the sub Saharan Africa down to Tanzania and Zambia (Castiglia *et al.*, 2003). Corti and Fadda (1996) noted that this genus (*Arvicanthis*) is widely spread from the Nile basin, the Horn of Africa and East Africa across the central and western sub Saharan regions to West Africa. The genus occurs in a great variety of habitats including croplands, where it may be a major pest (Kingdon, 1974). Its taxonomy has been, for a long time, the subject of controversy (Tesha, 2001; Castiglia, 2003). Data on the occurrence and distribution of *Arvicanthis* spp have been summarized by Musser and Carleton (1993) (cited by Castiglia *et al.*, 2003). *Arvicanthis niloticus* occurs west of the Rift Valley, while *A. neumanni* occurs in the center of the country east of the Rift Valley. Cytogenetic studies conducted by

Castiglia *et al.* (2003), showed that *A. neumanni* belongs to the East African lineage. *Arvicanthis neumanni* was previously known as *A. somalicus* (2n = 54, Nfa = 62) (Castiglia *et al.*, 2003). Earlier studies on *Arvicanthis* spp done in East Africa based their description on the colour of the belly. Roservear (1969) noted that belly colour was not a reliable criterion in species identification. However, Kingdon (1974) described *A. niloticus* by the dark belly, and *A. lacernatus* as having a white belly, where as Delany (1975) identified *A. testicularis* as having white belly as well. Individual animals weigh 50g – 120g depending on sex and age (Tesha, 2001). Table 1 indicates some *Arvicanthis* species listed by different authors.

Arvicanthis niloticus is a medium sized rodent, normally 80 g or more, have coarse, almost spiny hairs and a heavily specked back with a gray belly (Fiedler, 1994). The tail (125 mm) is shorter than the head and body (145 mm), and the hind foot is about 28 mm (Fiedler, 1994). The tail has some hairs present and is bi-coloured, dark above and light below, and ears are rounded, incisors are smooth and females have six mammae (1+2 = 6) (Fiedler, 1994). It is gray-buff in colour and has a plump appearance (Hubbard, 1973). Most of *Arvicanthis* species are more or less having the same characteristics.

Table 1. *Arvicanthis* species listed by different authors

Allen, 1939	Ellerman, 1941	Rosevear, 1969	Dorst, 1972	Yalden *et al*, 1976	Corbet and Hill, 1980	Rousseau, 1983
A. niloticus	*A. niloticus*	*A. niloticus*	*A. niloticus*	*A. niloticus*	*A. niloticus*	*A. niloticus*
A.Tenebrosus		*A. mordax*			*A.testicularis*	
		A.rufinus				
A. abyssinicus	*A. abyssinicus*	*A. abyssinicus*	*A. abyssinicus*	*A. abyssinicus*	*A. abyssinicus*	*A. abyssinicus*
A. ochropus			*A. blicki*	*A. blicki*	*A. blicki*	*A. blicki*
A. lacernatus	*A. lacernatus*	*A. lacernatus*	*A. lacernatus*	*A. lacernatus*	*A. lacernatus*	*A. lacernatus*
A. somalicus	*A. somalicus*	*A. somalicus*	*A. somalicus*	*A. somalicus*	*A. somalicus*	*A. somalicus*

Source: Capanna and Civitelli, 1986

2.2 Distribution of *Arvicanthis* species in Africa

The genus has a wide distribution from Egypt along the Nile valley, through Tanzania, Zambia and from Somalia to Senegal (Kingdon, 1974) (Fig. 1). Musser and Carleton (1993) listed distribution of *Arvicanthis* as follows:

Arvicanthis abyssinicus.- Ethiopia endemic 1300m – 3400m a.s.l.

Arvicanthis blicki- Ethiopia endemic 2750m – 3500m a.s.l., found only on the bale plateau on eastern side of Ethiopia and of Rift Valley

Arvicanthis somalicus- Northern and central Somalia, central Tanzania, Tabora, Kilimanjaro and Lake Victoria

Arvicanthis niloticus- Egypt and almost all of Africa

Arvicanthis nairobae- Type locality is Kenya, distributed in eastern side of the Rift Valley in Kenya, central and southern Kenya. Also in north east Tanzania, in the eastern Usambara mountains

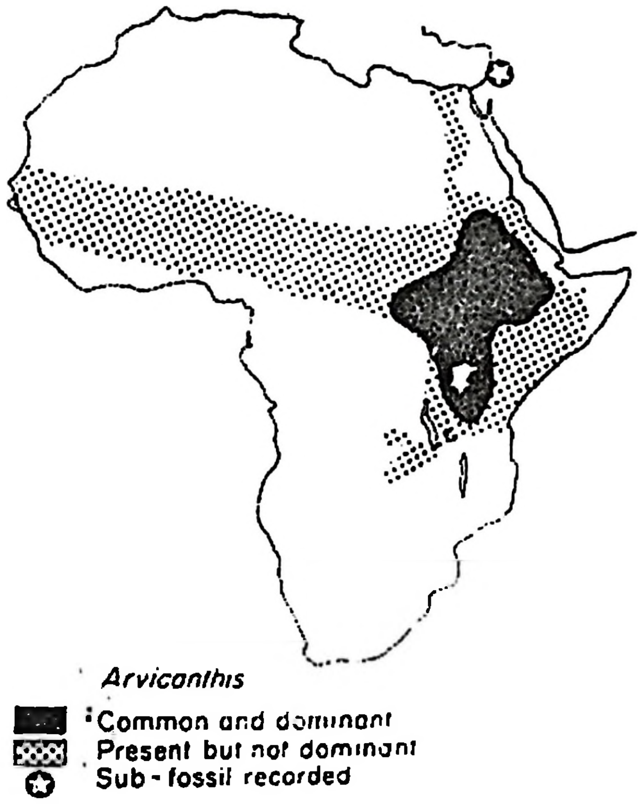


Fig. 1. A map of Africa showing distribution of *Arvicanthis* spp (Source: Kingdon, 1974)

2.3 Distribution of *Arvicanthis* spp in Tanzania

In recent surveys, no *Arvicanthis* species were captured in Ruvuma, Mtwara, or Lindi (Southern Tanzania) (P. Tesha, 2003: Personal communication). There are also no records of *Arvicanthis* spp ever been caught from these areas (Kingdon, 1974; Parker, 1983; Leirs, 1994). Tesha (2001) reported the occurrence of *Arvicanthis* spp in Mbeya (Mbarali), Iringa (Mweyembe, Mwangusi, Ruaha and Msembe), Dodoma (Matongolo, Ndaleta and Zoissa), Singida (Itigi), Mwanza (Kanyelele), Kilimanjaro (Lwami) and

Tanga (Manolo and Gologolo in Lushoto district). Furthermore, the effect of the Rift Valley and of the Eastern Arch mountains in Tanzania could be associated with the divergence of this genus by creating a geographical barrier separating central Tanzanian species from those of the north-east and preventing the genus from migrating into eastern Tanzania (Castiglia *et al.*, 2003). However, Tesha (2001) reported that the pattern of distribution of this species could not be precisely demarcated.

2.4 Ecology and Behaviour of *Arvicanthis* species

Arvicanthis spp are social, although relatively little is known of the composition and the stability of individual colonies (Parker, 1983; Fiedler, 1994). They establish sets of interconnected burrows either under dense herb mat, under a tree, small shrubs or along the hedge plants, sometimes underneath a rock (Parker, 1983). They make rush of fine grass in these holes, and occasionally in the base of grass tufts. *Arvicanthis* spp are mostly diurnal in their activities and sensitive to high temperatures (Kingdon, 1974). They are easily recognized by the behaviour of running across roads and along runways at daytime, especially around mid mornings and late afternoons when temperatures are not high (Personal observation). Feeding areas consist of cut grass piles (Delany and Neal, 1969; Kingdon, 1974).

These rodents are gregarious, but the number of rats within one hole is variable. Kingdon (1974) found 20 individuals of *Arvicanthis* sp per ha in Ituri (Uganda). However, the densities could be much higher during wet seasons and in areas where

Otomys species is absent or rare (Kingdon, 1974). The increase in number of *Arvicanthis* spp seems to lie in their ability to recoup after the annual dry season depletion, faster movement, and larger number of young (4 – 6). They also rely on their secure camouflage for safety as one only sees the animal as it breaks away at the last moment along its runway (Kingdon, 1974). *Arvicanthis* spp have ability to climb high. Taylor and Green (1976), reported that *Arvicanthis* spp can climb to a height of about 0.5 m, up the woody stems of pig weed (*Amaranthus* spp) to reach the seed heads.

2.5 Morphology measurements and Maturation

Achigan *et al.* (2003a) observed polymorphism in rodents as an implication on the use of body measures for species identification. However, other identification methods include gene sequencing, cytogenetics and PCR (Rahman, 2003). Chapman *et al.* (1959) found changes in the growth of body weight relative to body length that multimammate rats with lengths below 110 mm were found to have an increase in body weight by 10 g. The animals with lengths above 110 mm were found to have a mean increase of 7 g, at this stage, males tended to become heavier than females of the same body length (Chapman *et al.*, 1959). Chapman *et al.* (1959) found also, length of tail relative to body length to vary with season. The author found that from April to June, body and tail lengths of rodents were approximately equal but from July to September tail length tended to exceed body length.

2.6 Crop damage caused by the Grass rats, *Arvicanthis* spp

Grass rats (*Arvicanthis* spp) damage most cereal crops with severe damage to planted or maturing wheat (Fiedler, 1994). Field edges are mostly susceptible, but damage may occur all over the field especially when it is weedy. Where rice is grown, all stages are susceptible to damage (Fiedler, 1994). Maize is vulnerable at the planting or seedling growth stage but not at maturity stage since the rats are unable to climb the stalks unless lodging occurs (Fiedler, 1994). However, Taylor and Green (1976) reported that *Arvicanthis* spp were observed climbing to a height of about 0.5 m up the woody stems of pig weed (*Amaranthus* spp) to reach the seed heads. Other cereals damaged include millet, barley, and sorghum. The rats also damage groundnut, cassava, sweet potato and other root crops. Yields of sugar cane and cotton are seriously affected (Fiedler, 1994).

Despite the high rates of crop depredation by rodents, current control measures that include indiscriminate use of rodenticides are neither efficient nor sustainable (Vibe-Petersen *et al.*, 2003). Rodenticides are also expensive and hazardous (Oguge *et al.*, 1997). Control of rodent damage has never been very effective in Tanzania, and is now realized that more knowledge about the biology of the pest species is needed (Leirs, 1992). Inefficiency and non-sustainability of synthetic rodenticides prevails because management of these pests requires a sound ecological knowledge (Vibe-Petersern *et al*, 2003). An ecologically based rodent management strategy requires knowledge of the species that are present, their habitat use, breeding patterns and population dynamics (Cheeseman and Delany, 1978).

2.7 Reproduction and breeding patterns

2.7.1 Influence of rainfall on reproduction and breeding patterns

Rainfall has been linked to rodent reproductive activity and outbreaks (Leirs, 1994; Fiedler, 1994). Normal rainfall following extensive drought or excessive rain has preceded most outbreaks (Fiedler, 1994). Rainfall stimulates vegetation growth, which provides abundant shelter and food, resulting in optimal conditions for rodent reproduction and survival (Neal, 1981; Leirs, 1992). Areas subjected to annual wet and dry seasons favour increased breeding during the wet season. Fiedler (1994) and Achigan *et al.* (2003b) observed clear relationship between population density, the amount of rainfall, and the duration of rainy period in *Mastomys natalensis*, *Tatera kempi* and *Lemniscomys striatus*. Neal (1981) proposed an explanation for this reproductive response to rainfall to be due to increased dietary intake. This was also supported by studies by Christian (1979). Another reason is the cumulative substances found in germinating vegetation (Reichman *et al.*, 1975; Leirs, 1992) and nutritional status in terms of quality and quantity of available food (Delany and Happold, 1979).

