University of Venda

SCHOOL OF ENVIRONMENTAL SCIENCES

POTENTIAL IMPACTS OF CLIMATE CHANGE ON *MYOSOREX* SPECIES AS A MODEL FOR EXTINCTION RISK OF MONTANE SMALL MAMMALS IN SOUTH AFRICA

BY

OGONY LILIAN OWINO

STUDENT NUMBER: 11607I93

SIGNATURE.................................

A MASTERS DISSERTATION SUBMITTED TO THE DEPARTMENT OF ECOLOGY AND RESOURCE MANAGEMENT, SCHOOL OF ENVIRONMENTAL SCIENCES, UNIVERSITY OF VENDA, IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENVIRONMENTAL SCIENCES

SUPERVISOR : PROF. P. J. TAYLOR.................................

CO-SUPERVISORS : MR. R. M. BAXTER.................................

: PROF. J. S. OGOLA.................................

MAY: 2014

Declaration

I, Ogony Lilian Owino, hereby declare that this dissertation for the award of Master of Environmental Sciences in Ecology and Resource Management degree at the University of Venda, submitted by me, has not previously been submitted for a degree at this or any other university, and that it is my own original work in design and execution and that all reference material contained herein has been acknowledged.

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Abstract

The work focussed on the potential impacts of climate change on *Myosorex* species endemic to South Africa. The study investigated the potential impacts of climatic variables (temperature and rainfall) on the distribution of *M. cafer, M. varius, M. sclateri, M. longicaudatus*, southern and northern lineages of *M. varius*, and *Myosorex cf. tenuis* from Limpopo Province in space and time. The study also investigated the *Myosorex* species occurring in Limpopo Province by using morphological analysis. Ecological niche modelling using Maxent was applied to predict current and future distribution of these species. Eight bioclimatic variables for current and future projected scenarios together with occurrence data from South African Museums, new field collections from Soutpansberg Mountains and published data were used to build the models. Equal sensitivity and specificity threshold was used to map suitable habitat and the number of resolution were counted to get the present and future range including percentage decrease or increase in range. The current distributions and the future distributions for all the species were compared to determine the range shifts. The model results for range shifts revealed that the more temperate species such as *M. cafer, M. longicaudatus* and *M. varius* will suffer high profound contractions while those from the subtropical or coastal lowland ranges (*Myosorex* cf. tenuis, and *M. sclateri*) will even increase the range of suitable conditions, but given their poor dispersal capability and the absence of suitable habitat such as forest in the new ranges, these increases may not be realised. The northern and southern lineages *of M. varius* will suffer minimal range contraction. M. *longicaudatus* showed greatest contraction of suitable habitats, consequently, will experience the highest risk of extinction, at least in some parts of its range as a result of global warming associated with climate change by the year 2070. The results showed that global warming is an important factor that results in range shifts, thus affecting the distribution of *Myosorex* species in South Africa. Morphological results indicate that the *Myosorex* occurring in Limpopo Province is a distinct species that may be called *Myosorex cf. tenuis.*

Keywords: climate change, *Myosorex* species, range shifts, extinction risks, Maxent

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List of Abbreviations and Acronyms

AUC- Area under the Curve

BW- Bimaxillary Width

CI- Condy-incisive length

GCMs- Global Circulation Models

GHGs- Green House gases

GW- Greatest Width

ENMs-Ecological Niche Modeling

IPCC-Intergovernmental panel on Climate Change

LIW- Least Interobital Width

LTR- Lower Tooth Row

IUCN-International Union for Conservation of Nature

ROC- Receiver operation Curve

UTR- Upper Tooth Row

Definition of Terms

Biodiversity: Biodiversity is the variety of life on Earth, including genes, species and ecosystems.

Ecological Niche Modelling: is the process of using computer algorithms to predict the distribution of species in geographical space on the basis of mathematical representation of their known distribution in environmental space.

Climate Change: is a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods (IPCC, 2007).

Climatic Variation: is attributed mainly to natural processes (IPCC, 2007).

Endangered: A species is Endangered when the Extent of occurrence is <5000 km^2 and area of occupancy is <500 km^2, therefore considered to be facing risk of extinction.

Extinction: A species is extinct when the last individual has died.

Global Warming: is an increase in world mean temperature.

Habitat: is a home of species or where species occur.

Least Concern: A species is Least Concern when it has been evaluated against the criteria and does not qualify for critically Endangered or near Threatened.

Maxent: is a general purpose machine based learning method that makes predictions from incomplete information because it requires only presence data

Near threatened: A species is Near Threatened when it has been evaluated against the criteria but does not qualify for critically Endangered although close to qualifying for it.

Range Shifts: Range shifts are a natural response to climatic change where species will move to climatically suitable environment.

Vulnerable: A species is vulnerable when the extent of its occupancy is >20,000 km^2, area of occupancy is <2,000 km^2, habitat continue to decline and extreme fluctuations in area of occurrence and occupancy, therefore considered to be facing a very risk of extinction

CHAPTER ONE: INTRODUCTION

1.1 Background

Unprecedented increases in global temperatures and associated atmospheric changes have been documented in recent decades (IPCC, 2007). The observed increase of global temperature is a great concern regarding the future environment. Future global mean air temperature is projected to warm between 2^{0}-3^{0}C above preindustrial levels by 2100 (IPCC, 2007). According to future prediction, there will be an overall decrease in average rainfall and increase in temperature (IPCC, 2007). According to Parmesan and Yohe (2003), future changes in climate are expected to impact on the distribution of plant and animal species and affect individual species and populations.

The risk of extinction under predicted climate change is likely to differ considerably across geographical and latitudinal gradients and between ecosystems, animal communities and species (Thomas *et al*., 2004; Isaac and Williams, 2007). The species that are most vulnerable to extinction are those with restricted ranges, fragmented distribution within their range, small populations, and those that are already suffering from population decline (Price, 2000).

South Africa as a whole is characterized by a relatively dry climate with a high degree of inter-annual and inter-seasonal variability, and consequently, a high degree of vulnerability to change in the climate system (Hewitson, 1998). Therefore, the country is ill equipped for coping with extreme events (Williams *et al*., 2010) such as flooding or drought. In this case, climate change will have a significant impact on biodiversity in the region including small mammals with specialized habitats such as forest shrews (*Myosorex*). The anticipated increase in temperature may reduce the distribution range of temperate climate-adapted and montane *Myosorex* species in South Africa.

Myosorex species may be considered in this research to be good ecological indicators because they are sensitive to increases in temperature. They can also be considered as model taxa because they are widely distributed in the eastern part of southern Africa and also the results can give insights into the impacts of climate change on other montane small mammals. Ecological indicators aretaxa that are sensitive to identified environmental stress factors that demonstrate the effects of theseon biota and whose responses reflect responses of at least a subset of other taxa present in the habitat (Jones *et al*., 2009). No attempts have been made so far to develop a model which can monitor and predict the likely effects of future predicted climate change on the southern African *Myosorex* species. The research investigated the potential impacts of climate change on the South African *Myosorex* species, focusing mainly on how climatic variables impact on species distributions currently and by the year 2070.

1.2 Problem Statement

Climate change including global warming may have negative impacts on the population distribution of montane forest and grassland dwelling specieswith limited dispersal abilities such as *Myosorex*. *Myosorex* species are Afro-montane species that are likely to be of special concern, but the extent to which they are sensitive to climate change is currently unclear. Previous studies also suggested that some montane mammals face similar problems from rising temperature and shrinking habitat as the size of the mountain reduces as you go up (Colwell *et al.,* 2008; Gastner *et al.,* 2010), and some suggested that small mammals may be indicators of climate change, but this has not been tested on South African *Myosorex*. As such there is a need to develop a model which can predict and monitor effects of climatic changes on *Myosorex* and other montane small mammals in South Africa.

1.3 Justification

It is important to undertake this type of study because local case studies are important to test and fine–tune theoretical predictions of climate change, so appropriate mitigation can be derived at national level. This effectively includes useful information on extinction risks of forest shrews which can be applied in conservation planning and biodiversity policy in South Africa as shrews play an important role in some mammal ecosystems. The study also provides a model for predicting climate change impacts on forest shrews and other montane small mammals due to their highly specialized habitat and high sensitivity to temperature change because they are cool adapted mammals.

1.4 Hypotheses

- Due to the anticipated increases in temperature, the projected future climatic changes will decrease the distribution range of temperate and subtropical climate-adapted *Myosorex species* in South Africa by 2070.
- Species distributed in colder temperature or montane climates such as *M. varius, M. cafer* and *M. longicaudatus* would suffer significantly greater contractions than those from more sub-tropical climates such as Limpopo populations and lowland *M. sclateri* due to global warming associated with climate change.
- Habitat specialists such as *M. cafer* and *M. longicaudatus* are likely to experience higher extinction risks and range contraction due to global warming compared to habitat generalists such as *M. varius*.
- *Myosorex* from Limpopo Province is a distinct species from *varius* and *cafer*.

1.5. Objectives

The main objective was to determine potential impacts of climate change on *Myosorex* species ranges and to predict future range shifts and extinction risks of these predominantly montane small mammals.

The specific objectives were to;

- collect new field data and test whether *Myosorex* species from Limpopo Province are a distinct species from *M. cafer* and *M. varius* as literature is ambiguous about the status of Limpopo population;
- compile and verify existing published and museum datasets, and newly collected field data from Limpopo Province;
- apply Ecological Niche Modelling analyses using Maxent to determine predicted patterns of current distributions and to determine significant environmental drivers of distribution of the four *Myosorex* species;
- apply Maxent model analysis to predict changes in species distribution ranges in response to climate change in future scenarios by the year 2070;
- model genetic lineages of *M. varius* separately to determine if their current and future ecological niche are the same as that of *M. varius*;

- compare current and future predicted geographical distribution of *Myosorex* species to determine the species which has the highest extinction risk and if range shifts among specialist species and genetic lineages will be different from that of generalist species; and
- model recent collections from Limpopo Province separately given evidence of their distinct specific status.

2 CHAPTER TWO: LITERATURE REVIEW

2.1 Taxonomy and Evolutionary History of *Myosorex*

Genus *Myosorex* represents a small but interesting central, eastern and southern African radiation of Afro-montane shrews (Willows-Munro and Matthee, 2011). The genus is endemic to Africa with most members distributed in central and Southern Africa. Its evolutionary history and taxonomy isunclear and morphological differentiation among species is also complex (Furio *et al.*, 2007). Most of these species populations occur in the forested highlands of central, east and southern Africa (Kingdon, 1997). According to Butler and Hopwood (1957), *Myosorex* originated in central Africa, based on distributional data, and some paleontological suggestions. Southwards migrations led to the establishment of southern Africa species, but the exact timing is not clear (Heim de Balsac, 1967).

Most *Myosorex* species are difficult to distinguish morphologically. In Central and East Africa most of the taxonomy of the genus is based on the geographic location together with minor differences in tail length and skull size (Stanley and Hutterer, 2000). According to Meester (1958), the distribution of the limited morphological variation within the southern African *Myosorex*, was the product of dispersal events from East Africa. The first radiation gave rise to *M. varius* after the southern populations became isolated from the ancestral east African population during an arid period in the Quaternary, a second wave of colonization along the east coast of South Africa ledto the establishment of *M. cafer* and *M. sclateri* (Kearney, 1993).

The genus is made up of 14 species (Hutterer, 2013), *M. cafer, M. varius, M. sclateri, M. zinki, M. tenuis, M. schalleri, M. rumpii. M. okuensis, M. longicaudatus, M. kihaulei, M. geata, M. eisentrauti, M. blarina*, and *M. babauaiti*. The genus *Myosorex* mostly confined to high altitudes (Heimde Balsac and Lamotte, 1956, Huttterer, 2013). *Myosorex* is represented in South Africa by five species namely *M. cafer, M. varius, M. sclateri M. longicaudatus* and *M. tenuis*, but the validity of *M. tenuis* has been queried and the use of diploid chromosome data which was used to distinguish species is questionable (Willows-Munro and Matthee, 2011).

This is an area which needs further research because according to Taylor *et al*, (2013) DNA evidence points to the existence of cryptic un-described species of forest shrews and so the level of diversity is underestimated. *Myosorex* species at Soutpansberg in Limpopo Province needs further research for confirmation of identifications in order to clarify the distribution limits of *M. cafer* and *M. varius* in Limpopo Province (Taylor *et al*., 2013).

The endemic southern Africans pecialist *Myosorex cafer* species is generally confined to moist, densely vegetated, coastalscarp, forest and montane habitats (Willows-Munro and Matthee, 2008). Generalist *M. varius* is adapted to montane grassland or fynbos habitats and only moves into forest where *M. cafer* is absent. The current distribution of *M. cafer* closely follows that of indigenous forest along the eastern seaboard of southern Africa (Skinner and Chimimba, 2005).

2.2 Characteristicsof Shrews

Shrew is the common name for small, mouse-like insectivorous mammals. Small mammals such as shrews have a high surface area to volume ratio, which results in rapid heat exchange with the environment (Schmidt-Nielsen, 1990). Shrews are typically small, fast running, terrestrial or semi fossorial insectivores with long pointed snouts, minute eyes, small ears, short limbs, long tail and short dense fur (Hutterer, 2013).

They generally have poor vision and they rely on tactile, auditory and olfactory senses for navigation and orientation around their home- ranges for locating prey. The total number of teeth in extant species of shrews varies between 28 and 32. They have six teeth on each side of the lower jaw but a variable number in the upper jaw. They are found in Eurasia, South Asia, America and Africa. All African shrews are members of the Crocidurinae or Myosoricinae (Hutterer, 2013).

They have excellent senses of hearing and smell (Barnard, 1984). Soricine shrews have particularly high metabolic rates and energy requirements (Churchfield, 1990). They remain active in bursts throughout the 24-hour period and soon die if deprived of either food or water, even for relatively short periods (Meester, 1963). According to Taylor (1998), shrews often have a musky smell. They live for between 12 and 30 months (Macdonald, 2006). They have average daily energy expenditures significantly greater than those of rodents of similar size (Hutterer, 2013). Soricine shrews have particularly high metabolic rates and energy requirements (Churchfield, 1990).

Shrews feed on a variety of invertebrates. The principal prey of most species is arthropods (insects), mollucs and earthworms (Hutterer, 2013). Most species in Africa breed mostly during warm, wet months and reproduction declines in the dry seasons (Rowe-Rowe and Meester, 1985). The breeding season of shrews (*Myosorex*) in southern Africa coincides with the onset of the rains but also influenced by temperature. Those at higher altitudes commence breeding later than those at lower altitudes (Rowe-Rowe and Meester, 1985).

2.3 Different Species of Genus *Mysosorex*

*Myosorex*s pecies which are endemic to South Africa, Lesotho and Swaziland are represented in Figure 2.1.

M. cafer

M. sclateri

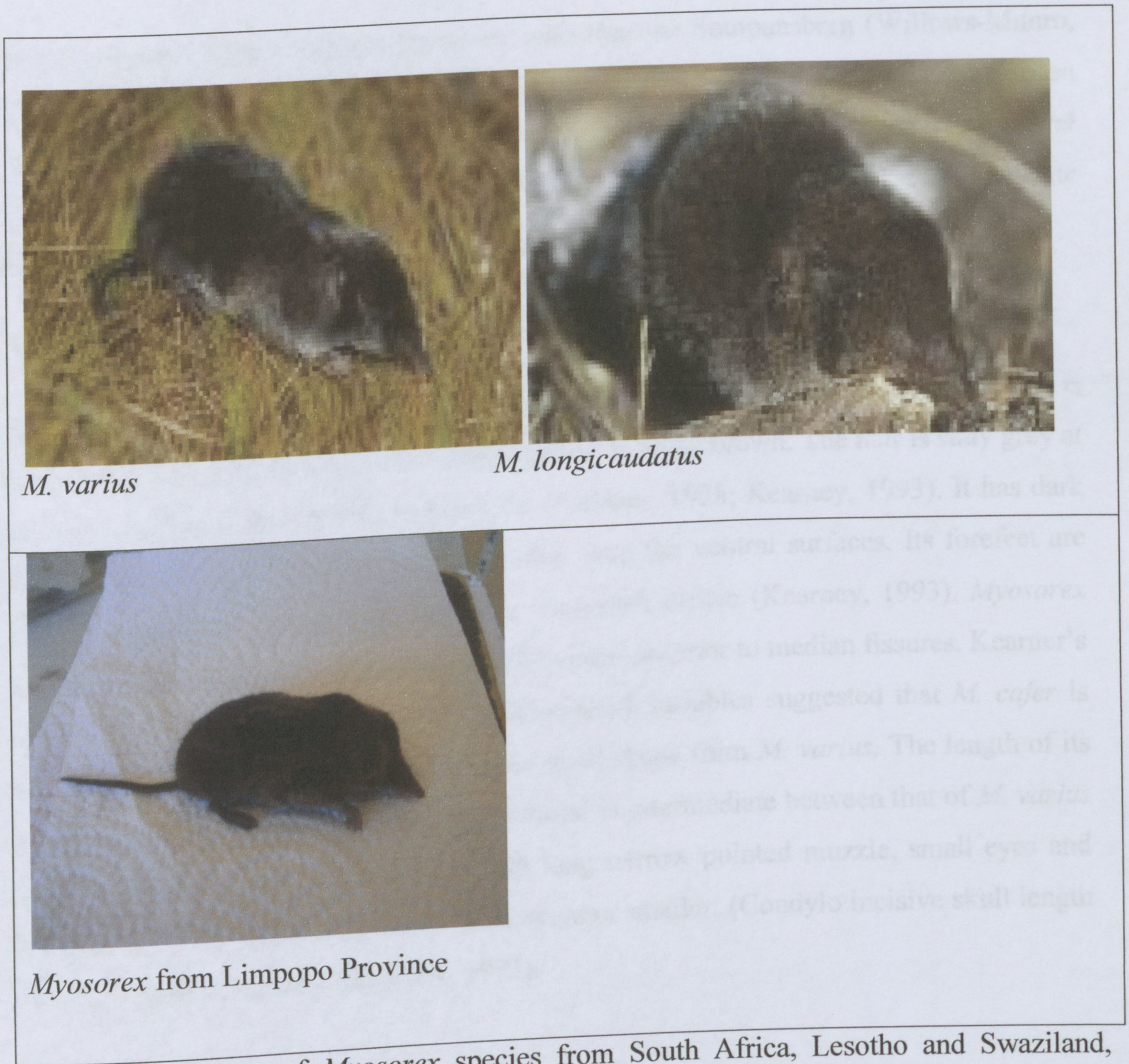


Figure 2.1: Photos of *Myosorex* species from South Africa, Lesotho and Swaziland, (Myers *et al*., 2013).

2.3.1 *Myosorex cafer*

Taxonomy

M. cafer was originally described in the genus *Sorex* and the status of the Zimbabwe and Mozambique populations is uncertain (Meester *et al*., 1958), variation in chromosome number in the more central parts of the geographic range in South Africa suggests the presence of another species. Willows-Munro, (2008) recognized *M. cafer* from Zimbabwe as a distinct species from South African *M. cafer* and *M. sclateri* based on mtDNA haplotypes. Within South African *M. cafer*, there is a distinct lineage which has been recognized from Limpopo Province, including the Soutpansberg (Willows-Munro, 2008; Taylor, *et al.,* 2013) which may also be a distinct species. *M. sclateri* has been regarded as a subspecies of *M. cafer* (Meester, 1986), however, the recent biochemical (Maddalena and Bronner, 1992) and morphological (Kearney, 1993) evidence indicate that *M. sclateri* is distinct from both *M. cafer* and *M. varius.*

Description and Diagnosis

Myosorex cafer is a medium-sized shrew with a medium sized tail. Its dorsal pelage is dark brown with a buffy tinge. The ventral pelage is buffy brown. The hair is slaty grey at the base and has a dark brown to black tip (Meester, 1958; Kearney, 1993). It has dark feet and the dorsal of its hind feet are darker than the ventral surfaces. Its forefeet are paler than the hind feet and the tail is an even dark brown (Kearney, 1993). *Myosorex cafer* has anterior palate with lateral palatal fissures anterior to median fissures. Kearner's (1993) principle component analysis of 22 cranial variables suggested that *M. cafer* is smaller than *M. sclateri* and has a different skull shape from *M. varius.* The length of its mandible and the width of the third upper molar is intermediate between that of *M. varius* and *M. sclateri.* The head is slender with long narrow pointed muzzle, small eyes and rounded ears. The skull of *M. cafer* is on average smaller; (Condylo incisive skull length 23.3 mm) than *M. sclateri* (Kearney, 1993).

Habitat and Ecology

Myosorex cafer typically occurs in forest although may also be found in montane grassland, for example in the Wolkberg, where *M. varius* is commonest in the adjacent forest (Rautenbach, 1982). The species is more abundant in damp microhabitats. It appears to have a stricter habitat requirement than *M. varius*, which occurs throughout its South African geographic range. *M. cafer* tends to be commonest species in the forests whereas *M. varius* in the grasslands (Baxter and Dippenaar, 2013). In KwaZulu-Natal, this species has been collected almost exclusively from Afromontane and coastal forest habitats (Skinner and Chimimba, 2005; Taylor, 1998).

Distribution and Diversity

Myosorex cafer is endemic to Africa especially Zambezian Woodland, Highveld and costal forest Mosaic of southern Africa (Baxter and Dippener, 2013). The distribution of species were recorded from three separate regions namely; eastern highlands of Zimbabwe and adjacent Mozambique; Soutpansberg Range (Fig. 2.2) in far northern South Africa and Siwaziland; eastern escarpement of Limpopo and Mpumalanga Province and into afromontane and coastal forests of southern KwaZulu-Natal and the eastern Cape Province (Meester, 1958, Rautenbach, 1982; Friedmann and Daly, 2004). However, according to the present study, the presence of *M. cafer* in Limpopo Province is not clear as the present studies suggest that Soutpansberg may contain *Myosorex* species which have not been identified (Taylor *et al*., 2013).

Conservation

Myosorex cafer is listed globally as Least Concern by IUCN (Baxter 2008a). Nationally it is Data Deficient (Friedman and Daly, 2004). Destruction of habitats is a potential threat to this species (Baxter and Dippenaar, 2013).

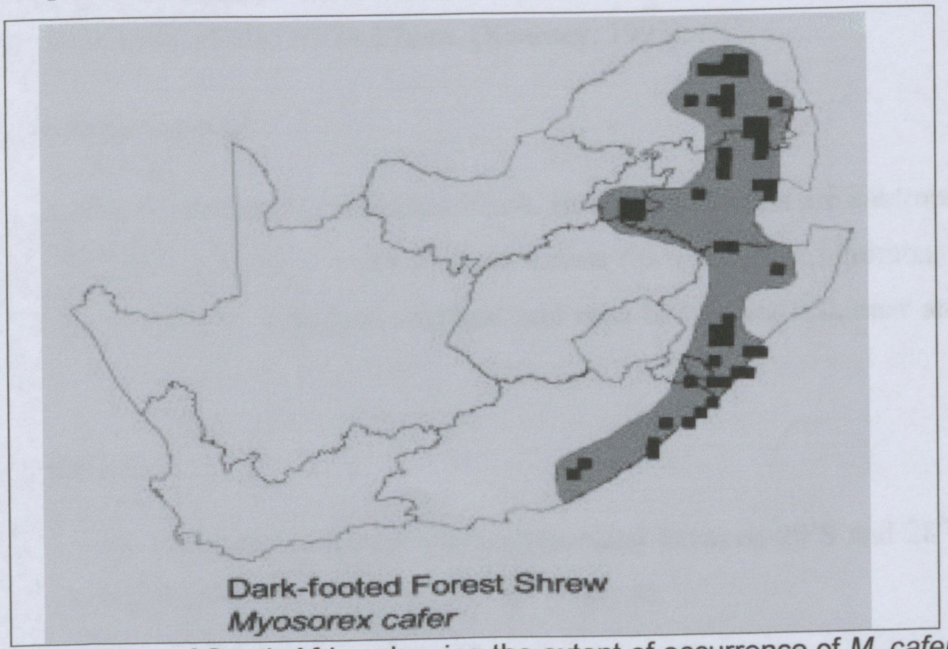


Figure 2.2: Map of South Africa showing the extent of occurrence of *M. cafer*, the black squares indicate the presence of *M. cafer* and dark grey indicates suitable habitat for the species (Friedmann andDaly, 2004).

2.3.2 *Myosorex sclateri*

Taxonomy

M. sclateri is sometimes regarded as a subspecies of *M. cafer* (Meester *et al*., 1986). According to the differences in karyotype and habitat suggest *sclateri* should be recognized as a valid species (Hutterer, 2005). The species can also be distinguished from *M. cafer* and *M. varius* on biochemical evidence (Maddalena and Bronner, 1992), and morphological grounds (Kearney, 1993), and mtDNA hyplotypes (Willows-Munro, 2008).

Description and Diagnosis

Myosorex sclateri is a large shrew but with considerable variation in size. *Myosorex sclateri* is darker on the whole and larger than *M. cafer*. Its dorsal pelage is bright reddish to brown or darkbrown to black and markedly tinged with black (Kearney, 1993). The pelage may also be glossy, having what appears to be a dark purple sheen, and in some cases grizzled in appearance (Kearney, 1993). The feet are broad and digits are relatively long. Hind feet are brown to black and tail is short to medium (43-63% of HB) and uniformly brown, skull: CI=24-27mm, (Kearney, 1993).

Habitat and Ecology

This species is endemic to KwaZulu-Natal. Its natural habitats are subtropical; swamps, coastal forests and tropical moist lowland forests (Skinner and Chimimba, 2005). It was also found present in grassland, wetland and reed bed habitat (Skinner and Chimimba, 2005).

Distribution

The species is endemic to northern KwaZulu-Natal between 29˚S and 28˚E and east of 31˚E. It is restricted to coastal forest mosaic (Fig.2.3).

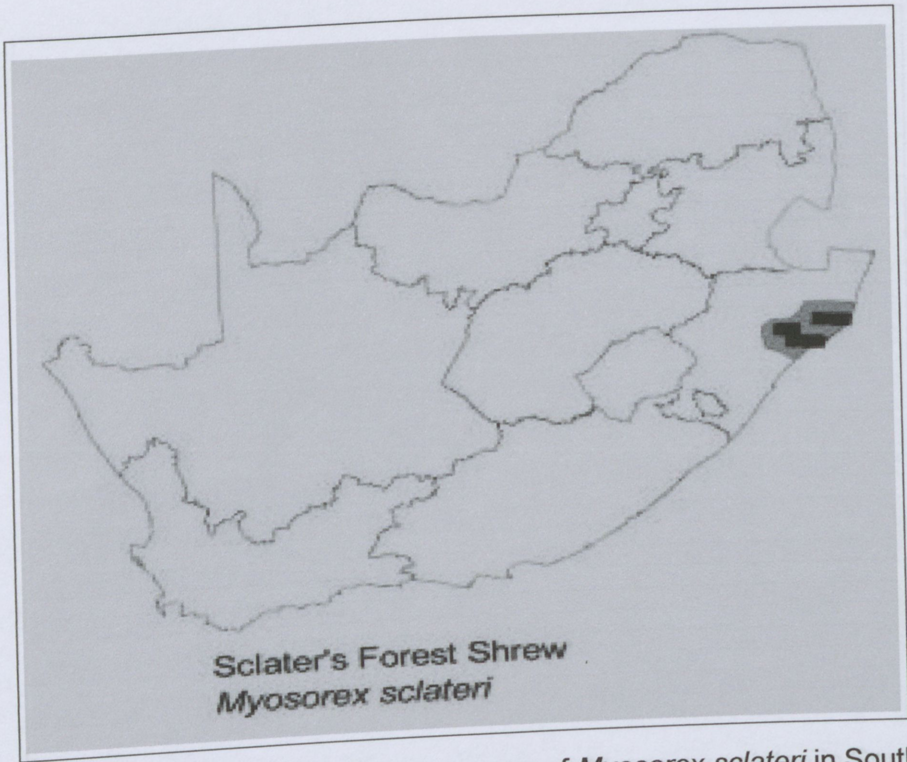


Figure 2.3: Map showing the extent of occurrence of *Myosorex sclateri* in South Africa, and black squares show species presence and dark grey indicate suitable habitat for the species (Friedmann and Daly, 2004).