Kingdon (1974), Berger *et al.* (1981), Klun and Robinson (1969) suggested that green food might provide a biochemical trigger to seasonal breeding in the wild. This situation was supported by Weinbren and Mason (1957) when they were able to induce breeding in a laboratory population by adding green plant materials to their diet. However, Taylor and Green (1976) observed extended breeding in *Arvicanthis* after having fed them seeds and/ or cereals. Therefore, Neal (1981) concluded that the relationship between breeding and rainfall is extremely variable in different areas. The author also stated that *Arvicanthis* spp is physiologically and ecologically well adapted for continuous breeding. The author further suggested that temperature and water stress have an effect on breeding and therefore, at the end of dry season, increased heat and/or water stress prevents breeding. Dunbar (1978) noted cessation of breeding in the rainy season most probably caused by intolerance of *Arvicanthis* spp to the cold and moist conditions.

Leirs (1992) noted that b reeding in *M. natalensis* is strictly seasonal and starts soon after the onset of the long (*Masika*) rains in May and continuous well in the dry season. If short rains (*vuli*) in the first half of the rainy season are already abundant, there is a short period of off-season breeding early in the year. Most mammals have quite restricted periods of reproductive activity (Leirs, 1992). The timing of such patterns can be influenced by many environmental factors, which include density-dependent regulation as well. High densities can prevent reproduction in particular conditions (Canham,1969; Heske *et al.*, 1988; Frost and Fellers, 1991, cited by Leirs (1992)). Leirs (1992) indicated that the strong relation between rainfall patterns and the onset of breeding suggests that environmental factors, somehow related to rainfall, might be responsible.

In the semi-arid species, *Dipodomys ordii*, it was demonstrated that chemicals present in sprouting grass initiate reproduction (O'Connor and Negus, 1987). Several vole species, *Microtus* spp. and *Clethrionomys* spp., though sometimes influenced by photoperiod, are mainly stimulated to reproduce when their diet contains young sprouting grass (Pinter and Negus, 1965; Alibhai, 1985).

Neal (1984) reported a decline of breeding activity of *Tatera nigricauda* in Meru National Park, Kenya, during the dry season, that increased during the rains, and reached a maximum at the end of the rains and during the intermediate seasons. Neal (1982) reported that there was probably a complete cessation of breeding activity towards the end of the dry season. However, reproductive activity in *Acomys percivali* did not appear to be associated with the seasonal pattern of rainfall. Also, it was found that large seasonal changes in breeding activity occurred in *Arvicanthis* spp in the same area (Neal, 1981). Seasonal recruitment of newborn rodents is variable (Workneh, 2003). Aenmey and Pillay (2003) observed high number of juveniles during the end of a breeding season. Aenmey and Pillay (2003) also found adult males with scrotal testes throughout the breeding season, but the number of females with perforated vagina decreased at the beginning to the end of the breeding season. Workneh (2003) reported bimodal peak breeding in *M. natalensis* which was associated with the main rainy season and the irrigation cultivation period. The Workneh (2003) also recorded highest mean number of *M. natalensis* embryos towards the end of the main rainy season and beginning of the dry season. *Mastomys natalensis* accounted for the highest mean number of embryos and contributed the highest percentage of recruitment of all rodents. Neal (1981) observed marked seasonal recruitment of young *Arvicanthis* sp in Mweya

Peninsula and Rojowero Plains (Meru) in Kenya. The author noted that breeding occurred at an early age, particularly during the rainy season.

Breeding often appears to reach a peak during the latter part of the rainy season and decline during the dry season (Taylor and Green, 1976). This pattern has been noted in *Mastomys natalensis* by several authors including Hanney (1965) in Malawi, Chapman *et al.* (1959), Leirs (1992) in Tanzania and Coetzee (1965) in South Africa. Pirlot (1954) reported reproductive activity of *Mastomys natalensis* in the dry season in Katanga but the situation is less marked in other places. This species responds by increased reproduction due to increased rainfall and the resultant increased vegetation (Sicard *et al.*, 1999; Fiedler, 1994; Taylor and Green, 1976). Neal (1981) reported that, in Uganda, where the climate is constant with rainfall distribution throughout the year, reproduction of *A. niloticus* is continuous but where the climate undergoes slight seasonal variations with two rainy periods, the reproduction of *A. niloticus* becomes seasonal.

Food quality as well as food availability may be important in determining when rodents breed. Stein (1953) for example, found that *Microtus arvalis* bred in winter amongst crops of rye and grape, but did not breed in nearby uncultivated land despite the presence of abundant green food. Similarly, Taylor and Green (1976) fed *Arvicanthis niloticus* heavily on grass during the early part of the rains when lush vegetative growth was available and yet they failed to breed until the flowers and fruit of weeds appeared two to three months later. Therefore, the authors concluded that, availability of nutritious food may be a key factor in determining when reproduction takes place and therefore, determining rodent numbers. Apart from food materials, cover is another item, which is very important for determining time of reproduction (Taylor and Green, 1976; Massawe, 2003); this feature was also pointed out by Green and Taylor (1975b). Taylor and Green (1976) stated that there was no evidence to contradict the hypothesis that reproduction in *Mastomys natalensis* (and perhaps other rodent species) is related to application of water to the ground, whether by rain or flood. Ground water can affect reproduction in rodents by generating plant growth (rodent food) and by softening the earth so that rodents can dig burrows (Taylor and Green, 1976). Rich foods and unrestricted water combined with high humidity and low temperature induce the strongest gonadal stimulation (Neal, 1981). Several litters may be born during favourable wet seasons (Fiedler, 1994). Peak populations are susceptible to mortality and populations dramatically decline during adverse conditions in the latter half of the dry season (Fiedler, 1994).

Coetzee (1975) reported a low breeding rate during the dry season in *Mastomys natalensis*, with a break in reproduction in September, while Delany and Neal (1969) found reproductive females in Uganda from May to July and October to December. Delany and Neal (1969) commented that peak breeding season occurs mainly towards the end of the rainy season and beginning of the dry season. Neal (1984) observed decline of breeding activity during the dry season, which increased during rains and reached its maximum at the end of the rains and during the intermediate seasons.

Growth may be influenced by rainfall. Leirs (1992) reported that growth in *M. natalensis* is a seasonal event related to rainfall. Growth stops at the end of the dry season and is only resumed after the heavy rains. The season of birth and occurrence of heavy rainfall in the months after birth determines growth rate and sexual maturation which seems to be linked to body size (Leirs, 1992). Leirs (1992) noted that January is the early breeding season and June – August as the main breeding season in *M. natalensis* in Morogoro, Tanzania. Chapman *et al.* (1959) investigated the growth and breeding of the multimammate rat *Mastomys natalensis* (Smith) in Rukwa Valley, Tanzania, and found that breeding occurred mainly at the end of the rainy season and the beginning of the dry season, which normally lasted from May to October, similar results were obtained by Rogers and Davis (1941) and Pirlot (1954). Breeding thus seemed to be at its peak when external conditions were most favourable. At this time of the year (end of the rainy season and beginning of the dry season) the soil was still wet, but not water logged, and this was probably important in burrowing and nest building (Chapman *et al.*, 1959). Ground temperatures never became excessive during this period and there was ample vegetation for cover and for food (Chapman *et al.*, 1959)

2.7.2 Sex ratio

Sex ratios may vary according to season and species. For example, Leirs (1992) found sex ratios near to parity outside the breeding season, but in periods of reproduction it shifted in favour of females. Kawalika *et al.* (2003) reported that in two species of mole rats, *Cryptomys anselli* and *C. mechawi,* among juveniles and sub adults, the sex ratio was male biased (*C. anselli* 1.3, n=115) and *C. mechawi* (1.22, n=40). However, among the adults (older than one year) the proportion of males decreased (C. *anselli*: 0.44, n=107 and *C. mechawi*: 0.96, n=85). The authors explained that the decrease of adult males could be due to the reason that, as the males become older; they tend to disappear from t he p opulation. A nother r eason t hat w ould b est e xplain t his o bservation i s s ex linked polytheism expressed in higher activity and/or trapability of sub adult males. With growing older, males could become more cautious or less active.

2.7.3 Litter size

Observations made by Neal (1981) showed variations in litter size of *Arvicanthis* spp in three sites namely, Mweya Peninsula, Crater and Rojowero Plains. The mean number of implanted embryos was also significantly different in those sites. Other studies show average litter size of 4.5 young of *Arvicanthis* spp for populations from Senegal and Ethiopia (Petter *et al.*, 1969), 7.0 in western Kenya (Taylor and Green, 1976), 4.9 in Ethiopia (Müller 1977), 6.0 young per litter in the southern Sudan (Happold, 1966), 4.0 young per litter in northern Tanzania (Misonne and Verschuren, 1966) and 7.5 young per litter in populations from Senegal (Quilici *et al.*, 1969, cited by Neal (1981). Neal

(1981) pointed out that litter size of *Arvicanthis* spp varies from 3 – 6 young depending on the locality. Pregnant females of *Arvicanthis niloticus* were found to have a mean of 6.0 ± 0.2 embryos per litter (Daouda *et al.*, 2003).

2.8 Population structure

2.8.1 Age determination

Age is one of the parameters used to indicate population structure (Leirs, 1992). Telford (1989) found out that three cohorts of *M. natalensis* could be identified in the population from September – December at Morogoro. These were adult males, post reproductive or females with perforated vagina and non – reproductive young of the year. However, Leirs (1992) pointed out that age determination in small mammals is not easy as the ideal situation would be to know the exact date of birth of individual and to follow it through a whole period which is virtually not existing for most wild living rodents. Leirs (1992) used body length, body weight and eye lens weight in determining age; eye lens weight being the most superior technique (Vandorpe and Verhagen, 1979). Other techniques such as tooth wear patterns have also been used (Chidumayo, 1980). In some cases, it would be enough to group animals in reproductive age groups (Juveniles, sub adults and adults). Leirs (1992) categorized *M. natalensis* juveniles as those having body weight less than 25g, sub adults between 25 – 40g and adults above 40g.

The age composition reflects reproduction patterns. Leirs (1992) noted presence of young *M. natalensis* in March and April which confirms the off-season breeding at the beginning of the year. In May and June the author observed absence of very young animals and in July they were present again as a result of reproduction in the main breeding season. After the breeding season, most adults gradually disappear from the population and they are replaced by the growing young. Amundala *et al.* (2003) reported that a stable population structure of four species of rodents (*Hybomys lunaris*, *Deomys ferrugineus*, *Lophuromys dudui* and *Praomys jacksoni*) in Kisangani, was characterized by a proportionally important adult class and by regular but no massive entry of young, thus ensuring permanent presence of different age classes. The ratios were slightly skewed towards males in *L. dudui* (Amundala *et al.*, 2003).

CHAPTER THREE

3.0. MATERIAL AND METHODS

3.1. Study areas

3.1.1 Location

The study was carried out at two localities in central Tanzania for a period of 12 months. One site was Ihanda village (1196 m.a.s.l.)(06^0 23'S; 36^0 71'E) within Mlali division in southeast of Kongwa district, Dodoma region. The other site was Msingisi village (1365 m.a.s.l.)(06^0 20'S; 36^0 87'E) within Gairo division in the northeast of Kilosa district, Morogoro region. The two sites were chosen for the purpose of having a replicate. Fig. 2 shows the location of the study villages.

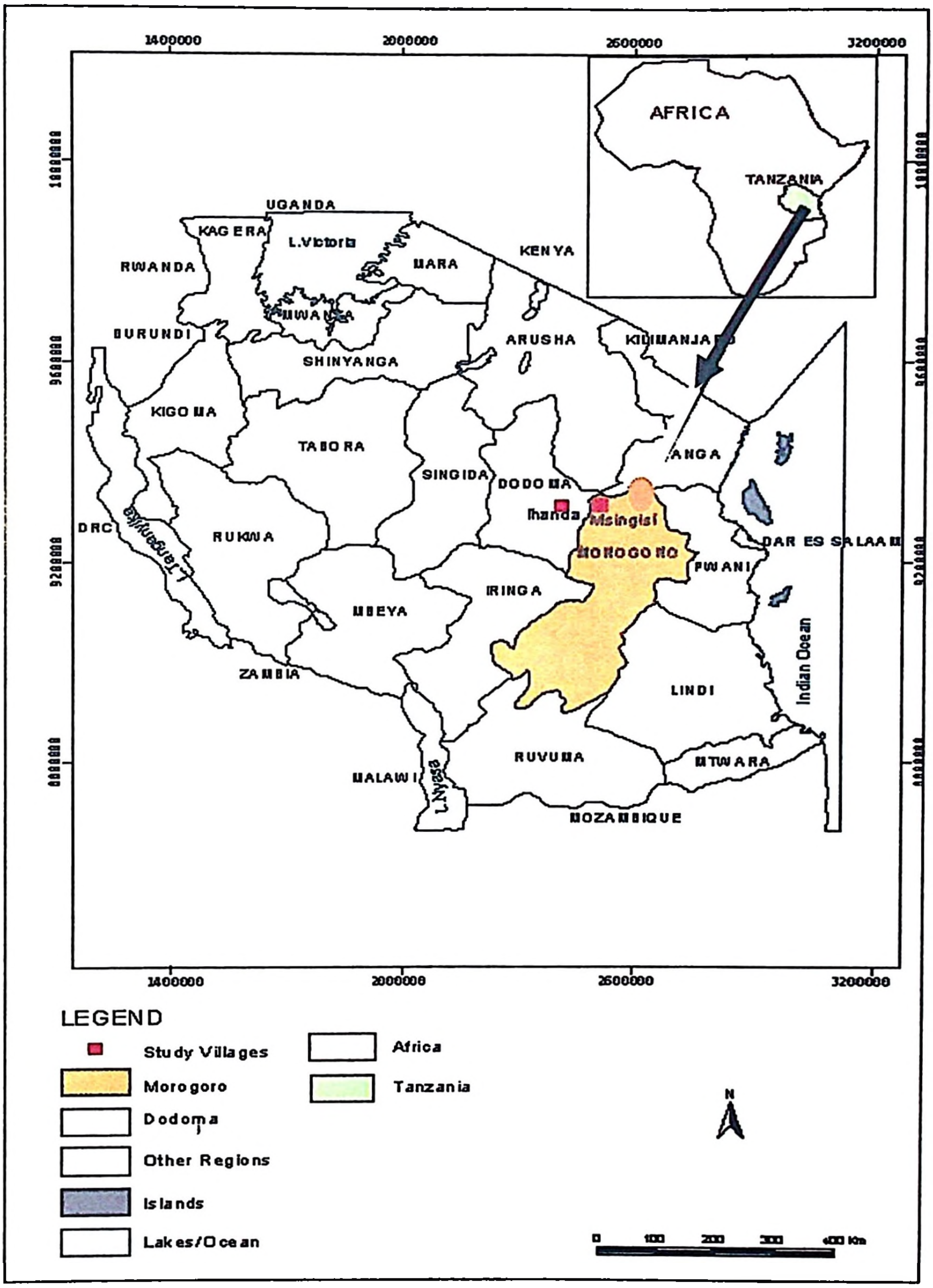


Fig. 2. Study villages

3.1.2 Climate

The general climate of the study areas can be defined as semi arid with unimodal pattern of rainfall, averaging 600 - 900 mm annually. The mean temperatures ranges from 15^0 C to 30^0 C. June and July are the coolest months while the period between October and November experiences the highest temperatures.

Rainfall data were collected during the whole study period. Rainfall data for Msingisi village were collected from the Sokoine University of Agriculture (SUA) weather station located at Makambini area in Gairo, while that for Ihanda village were collected from Mlali division center.

3.1.3 Land use

Msingisi village has a total land of 8094 ha. Out of this area, 3504 ha (43%) is allocated for crop production while about 4000 ha (49%) is set aside for grazing and only 200 ha (2.5%) is allocated for residential and institutional development. Ihanda village has a total land area of 4850 ha. Out of this, 1650 ha (40%) is devoted to crop production, 1200 ha for grazing and about 2000 ha is for forest/shrub area. Msingisi and Ihanda villages are predominantly for crop production, livestock keeping and residential/forest or fallow. The main crop is maize.

3.2 Experiment layout and design

3.2.1 Trapping techniques

Capture-Mark-Release (CMR) trapping (Hayne, 1949; Leirs, 1992; Pernetta, 1977) and removal trapping were used in the study. In the CMR study, two grids were laid, one in each village. Both were located in a fallow land, which was under maize cultivation. In the removal trapping, villagers were asked to trap *Arvicanthis neumanni* in selected fields.

3.2.1.1 Capture Mark Release trapping

The CMR grids consisted of 10 parallel lines each, 10 m apart, with 10 trapping stations per line, and were 10 m apart. Plate 1(a and b) shows the vegetation cover in the grids. The trapping stations were marked with painted numbered bricks for easy placement of the traps and identification. Each trapping station was identified by coordinates A to J, and numbered 1 –10 (Fig. 3).

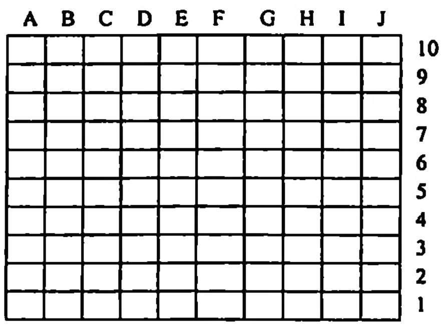


Fig. 3. Schematic map of the CMR-grids. Each trapping station was located at the intersection of the two coordinates (Adopted from Leirs, 1992).

Sherman live traps (Sherman LFA live Traps, 7.5 x 9.0 x 23.0 cm, HB Sherman Trap Inc, Tallahassee, USA) were used. Trapping was carried out for 3 consecutive nights every month for a period of 10 months from December 2002 to September 2003. Traps were baited with peanut butter (Pernetta, 1976; Neal, 1984) mixed with maize bran and the traps were re-baited daily (Michielson, 1966 and Pucek, 1969). Since *Arvicanthis neumanni* is diurnal and sensitive to high temperatures, traps were inspected every morning around 0900 hrs. Before repositioning, the traps were cleaned of old bait and droppings and new bait was added.

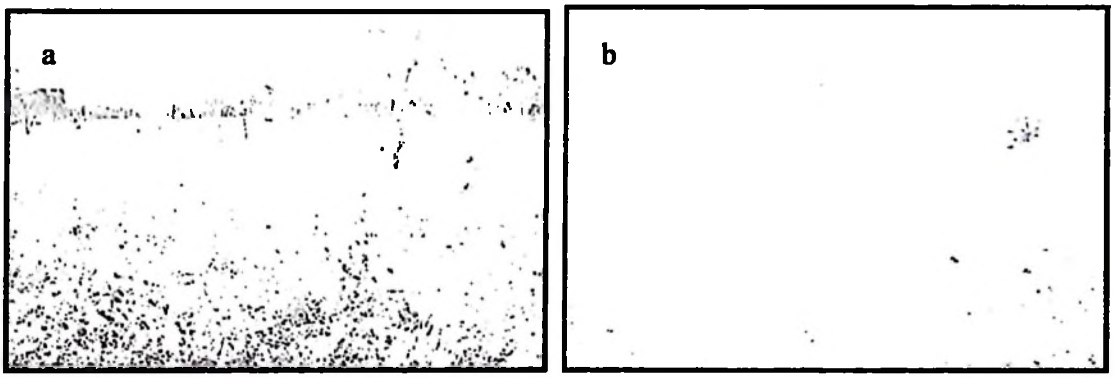


Plate 1. CMR grid sites: a - Msingisi village; b – Ihanda village

3.2.1.2 Removal trapping

The method of obtaining animals was as per Chapman *et al.* (1959), where collectors trapped *Arvicanthis neumanni* in their respective villages. Animals were caught monthly for a period of one year starting from October 2002 to September 2003. Collectors either dug out *A. neumanni* from burrows or used local traps locally known as *swadi* and wire mesh traps (Appendix 1). This method enabled collection of a large number of *A. neumanni* because few entered the Sherman traps.

3.2.2 Handling of animals

3.2.2.1 Handling of animals from the CMR trapping

The animals were handled in a standard way; shaking them gently out of the traps into a cloth bag and weighing using an electronic or spring balance . Each new capture was marked by toe clipping and identified by a combination of individual coding of the toes (Hayne, 1949) (Appendix 3). Each toe was assigned a number, fore feet: 1 – 8, hind feet 10 –100 and an individual code consisted of a combination of clipped toes (Appendix 3). This technique is a standard procedure for coding rodents for future identification in CMR studies.

3.2.2.2 Handling of animals from the removal trapping

The animals were anaesthetized by diethyl ether and external morphological measurements were taken. They were dissected immediately to examine internal sexual organs (Hayne, 1949). Some were labeled and preserved in formalin for future studies.

3.3 Data collection

3.3.1 Data collected from CMR grids

The following data were recorded for each trapped individual:

- Date of capture/recapture

- grid number and coordinates of trapping station
- toe clipping code
- body weight to the nearest gram
- sexual condition. Females were categorized as visibly pregnant, lactating, vagina closed/perforated. Males were examined for testes condition (scrotal/abdominal)

3.3.2 Data collected from the removal trapping

The following data were recorded for each trapped individual:

- date of collection
- head and body (HB) length, length of tail, ear length (Plate 2). Testes length for males (Plate 3), Head and body (HB) lengths were taken as the distance (in millimeters) from the tip of the snout to distal margin of anus, length of tail was taken as the distance from the anus to the tip of the tail (Singleton, 1985; Chapman *et al.*, 1959)
- body weight to the nearest gram (Plate 4)
- hind foot (Plate 5)
- sexual condition of females and males (Plate 6)
- number of embryos

The captured animals were categorized as juveniles (HBL < 95 mm), sub adults (HBL = 95 mm – 110 mm) and Adults (HBL > 110 mm)

Plate 2. Measuring ear length

Plate 3. Measuring testes length

Plate 4. Measuring body weight

Plate 5. Measuring hind feet length

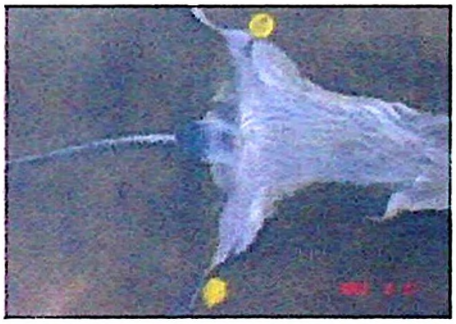


Plate 6. *A. neumanni* male with Scrotal testes

3.5 Data analysis

Microsoft Excel Software was used to:

- Perform Chi-square test (χ^2)
- Determine parameter measurements of internal and external measurements of the captured animals. Captures were grouped according to age and mean numbers ($\bar{x} \pm$ SE) were calculated. The mean litter size ($\bar{x} \pm$ SE) was also established from animals examined for embryos.
- Draw graphs to show trap success, sex ratio, gravid captures and testes size.

CHAPTER FOUR

4.0. RESULTS AND DISCUSSION

4.1 Habitat selection of *A. neumanni* in the study areas.

Arvicanthis neumanni were found to occupy a wide range of habitats. Most of the rodents were caught in hedges of either piled thorny shrub cuttings or planted materials such as sisal demarcating farmers' fields. Other places, which were found to have populations of *A. neumanni*, were covered by shrubs (Plate 7) and grassland; most of these were neighbouring maize fields. These are important harbourage habitats for the species. Some of *A. neumanni* were found in grass patches along the roads neighbouring maize fields (Plate 8).

Within residential areas, *A. neumanni* were found close to livestock paddocks, under thorny shrub cuttings or planted sisal. They were also found in piles of thrushes and dumped tufts. This kind of habitat for *Arvicanthis,* has been consistently mentioned by several authors such as Green and Taylor (1975 a & b) and Parker (1983).

Plate 7. Thorny shrub vegetation where *A. neumanni* were numerous.