Conservation Status

Myosorex sclateri is listed globally in the IUCN Red list as Near Threatened (Baxter, 2008c) and Nationally as Endangered (Friedmann and Daly, 2004).

2.3.3 *Myosorex varius*

Subspecies have been recognized by Willow Munro and Muthee (2011). Significant size variation is found across its range (Meester *et al*., 1986). The diploid number is 2n=40 or 42 (Dippenaar *et al.*, 1993). The species is often difficult to separate from *M. cafer* although Kearney (1993) showed that in KwaZulu-Natal, *M. varius* can be separated from both *M. cafer* and *M. sclateri* using multivariate morphometric methods.

Description and Diagnosis

Myosorex varius is a medium-sized shrew and considered to be a more generalist species, (Dippenaar *et al.,* 1983). The species has a total length of about120 mm, with tail that is

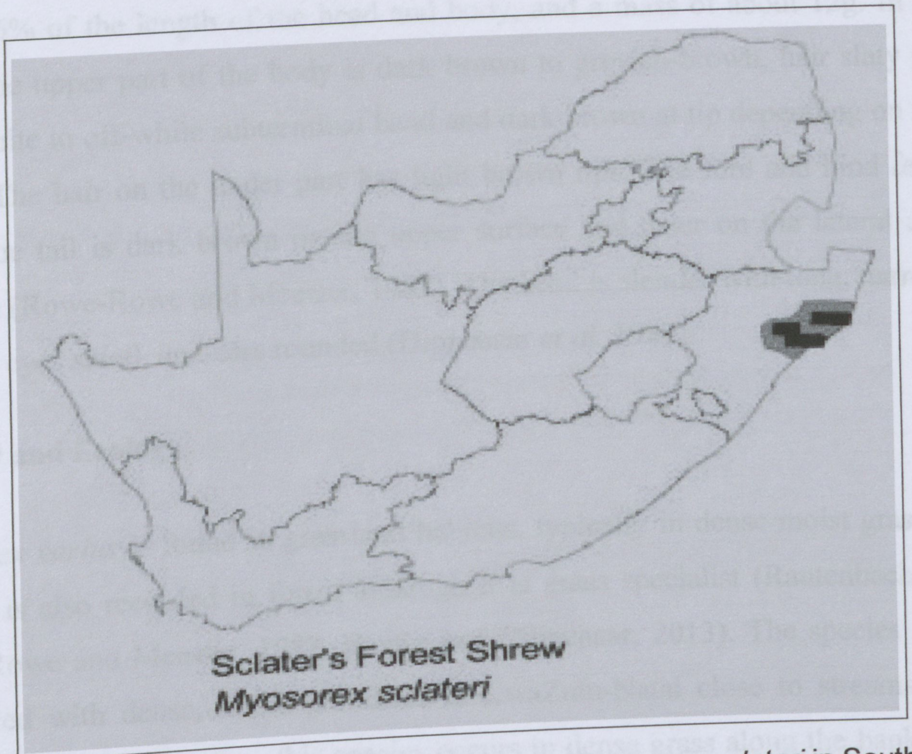


Figure 2.3: Map showing the extent of occurrence of *Myosorex sclateri* in South Africa, the black squares show species presence and dark grey indicate suitable habitat for the species (Friedmann and Daly, 2004).

Conservation Status

Myosorex sclateri is listed globally in the IUCN Red list as Near Threatened (Baxter, 2008c) and Nationally as Endangered (Friedmann and Daly, 2004).

2.3.3 *Myosorex varius*

Subspecies have been recognized by Willow Munro and Muthee (2011). Significant size variation is found across its range (Meester *et al.*, 1986). The diploid number is 2n=40 or 42 (Dippenaar *et al.*, 1993). The species is often difficult to separate from *M. cafer* although Kearney (1993) showed that in KwaZulu-Natal, *M. varius* can be separated from both *M. cafer* and *M. sclateri* using multivariate morphometric methods.

Description and Diagnosis

Myosorex varius is a medium-sized shrew and considered to be a more generalist species, (Dippenaar *et al.*, 1983). The species has a total length of about120 mm, with tail that is about 46% of the length of the head and body, and a mass of about 12g. In KwaZulu–Natal, the upper part of the body is dark brown to greyish-brown, hair slaty grey at the base, white to off-white subterminal band and dark brown at tip depending on its place of origin. The hair on the under part has light brown tips. The fore and hind feet are pale grey. The tail is dark brown on the upper surface and paler on the lateral and ventral surfaces (Rowe-Rowe and Meester, 1985). The head is slender with long, narrow pointed muzzle, eyes small, and ears rounded (Dippenaar *et al.* 1983).

Habitat and Ecology

Myosorex varius is found in grassland habitats, typically in dense moist grassland. This species is also recorded in forest although it is grass specialist (Rautenbach, 1982 and Rowe-Rowe and Meester, 1982, Baxter and Dippenaar, 2013). The species is typically associated with dense, moist grassland in KwaZulu-Natal close to streams and dams (Taylor, 1998). In Gauteng, this species occurs in dense grass along the banks of rivers. In Northern Cape, Western Cape and Eastern Cape it occurs on the coastal mountains (Rowe-Rowe and Meester, 1982). The species is also associated with rocky areas and in Lesotho it occurs in the moist regions with altitudes over 1750 m and more in particularly in high rainfall areas (Lynch, 1994). In South Africa *M. varius* is found at higher altitude than any other shrew species (Rowe-Rowe and Meester, 1982); and it has been reported from forest habitats in the Drakensberg at an altitude of 1500-1800 m. According to Rowe-Rowe and Meester, (1982), *M. varius* is also recorded in grasslands, woodlands and scrub from 1500-3000 m.

In the Eastern Cape the highest densities are found at altitudes of more than 1200 m. This species also shows geographic variability in overall body size and are able to adjust their reproductive cycle to suit different environmental conditions particularly rainfall (Baxter, 2005). Following the population genetic theory, the effect of habitat fragmentation due to climate cycles would be less severe on generalist species (*M. varius*) as genetic cohesiveness could be maintained through large effective population size, distance dispersal and recolonization, thus the species is considered to be a generalist species (Willows-Munro and Matthee, 2011).

Distribution and Diversity

Myosorex varius is ubiquitous in its habitats, found in many different biomes, and also in the relatively arid west coast of South Africa (Skinner and Chimimba, 2005). *M. varius* occurs in Gauteng, Mpumalanga, North eastern, Free State, throughout KwaZulu-Natal, the EasternCape, and along the coast from Western Cape to the north–western parts of the Northern Cape as far as Port Nolloth (Fig. 2.4). It is widely distributed in the dry fynbos habitats of Western Cape and the grassland of the northern interior of South Africa (Skinner and Chimimba, 2005).

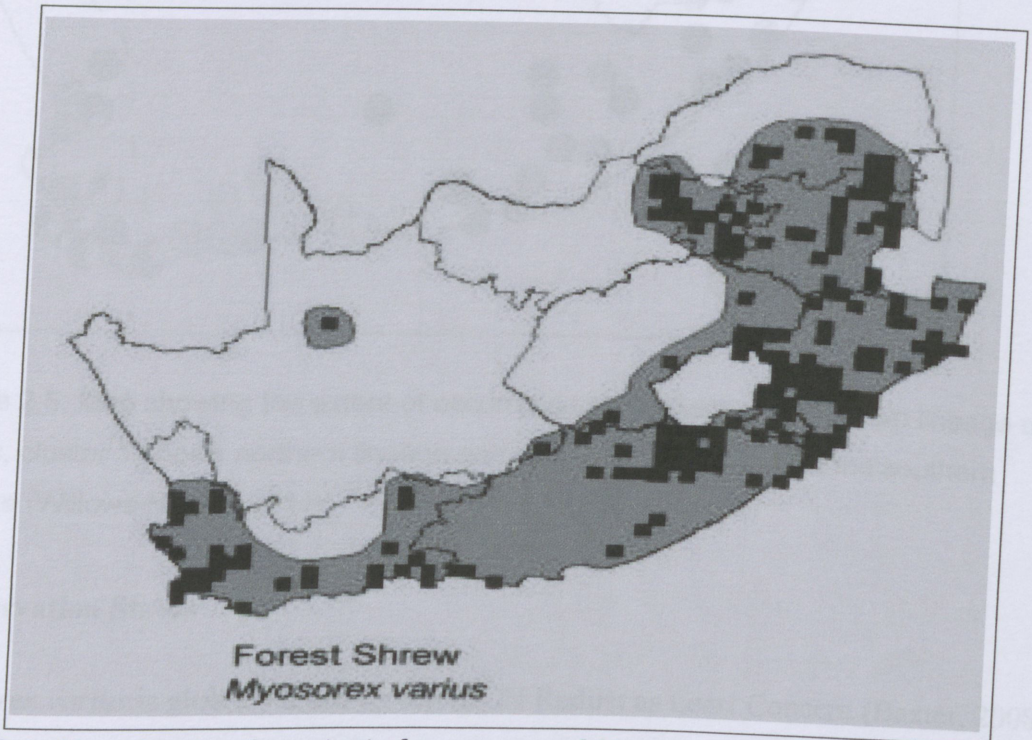


Figure2.4: Map showing the extent of occurrenceof *Myosorex varius* in South Africa, Swaziland and Lesotho, and the small squares show the presence of *M. varius* and dark grey indicates suitable habitat (Friedmann and Daly, 2004).

According to Willows- Munro and Matthee (2011), there is northern and southern lineage of *Myosorex varius*. The northern lineage is distributed predominantly within the summer rainfall, grassland, and savanna biomes (Willows-Munro and Mathee, 2011) while the southern is distributed in winter rainfall parts of the Western and Eastern Cape Provinces (Fig. 2.5).

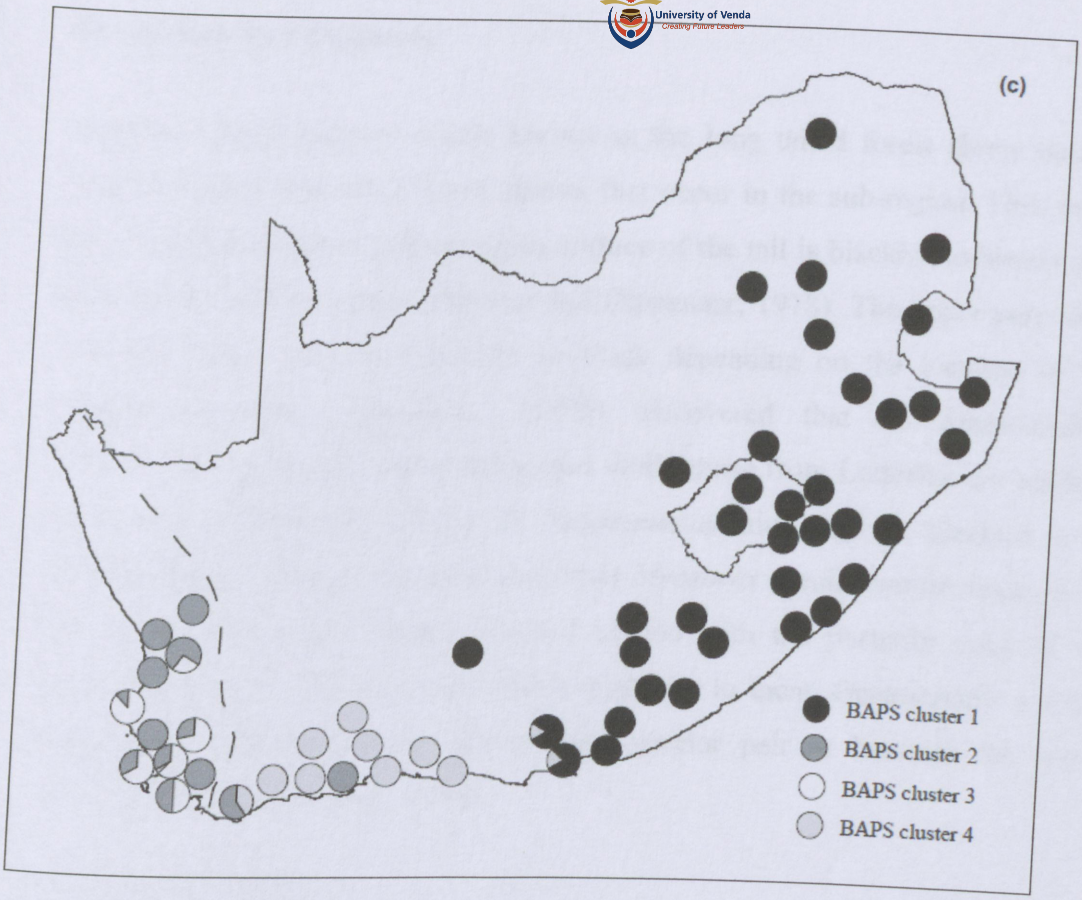


Figure 2.5: Map showing the extent of occurrence of northern and southern lineage of *M. varius*, cluster 1 shows northern lineage and claster 2, 3, and 4 show the southern lineage (Willows-Munro, 2011).

Conservation Status

Myosorex varius is globally listed by the IUCN Redlist as Least Concern (Baxter, 2008d) and Nationally as Data Deficient (Friedmann and Daly, 2004).

2.3 *Myosorex longicaudatus*

Taxonomy

Dippenaar (1995) described two subspecies: *M. longicaudatus*, from the Knysna forest, and *M. boosmani*, fromthe Boosmansbos Wilderness area, Langeberg Mountains.

Description and Diagnosis

Myosorex longicaudatus is also known as the long tailed forest shrew because it has longer tail than any other forest shrews that occur in the sub-region. This species has a thick tail near the base and the upper surface of the tail is blackish to brown and slightly paler on the under surface (Meester and Dippenaar, 1978). The upper parts of the body vary from dark grey to brownish or black depending on the location of its habitat (Dippenaar, 1995). Dippenaar, (1995) discovered that *M. longicaudatus* from Boosmansbos is slightly paler and greyer while those from Lottering are reddish brown. According to Dippenaar (1995), *M. longicaudatus* hind legs are blackish to brown or grayish and have longer feet than any other *Myosorex* species within South Africa. This species has two small fissures situated in line with the posterior edge of the larger anterior pair or in 76% of cases entirely posterior to them. Occasionally, a third fissure presence is situated directly behind the posterior pair or between the anterior and posterior pairs (Dippennaar, 1995).

Habitat and Ecology

M. longicaudatus is found in forests, forest edges, fynbos and boggy grassland. It is mainly found in a moist microhabitat and also restricted to pristine primary habitat that has not been degraded. *M. longicaudatus* occurs along entire elevational gradients at localities above the 800mm isohyets, in moist habitats (Dippenaar, 1995). Climate change is considered as the main threat to this species. Habitat in neighbouring areas is arid and unsuitable for this species as it depends on moist habitat. This would make it difficult for this species to move to other areas if climate in its range become unsuitable for its survival. The moist habitat of this species is fragmented and it is predicted that coastal population might be less risk than inland population.

Distribution and Diversity

Myosorex longicaudatus is endemic to South Africa and has been identified in five locations in Western Cape and Eastern Cape (Meester and Dippenaar, 1978). This species is mainly found along the entire altitudinal gradient from 240 m above sea level near

Nature's Valley to 200 m in the Outeniqua Mountains in NNW of Mossel Bay and NNE of Knysna (33◦57'S, 23◦10'E). It is also found in Lottering State Forest, near the eastern limits of Knysna forest, Diewalle State Forest, and Tonnelbos Forest (Fig. 2.6).

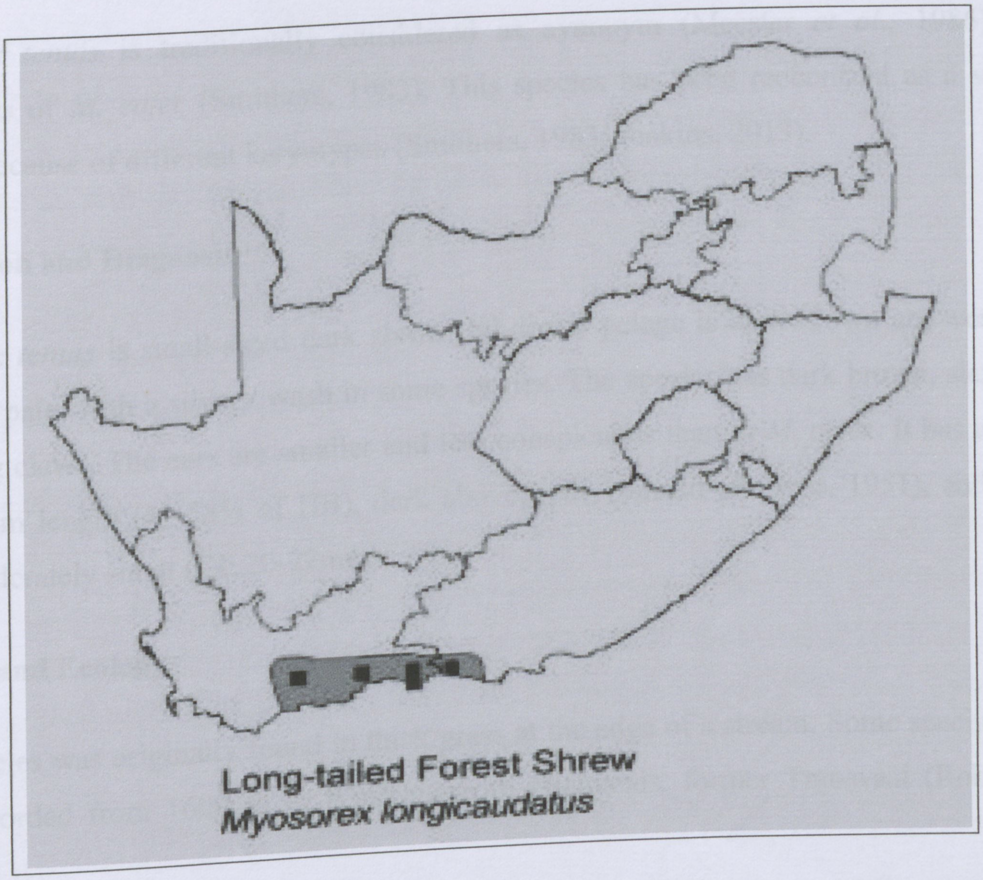


Figure 2.6: Map of South Africa, Swaziland and Lesotho showing the extent of occurance of *Myosorex longicaudatus* in South Africa, the small squares indicate the presence of *M. longicaudatus* and dark grey indicates suitable habitat (Friedmann and Daly, 2004).

Conservation Status

Global Redlist status is Vulnerable (Baxter, 2008b) and National status is Near Threatened (Friedmann and Daly, 2004). The conservation action that has been taken is that all indingenous forests in South Africa are protected by law (IUCN, 2012). This species is also present in protected areas such as the Diepwalle Reserve (IUCN, 2012).

2.3.5 Myosorex *tenuis*

Taxonomy

Myosorex tenuis is traditionally considered as aynonym (Meester *et al.*, 1986) or subspecies of *M. cafer* (Smithers, 1983). This species has been reoconized as a valid species because of different karyotypes (Smithers, 1983; Jenkins, 2013).

Discription and Diagnosis

Myosorex tenuis is small-sized dark shrew. Its dorsal pelage is dark brown and ventral pelage is pale, with a silvery wash in some species. The species has dark brown, slender with long claws. The ears are smaller and less conspicuous than in *M. cafer*. It has a tail of medium length (41-58% of HB), dark above, pale beneath (Roberts, 1951), and the skull moderately small (CI: 20-22mm).

Habitat and Ecology

This species was originally found in thick grass at the edge of a stream. Some specimens were recorded from 1600 m in Wakkerstroom Highlands, former Transvaal (Roberts, 1951).

Distribution

Myosorex tenuis has been recorded at Wakkerstroom highland in Mpumalanga Province, Woodbush and Entabeni in Limpopo Province (Roberts, 1951; Jenkins, 2013).

2.3.6 *Myosorex* from Limpopo Province

There is a misunderstanding about which species (*M. cafer* or *M. varius*) is found in northern Limpopo Province, in the mist belt forest, and grassland habitat of the Soutpansberg Mountains. Fromthe previous studies, *M. cafer* is found in the Soutpansberg. Friedmann and Daly (2004) and Willows-Munro (2008) suggested that the species collected from Soutpansberg is closely related to *M. cafer*. Traditional morphological studies led to assumption that *M. cafer* is found in the Soutpansberg Mountains (Meester, 1963; Meester, 1986). Genetic studies (Willows-Munro, 2008) indicated that specimens collected at Soutpansberg are genetically distinct from *M. cafer*.

Recentstudy (Taylor, *et al.*, 2013) suggests that Soutpansberg may contain *Myosorex* species which have not been identified and therefore tentatively assigned to *Myosorex cf. tenuis* based on small cranial size which was also recognized by Roberts (1951). According to Roberts (1951), *Myosorex* species from Woodbush, Entabeni Forest in Soutpansberg Mountains and Wakkerstroom in Mpumalanga Province were assigned to *M. tenuis* based on craniometrics.

2.4 Climate Change

Climate change is a change in climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods (IPCC, 2007). Climatic variations are attributed mainly to natural processes while the observed climate change is due to anthropogenic causes (IPCC, 2007). According to Intergovernmental Panel for Climate change (IPCC, 2007), climate change is primarily caused by increased atmospheric concentration of greenhouse gases (GHGs), due to human activities.

Increased concentration of these gases would cause global warming accompanied by a shift in rainfall patterns (IPCC, 2007). The IPCC, 2007, Third Assessment Report indicates that climate change is already happening and will continue to happen even if global greenhouse gas emissions are curtailed significantly in short to medium term. Current atmospheric levels are 390 ppm of CO_2 and are increasing at the rate above the worst case scenario of the Intergovernmental Panel for Climate Change (Canadell *et al*,. 2007). Global increase in mean surface air temperature between 0.3ºC and 0.6 ºC per decade has been experienced since about 1860 (IPPC, 2007). According to IPCC (2007), temperature increase of 2-3ºC is likely to trigger substantial changes in biodiversity.

Climate change poses a number of potential problems for biodiversity conservation and management. These include effects on species such as changes in phenology, extinction rates and geographic range (Hole *et al*., 2009). Climate change has been reported as a major driver of global biodiversity loss and has been linked to species level extinction (Pounds, *et al.,* 1999; Araujo *et al*., 2006; Thuiller *et al.,* 2008; Hole *et al*., 2009). Climate change is not only about temperature but it is also about precipitation. On land the two most important parameters are temperature and precipitation (Sodhi, 2008). Temperature increase is the main driver of climate change thus causes habitat loss at higher elevations (Enguist, 2002; Li *et al.,* 2009).

As summarised in the National Climate Change Response White paper (2011) South Africa is vulnerable to impacts of climate change. Under emission scenarios that are optimistic given current international emission trends, it has been predicted that by 2050, the South African coast will warm by around 1 to 2°C and the interior by aroundto 3°C. By 2100, warming is projected to reach around 3 to 4°C along the coast, and 6 to 7°C in the interior. With such temperature increase, both fauna and flora will be severely affected as most parts of the country will be much drier and increased evaporation will bring about decrease in water availability (Driver *et al*., 2011).

2.5 Effects of Climate Change on Biodiversity

Biodiversity is the variety of life on Earth, including genes, species and ecosystems. Biodiversity is important because it constitutes ecological infrastructure or natural capital on which human wellbeing depends. South Africa is diverse interms of biological resources and ecology. The country is home to 6% of the world's plant and mammal species, 8% of bird species and 5% of reptile species (Driver, *et al.,* 2011). South Africa has a huge range of habitats with nine biomes ranging from desert to grassland and forest (Driver, *et al.,* 2011).

Climate change has been postulated to be the main cause of biodiversity loss globally as it affects species habitats. It influences species distribution, population size, species richness as well as species composition (Thuiller *et al.,* 2008). The species may remain at and adapt to their current range or respond to environmental changes with range expansions, contractions or shifts (Parmesan, 2006). Increase temperature may force cool adapted species to move up - slope or pole–wards to new areas with suitable habitat (Parmesan, 2006).

Climate change may lead to diminishing of the surface area of specialized habitats and thus lead to extinction risk (Andrew, 2009). Cool adapted animals near the equator cannot tolerate environmental changes for the area experience intensive heat due to global warming. Decrease in temperature can cause warm adapted animals to be extinct and whist increase in temperature may cause cool adapted animals to decrease (Stanley, 1986). Climate change has already been seen to affect animals and plants in different ways: plants bloom earlier, mammals hibernate sooner and birds lay eggs earlier in the year than usual (Hughes, 2000).

2.6 Effects of Climate Change on Montane Mammalsdiversity

Mountains are centers of global biodiversity and threatened species (Hannah *et al.*, 2007). Climate change increases the risk of extinction of species that have narrow geographic and climatic ranges (Hannah *et al.*, 2007). Threatened and endemic species are most vulnerable. According to prevailing extinction theory, more highly specialized species are more likely to be lost due to habitat destruction and increase in temperature (Sodhi *et a.l*, 2004). This is a real factor that affect highland species which are sensitive to climate change (Pounds *et al*., 2006) and more likely to be at risk of extinction. This is because mountain climates change more rapidly with elevation at about 1°C per 160 m than it does with latitude at about 1°C per 150 km (IPCC, 1996).

Montane species are among the most vulnerable to climate change (Serkercioglu *et al*., 2008). Warming temperatures reduce small montane species range by forcing them to shift upslope and some species may be driven to local or global extinction (Colwell *et al.*, 2008; Gastner *et al.,* 2010). Highland habitat and especially small mammal species are vulnerable to warming temperatures (Williams *et al*., 2003).

Highland species are vulnerable to changing conditions because they have very little room to move up the slope (Andrew, 2009). This is because simple geometry dictates that small areas even those of irregular shape will have smaller perimeters. Species with limited distribution generally have smaller population sizes concentrated in smaller geographic areas (Andrew, 2009). This may make them more vulnerable to change than species with larger population size and distributions (Andrew, 2009).

Montane endemic specieshave limited capacity to shift their ranges across unsuitable habitat to other mountain ranges which could make them vulnerable to extinction due to climate change (Sekercioglu *et al.,* 2008).