(The picture was taken at Msingisi village, 2002/03)

Plate 8. Grass patches along roads, which harboured *A. neumanni*. In the picture, *Swadi* trap is laid on one of *A. neumanni* run ways along the Gairo – Kwipipa road, 2002/03

4. 2 Population dynamics and trap success from the CMR study

Population dynamics is essentially concerned with all processes that play a role in the determination of population size (Leirs, 1992). Minimum Number Alive (MNA) of *Arvicanthis neumanni* in both grids ranged from 0 – 3 animals per hectare. Msingisi grid had 3 *A. neumanni* per ha in December. No individuals were captured in other months. The population density of *A. neumanni* at Ihanda grid was 1 /ha in August, September and December. No captures were made during the other months. The low numbers of *A. neumanni* caught in both grids was probably because this species is trap-shy. Once caught in Sherman traps, no recaptures were made. However, relatively large numbers of the animals were captured using local traps.

A total of 49 captures and recaptures were made of 30 individual animals belonging to 5 species in 3000 trap nights at Msingisi grid while at Ihanda grid, a total of 91 captures and recaptures were made of 55 individual animals belonging to 5 species in 3000 trap nights. In the CMR grids, trap success varied from 0% (April, 2003 and August, 2003) to 8% (December, 2002) at Msingisi village and from 0% (April, 2003) to 10% (December, 2002) at Ihanda village, with an overall trap success of 1.6% and 3% in Msingisi and Ihanda grids respectively. Generally, the highest trap successes were recorded between December and March. Table 2 shows the species captured in the two trapping sites. *M. natalensis* had highest capture record (80%) which shows it was the dominant species in this area.

Table 2. Species captured in Msingisi and Ihanda villages, 2002/2003

Species	Percentage (%) Composition of Total capture
Mastomys natalensis	80
Arvicanthis neumanni	6.7
Lemniscomys sp	6.7
Tatera sp	3.3
Steatomys sp	3.3

Trap success for individual species is shown in Fig. 4 at Msingisi grid and in Fig. 5 at Ihanda grid. In general, trap success for *M. natalensis* in both sites was much higher in December to March than in the rest of the year indicating that this was the period of highest population density. This period also coincided with the highest rainfall (Appendix 2). Food availability and vegetation cover have been shown to induce population increase of rodents (Telford, 1989; Leirs, 1992), and most probably explains the higher rodent density observed in *M. natalensis* in the present study during the months of December to March. Trap success for the other species of rodents was low (less than 1%) throughout the year.

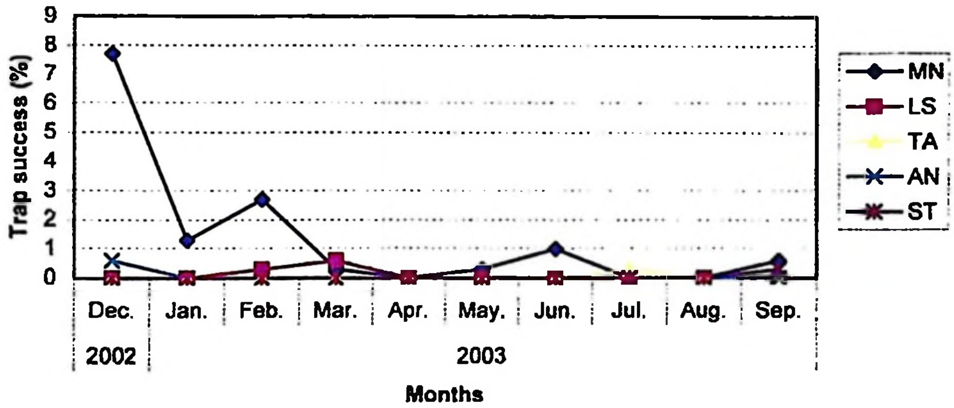


Fig. 4. Trap success of rodent species from the Msingisi grid.

MN- *M. natalensis,* LS – *Lemniscomys* sp, TA – *Tatera sp,* AN – *Arvicanthis* sp and ST – *Steatomys* sp

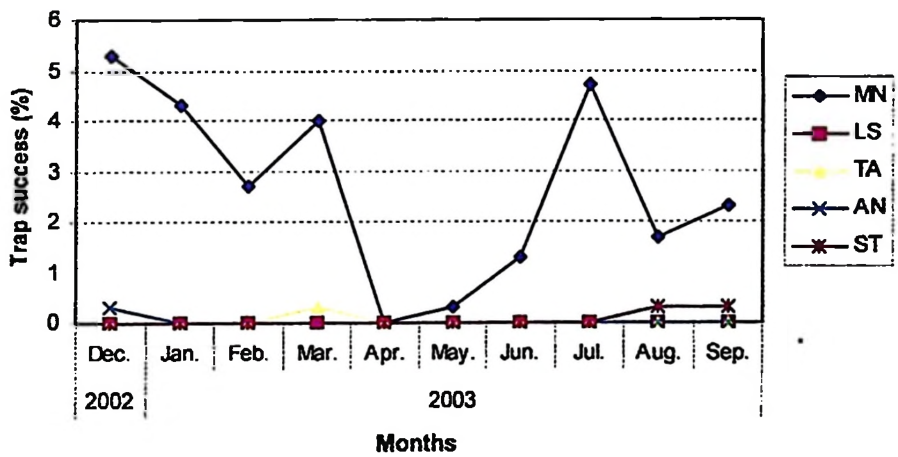


Fig. 5. Trap success of rodent species from Ihanda grid.

MN- *M. natalensis,* LS – *Lemniscomys* sp, TA – *Tatera sp,* AN – *Arvicanthis* sp and ST – *Steatomys* sp

4.3 Morphological measurements and body weight of *A. neumanni*

The mean body weight of adult *A. neumanni* males at Msingisi (n = 104, mean = 62.3 g) differed significantly ($t = 2.27$, $P < 0.05$) from that of the females (n = 104, mean = 57.7 g), (Fig. 6a). Animals caught in January, February and March had higher body weight than those captured in April – December. Similar results were obtained for subadults (Fig. 6b). This could be due to more food availability in this period since the onset of rainfall induces vegetation growth, thus increasing the abundance of food resources. Several authors (Leirs, 1992; Parker 1983; Taylor and Green, 1976) have reported similar phenomenon in other rodent species. Neal (1976) noted that weights in *M. natalensis* increased during the rains and decreased by approximately 25% during the dry season. The author reported that the weight changes are probably related to the seasonal cycle in body fat content. In the current study a net increase in body weight of adult *A. neumanni* occurred ($t = 3.99$, $P < 0.05$) for animals caught at Ihanda village (n = 152, mean = 62.3 g) and (n = 152, mean = 53.3 g) for males and females respectively (Fig. 7a). The animals with highest body weights were captured between December and March. However, the highest body weights of subadult *A. neumanni* at Ihanda village were observed in January and February (Fig. 7b). The mean body weight of adult males differed from that of adult females in Ihanda village by 9 g (16.9%). There are remarkable variations in the seasonal mean body weights of adult *A. neumanni* captured in the two villages. Generally, between December to April animals had comparatively larger body weights than in the rest of the year. Similar observations on seasonal variations in body weights were made by Leirs (1992), Chapman *et al.* (1959) and Telford (1989) in *M. natalensis*. Chapman *et al.* (1959) reported that *M. natalensis* with greater than 110 mm head body length had an increase of 7g in weight for every 10 mm increase in length. Animals less than 110 mm head body length had an increase of 10 g in weight for every 10 mm increase in length in the same duration.

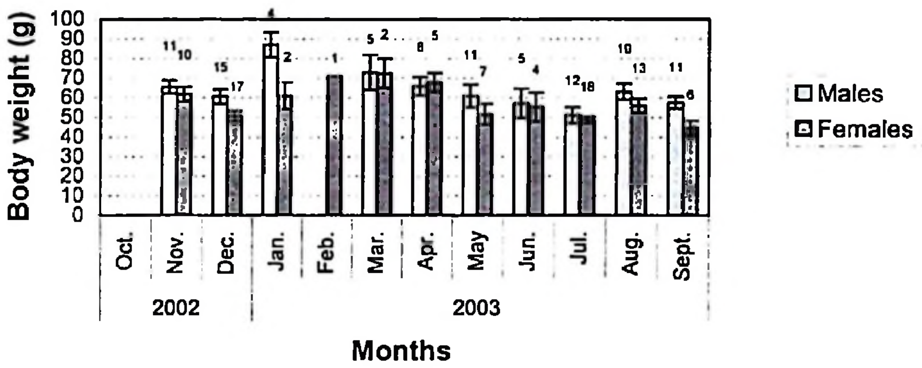


Fig. 6a. Body weight variations of adult *A. neumanni* males and females at Msingisi village, (Numbers above bars are the sample sizes and bars stands for ($\bar{x} \pm$ SE)

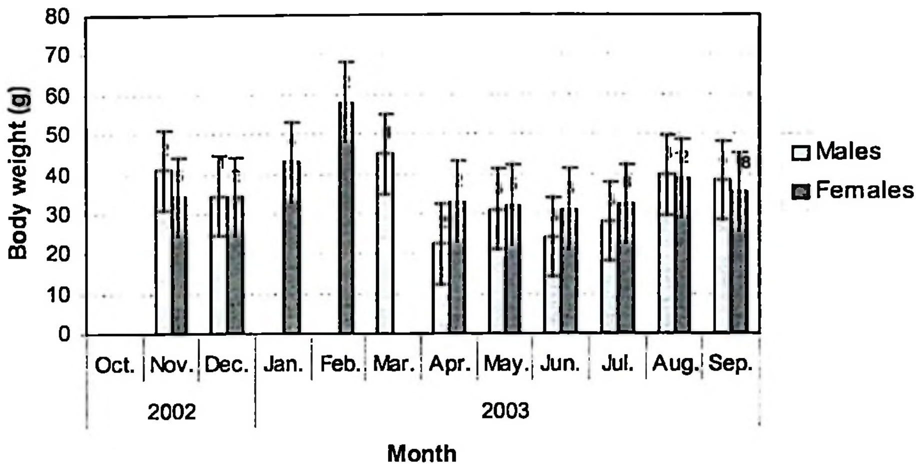


Fig. 6b. Body weight variations of subadult *A. neumanni* males and females at Msingisi village, (Numbers above bars are the sample sizes and bars stands for ($\bar{x} \pm$ SE)

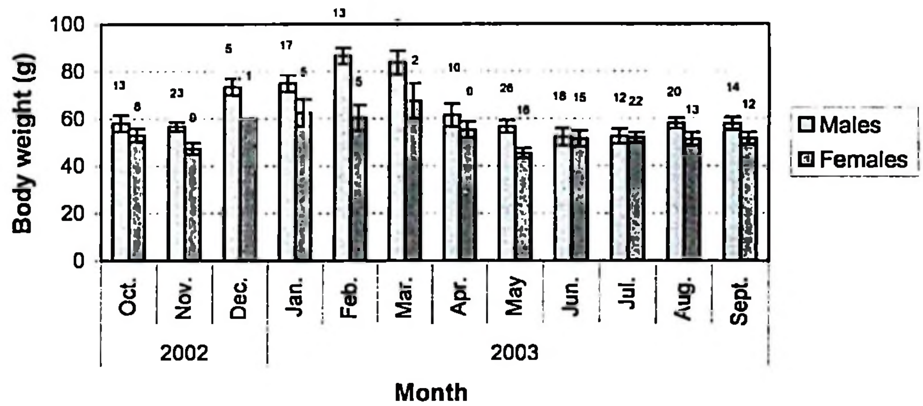


Fig. 7a. Body weight variations of adult A. *neumanni* males and females at Ihanda village, (Numbers above bars are the sample sizes and bars stands for ($\bar{x} \pm$ SE)

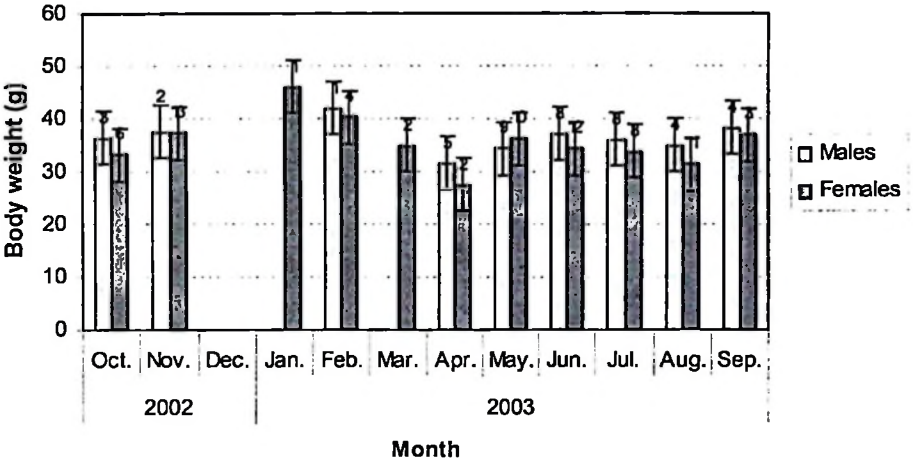


Fig. 7b. Body weight variations of subadult A. *neumanni* males and females at Ihanda village, (Numbers above bars are the sample sizes and bars stands for ($\bar{x} \pm$ SE)

4.4 Age structure of *A. neumanni* population in the study area

Figures 8 and 9 show the age category distribution of *A. neumanni* males and females in Msingisi village. In some months (October and February), very few captures (less than five animals) were obtained and therefore, it was not possible to compare age structure.

A large number of juveniles were present in the population in January to July. Low numbers of juveniles occurred from August to September. The occurrence of a large number of juveniles in January – July coincided with the main breeding season. Neal (1981) observed continuous breeding of *A. niloticus* throughout the year where rainfall was constant. Rainfall in the study areas during the study period, both in amount and distribution, was poor (Appendix 2). However, young *A. neumanni* were observed throughout the year, suggesting that *A. neumanni* were reproducing throughout the year. However, the proportion of young animals, in the population decreased from July but increased again in January. A similar trend in age composition occurred in Ihanda village (Fig. 10 and 11).

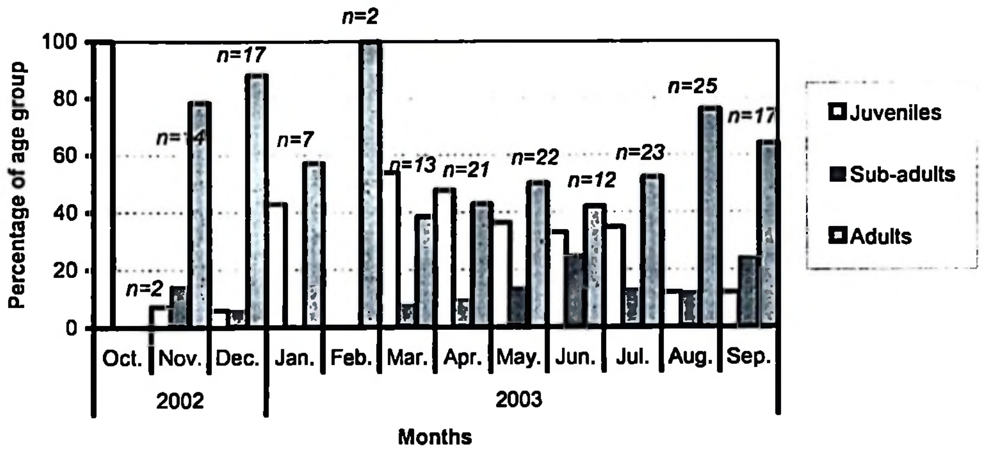


Fig. 8. Distribution of adults, subadults and juveniles of *A. neumanni* males in Msingisi village (2002/03)

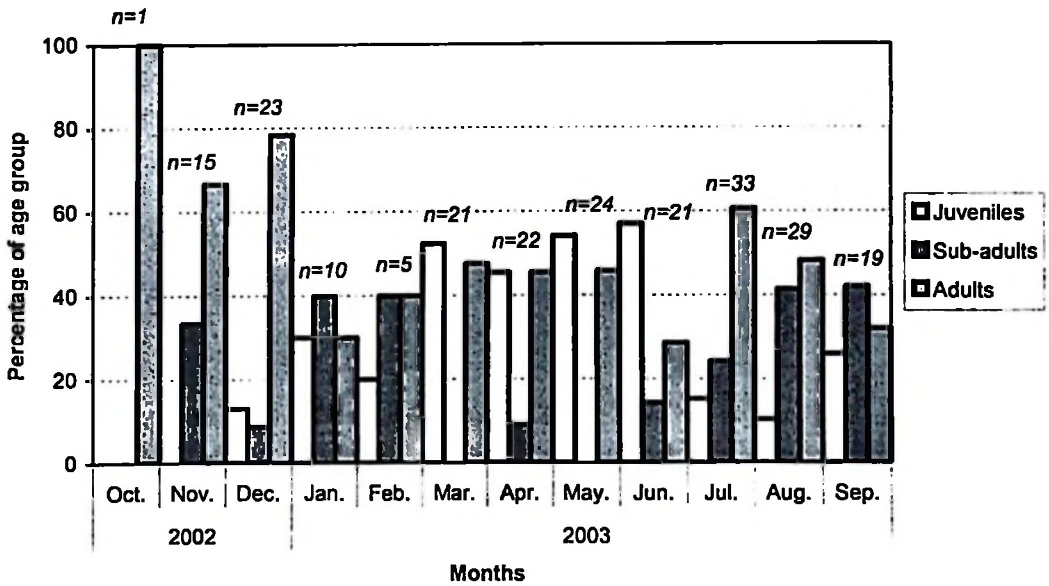


Fig. 9. Distribution of adults, subadults and juveniles of *A. neumanni* females in Msingisi village (2002/03)

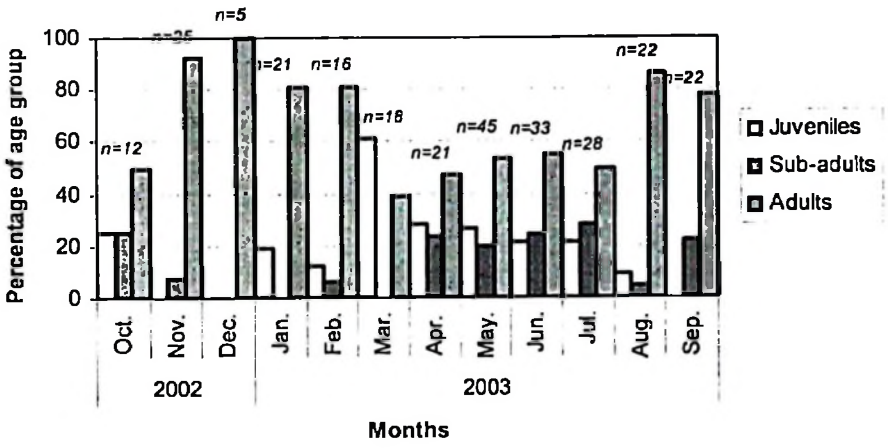


Fig. 10. Distribution of adults, subadults and juveniles of *A. neumanni* males in Ihanda village (2002/03)

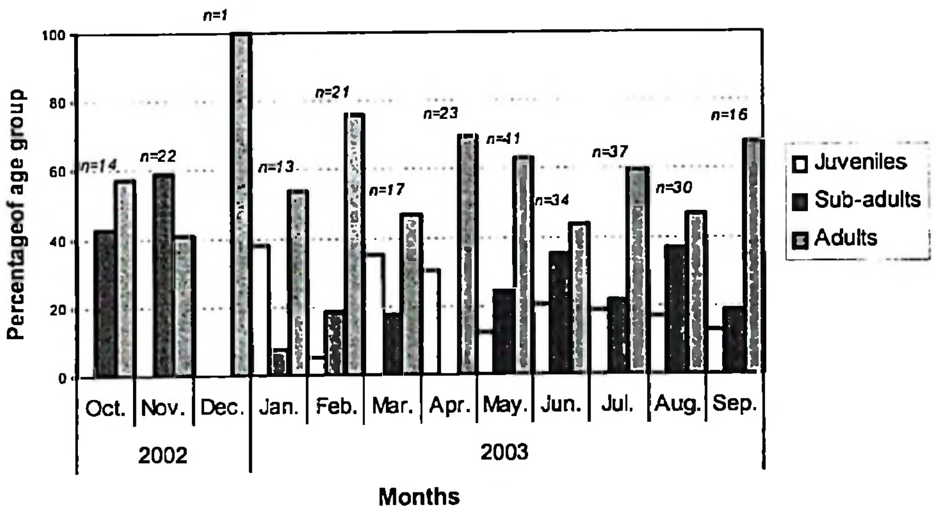


Fig. 11. Distribution of adults, subadults and juveniles of *A. neumanni* males in Ihanda village (2002/03)

4.5 Reproduction and breeding season of *A. neumanni* in the study area

4.5.1 Sex ratios

There was no significant difference in sex ratio within months from October – September at Msingisi (Table 3). There was also no significant difference in sex ratio within months from October – September at Ihanda village (Table 4). Therefore, abundance of males and females didn't differ significantly. Kawalika *et al.* (2003) found that among juveniles and sub adults of *Cryptomys anselli* and *Cryptomys mechawi* captured in a standardized grid in Zambia, the sex ratio was male biased. However, the author found that, among the adults (older than one year), the proportion of males decreased. The author explained that the decrease of adult males could be for the reason that as the males becomes older they tend to disappear from the population. Another reason that would best explain this observation is a sex linked polytheism, expressed in higher activity and/or trappability of adult males; with growing older, males could become more cautious or less active.

Table 3. Sex ratio of *A. neumanni* at Msingisi during the study period (2002/03) (Numbers in brackets are total number of animals captured)

Month	Males (N)	Monthly Sex ratio (Observed)	Monthly Sex ratio (Expected)	χ^2	
October, 2002	2 (3)	0.66	0.5	0.33	*ns*
November, 2002	14 (29)	0.48	0.5	0.03	*ns*
December, 2002	17 (40)	0.43	0.5	0.90	*ns*
January, 2003	7 (17)	0.41	0.5	0.53	*ns*
February, 2003	2 (7)	0.29	0.5	1.28	*ns*
March, 2003	13 (34)	0.38	0.5	1.88	*ns*
April, 2003	21 (43)	0.49	0.5	0.02	*ns*
May, 2003	22 (43)	0.51	0.5	0.02	*ns*
June, 2003	12 (33)	0.36	0.5	2.45	*ns*
July, 2003	23 (56)	0.41	0.5	1.79	*ns*
August, 2003	25 (54)	0.46	0.5	0.19	*ns*
September, 2003	17(36)	0.47	0.5	0.11	*ns*

Table 4. Sex ratio of *A. neumanni* at Ihanda during the study period (2002/03) (Numbers in brackets are total number of animals captured)

Month	Males (N)	Monthly Sex ratio (Observed)	Monthly Sex ratio (Expected)	χ^2	
October, 2002	25 (40)	0.63	0.5	2.50	*ns*
November, 2002	25 (48)	0.52	0.5	0.08	*ns*
December, 2002	5 (6)	0.83	0.5	2.67	*ns*
January, 2003	21 (34)	0.62	0.5	1.88	*ns*
February, 2003	16 (37)	0.43	0.5	0.68	*ns*
March, 2003	18 (35)	0.51	0.5	0.03	*ns*
April, 2003	21 (44)	0.48	0.5	0.09	*ns*
May, 2003	45 (45)	0.52	0.5	0.29	*ns*
June, 2003	33 (67)	0.49	0.5	0.15	*ns*
July, 2003	28 (65)	0.43	0.5	1.24	*ns*
August, 2003	23 (53)	0.43	0.5	0.92	*ns*
September, 2003	18 (34)	0.53	0.5	0.12	*ns*