2.7Range Shifts and Extinction Risk

Range shifts are a natural response to climate change. Species may respond to climate change by moving to different elevations or latitudes. Many tropical species have narrow elevation ranges and thermal tolerances and their local environmental conditionis not constant (Huey *et al*., 2009). As regional temperature increases, such species may not persist unless they move to high elevation. There are many records from temperate regions of species that have shifted their elevation ranges due to increase in temperature (Raxworthy *et al.,* 2007; Chen*et al*., 2009).

Species shift their ranges because most species are adapted to aspecific range of environmental conditions. These species are affected by many components of climate that alter these conditions such as raising mean temperature, variability in temperature, rainfall and humidity at various scales influence the distribution and persistence of species.

Changes in species assemblages in response to climatic changes are projected to occur in tropical montane areas (Pimm, 2008; Lawler, *et al.,* 2009). High numbers of extinctions have occurred along the lower elevational boundaries of mountain tops (Parmesan, 2006). Tropical lowland species richness may decline with global warming because there is no species pool to replace the lowland species that have migrated to high elevations (Colwell *et al*., 2008).

Some species are moving eleven meters per decade upslope and 16.9 km per decade pole-wards (Parmesan and Yohe, 2003). Temperature increase is driving these range shifts but not all species can keep pace with warming (Chen *et al*., 2011). Approximately one hundred species of birds, mammals and amphibians have gone extinct in the last one hundred years and extinction rates are expected to increase ten to a hundred times in this century (Millennium Ecosystem Assessment, 2005). The main reason why very many species will become extinct is because climate is changing at an unprecedented rate (Hof *et al*., 2011).

2.8 Ecological Niche Models

Ecological niche models (ENM) are also known as species distribution models and widely used to predict geographic ranges of species due to climatic changes (Pearson and Dawson, 2003). ENMs estimate the relationship between species records at sites and environmental variables (Franklin, *et al.,* 2009). Investigating the potential impacts of future climate change involves how climate variables impact on species distribution as species niche is defined solely in terms of climate niche (Pearson and Dawson, 2003) which represent climatic conditions that favour the species existence. Ecological niche modelling is the most accurate method for predicting the potential impact of climate change on species distribution (Elith, 2006).

Maximum entropy algorithm Maxent (Phillips *et al.*, 2004; 2006) is one of the most widely used approaches for estimating ENMs (Elith *et al.,* 2010). Maxent is a general purpose machine learning method that has been developed and specialized for predicting species distributions when only presence data are available for analysis. Maxent estimates the probability distributions of a species occurrence in the presence of point locality data together with environmental variables such as temperature, rainfall, soil type, elevations or vegetations (Phillips *et al.,* 2006). Point locality data comprise pairs of latitude and longitude coordinates for the sites where the species has been observed (Stockwell and Peterson, 2002).

Maxent has been extensively utilized for modeling species distributions since it became available in 2004. Some of the published examples cover different objectives such as finding species occurrences, mapping current distributions, predicting future distributions (Elith *et al*., 2011). Both the government and non-governmental organizations have used it (Elith *et al*., 2011). Maxent is regularly updated to suit the increasing applications (Elith*et al.,* 2011).

2.9 Limitations and Modelling Assumptions

To model *Myosorex* species, several assumptions were made. The biotic interactions between species such as competition and predators were not considered even though they were known to limit species distribution (Pearson and Dawson, 2003). An evolutionary adaptation of species to changing climate that may lead to species persistence in an area was not considered (Pearson and Dawson, 2003). The species are assumed to be in equilibrium with their environment. For example, species are believed to occur in all climatically suitable areas and be absent in unsuitable areas (Araujo and Pearson, 2005). There is also an assumption that the species will have no constrains to dispersal (Aruajo *et al.,* 2006). The future projection for species was also made with an assumption that the current species climatic niche will remain unchanged under changing climate (Fitzpatrick*et al.,* 2008).

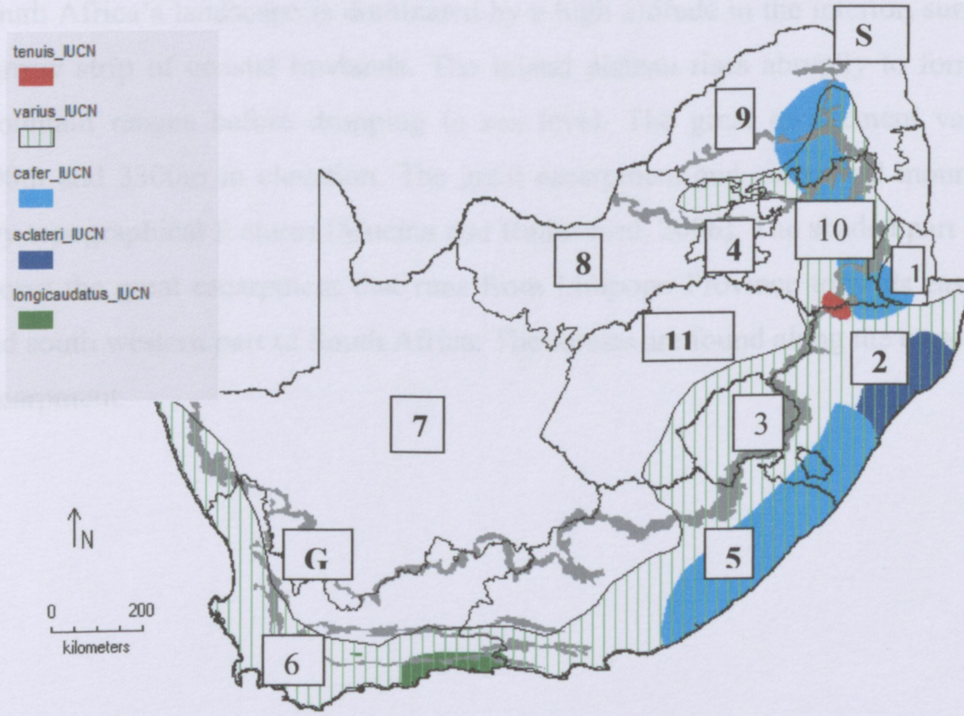
Effectiveness of Maxent as a tool for predicting future distributions and status of species has been challenged (Jimenez-Valverde *et al*., 2008). There is lack of relationship between probability of distribution and abundance (Jimernez-Valverde et al., 2009), confusion of potential and realized distribution (Jimenez-Valverder *et al*., 2008), inappropriate use of Area Under the Curve (Lobo *et al.,* 2007), biases due to small sample size (Wisz *et al*., 2008), lack of distinction between absence and pseudo-absence data, and the reliance on future climate models that cannot be tested at present.

Database from museums may have problems of labeling, thus some species may be given the wrong names and this will not give an accurate prediction (Funk and Richardson, 2002; Robert *et al*., 2010). Databases from museums may have also some areas that are over sampled, whereas others are under sampled and some areas may not have been sampled yet have the potential habitat for the species thus, gives inaccurate distribution in modeling (Robert *et al.*, 2010).

CHAPTER THREE: ECOLOGICAL SETTING OF THE STUDY AREAS

3.1 Study Area

This chapter highlights the study area, which includes the whole of the South African mainland, Lesotho and Swaziland (Fig. 3.1). The shaded parts show the extent of distribution of *Myosorex*. Fieldwork collection of *Myosorex* species was undertaken in the Soutpansberg Mountain in Limpopo Province.



1. Swaziland
2. KwaZulu-Natal
3. Lesotho
4. Gauteng
5. Eastern Cape
6. Western
7. Northern Cape
8. North West
9. Limpopo
10. Mpumalanga
11. Free State

S- Soutpansberg Mountain
G-Grey shading- Escarpment

Figure 3.1: Map of the study area showing the distribution of *Myosorex* species in South Africa, Lesotho and Swaziland (maps from IUCN website).

3.2 Climate

The climate of South Africa is generally warm and hot. Climatic conditions range from Mediterranean in the southwest corner of the country to temperate in the interior plateau and subtropical on the northeast coast. A small area in the north has arid climate. Most of the country has warm sunny days and cool nights. Rainfall generally occurs in summer except for Cape Floristic Region which has winter rainfall. Temperatures are influenced by variations in elevation, terrain and ocean currents (Mucina and Rutherford, 2006).

3.3 Topography

South Africa's landscape is dominated by a high altitude in the interior, surrounded by a narrow strip of coastal lowlands. The inland plateau rises abruptly to form a series of mountain ranges before dropping to sea level. The great escapement varies between 200m and 3300m in elevation. The great escarpment and associated mountains are the key topographical features (Mucina and Rutherford, 2006). The shaded part of Figure 3.2 shows the great escarpment that runs from Limpopo Province towards eastern to south and south western part of South Africa. The forests are found along the eastern side of the escarpment.

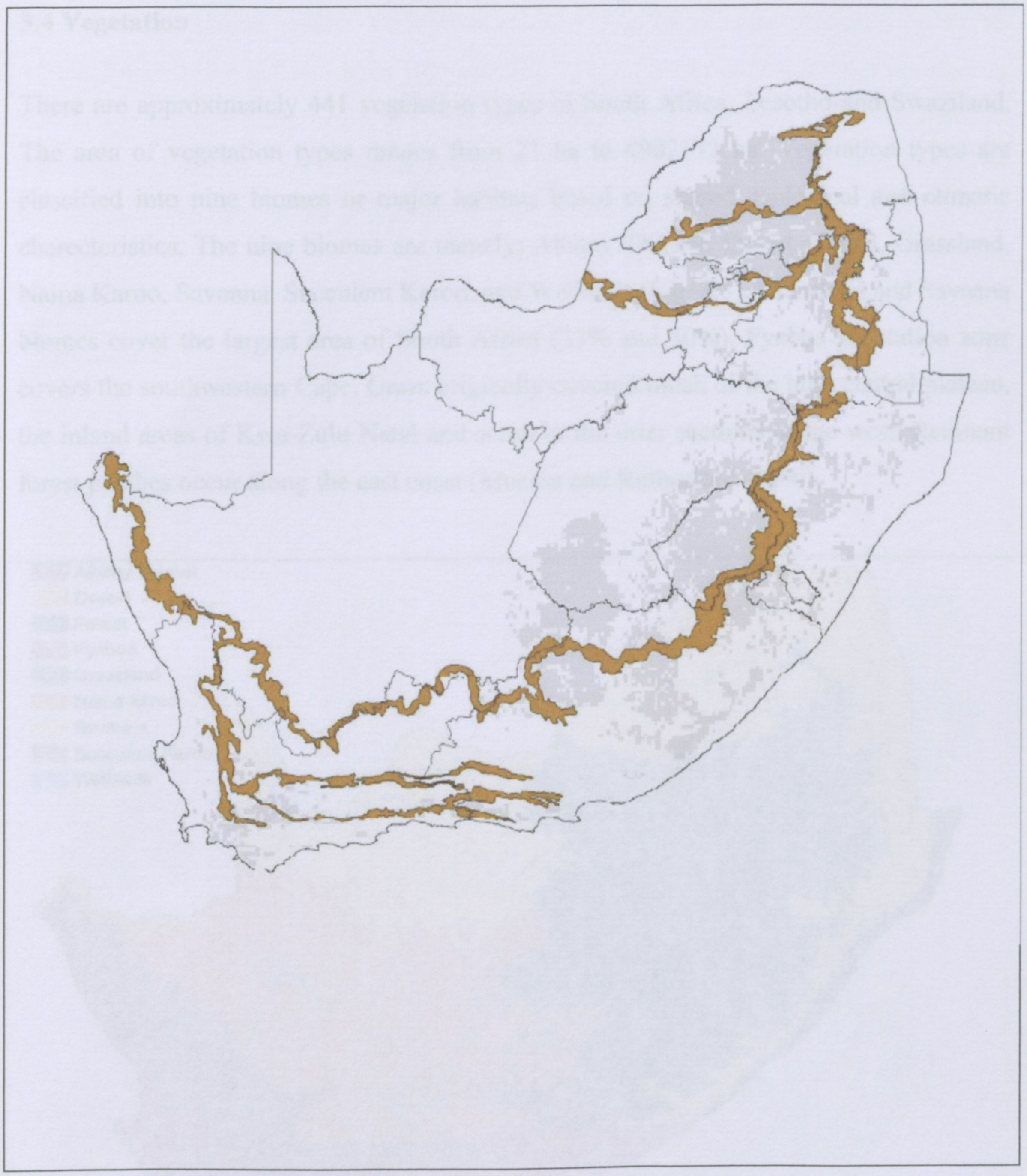


Figure 3.2: Topography map showing upland and lowland gradients along the escarpment and associated mountain ranges. The brown shadings show the escarpment and the grey shades show the forests (Mucina and Rutherford, 2006).

3.4 Vegetation

There are approximately 441 vegetation types in South Africa, Lesotho and Swaziland. The area of vegetation types ranges from 21 ha to 4982132 ha. Vegetation types are classified into nine biomes or major habitats based on shared ecological and climatic charecteristics. The nine biomes are namely; Albany Thicket, Desert, Forest, Grassland, Nama Karoo, Savanna, Succulent Karoo, and Wetlands (Fig. 3.3). Grassland and Savaana biomes cover the largest area of South Africa (33% and 30%). Fynbos vegetation zone covers the southwestern Cape. Grass originally covered much of the high central plateau, the inland areas of Kwa-Zulu Natal and scrub in the drier sections of the west. Remnant forest patches occur along the east coast (Mucina and Rutherford, 2006).

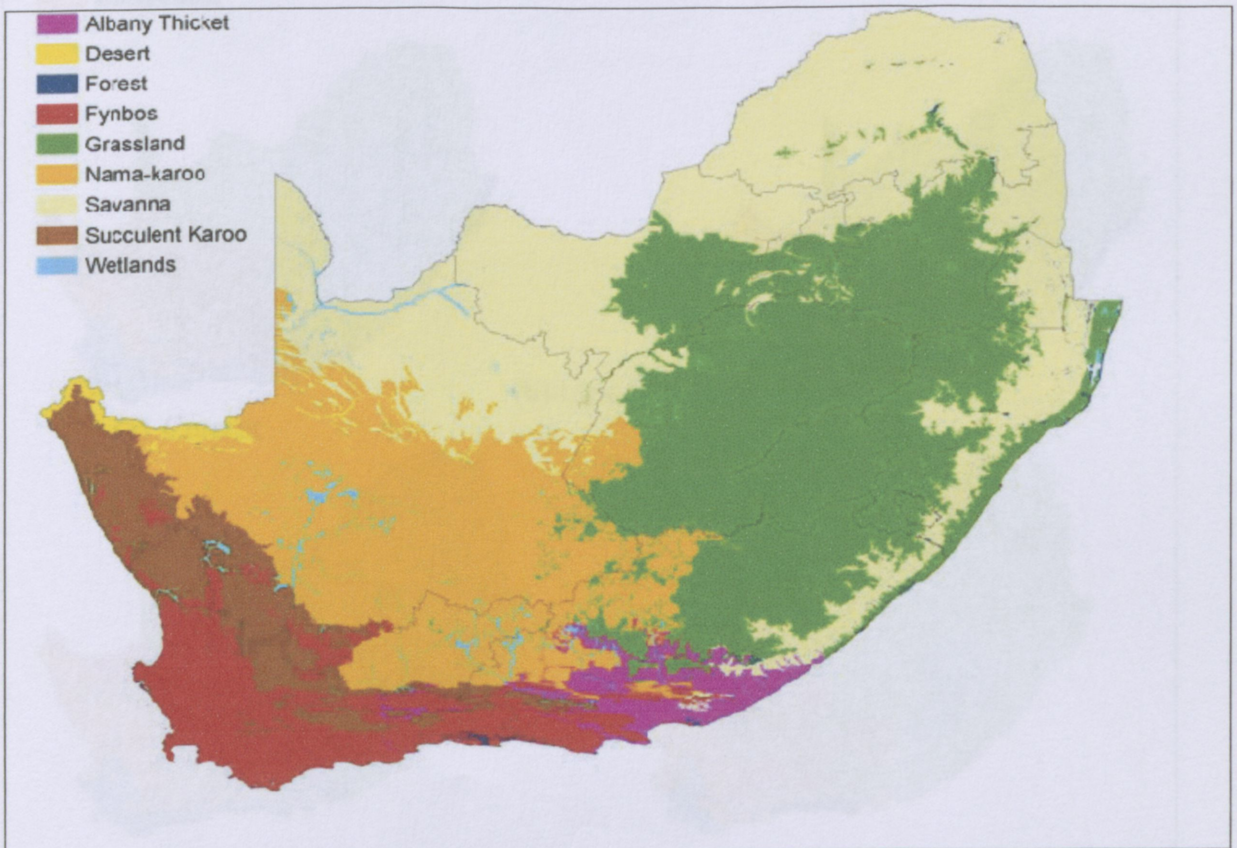


Figure 3.3: Showing biomes regions of South Africa including Lesotho and Swaziland (Mucina and Rutherford, 2006).

Predictions of biome climate envelopes under different climatic scenarios in South Africa, Swaziland and Lesotho by the year 2050 (Fig. 3.4) shows how biomes are most at risk as a result of climate change. Grassland is most at risk, Nama-Karoo will resemble Savanna, and eastern and northern Fynbos will become succulent Karoo and the desert will expand. The biomes are being transformed at accelerated speed (Driver *et al.,* 2011).

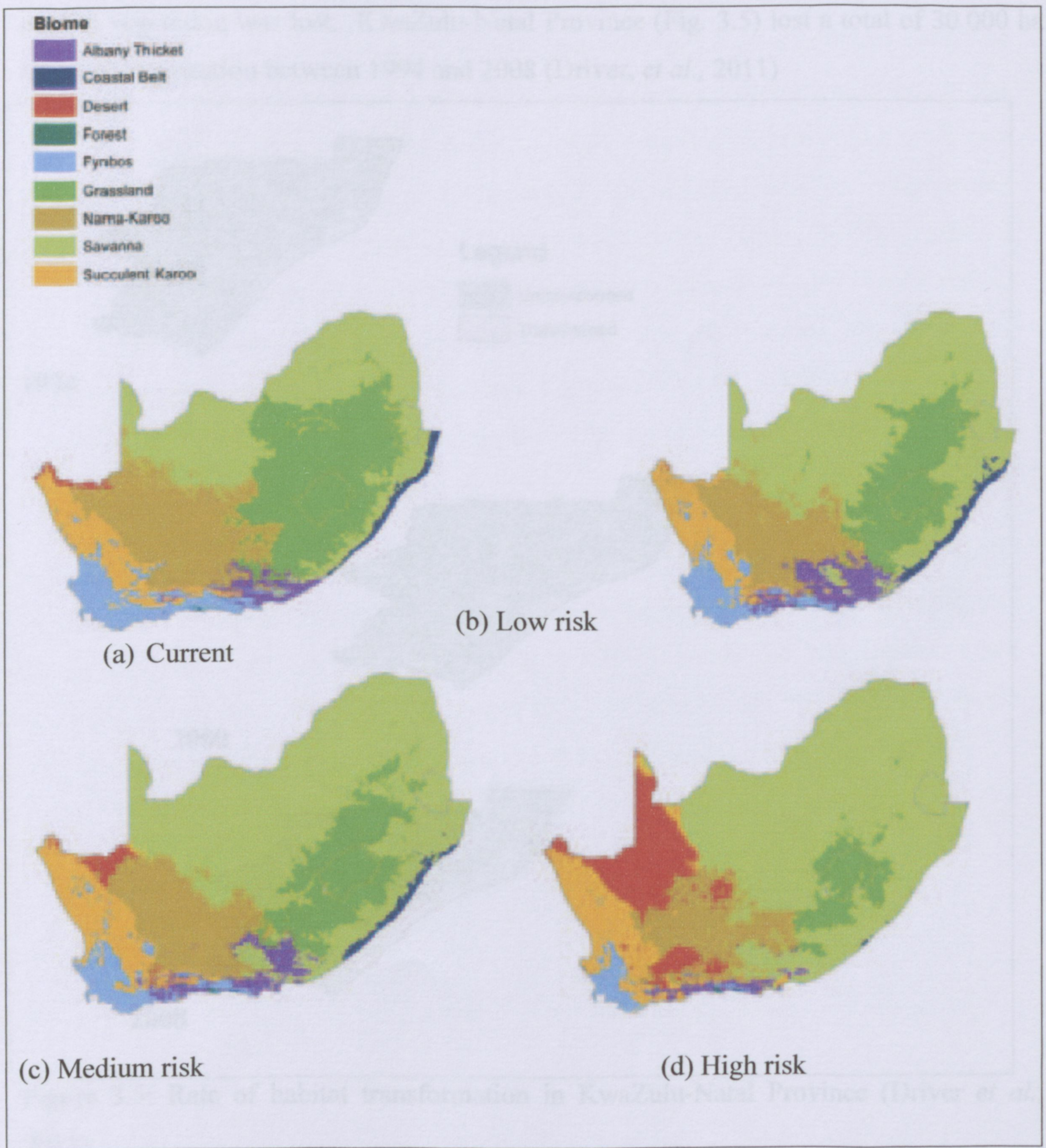


Figure 3.4: Map of South Africa, Swaziland and Lesotho showing the predictions of biome climate envelopes under different climatic scenarios by 2050 (Driver *et al*. 2011).

There is high rate of loss of natural vegetation in parts of South Africa. Habitat transformation is really accelerating in KwaZulu-Natal, North-West and Gauteng Province, hence at this rate, by the year 2050 most natural habitats will be affected (Driver *et al*., 2011). Between 1994 and 2006, North West province lost the natural vegetation at an average of nearly 100 000 ha per year (Driver *et al.,* 2011). Gauteng Province has a similar picture between 1995 and 2009, approximately 230 000 ha of natural vegetation was lost. KwaZulu-Natal Province (Fig. 3.5) lost a total of 30 000 ha of natural vegetation between 1994 and 2008 (Driver, *et al.,* 2011)

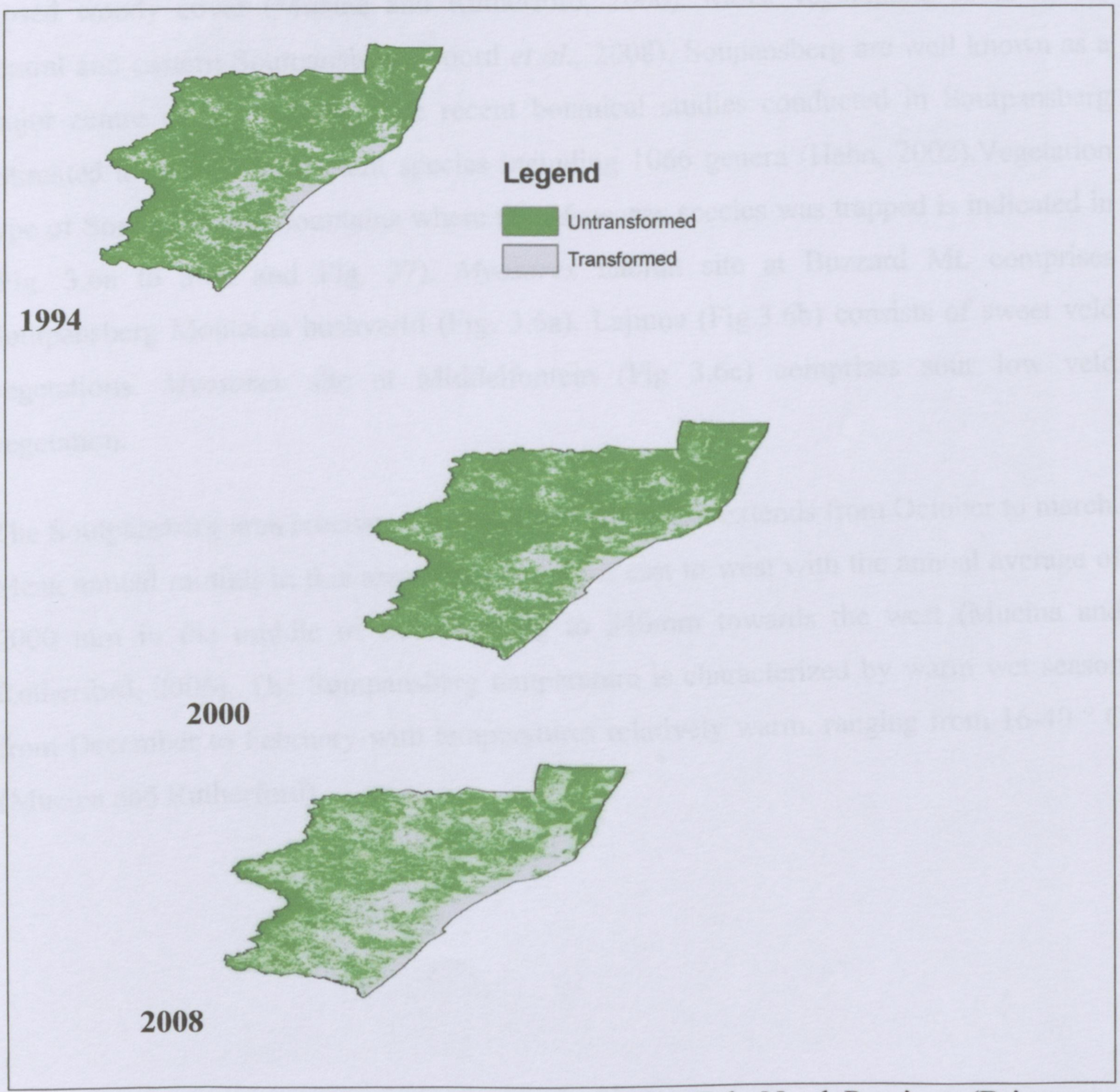


Figure 3.5: Rate of habitat transformation in KwaZulu-Natal Province (Driver *et al.*, 2011).

Vegetation of Soutpansberg Mountain in Limpopo Province

Vegetation of Soutpansberg Mountains comprises Soutpansberg Summit Sourveld, Soutpansberg Mountain bushveld, Sweet Bushveld Mopane, Bushveld and Northern Mist belt Forest (Mucina and Ruthford, 2006). The mountains have the highest plant generic and family level diversity in South Africa (Foord *et al.,* 2008). Some of the areas are composed of dense tree layer and poorly developed grass layer (Mucina and Rutherford, 2006). Higher altitudes are characterized by areas with short grassland and island of closed woody cover (Mucina and Rutherford, 2006). Moist vegetations occur in the central and eastern Soutpansberg (Foord *et al.,* 2008). Soupansberg are well known as a major centre of biodiversity. The recent botanical studies conducted in Soutpansberg estimated a total of 3000 plant species including 1066 genera (Hahn, 2002).Vegetation type of Soutpansberg Mountains where the *Myosorex* species was trapped is indicated in (Fig. 3.6a to 3.6c and Fig. 37). *Myosorex* habitat site at Buzzard Mt. comprises Soutpansberg Moutains bushverld (Fig. 3.6a). Lajuma (Fig.3.6b) consists of sweet veld vegetations. *Myosorex* site at Middelfontein (Fig 3.6c) comprises sour low veld vegetation.

The Soutpansberg area receives one cycle of rainfall that extends from October to march. Mean annual rainfall in this area decreases from east to west with the annual average of 2000 mm in the middle of Soutpansberg to 340mm towards the west (Mucina and Rutherford, 2006). The Soutpansberg temperature is characterized by warm wet season from December to February with temperatures relatively warm, ranging from 16-40 ° C (Mucina and Rutherford).