4.5.2 Changes in reproductive conditions of males and females of *A. neumanni*.

Males with scrotal testes, females with perforated vagina and non-reproductive individuals were caught every month from November – July at Msingisi village. Females with perforated vagina increased in numbers from November and reached a peak in February, when more than 59% of the individuals captured had perforated vagina. However, numbers decreased until there were none in August (Fig.12b). Males with scrotal testes were present throughout the study period except in October, with peaks in January and February (Fig. 12a), when the highest number of females had perforated vagina (Fig. 12b). In February, the number of animals in non-reproducing condition dropped drastically to less than 15% (Fig. 12 a & b). Generally, the period with highest non-reproducing individuals was between August and September. The same trend of changes in reproductive conditions was observed in Ihanda village (Fig. 13 a & b). The appearance of females with perforated vagina and males with scrotal testes nearly throughout the study period indicates that *A. neumanni* has an extended reproductive period. Neal (1981) observed that *Arvicanthis niloticus* is physiologically and ecologically well adapted for continuous breeding. Therefore, the observations made in this study conform to Neal's (1981) observations. However, peak reproductive activity occurs in the months of January to April suggesting that this is the main breeding period. This is also the rainy season for the study sites. The breeding season of *A. neumanni*, appear to be linked to rainfall in the study areas. Other studies have also linked reproduction of rodents with rainfall (Neal, 1981; Reichman *et al.*, 1975; Leirs, 1992; Weibren and Mason, 1957; Kingdon, 1974; Berger *et al.*, 1981;

Madsen and Shine, 1999). Breeding of many species of rodents in tropical Africa has been linked to rainfall (Fiedler, 1994; Achigan *et al.* 2003b; Workneh, 2003; Leirs, 1992; Fiedler, 1994; Massawe, 2003; Delany and Happold, 1979). Although the animals were in active reproductive condition in January to April, the rains started in October and November, which is three months duration before the start of the main reproductive period. Neal (1981) reported that breeding in *Arvicanthis niloticus* began some two to three months after the onset of rainfall and continued during the rains and into the early part of the dry season and then declined during the mid part of the dry season. There are several schools of thoughts regarding the relationship between breeding activity and rainfall in many rodent species. Neal (1981) proposed that it is due to increased dietary intake, which is also supported by Christian (1979). Leirs (1992) and Reichman *et al.* (1975) suggested it is due to the effect of substances found in germinating vegetation. Delany and Happold (1979) reported that the relationship between reproduction and rainfall is due to the nutritional status in terms of quality and quantity of available food. Klun and Robinson (1969), Berger *et al.*, (1981), Leirs (1992) and Kingdon (1974) suggested that green food might provide a biochemical trigger to seasonal breeding in the wild which was demonstrated by Weibren and Mason (1957). These reports suggest that, probably, the substances which trigger seasonal breeding are available both in the germinating and non germinating seeds or there is more than one substance with a triggering effect in rodent breeding. Taylor and Green (1976) fed *Arvicanthis* sp on seeds and/or cereals and showed that the animals continued breeding up to when these foods were stopped.

(1976) fed *Arvicanthis* sp on seeds and/or cereals and showed that the animals continued breeding up to when these foods were stopped.

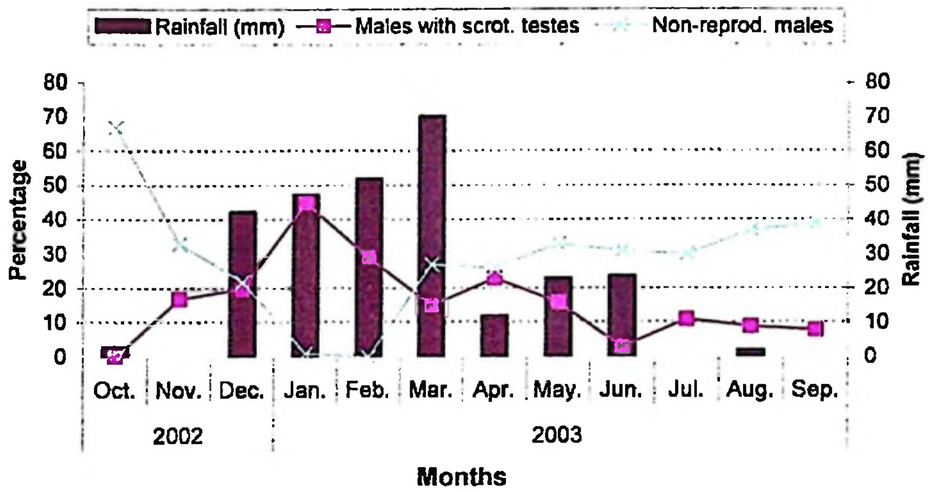


Fig. 12a. Changes in reproductive conditions of *A. neumanni* males at Msingisi village (2002/03), Morogoro region, Tanzania

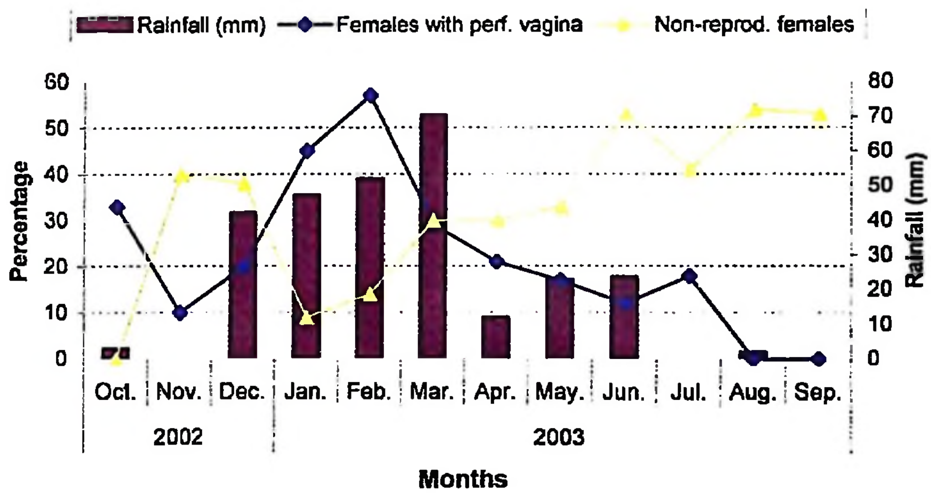


Fig. 12b. Changes in reproductive conditions of *A. neumanni* females at Msingisi village (2002/03), Morogoro region, Tanzania

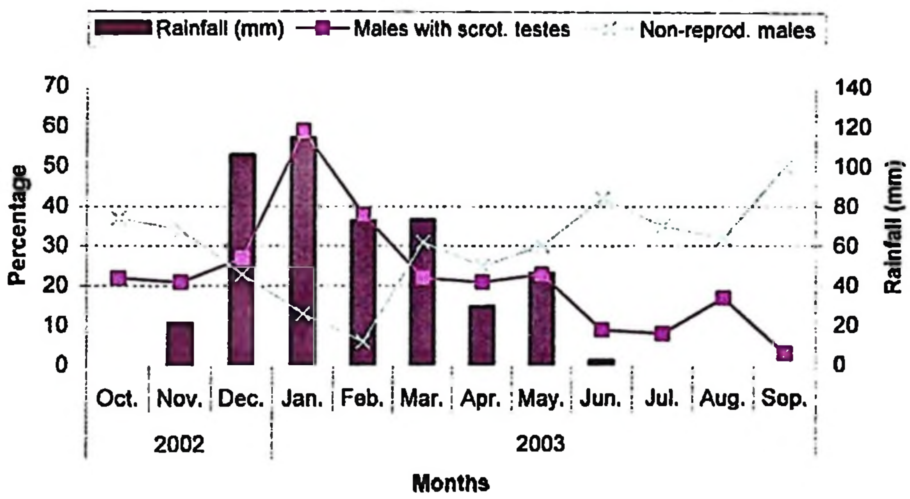


Fig. 13a. Changes in reproductive conditions of *A. neumanni* males at Ihanda village (2002/03), Dodoma Region, Tanzania

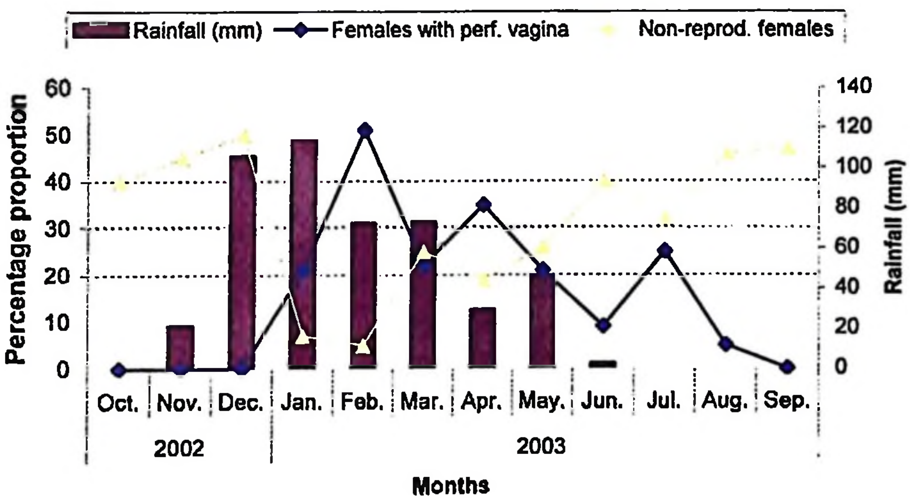


Fig. 13b. Changes in reproductive conditions of *A. neumanni* females at Ihanda village (2002/03), Dodoma Region, Tanzania

4.5.3 Variation in testes size of adult *A. neumanni* (males with scrotal testes)

There were clear seasonal variations in testes size in both villages (Figs 14 and 15). The mean testes size was highest in February and March (Fig. 14), when most of the males were in reproductive condition. Similar observations were made in Ihanda village (Fig. 15). A similar seasonal change in testes length has been recorded in *M. natalensis* (Neal, 1976). Studies by Neal (1981) showed that, rich foods and unrestricted water combined with high humidity and low temperature induce the strongest gonadal stimulation in rats.

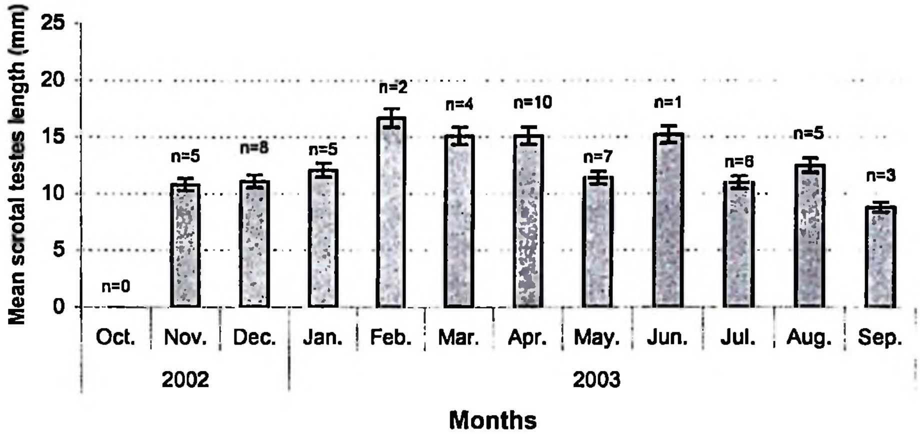


Fig. 14. Variations in testes size of *A. neumanni* males with scrotal testes in Msingisi village, 2002/03 (n = Number of individuals)

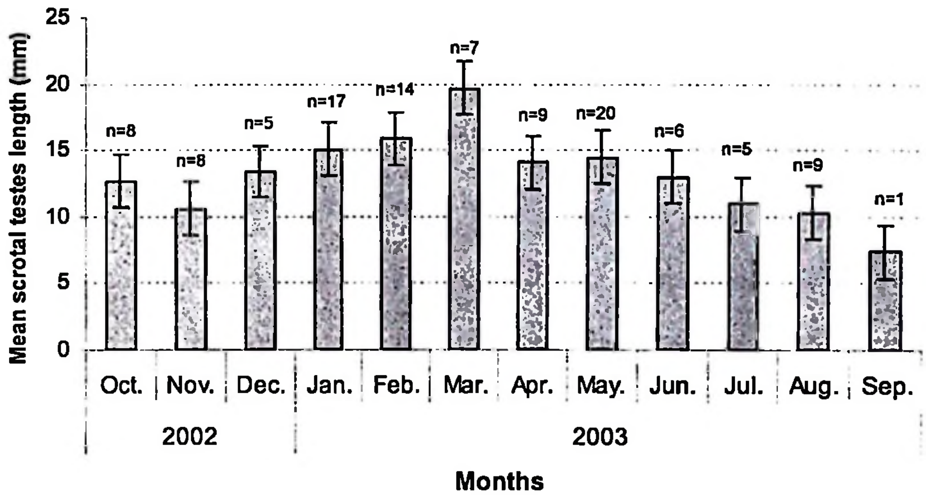


Fig. 15. Variations in testes size of *A. neumanni* males with scrotal testes at Ihanda village, 2002/03 (n = Number of individuals)

4.5.4 Litter size and implantation

4.5.4.1 Litter size

Table 5 shows the mean litter size of *A. neumanni* at Ihanda and Msingisi villages. Variations in litter size of *Arvicanthis* spp have been reported else where. For example, Neal (1981) reported variations in litter size at three sites in Kenya. Petter *et al.*, (1969) found a mean litter size of 4.64 (range 2 – 7), Taylor and Green (1976) reported a mean litter size of 6 (range = 2 – 12). Happold (1966) reported a mean litter size of 2 – 10 while Misonne and Verschuren (1966) found a litter size of 3 – 5. Daouda *et al.* (2003) observed a mean litter size of 6 ± 2. Probably, the variation in litter size of *Arvicanthis* spp could be due to variations in habitats. Neal (1976) reported that the litter size of *M. natalensis* was highest near the equator and decreased at higher latitudes, while Sheppe (1972) has reported local variations in litter size in Zambia, which may reflect habitat differences. The litter size of 5.85 ± 0.34 established in this study indicates that the potential to increase in population size is high for this species.

Table 5. Litter size of female *A. neumanni* in Msingisi and Ihanda villages (2002/03)

Village (site)	N	Mean ± SE	Range (Min. – Max.	SD
Ihanda	37.0	6.10 ± 0.26	4 - 11	1.6
Msingisi	24.0	5.58 ± 0.42	1 - 9	2.0
Total	61.0			
Mean		**5.85 ± 0.34**	2.5 - 10	

4.5.4.2 Implantation

Table 6 shows the number of embryos positioned in the left and right horn of the uterus in the two study sites. There were no significant differences in numbers of embryos implanted in the left and right horns of the uterus in both study villages ($t_{22} = 0$, $P > 0.05$; $t_{36} = 1.88$, $P > 0.05$). These results show equal numbers of embryos positioned in the right horn and left horn in pregnant female *Arvicanthis neumanni*.

Table 6. Number of embryos implanted in the right and left horns of pregnant females at Msingisi and Ihanda villages (2002/03)

Village (site)	N	Left horn Mean ± SE	Left horn Range Min. – Max.	Right horn Mean ± SE	Right horn Range Min. – Max.
Ihanda	37.0	3.29 ± 0.17	2.0 – 7.0	2.81 ± 0.19	1.0 – 6.0
Msingisi	23.0	2.87 ± 0.27	1.0 – 5.0	2.87 ± 0.25	1.0 – 5.0
Total	60.0				
Mean		**3.08 ± 0.22**	1.5 – 6.0	**2.84 ± 0.22**	1.0 – 5.5

CHAPTER FIVE

5.0 CONCLUSSIONS AND RECOMMMENDATIONS

5.1 CONCLUSSIONS

The present study has shown that juveniles, subadults and adults of *A. neumanni* were present in the population almost throughout the year suggesting continuous reproduction. However, the proportions of these age categories differed with time and showed some seasonality. Juveniles were more abundant from January - March. Adult proportions were generally highest during July – December. The study shows that active breeding in *A. neumanni* in central Tanzania is generally from January to April. Juveniles start appearing in large numbers one to two months after the onset of rainfall. In view of the above observations, the management of this pest should however being done at their lowest density level. The mean litter size of *A. neumanni* established which was 5.85 ± 0.34 young (range from 2 – 10) should be regarded as high. Proper control techniques if applied one to two months before rains in the season would decrease the probability of high rodent density later in the year.

5.2 RECOMMENDATIONS

As a follow-up of this investigation, it is important to conduct more studies on:

i) Long term ecological studies on *A neumanni*

ii) Studies on the behaviour of *A. neumanni*

Amundala, D., Bapeamoni, A., Lyongo, W., Gambalemoke, M., Kadange, N., Katuala, P.G.B. and Dudu, A. (2003). The structure of some rodent populations in Kisangani and its surrounding (Democratic Republic of the Congo) from 1984 to 2000. In: *Abstracts of the 9th International African Small Mammal Symposium.* (Edited by Makundi R.H.). 14 – 18 July 2003, Sokoine University of Agriculture, Morogoro, Tanzania, p.15.

Berger, P.J., Negus, N.C., Sanders, E.H. and Gadner, P.D. (1981). Chemical triggering of reproduction in *Microtus montanus*. *Science* 214: 69 - 70

Capanna, E., and Civitelli, M.V. (1986). A cytotaxonomic approach of the systematics of *Arvicanthis niloticus* (Desmarest 1822). *Tropical Zoology* 1: 29 - 37

Castiglia, R., Corti, M., Tesha, P., Scanzani, A., Fadda, C., Capanna, E. and Verheyen, W. (2003). Cytogenetics of the genus *Arvicanthis* (Rodentia, Muridae) Comparative cytogenetics of *A. neumanni* and *A. nairobae* from Tanzania. *Genetica* 118: 33 – 39, 2003

Chapman, B.M., Chapman, R.F. and Robertson, I.A.D. (1959). The growth and breeding of the multimammate rat, *Rattus (Mastommys) natalensis* (Smith) in Tanganyika Teritory. *Proceeding of the Zoological Society* 133: 1 - 9

Cheeseman, C.L. and Delany, M.J. (1978). The population dynamics of small rodents in tropical African grassland. *Journal of Zoology* 188: 451 – 475

Chidumayo, E.N. (1980). Ecology of rodents at an old quarry in Zambia. *South African Journal of Zoology* 15(1): 44 – 49

Amundala, D., Bapeamoni, A., Lyongo, W., Gambalemoke, M., Kadange, N., Katuala, P.G.B. and Dudu, A. (2003). The structure of some rodent populations in Kisangani and its surrounding (Democratic Republic of the Congo) from 1984 to 2000. In: *Abstracts of the 9th International African Small Mammal Symposium.* (Edited by Makundi R.H.). 14 – 18 July 2003, Sokoine University of Agriculture, Morogoro, Tanzania, p.15.

Berger, P.J., Negus, N.C., Sanders, E.H. and Gadner, P.D. (1981). Chemical triggering of reproduction in *Microtus montanus*. *Science* 214: 69 - 70

Capanna, E., and Civitelli, M.V. (1986). A cytotaxonomic approach of the systematics of *Arvicanthis niloticus* (Desmarest 1822). *Tropical Zoology* 1: 29 - 37

Castiglia, R., Corti, M., Tesha, P., Scanzani, A., Fadda, C., Capanna, E. and Verheyen, W. (2003). Cytogenetics of the genus *Arvicanthis* (Rodentia, Muridae) Comparative cytogenetics of *A. neumanni* and *A. nairobae* from Tanzania. *Genetica* 118: 33 – 39, 2003

Chapman, B.M., Chapman, R.F. and Robertson, I.A.D. (1959). The growth and breeding of the multimammate rat, *Rattus (Mastommys) natalensis* (Smith) in Tanganyika Teritory. *Proceeding of the Zoological Society* 133: 1 - 9

Cheeseman, C.L. and Delany, M.J. (1978). The population dynamics of small rodents in tropical African grassland. *Journal of Zoology* 188: 451 – 475

Chidumayo, E.N. (1980). Ecology of rodents at an old quarry in Zambia. *South African Journal of Zoology* 15(1): 44 – 49

Christian, D.P. (1979). Physiological correlates of demographic patterns in three sympatric Namib Desert rodents. *Physiology and Zoology Journal* 51: 329 - 340

Coetzee, C.G. (1965). The breeding season of the Multimammate mouse, *Mastomys natalensis* (A. Smith) in the Transvaal Highveld. *Zoologica Africana* 1: 29 - 39

Coetzee, C.G. (1975). The biology, behaviour and ecology of *Mastomys natalensis* in Southern Africa. *WHO Bulletin* 52: 637-644

Corti, M. and Fadda, C. (1996). Systematics of *Arvicanthis* (Rodentia,Muridae) from the Horn of Africa: a geometric morphometrics evaluation. *Italian Journal of Zoology* 63: 185 – 192

Daouda, IHA, Ba, CT, Sinsin, B. and Moutairou, K. (2003). Diversity and reproductive characteristics of rodent populations in different sites of the Retba Lake Station near Dakar (Senegal). In: *Abstracts of the 9th International African Small Mammal Symposium.* (Edited by Makundi R.H.). 14 – 18 July 2003, Sokoine University of Agriculture, Morogoro, Tanzania, p 29.

Delany, M.J. (1975). The rodents of Uganda. *Trustees of the British museum (National History). London Journal of Science* p. 206.

Delany, M.J. and Happold, D.C.D. (1979). Ecology of African mammals. *Journal of Ecology* p. 434.

Delany, M. J. and Neal, B.R. (1969). Breeding season of rodent in Uganda. *Journal of Social Reproduction and Fertility* 6: 229 – 235

Dunbar, R.I.M. (1978). Competition and niche separation in a high altitude herbivore community in Ethiopia. *East Africa Wildlife Journal* 16: 183 - 199

Fiedler, L.A. (1994). Rodent pest management in eastern Africa. FOA, Rome, Italy. *FAO Plant Production and Protection Paper* 123: 15 - 18

Green, M. and Taylor, K.D. (1975a). Preliminary experiments in habitat alteration as a means of controlling field rodents in Kenya. In: *Hanson, L. and Nilson, B.(ed.) Biocontrol of rodents. Ecological Bulletin:* 19: 175 – 181.

Green, M. and Taylor, K.D. (1975b). Biocontrol of rodents: Preliminary experiments with habitat alteration as a means of controlling field rodents in Kenya. *Bulletin of Ecology* 19: 175 – 186.

Hanney, P. (1965). The Muridae of Malawi. *Journal of Zoology, London* 146: 577 – 633.

Happold, D.C.D. (1966). Breeding periods of rodents in the Northern Sudan. *African Journal of Zoology and Botany* 74: 257 – 263

Hayne, D.W. (1949). Two methods for estimating population from trapping records. *Journal of Mammalogy* 30 (4): 399 – 411

Hubbard, C.A. (1973). Observations on the life histories and behaviour of some small rodents from Tanzania. *Zoologica Africana* 7(2): 419-449

Kawalika, M., Burda, H., Dammann, P. and Schaff, A. (2003). Age-dependent changes in sex ratios in two species of Zambian mole rats, *Cryptomys anselli* and *C. mechowi*, Bethyergidae). In: *Abstracts of the 9th International African Small*

Mammal Symposium. (Edited by Makundi R.H.). 14 – 18 July 2003, Sokoine University of Agriculture, Morogoro, Tanzania, p 42.

Kilonzo, B.S. (1976). A survey of rodents and their flea ectoparasites in North-eastern Tanzania. *East African Journal of Medical Research* 3: 117 – 125.

Kilonzo, B.S. (1984). Studies on the present status of endemicity, mammalian reservoirs and flea vector of plague in Tanzania. *PhD Degree awarded at* University of Dar es Salaam, Tanzania, pp 1 - 10.

Kingdon, J. (1974). *East African mammals: an atlas of evolution in Africa*. Volume II Part B (Hares and Rodents). Academic Press, London & New York, pp 625 - 630

Klun, J.A. and Robinson, J.F. (1969). Concentration of two 1,4-benzoxazinones in dent corn at various stages of development of the plant and its relation to resistance of the host plant to the European corn borer. *Journal of Economic Entomology,* 62: 214 - 220

Krebs, C.J. (1966). Demographic changes in fluctuating populations of *Microtus californicus*. *Ecological Monographs* 36: 239 - 273

Leirs, H. (1992). Population ecology of *Mastomys natalensis* (Smith 1834) multimammate rats: possible implications for rodent control in Africa. PhD Degree warded at University of Antwerp, Belgium, pp 2 - 45.