Figure 3.6a: *Myosorex* habitat at Buzzard comprises Soutpansberg Mountains bushverld.

Figure 3.6b: *Myosorex* habitat at Lajuma consists of sweet veld vegetations.

Figure 3.6c: *Myosorex* habitat at Middelfontein comprises sour low veld vegetation.

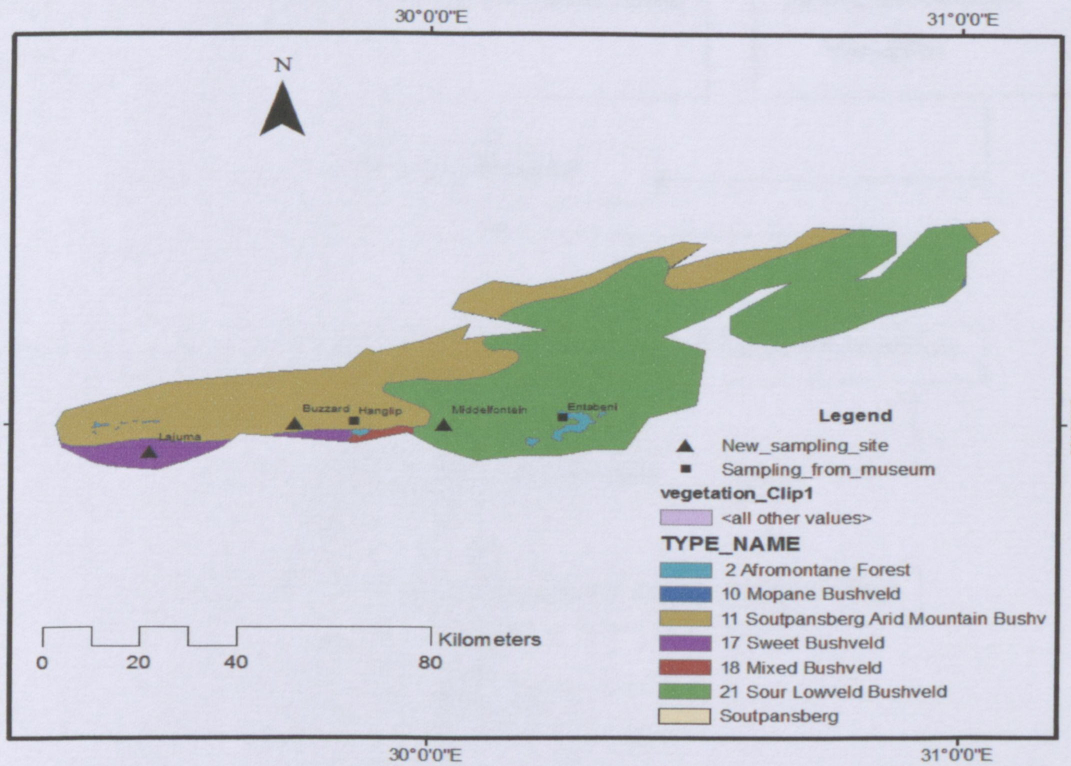


Figure 3.7: Map of Soutpansberg Mountain showing vegetation types where *Myosorex* species have been trapped.

4. CHAPTER FOUR: MATERIALS AND METHODS

4.1. Study Approach

This chapter highlights research methods, types and sources of data which were used to investigate the potential impacts of climate change on *Myosorex* species through modelling the species current and future distributions. The study used one modelling approach with two types of data. The model was built with current bioclimatic variables; predicted future climatic scenarios for the year 2070, together with occurrence data from museum records, published data and new field collections from Limpopo Province (Fig.4.1). These data were analysed by statistical method, Maximum entropy Maxent (Phillips*et al.*, 2006) to estimate the relationship between the values of the bioclimatic variables and the point locations defining a species geographic range.

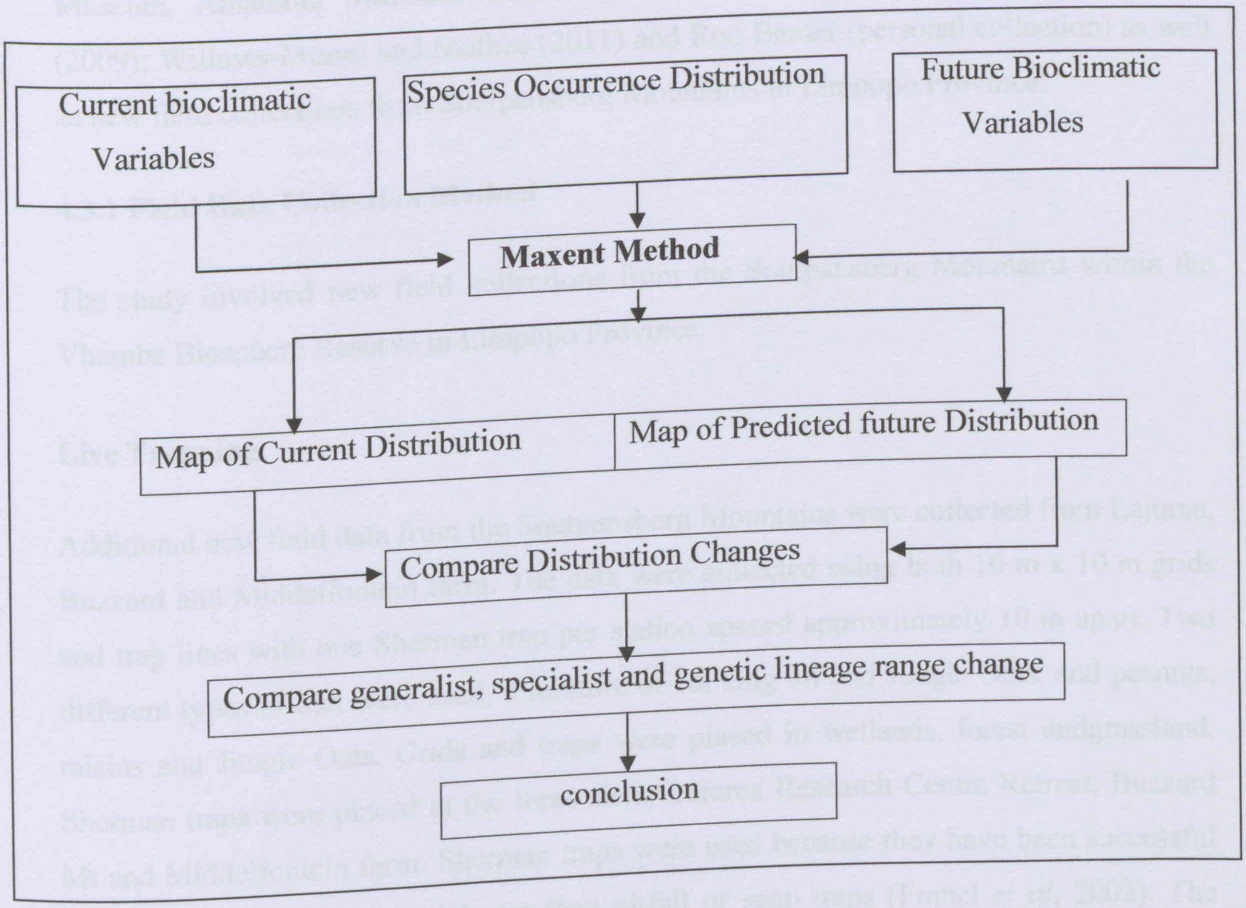


Figure 4.1: Research approach conducted for each *Myosorex* species and genetic lineage.

4.2 Sites Selection

The research was designed to use data from museums covering the whole of South Africa, Swaziland, and Lesotho. New field data collection was carried out in the Soutpansberg Mountains in Limpopo Province and was modelled separately since the evidence pointed to Limpopo comprising a lineage (Willows-Munro, 2008; Taylor, *et al.*, 2013).

4.3 SpeciesDistribution Records

Species distribution data is presence only data that is the record localities of *Myosorex* specimens from several South African Museums. The sources include the Ditsong Natural History Museum, (formerly Transvaal Museum), Durban Natural Science Museum, Amathole Museum, Willows-Munro (2008), Willows-Munro and Mathee (2009); Willows-Munro and Mathee (2011) and Rod Baxter (personal collection) as well as new field collections from Soutpansberg Mountains in Limpopo Province.

4.3.1 Field Data Collection Method

The study involved new field collections from the Soutpansberg Mountains within the Vhembe Biosphere Reserve in Limpopo Province.

Live Trapping

Additional new field data from the Soutpansberg Mountains were collected from Lajuma, Buzzard and Middelfontein farm. The data were collected using both 10 m x 10 m grids and trap lines with one Sherman trap per station spaced approximately 10 m apart. Two different types of bait were used, a mixture of cooking oil and Jungle Oats, and peanuts, raisins and Jungle Oats. Grids and traps were placed in wetlands, forest andgrassland. Sherman traps were placed at the three sites, Lajuma Research Centre Retreat, Buzzard Mt and Middelfontein farm. Sherman traps were used because they have been successful in attaining higher species richness than pitfall or snap traps (Francl *et al*, 2002). The point of capture was recorded using GPS in terms of latitudes and longitudes which were used for modeling. The species were identified before modeling because there is confusion as to which species is found in the Soutpansberg Mountains.

The trapped shrews were identified and weighed (to the nearest gram) using a Pesola spring balance. Penile extrusion was used to identify their sex. Females are regarded as reproductive if they have evidence of pregnancy or lactation. Trapped forest shrews were sacrificed and museum specimens produced and deposited at the Durban Natural Science Museum. Identification was determined from skull and skin characters as described below. The following external measurements were taken; head and body length, tail, hind foot and ear length to the nearest millimeter (Nagorsern and Peterson, 1980). The collection points are indicated in Figure 4.2. New collection points are represented by triangles and those from Museum by squares. The details of collections of *Myosorex* from Limpopo Province are in Appendix A.

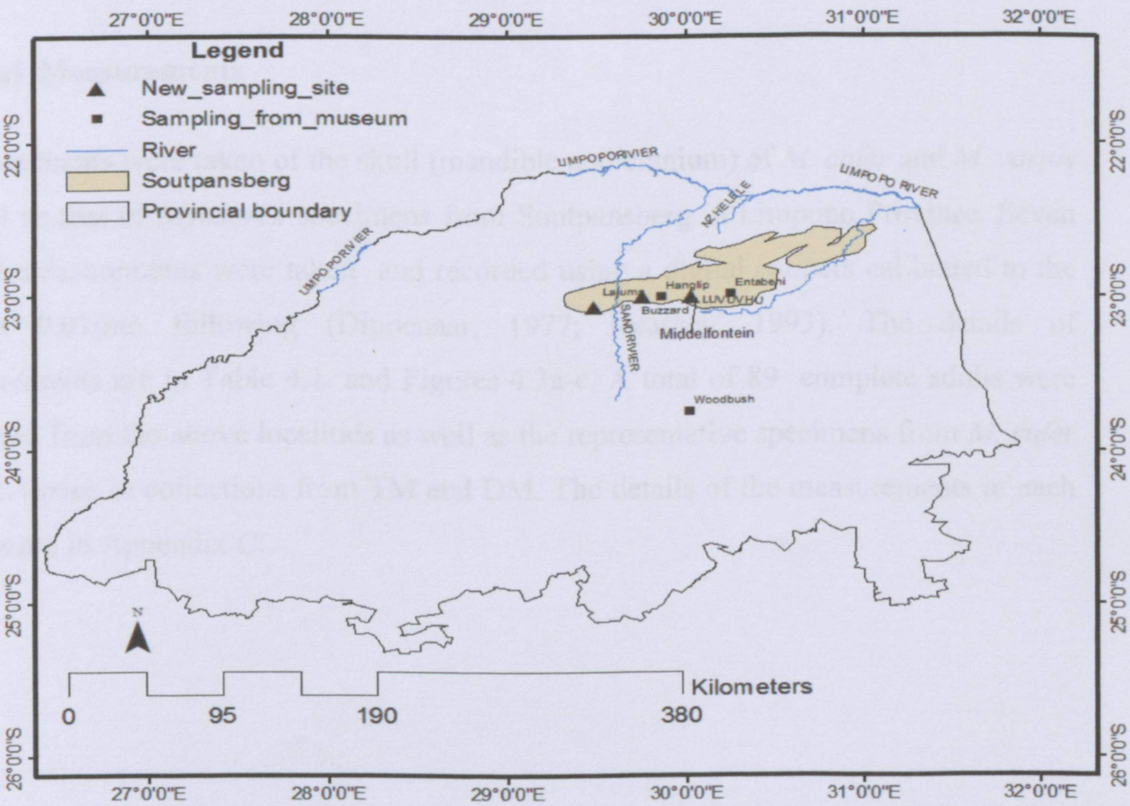


Figure 4.2: Map showing sampling localities in the Soutpansberg Mountains of Limpopo Province. The triangles show new sampling and the squares show sampling from the Museums.

4.3.2 External Identification

The specimens collected from Lajuma, Buzzard Mountain and Middelfontein farm were compared with species from Woodbush, Entabeni and Hanglip from TM and DM using colour charactaristics of the upper parts and under parts of the body, tail and feet to differentiate them. These specimens were also compared to reference samples of *M. varius* and *M. cafer* from Kwa-zulu-Natal from TM and DM collection using the colour characters. *M. varius*is characterised by dark brown colour on the upper parts of the body and the under parts is light brown, bicoloured tail and the feet are pale gray (Rowe-Rowe and Meester, 1985). *M. cafer* is characterised by blackish-brown colour on the dorsal, ventral colour is darker with very little gray, black hind feet colour and unicoloured tail (Meester, 1958; Kearney, 1993). The details of the specimens used are in Appendix B

4.3.3 Morphological Identification

Cranial Measurements

Measurements were taken of the skull (mandible and cranium) of *M. cafer* and *M. varius* as well as that of *Myosorex* specimens from Soutpansberg in Limpopo Province. Seven cranial measurements were taken and recorded using a digital calipers calibrated to the nearest 0.01mm following (Dippenaar, 1977; Kearney, 1993). The details of measurements are in Table 4.1. and Figures 4.3a-c. A total of 89 complete adults were measured from the above localities as well as the representative specimens from *M. cafer* and *M. varius* in collections from TM and DM. The details of the measurements of each species are in Appendix C.

Table 4.1: Skull Measurements

Cl	Condylo-incisive length
PPL	Post-palatal length,
UTR	Upper Tooth Row
LIW	Least Interobital Width
BW	Bimaxillary Width
GW	Greatest Width
LTR	Lower Tooth Row

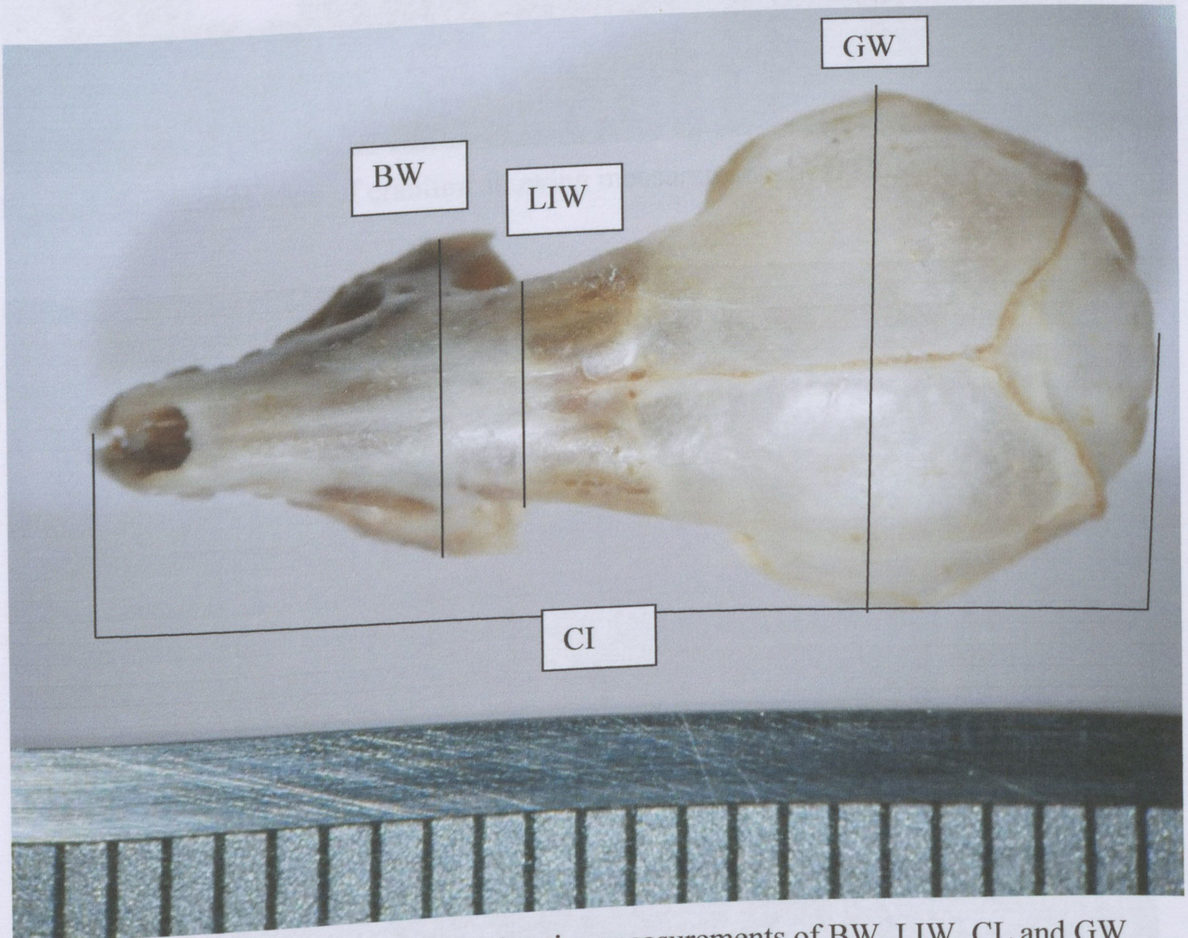


Figure 4.3a: Dorsal view of cranium showing measurements of BW, LIW, CL and GW.

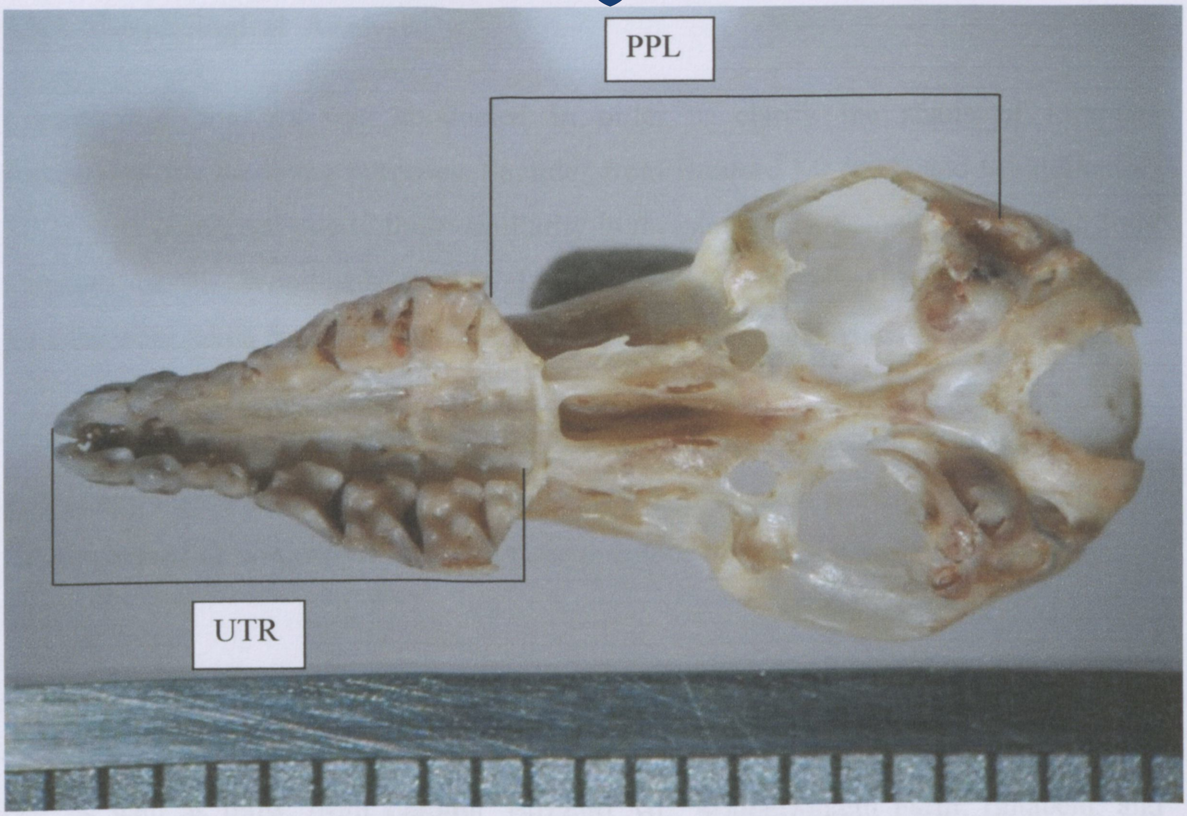


Figure4.3b: Ventral view of cranium showing measurements of UTR and PPL.

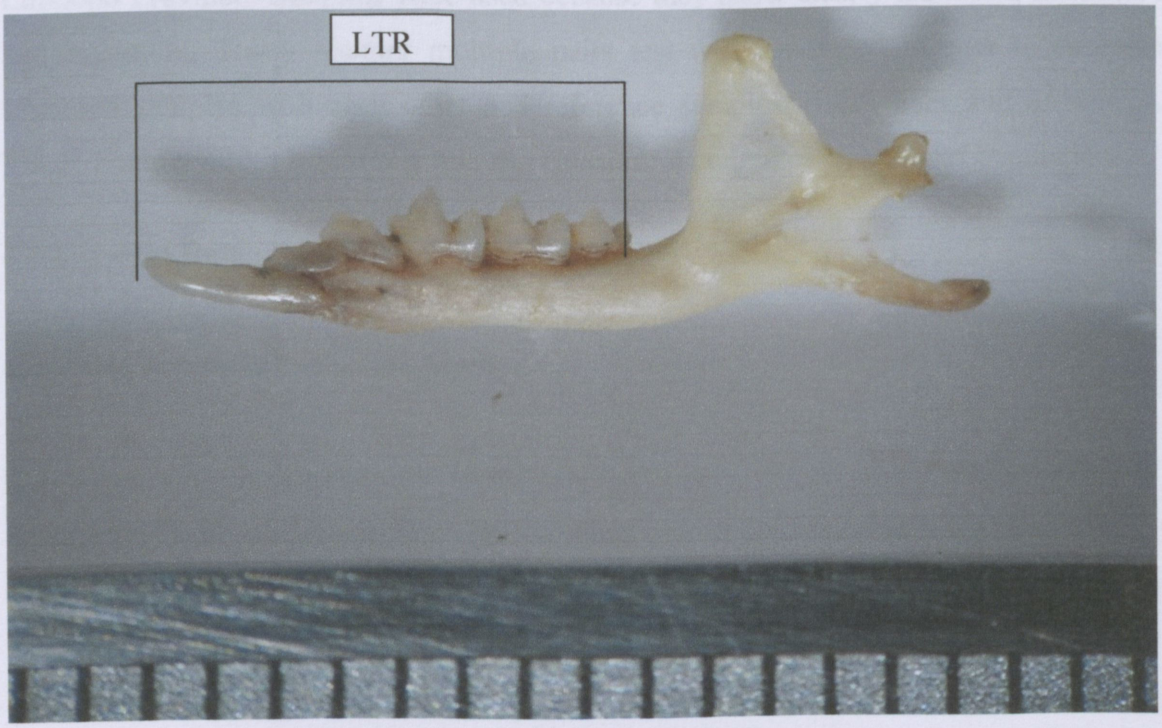


Figure 4.3c: Lateral view of mandible showing measurement of LTR.

4.3.4 Morphological Analysis

Craniometric analysis was conducted in order to clarify the status of Limpopo populations for modeling purposes. Samples from Buzzard Mt (n=2) and Middelfontein (n=2) were combined due to their similarity in measurements. Samples were taken from Entabeni (n=9), Woodbush (n=34), Lajuma (n=11) and Hanglip (n=6). Reference samples were taken from DM and TM of *M. varius* (n=10), and M. cafer (n=9).

The following diagnostic cranial characters were recorded; the extent of overlap between medial and lateral palatal foramina. Diagnostic pelage characters that were recorded were tail bicoloured or not; colour of dorsal pelage; colour of ventral pelage and colour of hind foot.

The standard descriptive statistics (mean, minimum, maximum, and standard deviation) were calculated and boxplots for the samples of *M. varius* and *M. cafer* from TM and DM as well as those from Lajuma, Buzzard Mt., Middelfontein Farm, Entabeni, and Hanglip on Soutpansberg Mountains and Woodbush on the northern Drakensberg in Limpopo Province. Boxplots were used because they show clearly the mean, maximum and minimum. Tukey Kramer multiple pairs test was conducted in oder to compare Limpopo samples with each other and reference samples of *M. cafer* and *M. varius*. Tukey Kramer multiple pair test was used because it compares all pairs of populations.

4.4 Museum Data

4.4.1 MuseumData Collection Method

Specimens were checked because identification errors may occur in museum collections. Specimens from museums were identified using microscopic examination of the dentition and skull character using existing characters (Meester, 1958; Meester and Dippenaar 1978; Meester, 1986; Kearney, 1993; Skinner and Chimimba, 2005).

The microscope was used to identify the relative positions of the lateral and medial palatal fissures for *M. varius, M. cafer,* and *M. longicaudatus* (Fig. 4.4) using existing diagrammatic representation of the relative positions of the palatal foramina (Meester, 1958). *M. sclateri's* key for palatal foramina was not available and therefore was identified using the skin and skull characters since it has larger skull size compared to *M. cafer* (Kearney, 1993).The skull character was checked where possible especially when the foramina had not been damaged. This was done for confirmation of the museums' records. Any ecological information records such as habitat, location, sex, collector and year of collection was recorded.

Figure 4.4: Identification of *Myosorex* species at DitsongNational Museum of Natural History, (formerlyTransvaal).

For the identification of the three *Myosorex* species, Figure. 4.5 was used. Diagram (a) Represents *M. varius*, and has anterior palate with rear margin of lateral foramina overlapping from margin of median foramina. *M. cafer* is represented in diagram (b) and the anterior palate with lateral palatal foramina anterior to median foramina. Diagram (c) represents *M. longicaudatus* with median palatal foramina paired, and additional unpaired foramina occasionally present.