Leung, L.K.P, Singleton, G.R., Sudarmaji and Rahmini. (1999). Ecologically-based population management of the rice-field rat in Indonesia. In: *Ecologically-*

based Rodent Management. (Edited by Grant Singleton, Lyn Hinds, Herwig Leirs, and Zhibin Zhang) ACIAR Canberra, Australia. pp *305* – 317.

Madsen, T. and Shine, R. (May 1999). Rainfall and rats: Climatically-driven dynamics of tropical rodent population. *Australian Journal of Ecology,* 24 (1): 80. Online: http://www.blackwell.synergy.com/links/doi/10.1046/j. 1442 - 9993.1999.00948.x/abs. Cited on 09/01/2004

Makundi, R.H., Mbise T.J. and Kilonzo B.S. (1991). Observations on the role of rodents in crop losses in Tanzania and control strategies. *Beitrage zur Tropischen Landwirtschaft und Veterinaemedizin* 4: 465 - 474

Makundi, R.H., Oguge, N.O and Mwanjabe, P.S. (1999). Rodent pest management in East Africa – an Ecological approach. In: *Ecologically-based Rodent Management. (Edited by Grant Singleton, Lyn Hinds, Herwig Leirs, and Zhibin Zhang)* ACIAR Canberra, Australia. pp 460 – 476.

Massawe, A.W. (2003). Effect of cropping systems and land management practices on rodent population characteristics. PhD Degree awarded at Sokoine University of Agriculture, Morogoro, Tanzania, pp. 3 - 20

Michielson, N.C. (1966). Intraspecific and interspecific competition in the shrews *Sorex araneus* L. and *Sorex minutes* L. *Netherlands Journal of Zoology* 17 (1) 73 – 174

Misonne, X. and Verschuren, J. (1966). Les rongeurs et Lagomorphes de la région du Parc National du Serengeti (Tanzanie). *Mammalia* 30: 517 - 537

Müller, J.P. (1977). Populationsökologie von *Arvicanthis abyssinicus* in der Grassteppe des Semien Mountains National Park (Äthiopien). *Zeitschrift fur Saügetierkunde* 42: 145 – 172

Mulungu, L.S. (2003). Assessment of maize (*Zea mays*L.) damage and yield loss due to rodent in the field. PhD Degree awarded at Sokoine University of Agriculture, Morogoro, Tanzania, pp.1 - 20

Mulungu, L.S. Makundi, R.H.; Leirs, H.; Massawe A.P.; Vibe-Petersen, S. and Stenseth, N.C. (2003). The rodent density – damage function in maize fields at early growth stage. In: *Rats, mice and people: Rodent biology and management Singleton. (Edited by Singleton G.R.,Hinds, L.A., Krebs, C.J. and Spratt, D.M.)* ACIAR, Canberra. pp 301 - 313.

Musser, G.G. and Carleton, M. (1993). Family Muridae. *Mammal Species of the World,* A taxonomic and geographic reference. D.E. Wilson and D.M. Reeder (ed.). Smithsonian Institution Press, Washington. pp 576 - 578.

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

Mwanjabe, P.S. (1993). The role of weeds on population dynamics of *Mastomys natalensis* in Chunya (Lake Rukwa) valley. In: *Workshop proceedings of Economic importance and control of rodents in Tanzania.* (Edited by Machang'u R.S.). 6 – 8 July 1992, Sokoine University of Agriculture Morogoro, pp, 34 – 42.

Mwanjabe, P.S., Sirima, F. B., Lusingu, J. (2002). Crop losses due to outbreaks of *Mastomys natalensis* (Smith, 1834) (Muridae, Rodentia) in the Lindi region of Tanzania. *International Biodeterioration and Biodegradation* 49: 133 – 137.

Neal, B.R. (1976). Reproduction of the multimammate rat, *Mastomys natalensis* (Smith), in Uganda. *Sonderdruck aus Zeitschrift fur Saügetierkunde* 42: 221 - 231

Neal, B.R. (1981). Reproductive biology of the unstriped grass rat, *Arvicanthis*, in East Africa. *Zeitschrift fur Saügetierkunde* 46: 174 – 189.).

Neal, B.R. (1982). Reproductive biology of three species of gerbils (Genus *Tatera*) in East Africa. *Zeitschrift fur Säugetierk* 47: 287 – 296

Neal, B.R. (1984). Relationship between feeding habits, climate and reproduction of small mammals in Meru National Park, Kenya. *African Journal of Ecology* 22: 195 – 205.

Stenseth, N.; Leirs, H.; Mercelis, S and Mwanjabe, P. (2001). Comparing strategies for controlling an African pest rodent: an empirically based theoretical study. *Journal of Applied Ecology* 38: 1020 – 1031

O'Connor, A.J. and Negus, N.C. (1987). 6-MBOA triggers reproductive activity in a wild population of *Dipodomys ordii*. In: *Proceeding of the American Society of Mmmology 67th Annual Meeting,* Albuquerque, USA, 21, 21 – 25 June

Oguge, N. Ndung'u, D. and Okemo, P. (1997). Effect of neem plant (*Azadirachta indica* Juss, Meliaceae) products on maize grain consumption by three common rodents pests in Kenya. *Belgium Journal of Zoology* 127 (1): 129 – 135.

Parker, G. (1983). Demographic changes in a colony of Nile grass rats *Arvicanthis niloticus* in Tanzania. *Journal of Mammals* 64 (1): 159 – 161

Pernetta, J.C. (1976). Diets of the shrews *Sorex araneus* L. and *Sorex minutus* L. in Wytham grassland. *Journal of Animal Ecology* 45:899 - 912.

Pernetta, J.C. (1977). Population Ecology of British Shrews in Grassland. *Acta Theoriologica* 20: 279 – 296.

Petter, F.; Quilici, M.; Ranqouf, P.; Camerlynck, P. (1969). Croisement d' *Arvicanthis niloticus* (Rongeurs, Muridés) du Senegal et d' Ethiopie. *Mammalia* 33: 540 – 541.

Pinter, A.J. and Negus N.C. (1965). Effects of nutrition and photoperiod on reproductive physiology of *Microtus montanus*. *American Journal of Physiology* 208: 633 - 638

Pirlot, P.L. (1954). Pourcentages de jeunes et périodes de reproduction chez quelques Rongeurs du Congo Belge. *Annls Mus. Congo Belge (N.S.) Zoology* 1: 41 - 46

Pucek, Z. (1969). Trap response and estimation of the numbers of shrews in removal catches. *ActaTheoriologica* 14: 403 - 426

Quilici, M., Ranque, Ph. and Camerlynck, P. (1969). Elevage au laboratoire d' *Arvicanthis niloticus* (Desmarest, 1822). *Mammalia* 33: 345 - 347

Rahman, A.E.H. (2003). Taxonomical status of *Arvicanthis* Lesson, 1842 from Sudan. In: *Abstracts of the 9th International African Small Mammal Symposium.* (Edited by Makundi R.H.). 14 – 18 July 2003, Sokoine University of Agriculture, Morogoro, Tanzania, p12 .

Reichman, O.J. and Graaf, K.M. V an de. (1975). Association between ingestion of green vegetation and desert rodent reproduction. *Journal of Mammology* 56: 503 - 506

Rogers B.F.W. and Davis D.H.S. (1941). Reproduction in the multimammate mouse (*Mastomys erythroleucus*) of Sierra Leone. *London Journal of zoology.* 111B: 1.

Roservear, D.R. (1969). *The rodents of West Africa.* Trustees of the British Museum. (Natural History), *London Journal of Science* 677: 604

Senzota, R.B.M. (1982). The habitats and food habits of grass rats (*A. niloticus*) in the Serengeti National Park, Tanzania. *African Journal of Ecology* 20: 241 - 252

Sheppe, W.A.C. (1972). The annual cycle of small mammals populations on Zambian flood plain. *Mammalia* 53: 445 – 460

Sicard, B., Diarra, W., Cooper, H.M. (1999). Ecophysiology and Chronobiology Applied to Rodent Pest Management in Semi-arid Agricultural Areas in Sub-Saharan West Africa. In: *Ecologically-based Rodent Management. (Edited by Grant Singleton, Lyn Hinds, Herwig Leirs, and Zhibin Zhang)* ACIAR Canberra, Australia. pp 409 - 440

Singleton, G.R. (1985). Population dynamics of *Mus musculus* and its parasites in Mallee Wheatlands inVictoria during and after a drought. *Australian Wildlife Research* 12: 41 – 45

Stein, G.W.H. (1953). Über Umweltabhängigkeiten bei der Vermehrung der Feldmaus, *Microtus arvalis*. Population-sanalytische Untersuchungen an deutschen kleinen Saugetieren IV. *Systematic Zoology Journal* 81: 527 – 547.

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

Taylor, K.D. and Green M.G. (1976). The influence of rainfall on diet and reproduction in four African rodents species. *Journal of Zoology* 180:367-389

Telford, S.R, Jr. (1989). Population biology of the multimammate rat, *Praomys (Mastomys) natalensis* at Morogoro, Tanzania, 1981 – 1985. *Bulletin of the Florida State Museum, Biological Sciences* 34 (6): 249 – 288.

Tesha, P.P.H. (2001). Multidisplinary evaluation of the systematics of Tanzania species of unstriped grass rat (*Arvicanthis*) species. Msc Degree awarded at Sokoine University of Agriculture, Morogoro, Tanzania, 5 - 26.

Vandorpe, E. and Verhagen, R. (1979). An age reference model for the wood mouse, *Apodemus sylvaticus* (Linnaeus, 1758) by use of the lens technique. *Annales de la Societe* royale *Zoologique de Belgique* 109 (2 – 4): 133 - 140

Vibe-Petersen, S., Leirs, H., Oguge, N.O. Makundi, R.H. Sichilima, A.M. and Bekele, A.. (2003). Rodent population dynamics in eastern Africa – a comparative study. In: *Abstracts of the 9th International African Small Mammal Symposium.* (Edited by Makundi R.H.). 14 – 18 July 2003, Sokoine University of Agriculture, Morogoro, Tanzania, p 78.

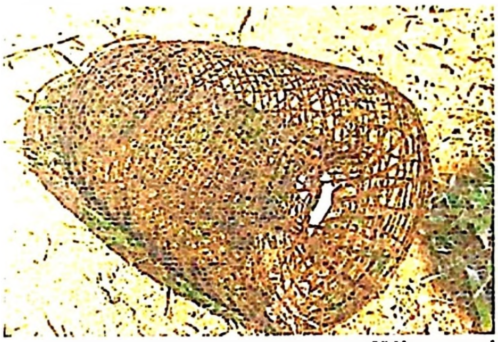
Weinbren, M.P. and Mason, P.J. (1957). Rift valley fever in a wild field rat *Arvicanthis abyssinicus*. A possible natural host. *South African Medical Journal*, 31: 427 – 430

Workneh G. (2003). Population dynamics of small mammals in Maynugus irrigation field, northern Ethiopia. In: *Abstracts of the 9th International African Small Mammal Symposium*. (Edited by Makundi R.H.). 14 – 18 July 2003, Sokoine University of Agriculture, Morogoro, Tanzania, p 36.

7. APPENDICES

Appendix 1. Types of traps used in the study, 2002/2003 season

Swadi (locally made)



Wire mesh traps (locally made)

Sherman live traps (Imported)

Appendix 2. Rainfall data obtained from Makambini Gairo-Morogoro (for Msingisi village) and Mlali-Dodoma (for Ihanda village), October 2002 – September 2003.

Month	Msingisi village		Ihanda village	
	Total (mm)	Number of days	Total (mm)	Number of days
October-02	3.0	1	0.0	0
November-02	0	0	21.5	1
December-02	42.3	5	106.1	4
January-03	47.3	4	114.3	7
February-03	52.0	2	72.7	3
March-03	70.3	7	73.3	6
April-03	12.0	3	29.4	3
May-03	23.0	6	46.4	5
June-03	23.7	4	2.5	1
July-03	0.0	0	0.0	0
August-03	2.0	1	0.0	0
September-03	0.0	0	0.0	0
Total	275.6	33	466.2	30
Average	8.4		15.5	

Appendix 3. Schematic presentation of toe clipping code