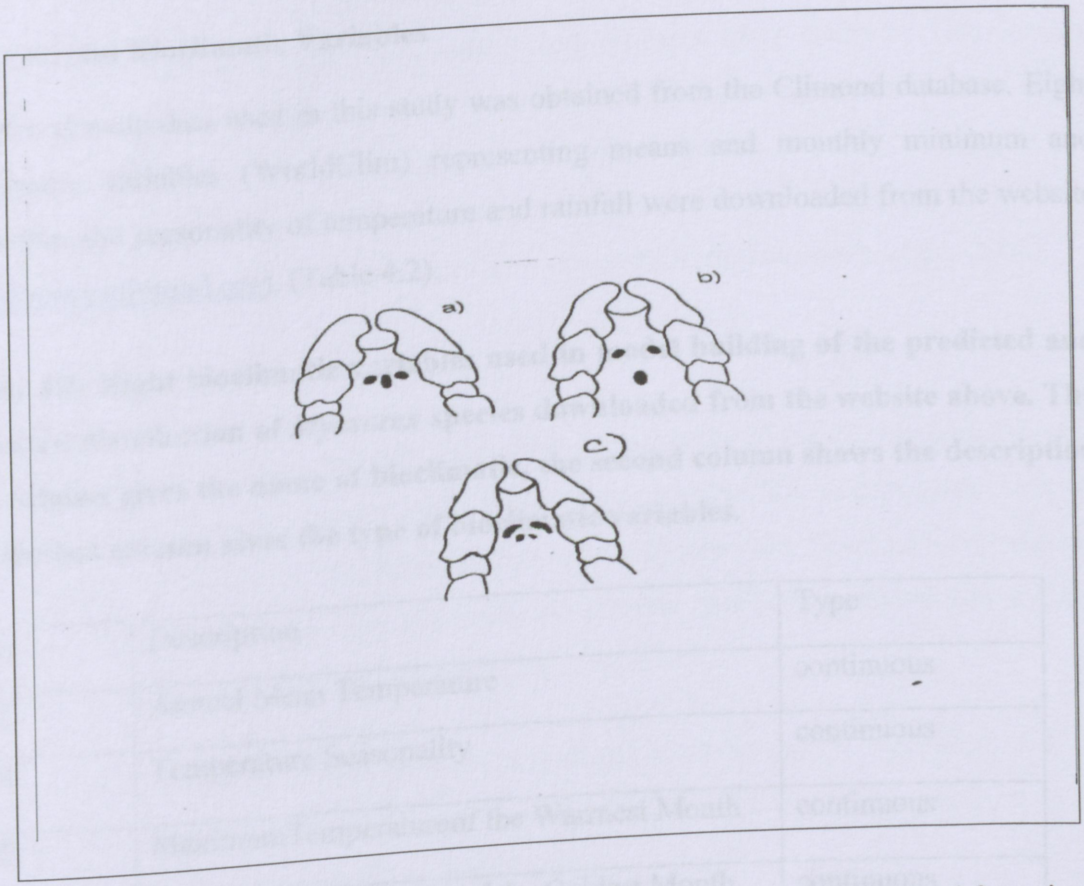


Figure 4.5: Diagrammatic representation of the relative positions of the palatal foraminas appearsunder microscope in, (a) *M. varius*, (b) *M. cafer* and (c) *M. longicaudatus* (after Meester, 1958).

All the coordinates from the museums and published data were confirmed and compiled in terms of latitudes and longitudesin decimal-degrees format for modeling. Each specimen was given unique identification number different from that of the museums. This is indicated in the first column and museum identification number in the last column. The source of each species including those from publications was indicated in the last column in the form of acronym; TM-Ditsong National Museum of Natural History (formerly Transvaal Museum; TM), DM-Durban Museum, AM-Amatole Museum, R.B- Rod Baxter and MW-Willows-Munro and the details of these are found in the Appendix (D-J).

4.5 Climate Data

4.5.1 Current Bioclimatic Variables

Current climate data used in this study was obtained from the Climond database. Eight bioclimatic variables (WorldClim) representing means and monthly minimum and maximum and seasonality of temperature and rainfall were downloaded from the website (http://www.climond.org), (Table 4.2).

Table; 4.2: Eight bioclimatic variables used in model building of the predicted and projected distribution of *Myosorex* species downloaded from the website above. The first column gives the name of bioclimatic, the second column shows the description and the last column gives the type of bioclimatic variables.

Name	Description	Type
Bio 1	Annual Mean Temperature	continuous
Bio 4	Temperature Seasonality	continuous
Bio 5	MaximumTemperatureof the Warmest Month	continuous
Bio 6	Minimum Temperature of the Coldest Month	continuous
Bio 12	Annual Precipitation	continuous
Bio 13	Precipitation of the Wettest Month	continuous
Bio 14	Precipitation of the driest Month	continuous
Bio 15	Precipitation Seasonality	continuous

4.5.2 Future Projected Climate Scenarios

For future climate scenarios, the same bioclimatic variables were obtained from the same website (http://www.climond.org). Global Change Model (GCM) scenarios with Resolution–10‘(approx15x15km), CliMond database (Kriticos *et al.,* 2012) were used to model historical and future climatic surfaces. The same eight continuous bioclimatic variables were used tobuild the model of the future projected distribution. Scenario A2 emission was chosen as it is more radical and probably more realistic. This scenario depicts a heterogeneous future world based on a high human population growth rate coupled with increased energy expenditure and large land use changes resulting in CO_2 emissions. Consequently, the use of more extreme scenarios such as A2 and A1 instead of conservative B1 and B2 scenarios has been recommended (Beaumont *et al*., 2008).

4.6 DataCleaning

Cleaning was done to presence data to confirm the accuracy of the coordinates. Presence data were plotted on the map using DIVA-GIS version 7.4 and records with no coordinates were removed. Duplicate records were also removed. The data were prepared in three columns to hold species, longitude and latitude coordinates, and stored in Excel database as comma separated values file (CSV).

Environmental predictor variables were organized as raster (grid) type files. All the variables were masked using the background mask. The variables were organized in the same spatial resolution and stored as ASCII files.

4.7 Modelling Method

There are two methods by which modeling can be done. One is mechanistic and the other is correlative. Mechanistic models require detailed understanding of the physiological response of species to environmental factors. However, in the case of *Myosorex* species, there is poor understanding of physiological responses so this method was ruled out; hence correlative models with Maxent were applied. There are also many different species distribution model methods but in this study Maxent (Phillips *et al.,* 2006) was used to estimate the relationship between the values of bioclimatic variables and the point locations defining species range. Maxent was used to model both current and projected future distribution.

4.7.1 Maxent

Maxent is a general purpose machine based learning method that makes predictions from incomplete information because it requires only presence data. Maxent attempts to estimate the probability distribution for the occurrence of species as the Maximum entropy distribution. The result is an approximation to a uniform probability distribution subject to constraint imposed by the environmental conditions associated with the known occurrences of species (Phillips *et al.*, 2006).

Maxent was used due to different reasons. Firstly, it was used because it is the most accurate and popular method which is widely used in comparison with other approaches (Elith, *et al.*, 2006; Pearson *et al*, 2007; Wisz *et al.*, 2008, Elith *et al.*, 2011). Maxent program is regularly updated to include new capabilities and to accommodate the increasing number of applicants (Elith *et al.*, 2011). Maxent is consistently used because it offers several advantages such as (1) it can be used with small number of presence records (Hernandez *et al.,* 2006; Pearson *et al.,* 2006; Wisz *et al.,* 2008; Phillip *et al.*, 2009), (2) it uses both continuous and categorical data (Phillip *et al.*, 2006, Suarez-Seone *et al.*, 2008), (3) regularization parameters can be used to avoid over fitting (Suarez-Seoane *et al.*, 2008).

Maxent program allows random selection of the occurrence points to be used for building the model (training points) and the remaining to be used for testing the accuracy of the model (testing points). The Maxent program uses a maximum likelihood method to generate probability distribution over pixels in the study area. It takes a set of environmental layers and species locality points to produce a map of species predicted potential distribution. It produces output map of values ranging from 1 to 100 over the area covered by the point locality data. These values show the relative likelihood that each pixel in the study area contains environmental conditions corresponding to those at the point locations.

Maxentmodel version 3.3.3k (Phillips *et al.*, 2006) was used in this study to model the distribution of four *Myosorex* species and the twolineages of *Myosorex varius* defined by Willows- Munro and Matthee (2011). The model was built using the current bioclimatic variables (1975) and future projected scenario A2 for 2070, together with presence data. Eight continuous environmental variables were used as predictors.

To run the model, Maxent was supplied with a file containing eight continuous environmental variables which were cropped to the diamensions of the masks. All the variables were masked with the background which combined South Africa, Lesotho and Swaziland map and a file containing presence localities of different *Myosorex* species in csv format as an input. Different masks were also tried such as a mask comprising a minimum convex polygon around all the points of current suitable climatic area of species but the results were identical with the whole of South Africa. Exploratory analyses showed almost no differences between the polygon masks and masks using all South Africa and for this reason, and because some models showed expansion of suitable habitats outside the study points, thus the South Africa background was used in the final model.

The model was run 14 times using different *Myosorex* species coordinates and a total of 14 distribution maps were produced. The models were generated randomly assigning 70% of occurrence points as training data with remaining 30% used as testing data for each *Myosorex* species. Selection of features was carried out automatically following default rules depending on the number of presence records. Logistic output format was selected which yields continous values ranging from 0 to 1 which indicate relative environmental suitability for the species (Philips and Dudik, 2008). The Regularization multiplier was set to a value of 1 (Lamb *et al*., 2008). A jackknife test was run to all the models to select variable contributing positively to model quality for species distribution. The predictions were mapped in DIVA- GIS version 7.4.

Model Evaluation

The area Under the Curve (AUC) of the Receiver Operation Characteristic (ROC) function was used for evaluating the fitness of the models. AUC of ROC function is an index of model performance that provides a single measure of occurrences that is independent of any particular threshold (Fielding and Bell, 1997). The AUC is the probability that a randomly chosen presence site is ranked above the background site. A random model has AUC of 0.5 while a perfect model should have 1. However, Phillip *et al.* (2006) demonstrated that when using presence only data, the maximum achievable AUC is less than 1. The area under the ROC curves was produced with sensitivity plotted on the y-axis and (-1specificy) plotted on the x-axis for all the models. The sensitivity for a particular threshold is the fraction of all the positive that are classified as present and specificity is the fraction of all negative that is classified as not presence (Phillip *et al.*, 2006). This means that the values above the threshold were those that were suitable while the values below the threshold indicate areas that were unsuitable for the species.

4.7.2 Range Shift Analysis

To evaluate the species range shifts, the equal Sensitivity and Specificity threshold for current and future A2 emission scenario for eight BioClim variables were used to map suitable habitats as presence or absence for all the models. Asingle pixel at 10'resolution translates to approximately 18 x 18 km or 324 km square. The numbers of Pixels were counted to get an idea of the present and future range and the percentage decrease or increase in range. The produced predicted current and projected future the year 2070 distribution maps were compared by using suitable and unsuitable areas (Araujo and Pearsons, 2005). The areas experiencing a decline in suitability were interpreted as range contraction while the areas experiencing increase in suitability interpreted as range expansion.

CHAPTER FIVE: RESULTS AND DISCUSSION

5.1 Results: Status of Limpopo Populations

5.1.1 External Character Analysis

Field collections from Soutpansberg Mountains were compared interms of external characters. The first five specimens on the left are from Lajuma and two middle ones are from Buzzard Mountain and the two on the right are from Middelfontein Farm (Fig.51a and 5.1b). Specimens from Middelfontein (right) are dark (almost blackish) in dorsal colour, have unicoloured tail colour and dark hind feet like *M. cafer,* (Fig.5.1a and Fig. 5.1c) while those from Lajuma and Buzzard Mt. are brownish in dorsal pelage and paler hind feet just like *M. varius*.Ventral colour is pale gray for specimens from Lajuma and Buzzard and darker gray for specimen from Middelfontein (Fig. 5.1b). The result shows that these specimens have some mixed up colour characters of *M. varius* and *M. cafer*. This revealed that even external appearances do not give clear distinction for *Myosorex* species in Limpopo Province (Taylor *et al*., 2013)

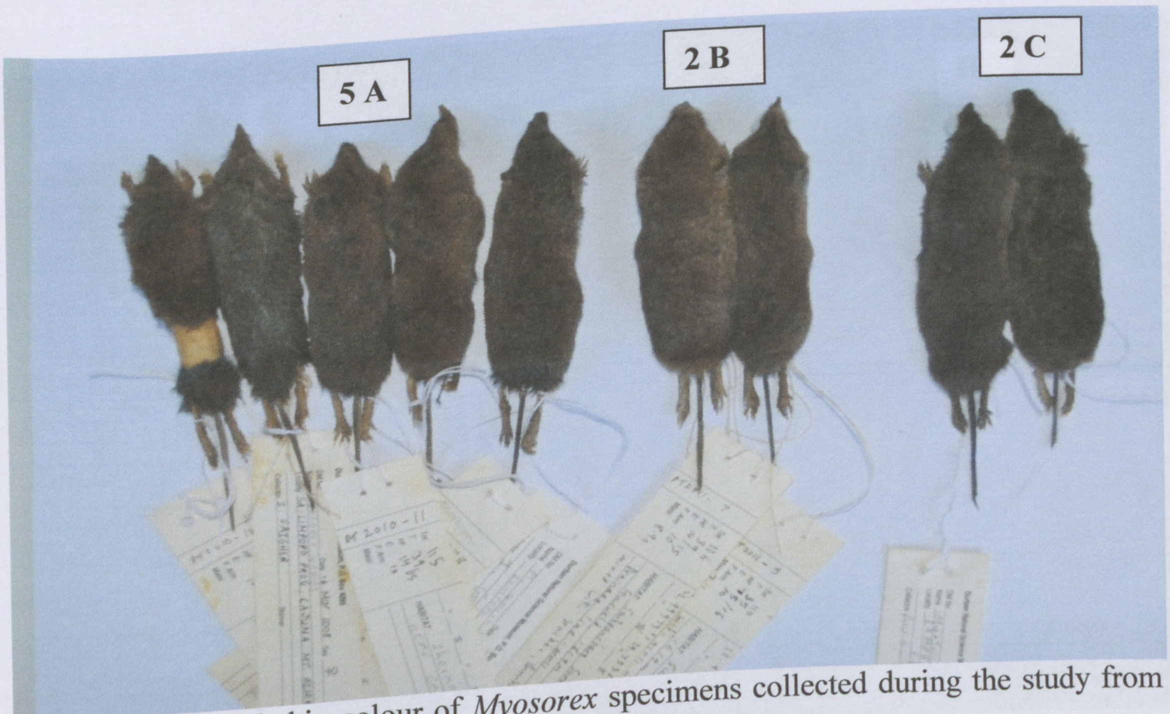


Figure 5.1a: Dorsal skin colour of *Myosorex* specimens collected during the study from different sites; 5A- Lajuma brownish; 2B- Buzzard brownish and 2C- Milddelfontain Farm blackish.

Figure 5.1b: Ventral skin colour of *Myosorex* specimens; 5D- Lajuma pale gray; 2E-Buzzard pale gray, and 2F- Middelfontein darker gray.

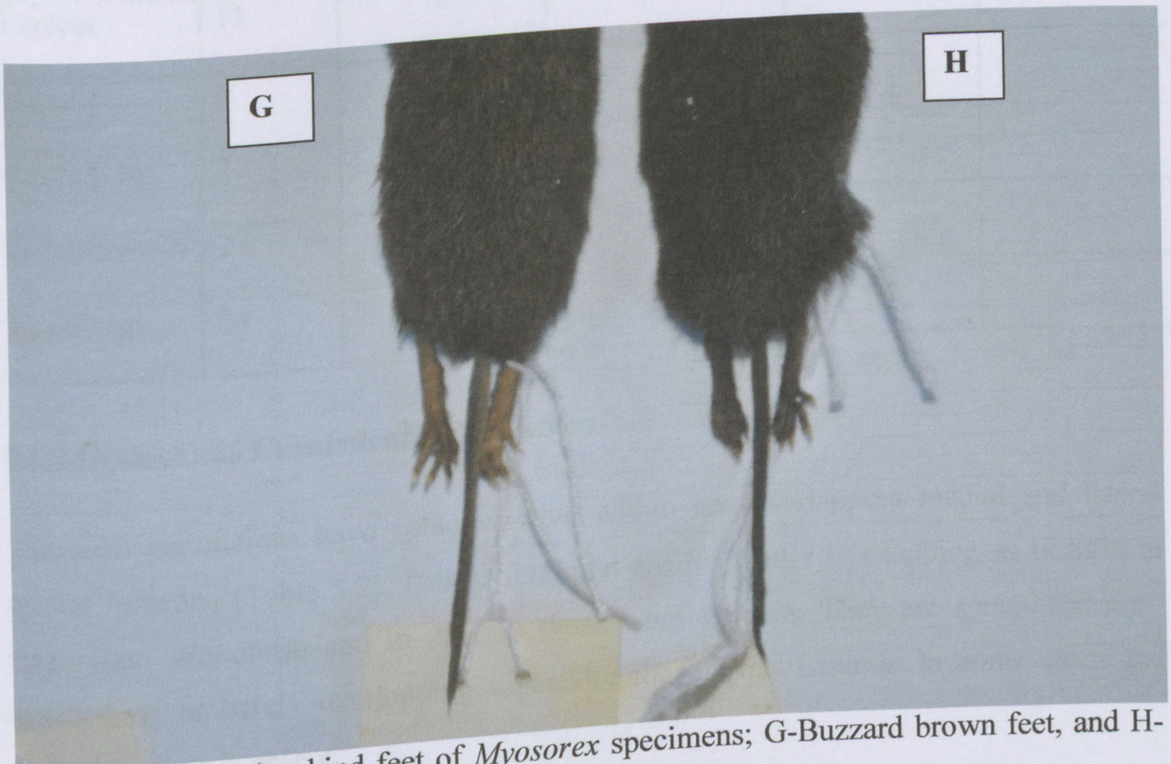


Figure 5.1c: Showing hind feet of *Myosorex* specimens; G-Buzzard brown feet, and H-Middelfontein dark black feet.

Myosorex from Limpopo Province show some variability in the usual characters used to identify *Myosorex* species (Table 5.1). Most of these specimens show *M. varius*-like characters such as a bicoloured, paler dorsal and hind foot coloration and tail. Some specimensfrom Middelfontein Farm and Entabeni Forest show pelage characters clearly reminiscent of *M. cafer* like blackish dorsal pelage, hind foot and unicolored tail colour.

Table 5.1: Pelage diagnostic traits in study samples

Species	No	Hind foot colour		Tail	
		Dark	Pale	Bi-colour	Uni-colour
M. cafer	9	9	-	-	9
M. varius	10	-	4	4	-
Entabeni	15	12	3	14	1
Lajuma	11	-	4	4	-
Hanglip	6	-	-	-	-
Buzzard Mt.	2	-	2	2	-
Middelfontein	2	2	-	-	2
Woodbush	34	-	32	33	1

5.1.2 Cranial and Craniodental Characters

Limpopo populations have some variable within non-overlapping medial and lateral palatal foramina (Table 5.2). Palatal foramina are frequently overlapping as in 84% in those from Woodbush and in 25% in those from Lajuma. They are sometimes non-overlapping or barely overlapping especially those from Lajuma. In some cases the medial foramen is absent.

Table 5.2: Character of Palatal foramina in the study sample

Species	No	Arrangement of palatal foramina		
		Overlap	No overlap	Medial absent
M. cafer	9	1	8	-
M. varius	10	9	1	-
Entabeni	15	13	-	2
Lajuma	12	8	3	1
Hanglip	6	5	1	-
Buzzard Mt.	2	2	-	-
Middelfontein	2	2	-	-
Woodbush	34	31	2	1

Summary results of cranial measurements are presented in Table 5.3 and Figures 5.2a and 5.2b. The differences in skull length are clearly shown in Boxplots (Figs 5.2a and 5.2b). Results showed minimal differences in Mean, Maximum, Minimum and Standard Deviation (SD), although specimens from Lajuma and Woodbush have a smaller skull than other specimens. On the whole, in craniodental variables, *M. cafer* is the largest while Lajuma and Woodbush populations have the smallest skull size. Population from Eastern Soutpansberg such as Buzzard Mt, Middelfontain, Hanglip and Entabeni in the case of skull length (CI, PPL), dental (UTR, LTR) measurements, these differences are signicant (p. 0.05) between groups of *M. cafer*, *M. varius*, Lajuma and Woodbush. Measurements of the skull width (LIW, GW, and BW) the group differences are less marked and not significant. The skull measurements exclude the possibility of Limpopo populations belonging to *M. cafer*.

Table 5.3: Summary the results of craniodental measurements of maximum, minimum, mean and standard deviation of *M. cafer, M. varius,* and *Myosorex* populations from Limpopo Province.

	cafer	Entabeni	Buzzard +Middel fontein	Woodbush	Lajuma	*varius*	Hanglip
CI							
N	9	15	4	34	11	10	6
Min	22.9	21.6	22.0	20.8	20.9	21.3	22.0
Max	24.0	22.9	22.5	22.1	21.6	23.2	23.2
Mean	23.41	22.31	22.31	21.29	21.23	22.25	22.25
SD	0.35	0.35	0.20	0.33	0.21	0.57	0.47
PPL							
N	9	15	4	34	11	10	6
Min	10.1	9.4	9.8	9.2	9.2	9.6	9.9
Max	11.1	10.4	10.5	10.0	9.8	10.4	10.8
Mean	10.60	9.95	10.04	9.6	9.53	9.96	10.15
SD	0.34	0.30	0.35	0.22	0.21	0.27	0.34
UTR							
N	9	15	4	34	11	10	6
Min	9.6	9.1	9.4	8.5	8.7	8.7	9.1
Max	10.5	9.7	9.8	9.4	9.3	9.9	9.7
Mean	10.10	9.52	9.57	8.96	9.03	9.46	9.40
SD	0.31	0.19	0.18	0.18	0.17	0.34	0.21
LIW							
N	9	15	4	34	11	10	6
Min	4.4	4.3	4.5	4.0	4.3	4.1	4.4
Max	4.9	4.7	4.8	5.0	4.6	4.5	4.6
Mean	4.59	4.46	4.64	4.28	4.45	4.30	4.53

BW							
N	9	15	4	34	11	10	6
Min	6.8	6.4	6.6	6.1	6.06	6.4	6.6
Max	7.4	7.0	6.8	6.7	6.66	7.1	7.0
Mean	7.02	6.74	6.70	6.32	6.32	6.75	6.79
SD	0.15	0.16	0.10	0.14	0.1386	0.20	0.17
GW							
N	9	15	4	34	11	10	6
Min	10.6	10.5	10.3	10.1	10.1	10.3	10.4
Max	11.4	11.1	11.10	10.9	10.6	11.5	11.1
Mean	11.16	10.77	10.72	10.47	10.37	10.74	10.71
SD	0.25	0.19	0.32	0.20	0.13	0.41	0.23
LTR							
N	9	15	4	34	11	10	6
Min	8.7	8.3	8.6	8.58	7.9	7.98	7.8
Max	9.4	8.9	8.7	8.7	8.5	8.48	8.9
Mean	9.11	8.68	8.64	8.65	8.16	8.27	8.54
SD	0.23	0.16	0.06	0.06	0.15	0.15	0.33

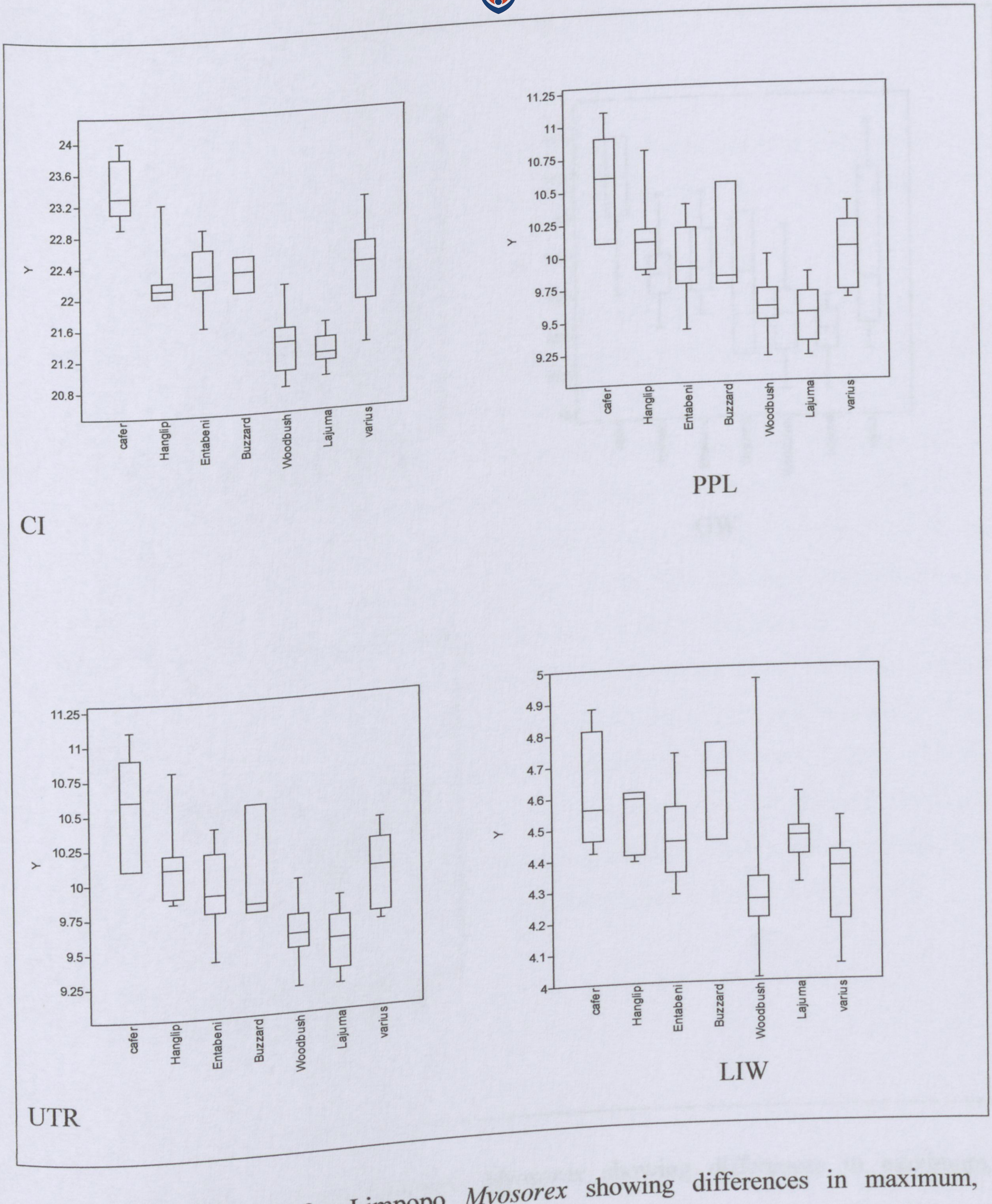


Figure 5.2a: Boxplots for Limpopo *Myosorex* showing differences in maximum, minimum and mean of cranial measurements.

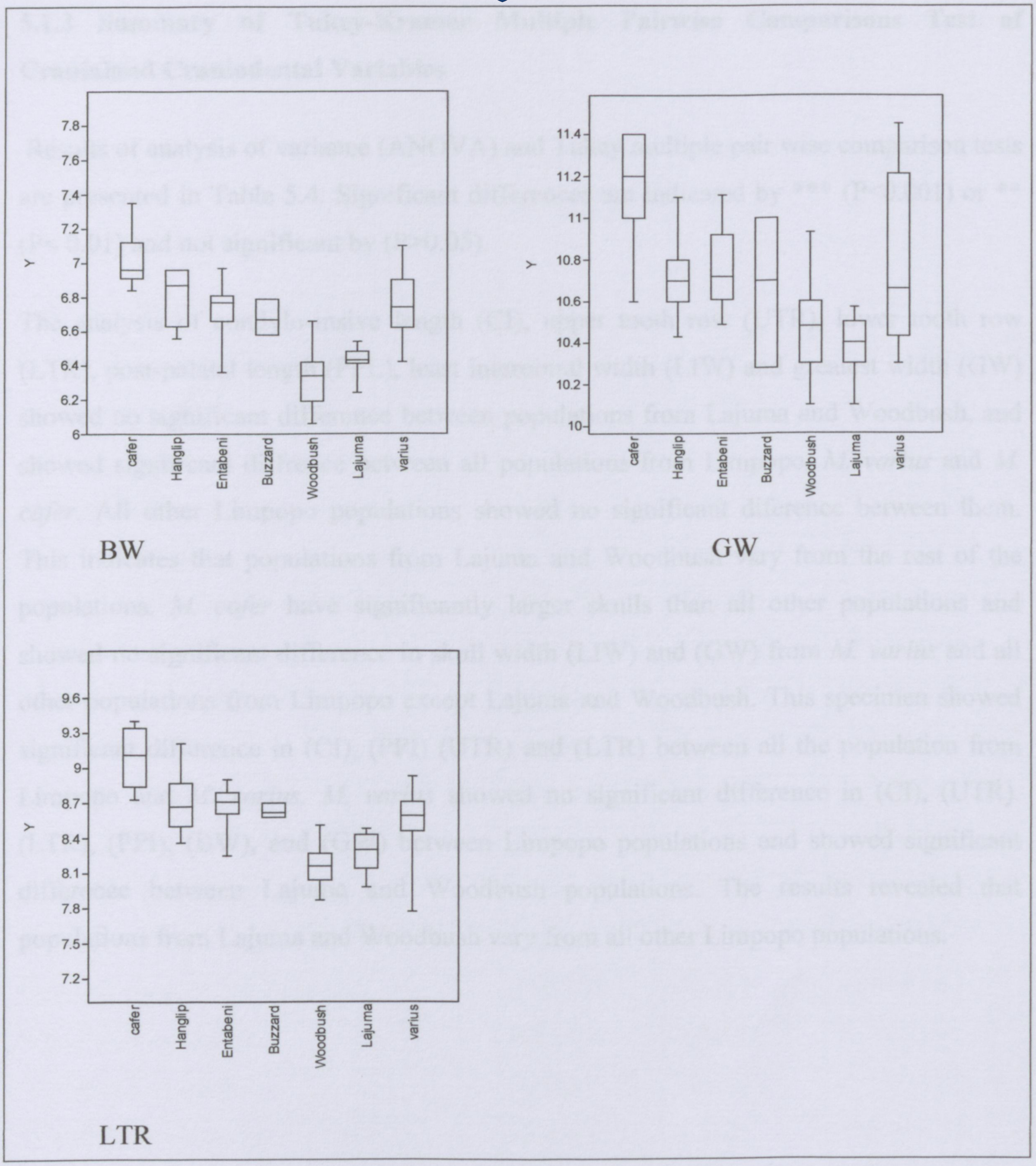


Figure 5.2b: Boxplots for Limpopo *Myosorex* showing differences in maximum, minimum and mean of cranial measurements.

5.1.3 Summary of Tukey-Kramer Multiple Pairwise Comparisons Test of Cranialand Craniodental Variables

Results of analysis of variance (ANOVA) and Tukey multiple pair wise comparison tests are presented in Table 5.4. Significant differences are indicated by *** (P<0.001) or ** (P< 0.01) and not significant by (P>0.05).

The analysis of condylo-insive length (CI), upper tooth row (UTR), lower tooth row (LTR), post-palatal length (PPL), least interobital width (LIW) and greatest width (GW) showed no significant difference between populations from Lajuma and Woodbush, and showed significant diffrence between all populations from Limpopo, *M. varius* and *M. cafer*. All other Limpopo populations showed no significant diference between them. This indicates that populations from Lajuma and Woodbush vary from the rest of the populations. *M. cafer* have significantly larger skulls than all other populations and showed no significant difference in skull width (LIW) and (GW) from *M. varius* and all other populations from Limpopo except Lajuma and Woodbush. This specimen showed significant difference in (CI), (PPI) (UTR) and (LTR) between all the population from Limpopo and *M. varius*. *M. varius* showed no significant difference in (CI), (UTR). (LTR), (PPI), (BW), and (GW) between Limpopo populations and showed significant difference between Lajuma and Woodbush populations. The results revealed that populations from Lajuma and Woodbush vary from all other Limpopo populations.

Table 5.4: Tukey-Kramer multiple pairwise mean comparation test of cranial and croniodetal variables

Comparison	Mean diffference	q	P-values
CI			
cafer vs Entabeni	1.106	10.168	*** P<0.001
*Cafer*vs Buzzard + Middelfontein	1.104	7.120	*** P<0.001
cafer vs Woodbush	2.118	21.901	*** P<0.001
cafer vs Lajuma	2.184	18.837	*** P<0.001
cafer vs *varius*	1.159	9.781	*** P<0.001
cafer vs Hanglip	1.161	8.541	*** P<0.001
Entabenivs Buzzard + Middelfontein	-0.002167	0.01493	ns*** P>0.001
Entabeni vsWoodbush	1.012	12.655	*** P<0.001
Entabeni vs Lajuma	1.078	10.529	*** P<0.001
Entabeni vs *varius*	0.05333	0.5065	ns P>0.05
Entabeni vsHanglip	0.05333	0.4441	ns P>0.05
Buzzard + Middel vs Woodbush	1.014	7.437	*** P<0.001
Buzzard + Middel vs Lajuma	1,080	7.173	*** P<0.001
Buzzard + Middel vs *varius*	0.05550	0.3637	ns P>0.05
Buzzard + Middel vs Hanglip	0.05750	0.3454	ns P>0.05
Woodbush vs Lajuma	0.06626	0.7405	ns P>0.05
Woodbush vs *varius*	-0.9585	10.330	*** P<0.001
Woodbush vs Hanglip	-0.9565	8.374	*** P<0.001
Lajuma vs *varius*	1.025	09.093	*** P<0.001
Lajuma vs Hanglip	1.023	7.813	*** P<0.001
Varius vs Hanglip	0.002000	0.01502	ns P>0.05
PPL			
cafer vs Entabeni	0.6487	8.197	*** P<0.001
cafer vs Buzzard + Middelfontein	0.5550	4.921	* P<0.05

cafer vs Woodbush	1.004	14.263	*** P<0.001
cafer vs Lajuma	1.067	12.651	*** P<0.001
cafer vs *varius*	0.6360	7.375	*** P<0.001
cafer vs Hanglip	0.4500	4.549	*P < 0.05
Entabeni vs Buzzard + Middelfontein	-0.09367	0.8868	ns P > 0.05
Entabeni vsWoodbush	0.3549	6.100	*** P<0.001
Entabeni vs Lajuma	0.4186	5.618	** P<0.01
Entabeni vs *varius*	-0.01267	0.1653	ns P > 0.05
Entabeni vsHanglip	-0.1987	2.191	ns P >0.05
Buzzard + Middelfontein vs Woodbush	0.4485	4.521	* P < 0.05
Buzzard + Middelfontein vs Lajuma	0.5123	4.674	* P < 0.05
Buzzard + Middelfontein vs *varius*	0.08100	0.7295	ns P >0.05
Buzzard + Middelfontein vs Hanglip	-0.1050	0.8667	ns P >0.05
Woodbush vs Lajuma	0.06374	0.9791	ns P >0.05
Woodbush vs *varius*	-0.3675	5.443	** P<0.01
Woodbush vs Hanglip	-0.5535	6.660	*** P<0.001
Lajuma vs *varius*	-0.4313	5.259	** P<0.01
Lajuma vs Hanglip	-0.6173	6.480	*** P<0.001
varius vs Hanglip	-0.1860	1.919	ns P > 0.05
UTR			
cafer vs Entabeni	0.5720	8.818	*** P<0.001
cafer vs Buzzard + Middelfontein	0.5257	5.697	** P<0.01
cafer vs Woodbush	1.136	19.694	*** P<0.001
cafer vs Lajuma	1.068	15.439	*** P<0.001
cafer vs *varius*	0.6367	8.950	*** P<0.001
cafer vs Hanglip	0.7000	8.633	*** P<0.001
Entabeni vs Buzzard + Middelfontein	-0.04533	0.5236	ns P > 0.05
Entabeni vsWoodbush	0.5638	11.823	*** P<0.001
Entabeni vs Lajuma	0.4956	8.115	*** P<0.001
Entabeni vs *varius*	0.06067	0.9659	ns P > 0.05

Entabeni vsHanglip	0.1280	1.722	ns P > 0.05
Buzzard + Middelfontein vs Woodbush	0.6091	7.490	*** P<0.001
Buzzard + Middelfontein vs Lajuma	0.5409	6.022	** P<0.01
Buzzard + Middelfontein vs *varius*	0.1060	1.165	ns P > 0.05
Buzzard + Middelfontein vs Hanglip	0.1733	1.745	ns P > 0.05
Woodbush vs Lajuma	-0.06821	1.278	ns P > 0.05
Woodbush vs *varius*	-0.5031	9.091	*** P<0.001
Woodbush vs Hanglip	-0.4358	6.397	*** P<0.001
Lajuma vs *varius*	-0.04349	6.470	*** P<0.001
Lajuma vs Hanglip	-0.3676	4.708	* P < 0.05
varius vs Hanglip	-0.06733	0.8475	ns P > 0.05
LTR			
cafer vs Hanglip	0.4161	5.648	** P<0.01
cafer vs Entabeni	0.4318	7.326	*** P<0.001
cafer vs Buzzard + Middelfontein	0.4603	5.479	** P<0.01
cafer vs Woodbush	0.9454	18.041	*** P<0.001
cafer vs Lajuma	0.8323	13.247	*** P<0.001
cafer vs *varius*	0.5688	8.885	*** P<0.001
Hanglip vs Entabeni	0.01567	0.2320	ns P > 0.05
Hanglip vs Buzzard + Middelfontein	0.04417	0.4895	ns P >0.05
Hanglip vs Woodbush	0.5293	8.551	*** P<0.001
Hanglip vs Lajuma	0.4162	5.867	** P<0.01
Hanglip vs *varius*	0.1527	2.115	ns P >0.05
Entabeni vs Buzzard + Middelfontein	0.02850	0.3623	ns P > 0.05
Entabeni vs Woodbush	0.5136	11.854	*** P<0.001
Entabeni vs Lajuma	0.4005	7.218	*** P<0.001
Entabeni vs *varius*	0.1370	2.401	ns P > 0.05
Buzzard + Milddelfontein vs Woodbush	0.4851	0.566	*** P<0.001
Buzzard + Middelfontein vs Lajuma	0.3720	4.558	*P<0.05
Buzzard+ Milddelfontein vs *varius*	0.1085	1.312	ns P > 0.05

Woodbush vs Lajuma	-0.1131	2.332	ns P > 0.05
Woodbush vs *varius*	-0.3766	7.490	*** P<0.001
Lajuma vs *varius*	-0.2635	4.315	*P<0.05
LIW			
cafer vs Hanglip	0.05722	1.043	ns P > 0.05
cafer vs Entabeni	0.1282	2.921	ns P >0.05
cafer vs Buzzard + Middelfontein	-0.05111	0.8169	ns P >0.05
cafer vs Woodbush	0.3124	8.005	*** P<0.001
cafer vs Lajuma	0.1407	3.007	*** P<0.001
cafer vs *varius*	0.2869	5.997	** P<0.01
Hanglip vs Entabeni	0.07100	1.412	ns P > 0.05
Hanglip vs Buzzard + Middelfontein	-0.1083	1.612	ns P > 0.05
Hanglip vs Woodbush	0.2552	5.535	** P<0.01
Hanglip vs Lajuma	0.08348	1.580	** P<0.01
Hanglip vs *varius*	0.2297	4.272	ns P >0.05
Entabeni vs Buzzard + Middelfontein	-0.1793	3.061	ns P >0.05
Entabeni vs Woodbush	0.1842	5.708	** P<0.01
Entabeni vs Lajuma	0.01248	0.3021	** P<0.01
Entabeni vs *varius*	0.1587	3.733	ns P > 0.05
Buzzard + Middelfontein vs Woodbush	0.3635	6.605	*** P<0.001
Buzzard + Milddel fontain vs Lajuma	0.1918	3.155	*** P<0.001
Buzzard + Milddelfontein vs *varius*	0.3380	5.487	ns P > 0.05
Woodbush vs Lajuma	-0.1717	4.755	ns P>0.05
Woodbush vs *varius*	-0.02553	0.6816	*** P<0.001
Lajuma vs *varius*	0.1462	3.213	*** P<0.001
BW			
cafer vs Hanglip	0.2278	4.183	*** P<0.001
cafer vs Entabeni	0.2791	6.407	*** P<0.001
cafer vs Buzzard + Middelfontein	0.3153	5.078	* P<0.05
cafer vs Woodbush	0.6966	17.987	*** P<0.001

cafer vs Lajuma	0.5905	12.717	*** P<0.001
cafer vs *varius*	0.2668	5.620	** P<0.01
Hanglip vs Entabeni	0.05133	1.029	ns P>0.05
Hanglip vs Buzzard + Middelfontein	0.08750	1.312	ns P>0.05
Hanglip vs Woodbush	0.4688	10.248	*** P<0.001
Hanglip vs Lajuma	0.3627	6.918	*** P<0.001
Hanglip vs *varius*	0.03900	0.7310	ns P>0.05
Entabeni vs Buzzard + Middelfontein	0.03617	0.6221	ns P>0.05
Entabeni vs Woodbush	0.4175	13.037	*** P<0.001
Entabeni vs Lajuma	0.3114	7.593	*** P<0.001
Entabeni vs *varius*	-0.01233	0.2924	ns P>0.05
Buzzard vs Woodbush	0.3813	6.983	*** P<0.001
Buzzard vs Lajuma	0.2752	4.563	* P<0.05
Buzzard vs *varius*	-0.04850	0.7935	ns P>0.05
Woodbush vs Lajuma	-0.1061	2.961	ns P>0.05
Woodbush vs *varius*	-0.4298	11.565	*** P<0.001
Lajuma *varius*	-0.3237	7.172	*** P<0.001
GW			
cafer vs Hanglip	24.194		ns P>0.05
cafer vs Entabeni	17.811		ns P>0.05
cafer vs Buzzard + Middelfontein	24.819		ns P>0.05
cafer vs Woodbush	46.812		** P<0.01
cafer vs Lajuma	57.717		*** P<0.001
cafer vs *varius*	28.294		ns P>0.05
Hanglip vs Entabeni	-6.383		ns P>0.05
Hanglip vs Buzzard + Middelfontein	0.6250		ns P>0.05
Hanglip vs Woodbush	22.618		** P<0.01
Hanglip vs Lajuma	33.523		** P<0.01
Hanglip vs *varius*	4.100		ns P>0.05

Entabeni vs Buzzard + Middelfontein	7.008	ns P>0.05
Entabeni vs Woodbush	29.001	** P<0.01
Entabeni vs Lajuma	39.906	** P<0.01
Entabeni vs *varius*	10.483	ns P>0.05
Buzzard + Mildelfontein vs Woodbush	21.993	** P<0.01
Buzzard + Milddelfontein vs Lajuma	32.898	** P<0.01
Buzzard + Milddelfontein vs *varius*	3.475	ns P>0.05
Woodbush vs Lajuma	10.905	ns P>0.05
Woodbush vs *varius*	-18.518	** P<0.01
Lajuma *varius*	-29.423	** P<0.01

5.2 Model Analysis Results

The results showed that all the models have good fit for the potential distribution for *Myosorex* species according to training data Area under the curve values (AUC) and test AUC (Table 5.5). The ability of the model is assessed by comparing the AUC of ROC (Anderson and Raza, 2010). Area under the curve values represents a threshold independent measure of productivity. AUC values represent a threshold independent measure of predictivity. AUC values provide an overall assessment of how well the model of each species predicts localities (Anderson and Roza, 2010). The model accuracy is classified as fair if the value is 0.5 is obtained and excellent if the value lies between 0.85 and 0.99 (Guissan and Zammermann, 2000). The best results were from *M. longicaudatus* with 0.997. *M. sclateri* is 0.982 and *M. cafer* with 0.967 respectively. The rest are in between 0.951 to 0.868 which is still above 0.85. Area under the curve which is above 0.85 is considered as perfect (Phillips *et al*,. 2006). The model performance was measured using the AUC. The AUC ranges from 0.5 which is no better than random up to 1.0 representing perfect discriminatory capacity (Phillips *et al.*, 2006). The model results for training and testing data for all the species are found in Appendix K.

Table 5.5: Models results for training and testing data for the AUC for *Myosorex* species.

Species	Training AUC	Test AUC
cafer	0.967	0.970
varius	0.864	0.882
sclateri	0.982	0.987
longicaudatus	0.997	0.997
Myosorex Limpopo	0.923	0.933
varius southern lineage	0.951	0.951
varius northern lineage	0.868	0.868

5.3 Analysis of Variable Contributions to *Myosorex* species Models

The model was run with eight bioclimatic variables for each species. Estimate of relative contributions of bioclimatic variables to each species in percentage are given in Table 5.6. Maxent estimates the importance of the variables with percentage contribution and permutation importance values. Percentage contribution represent how much the variable contributed to the model based on the path selected for a particular run. The percentage for one run was considered and a total of 7 run was considered. All the variables in the table with the highest percentage contribution gain when used in isolation to the model had the most useful information for the model. Consequently, annual precipitation (Bio 12) had the highest percentage contribution for *M. cafer, M. varius* northern lineage, and *Myosorex* from Limpopo Province. Precipitation seasonality (Bio15) had the highest percentage contribution gain when used in isolation for *M. varius* southern lineage and *M. longicaudatus* models. For *M. varius*, the variable that had the highest gain when used in isolation was maximum temperature of the warmest month (Bio 5) and temperature seasonality (Bio 6) had the highest gain for *M. sclateri* model. However, similar variables showed the highest decline in the training gains when omitted in the specie models hence indicating that they still have the most information that is not present in other variables. Similaly the results of jackknife test of variable importance for all the species (Figs. 5.3 – 5.9) showed the same variable contribution.

Table 5.6: Variable contributions to *Myosorex* species models

Variables	*cafer*	*varius*	*sclateri*	*longicaudatus*	*Myosorex* Limpopo	*Varius* Lineage	*varius*.N. Lineage
Annual meanTemperature (Bio1)	0	3.1	0	0	6.5	4.4	2.3
Temperature Seasonality (Bio 4)	0.1	7	0	0	9.8	1.5	12
Maximum Temperature of the WarmestMonth (Bio5)	0.3	17.6	0.2	3.8	16.6	1.3	5.7
Maximum Temperature of the Coldest Month (Bio6)	2.5	1.5	51.6	0	0	15	0.2
Annual Precipitation (Bio 12)	48.3	3.3	7.5	0	47	0.6	47.5
Precipitation of the Wettest Month (Bio 13)	4.9	4.2	2.3	0	7	3.5	0
Precipitation of the driest month (Bio 14)	44	7.2	9.7	0	12	19.4	42.4
Precipitation Seasonality (Bio15)	0.1	2.2	0.1	96.2	1.2	54.3	0.6

Figure 5.3: The jackknife test for *M. cafer*.

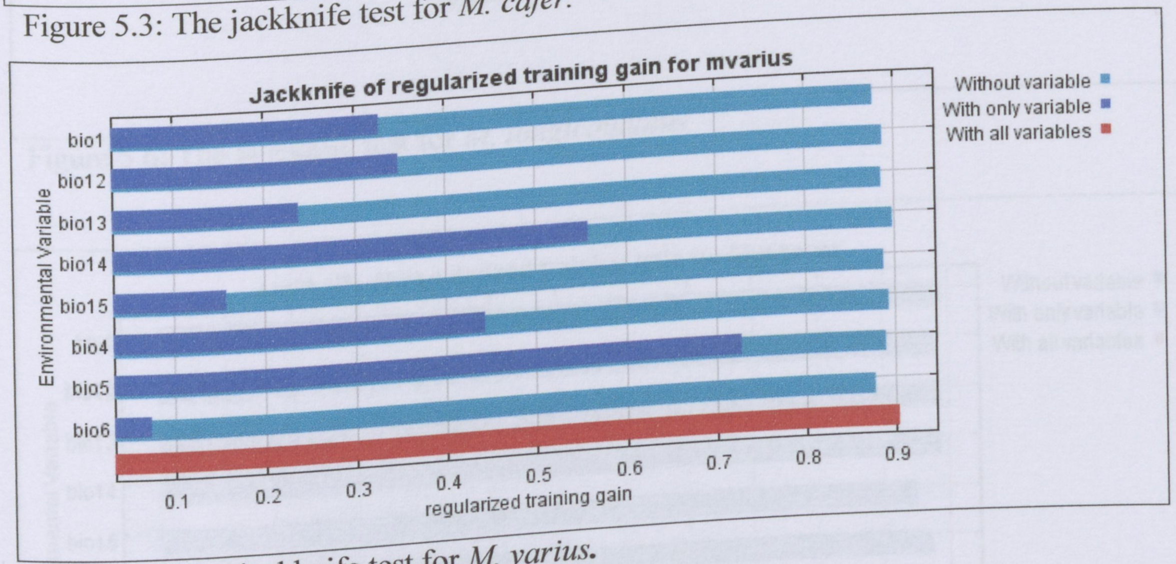


Figure 5.4: The jackknife test for *M. varius*.

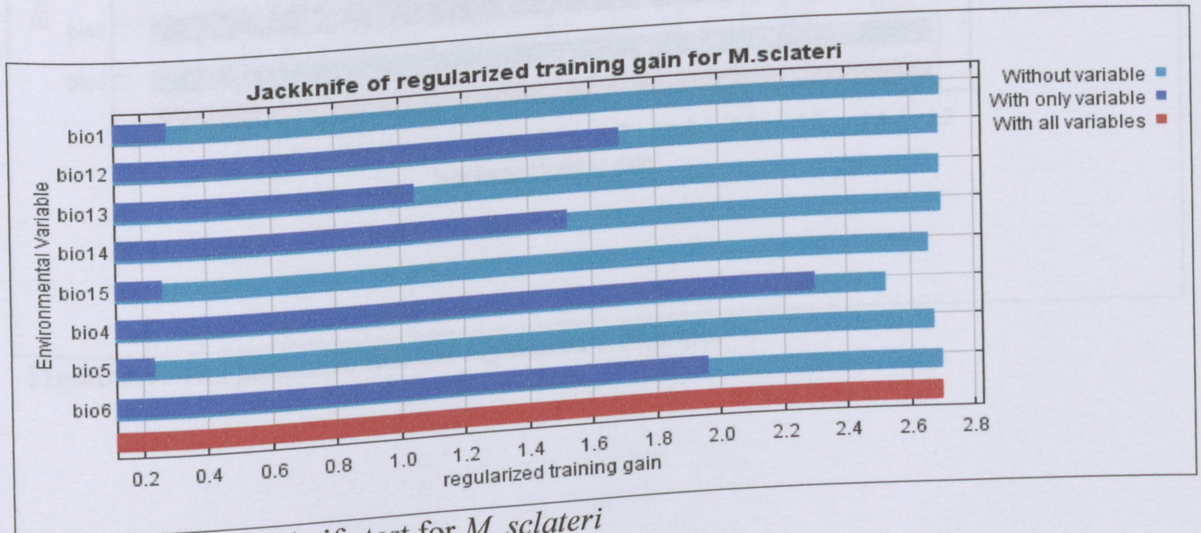


Figure 5.5: The jackknife test for *M. sclateri*

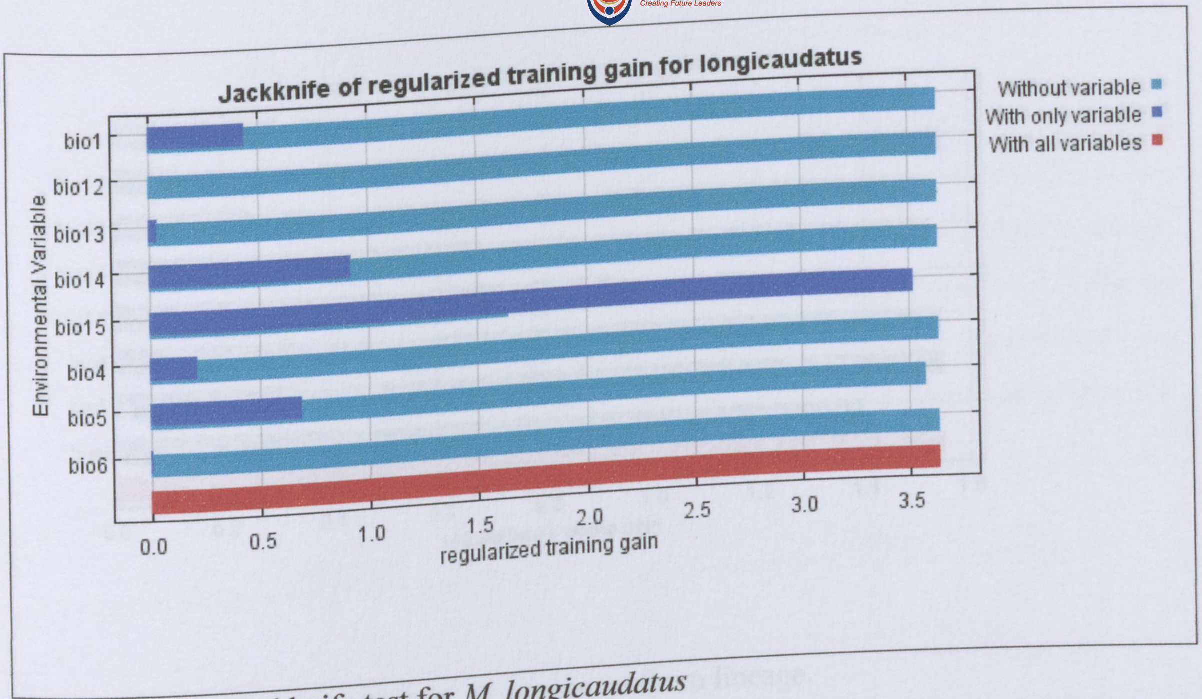


Figure 5.6: The jackknife test for *M. longicaudatus*

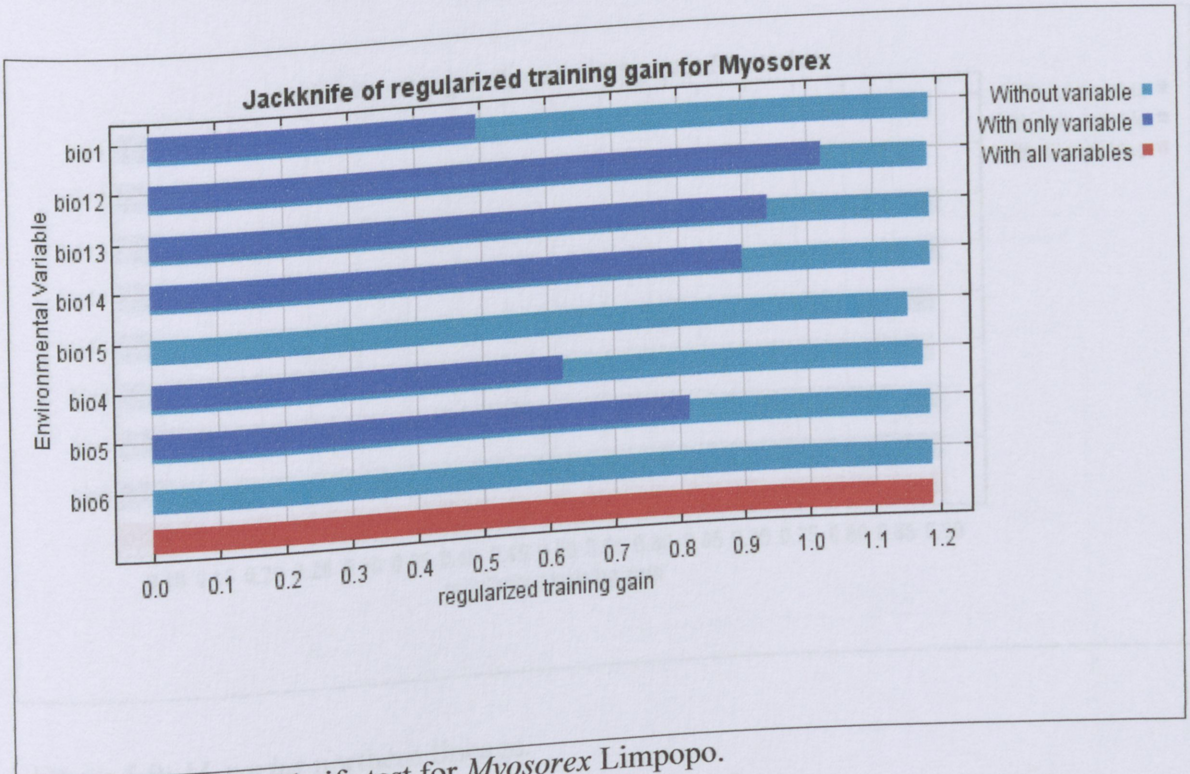


Figure 5.7: The jackknife test for *Myosorex* Limpopo.

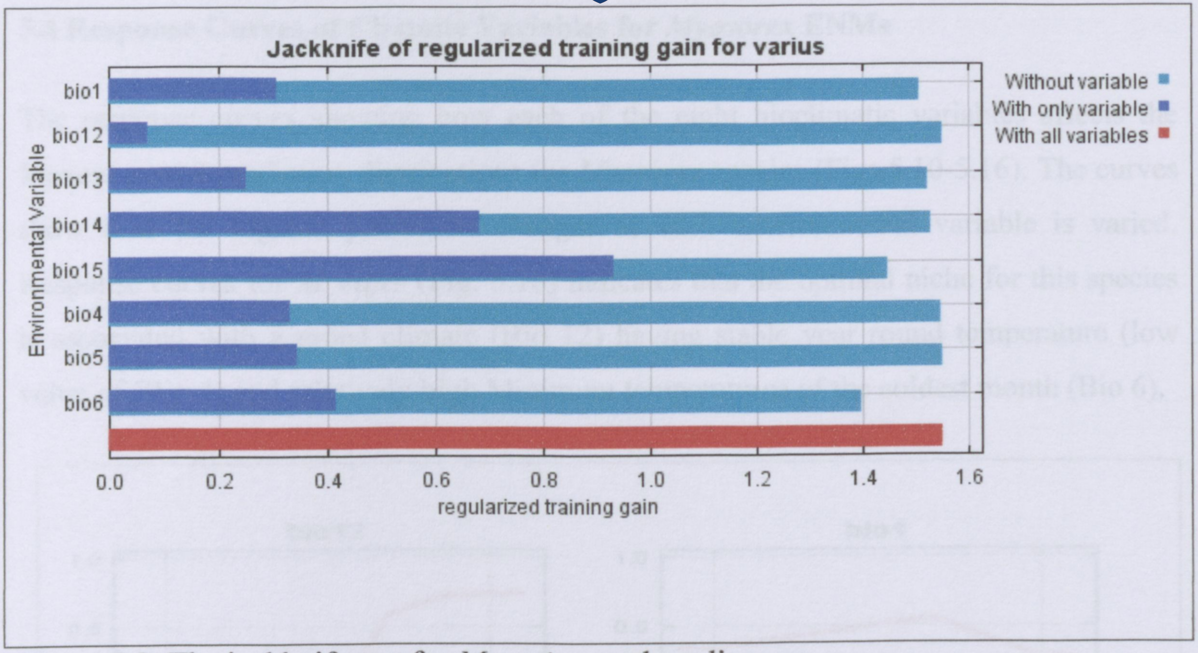


Figure 5.8: The jackknife test for *M. varius* southern lineage.

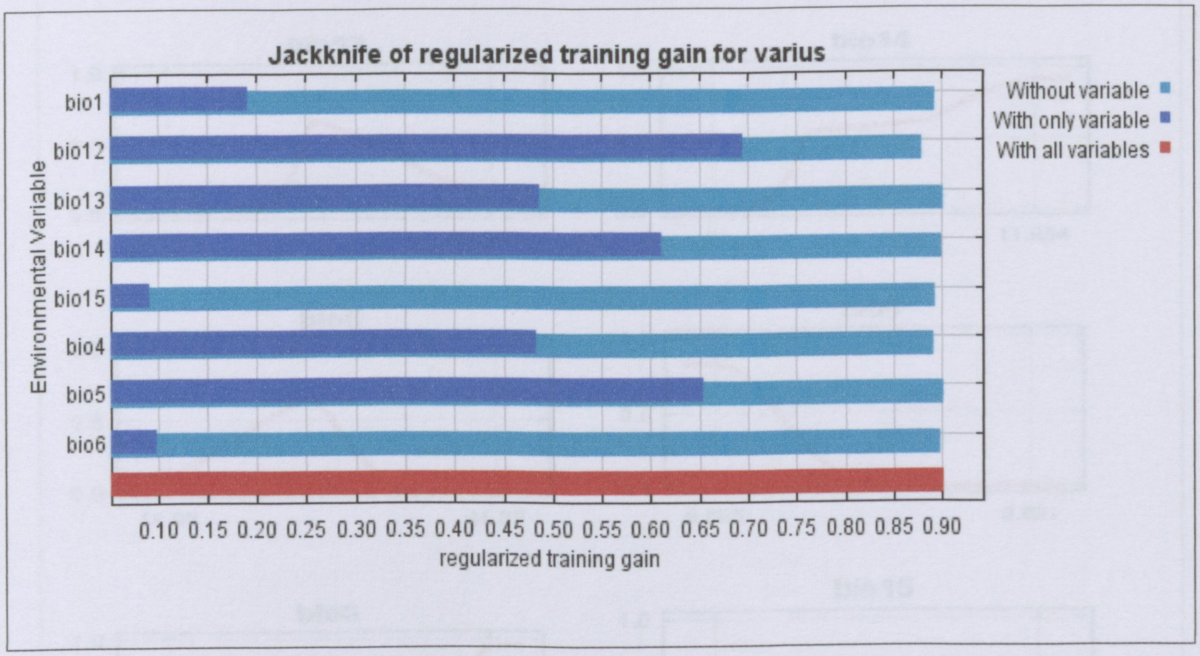


Figure 5.9: *M. varius* northern lineage.

5.4 Response Curves of Climatic Variables for *Myosorex* ENMs

The response curves showing how each of the eight bioclimatic variables affects the Maxent model prediction distributions for *Myosorex* species (Figs.5.10-5.16). The curves show how the logistic prediction changes as each environmental variable is varied. Response curves for *M. cafer* (Fig. 5.10) indicates that the optimal niche for this species is associated with a moist climate (Bio 12) having stable year round temperature (low value of (Bio 4) and relatively high Minimum temperatures of the coldest month (Bio 6).

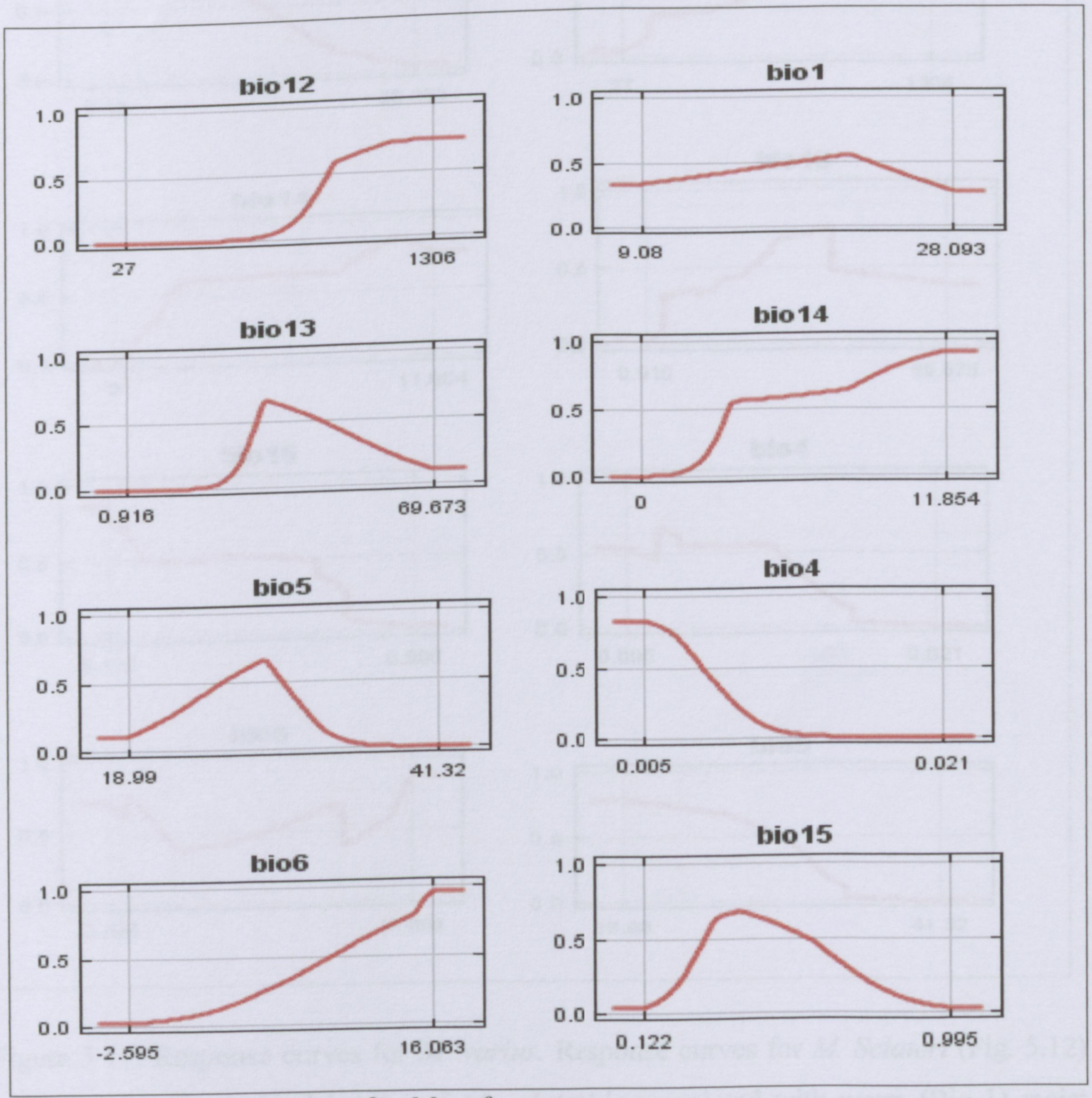


Figure 5.10: Response curves for *M. cafer*.

M. varius showed only two variables with strong responses indicating optimal cool (Bio 5) and moist (Bio 1) climate (Fig. 5.11).

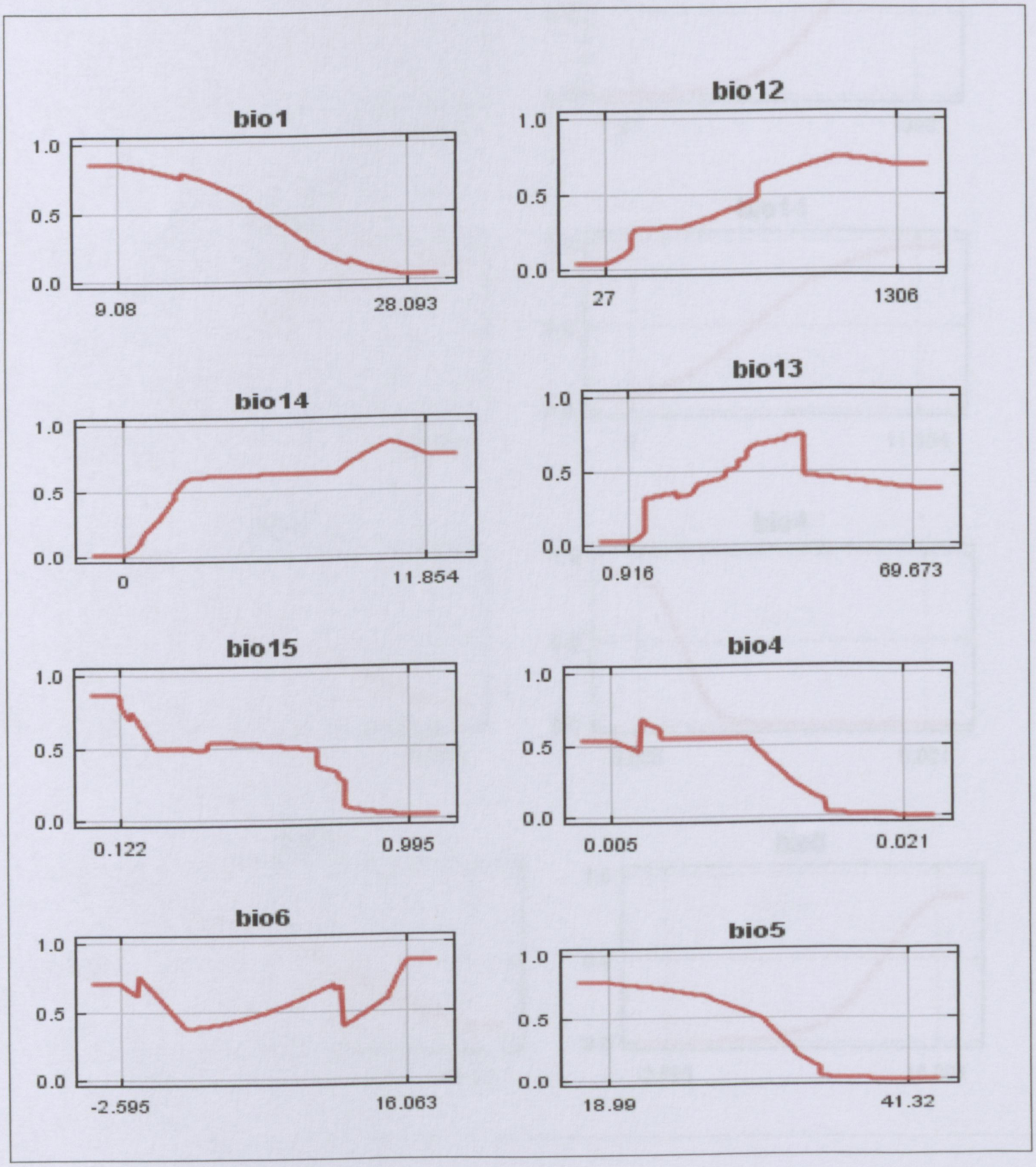


Figure 5.11: Response curves for *M. varius.* Response curves for *M. Sclateri* (Fig. 5.12) indicates that the optimal habitat of *M. sclateri* is associated with warm (Bio 1) moist climate with stable temperatures (low Bio 12).

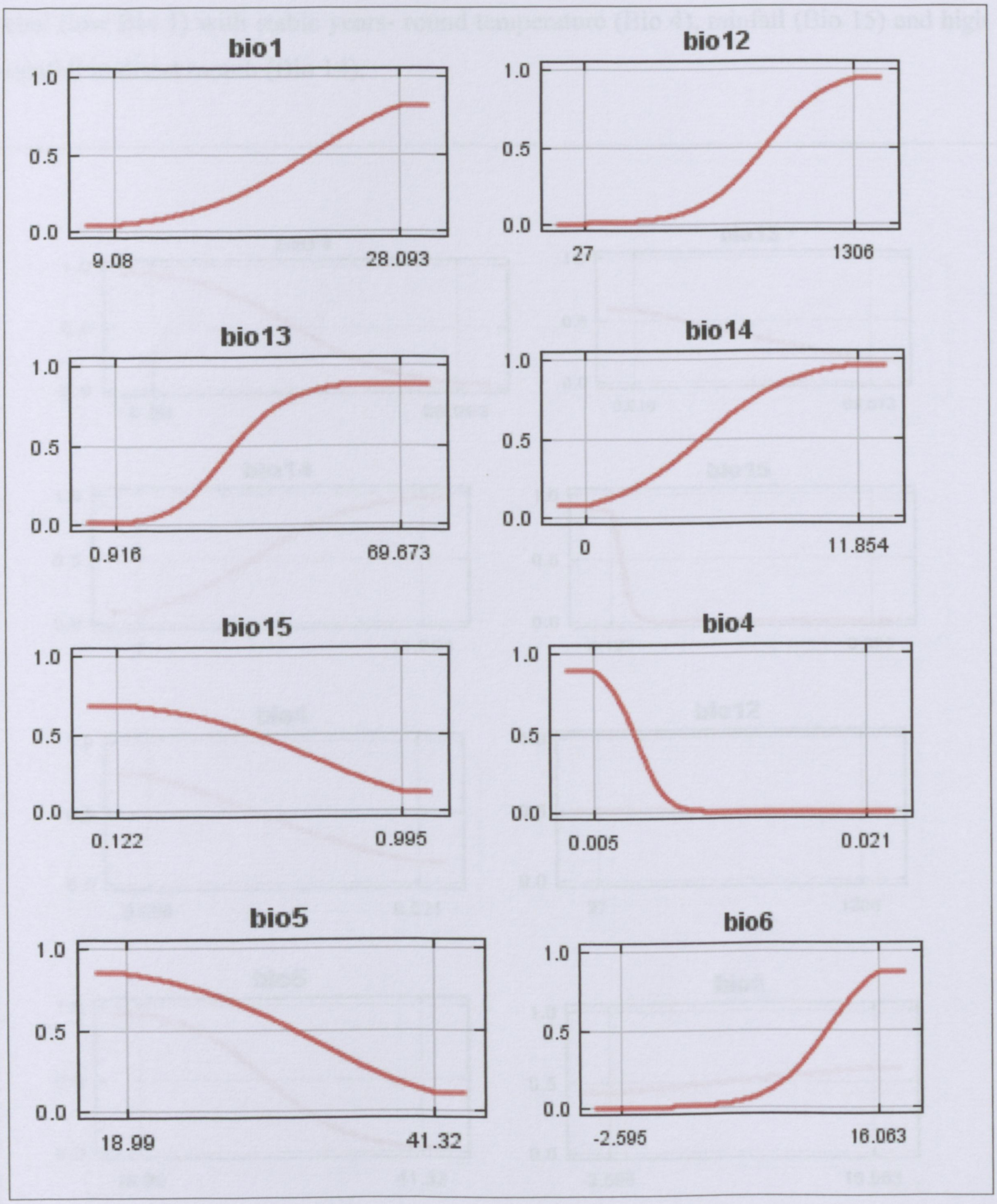


Figure 5.12: Response curves for *M. sclateri.*

M. longicaudatus' curve (Fig. 5.13) indicates that the optimal niche for this species is cool (low Bio 1) with stable years- round temperature (Bio 4), rainfall (Bio 15) and high rainfall in driest month (Bio 14).

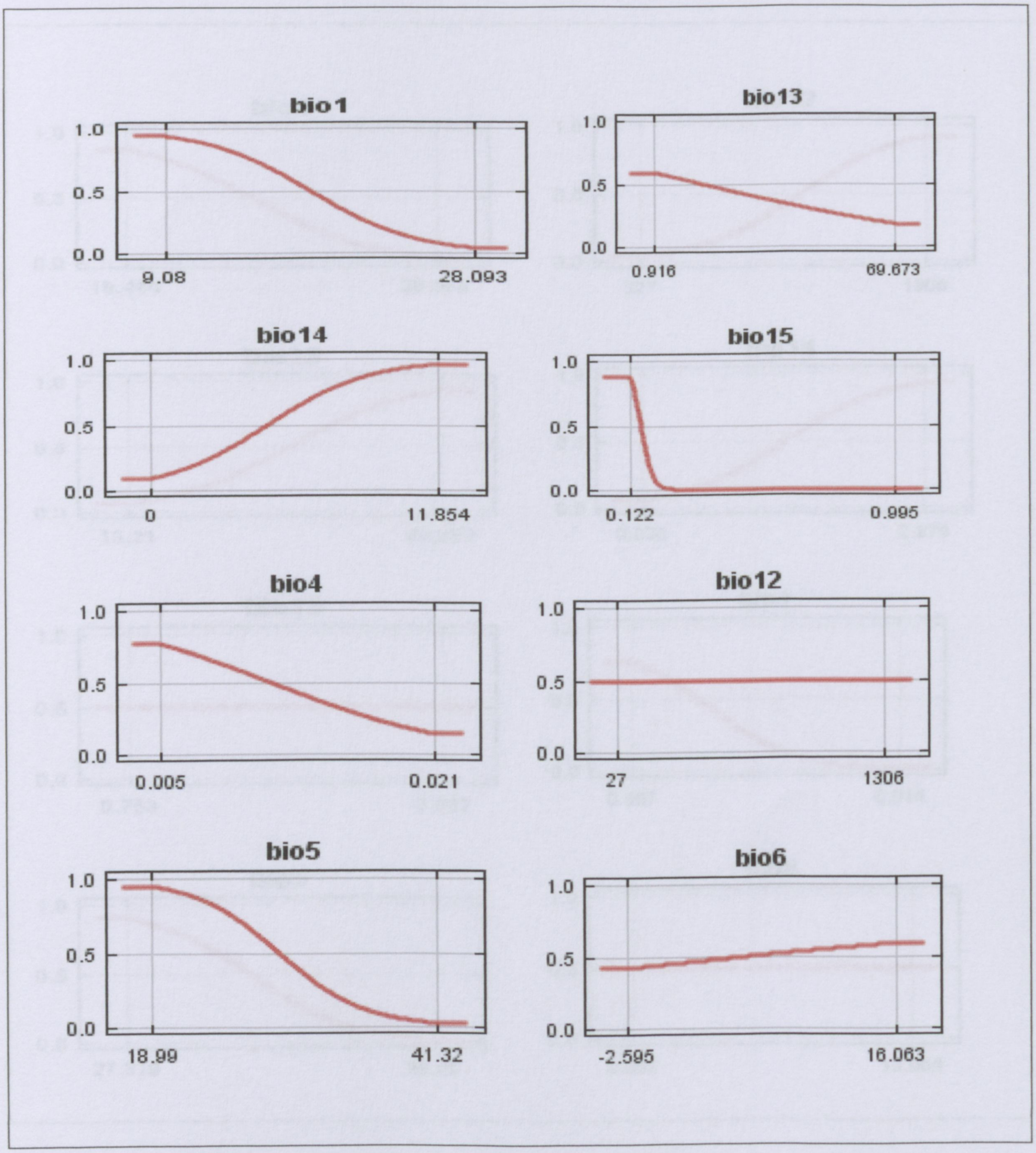


Figure 5.13: Response curves for *M.longicaudatus.*

Response curves for *Myosorex* from Limpopo cf. (Fig. 5.14) showing optimal habitat for this species as cool (low Bio 1), moist (Bio 12 and 14) with stable temperatures (low Bio 4).

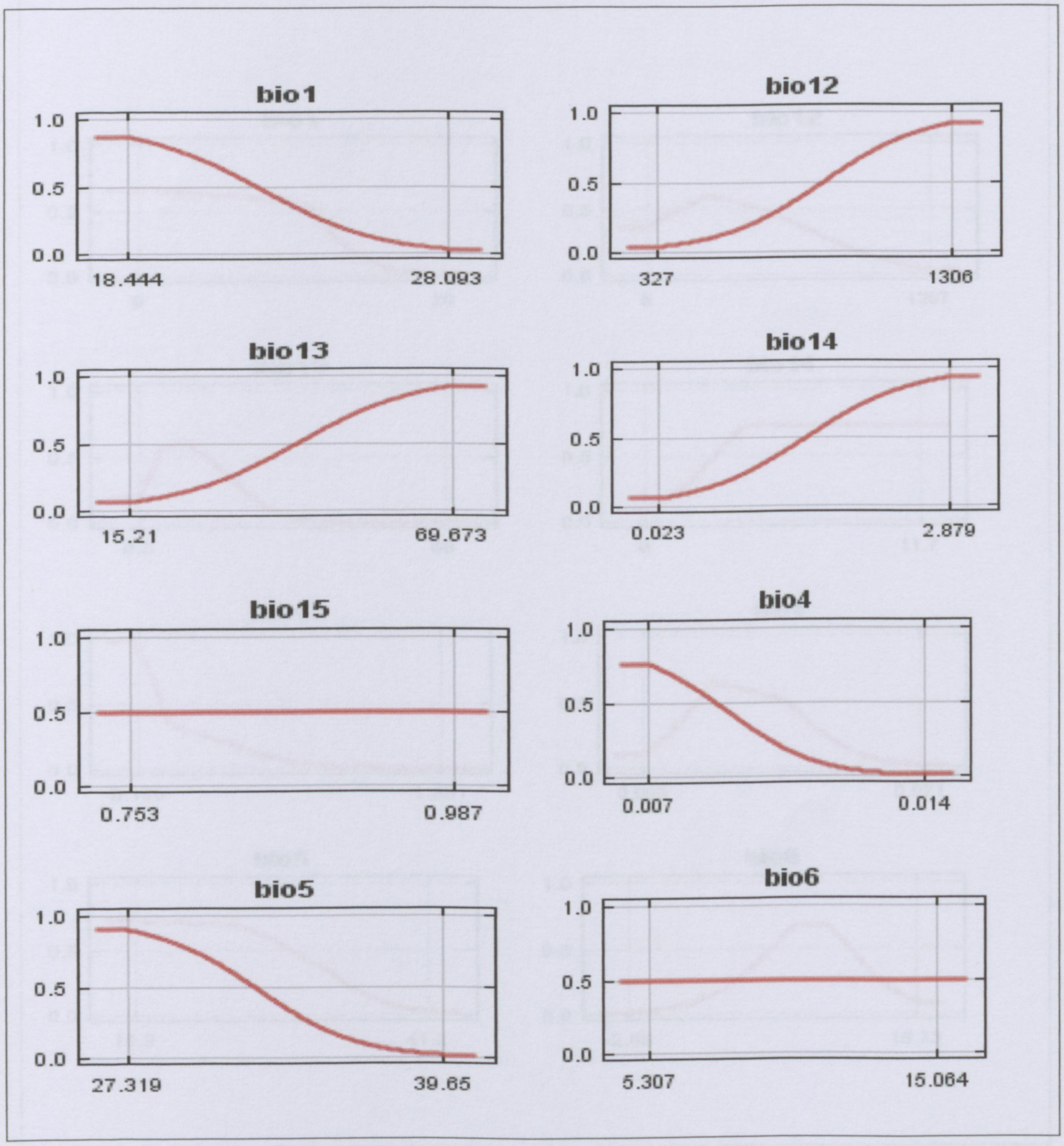


Figure 5.14: Response curves for *Myosorex* species from Limpopo Province.

Response curves for Southern lineage (Fig. 5.15) showing optimal habitat for this species as cool (low Bio 1), moist (Bio 15 and 14) with stable temperature throughout the year (Bio 6).

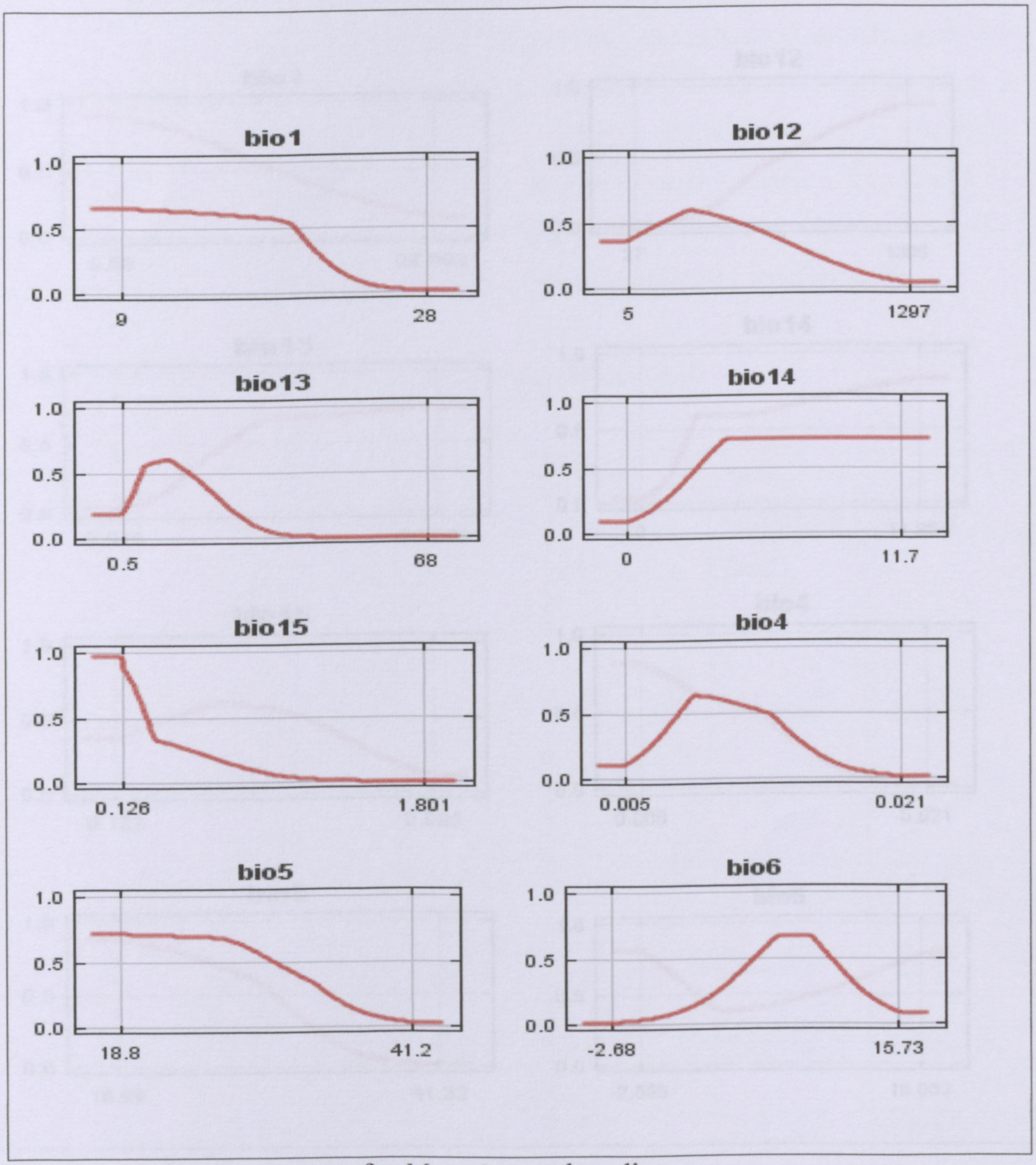


Figure 5. 15: Response curves for *M. varius* southern lineage.

M. varius northern lineage (Fig. 5.16) indicates that optimal habitat for this lineage is cool (Bio 1) with moist climate (Bio 12) and stable temperature.

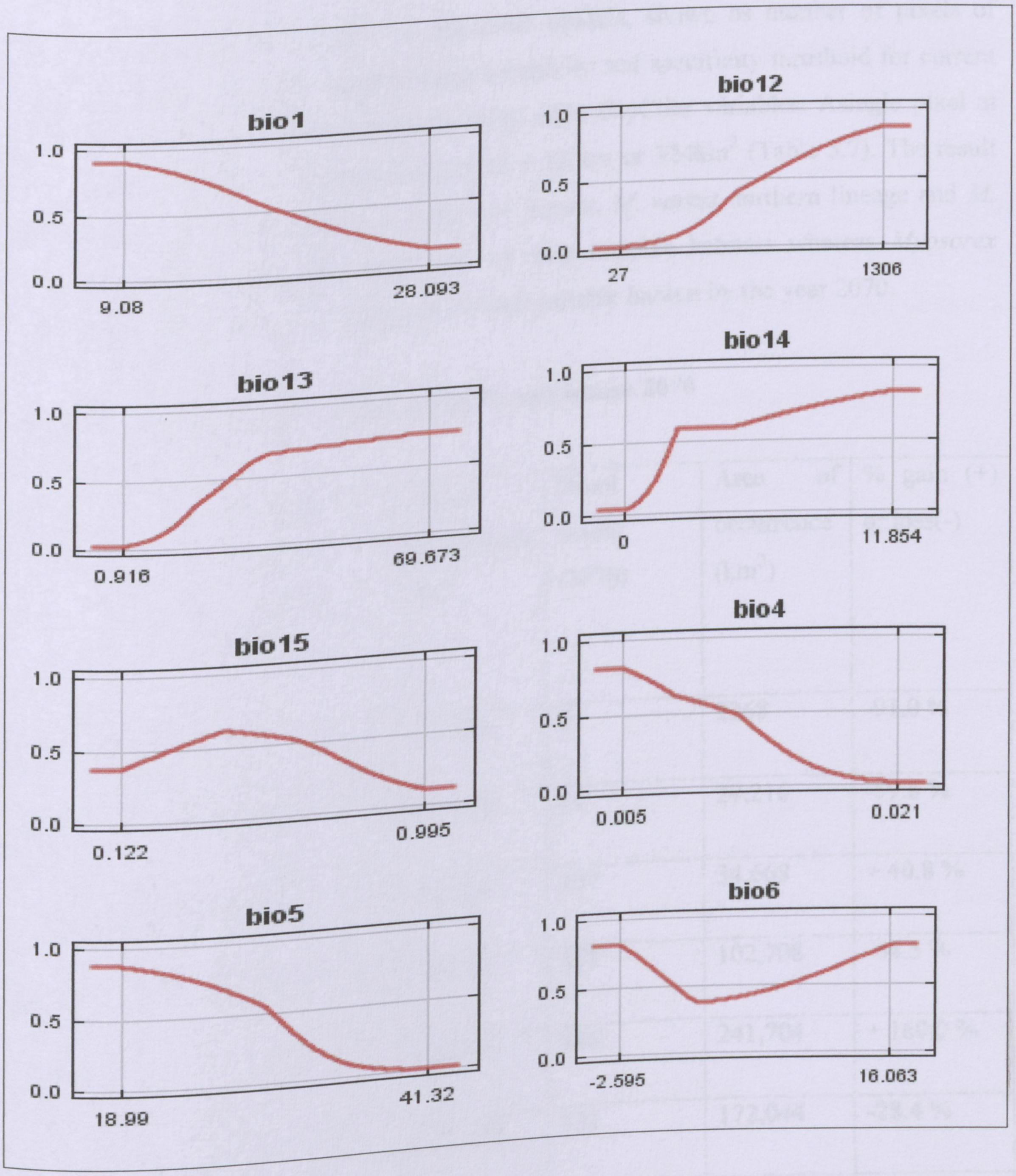


Figure 5. 16: Response curves for *M. virius* northern lineage.

5.5 Species Range Shifts Analysis

5.5.1 Predicted Current and Projected Future Distributions

The results of Maxent models for *Myosorex* models, shown as number of pixels of suitable habitat defined by equal training sensitivity and specificity threshold for current 1975 and future A2 emission scenario using eight BioClim variables. Asingle pixel at 10'resolution translates to approximately 18 x 18 km or 324km^2 (Table 5.7). The result showed that *M. longicaudatus*, *M. cafer*, *M. varius*, *M. varius* northern lineage and *M. varius* southern lineage will loose part of their suitable habitats whereas *Myosorex* Limpopo and *M. sclateri* will gain part of their suitable habitat by the year 2070.

Table 5.7: Model results of current (1975) and future 2070

Species	No.of pixels (1975)	No.of occurrence km^2	No.of pixels (2070)	Area of occurrence (km^2)	% gain (+) or loss(-)
M. longicaudatus	79	25,596	7	2268	-91.0 %
cafer	209	67,716	84	27,216	-59.8 %
Limpopo*Myosorex*	76	24,624	107	34,668	+ 40.8 %
varius	89	28,836	317	102,708	-64.5 %
sclateri	287	92,988	746	241,704	+ 160.0 %
varius north	742	240,408	531	172,044	-28.4 %
varius south	766	248,184	617	199.908	-19.4 %

The potential predicted current distribution and projected predicted future distribution maps of all the *Myosorex* species are presented in Figs.5.17 to Fig. 5.23. The modeled current and future distribution were based on Maxent model using eight bioclimatic variables and the future was based on A2 scenario which represents an economically-oriented world with high human population growth rate, increased energy expenditure and accelerated land- use changes.

The predicted current distributions map for *M. cafer* (Fig.5.17a) showed that the areas with suitable habitat for this species are found in the eastern part of the country along the coastline of northern Eastern Cape and southern KwaZulu-Natal Provinces. They avoid the dry hot north western and western part of the country. The model revealed that the future distribution (Fig. 5. 17b) showed remarkable range shifts towards the south east along the coastal region of northern Eastern Cape and southern KwaZulu-Natal as reflected by drastic reduction of 59.8 % of the suitable habitatby the year 2070. Current distribution of suitable habitat is of 209 pixels (67,716km^2) and this will be reduced to 84 pixels (27,216km^2) by the year 2070. This may increase the extinction risk of this species by the year 2070.

Myosorex varius predicted current distribution map (Fig. 5.18a) showed that current distribution of this species is within eastern, north-eastern, southern and south-western regions of the country. This showed that suitable habitats for *M. varius* are found in all almost all the provinces except North West Province. Projected future distributions of *M. varius* (Fig.5.18b) showed that this species will shift eastwards and southwards along the coastline of the country by the year 2070. The current model indicates 317 pixels (102,708 km^2) which will decline to 89 pixels (28,836km^2) by the year 2070. This revealed that *M. varius* will lose 64% in the case of the pixels with current high suitable habitats by the year 2070. Considerable reduction of the actual area of suitable climatic conditions is likely to increase the extinction risk of this species.

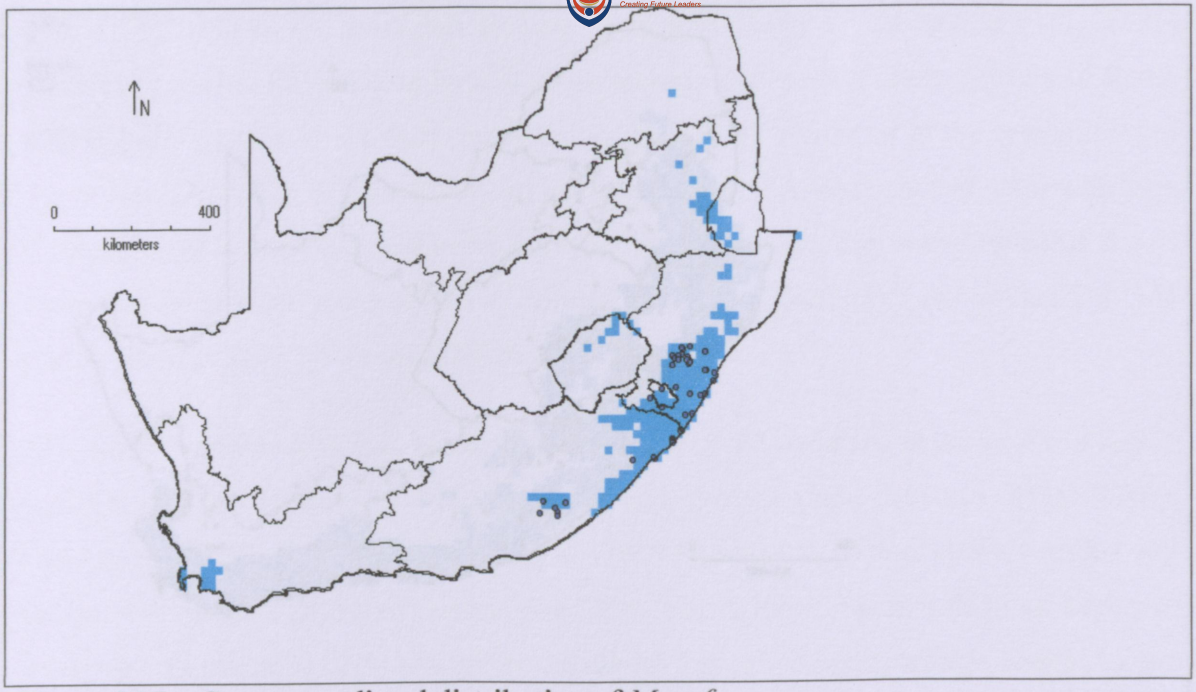


Figure 5.17a: Current predicted distribution of *M. cafer*.

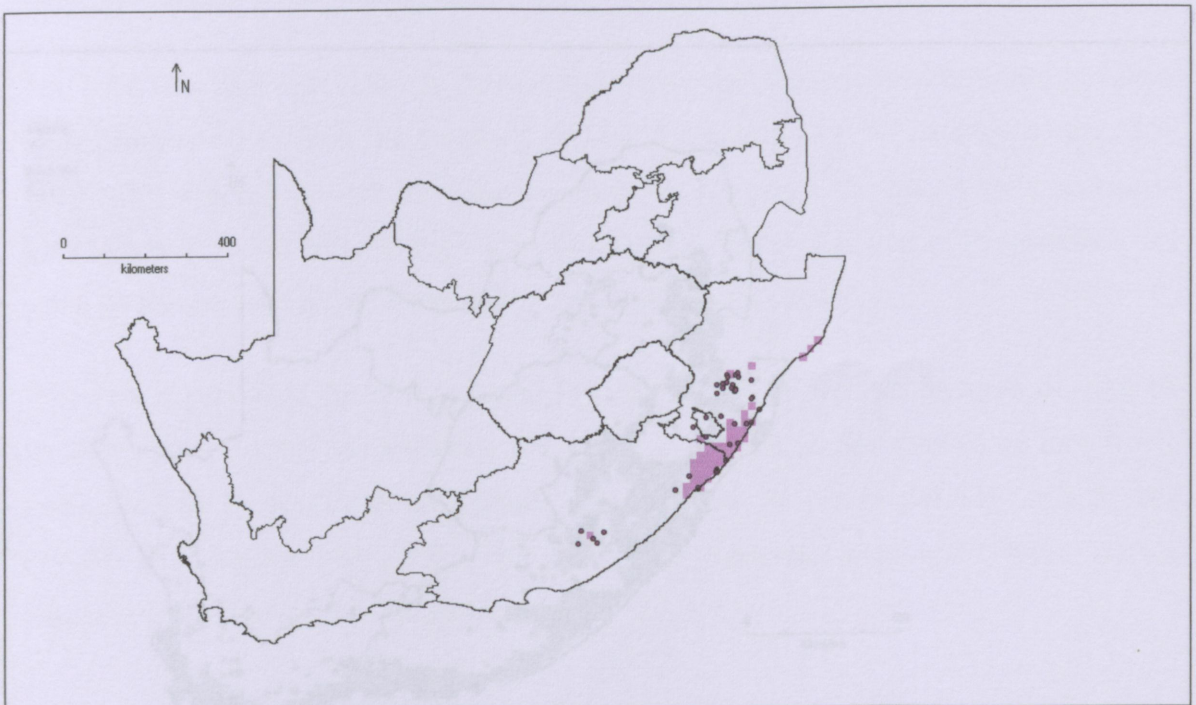


Figure 5.17b: Future projected distribution of *M. cafer* by the year 2070.

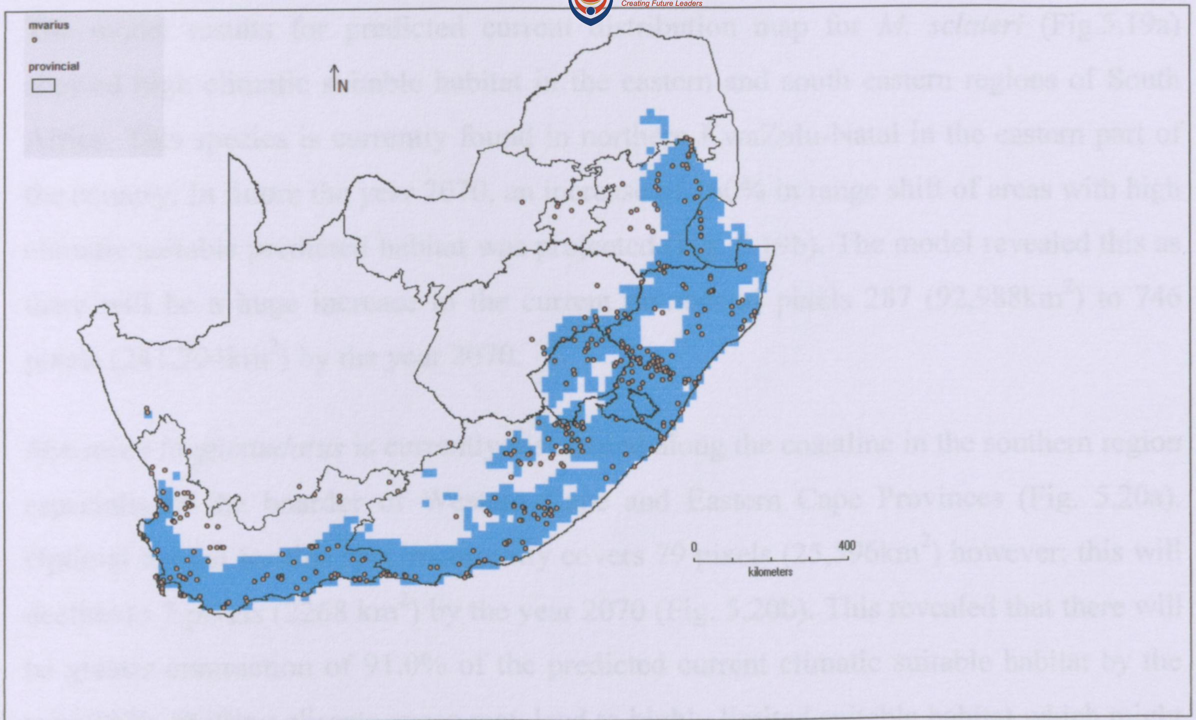


Figure 5.18a: The current predicted distribution of *M. varius*.

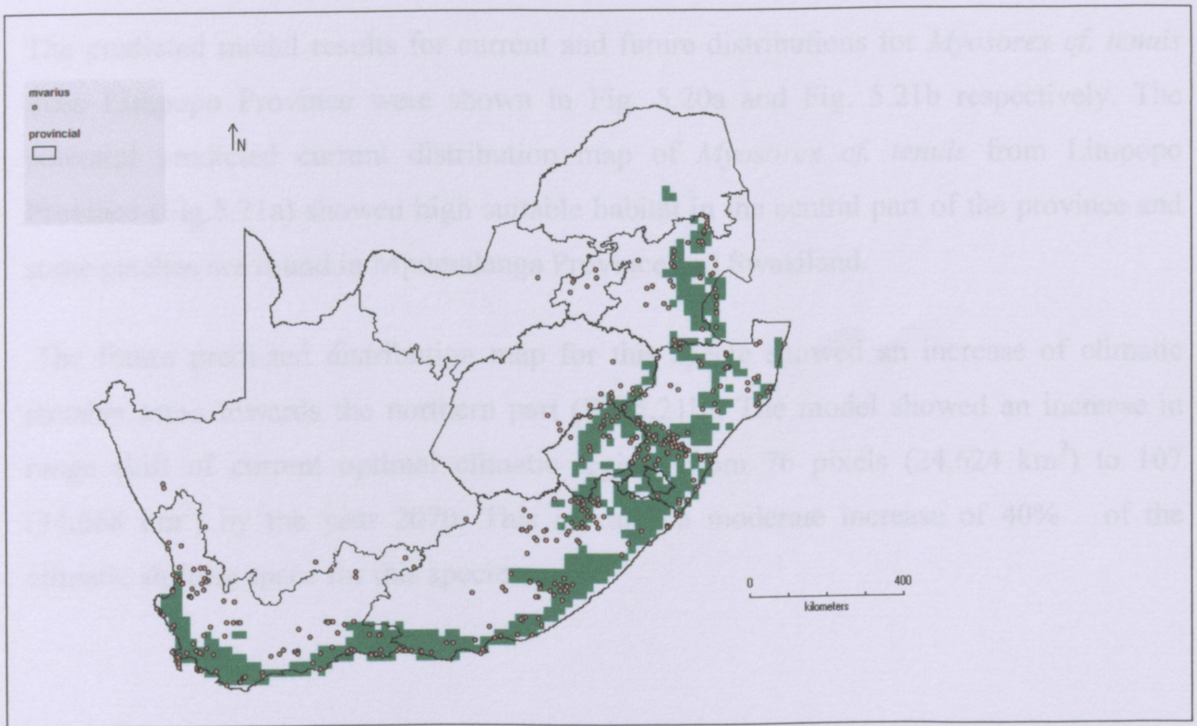


Figure 5.18b: The future projected distribution of *M. varius* by the year 2070.

The model results for predicted current distribution map for *M. sclateri* (Fig.5.19a) showed high climatic suitable habitat in the eastern and south eastern regions of South Africa. This species is currently found in northern KwaZulu-Natal in the eastern part of the country. In future the year 2070, an increase of 160% in range shift of areas with high climatic suitable predicted habitat was projected (Fig. 5.19b). The model revealed this as there will be a huge increase in the current number of pixels 287 (92,988km^2) to 746 pixels (241,704km^2) by the year 2070.

Myosorex longicaudatus is currently distributed along the coastline in the southern region especially at the boarder of Western Cape and Eastern Cape Provinces (Fig. 5.20a). Optimal habitat for this speciescurrently covers 79 pixels (25,596km^2) however; this will decline to 7 pixels (2268 km^2) by the year 2070 (Fig. 5.20b). This revealed that there will be greater contraction of 91.0% of the predicted current climatic suitable habitat by the year 2070. Shifting climate space may lead to highly limited suitable habitat which might increase chances of extinction for this species.

The predicted model results for current and future distributions for *Myosorex cf. tenuis* from Limpopo Province were shown in Fig. 5.20a and Fig. 5.21b respectively. The potential predicted current distribution map of *Myosorex cf. tenuis* from Limpopo Province (Fig.5.21a) showed high suitable habitat in the central part of the province and some patches are found in Mpumalanga Province and Swaziland.

The future predicted distribution map for this specie showed an increase of climatic suitable areas towards the northern part (Fig.5.21b). The model showed an increase in range shift of current optimal climatic regions from 76 pixels (24,624 km^2) to 107 (34,668 km^2) by the year 2070. This revealed a moderate increase of 40% of the climatic shifting space for this species.

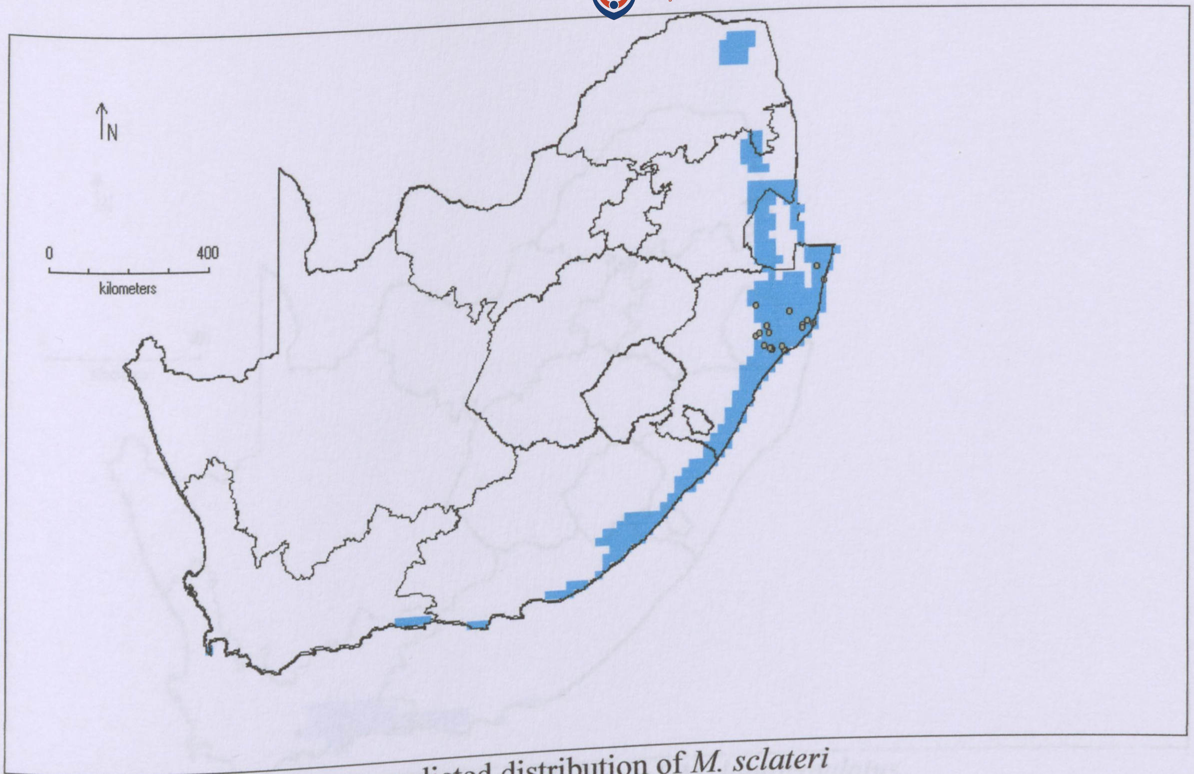


Figure 15.19a: The current predicted distribution of *M. sclateri*

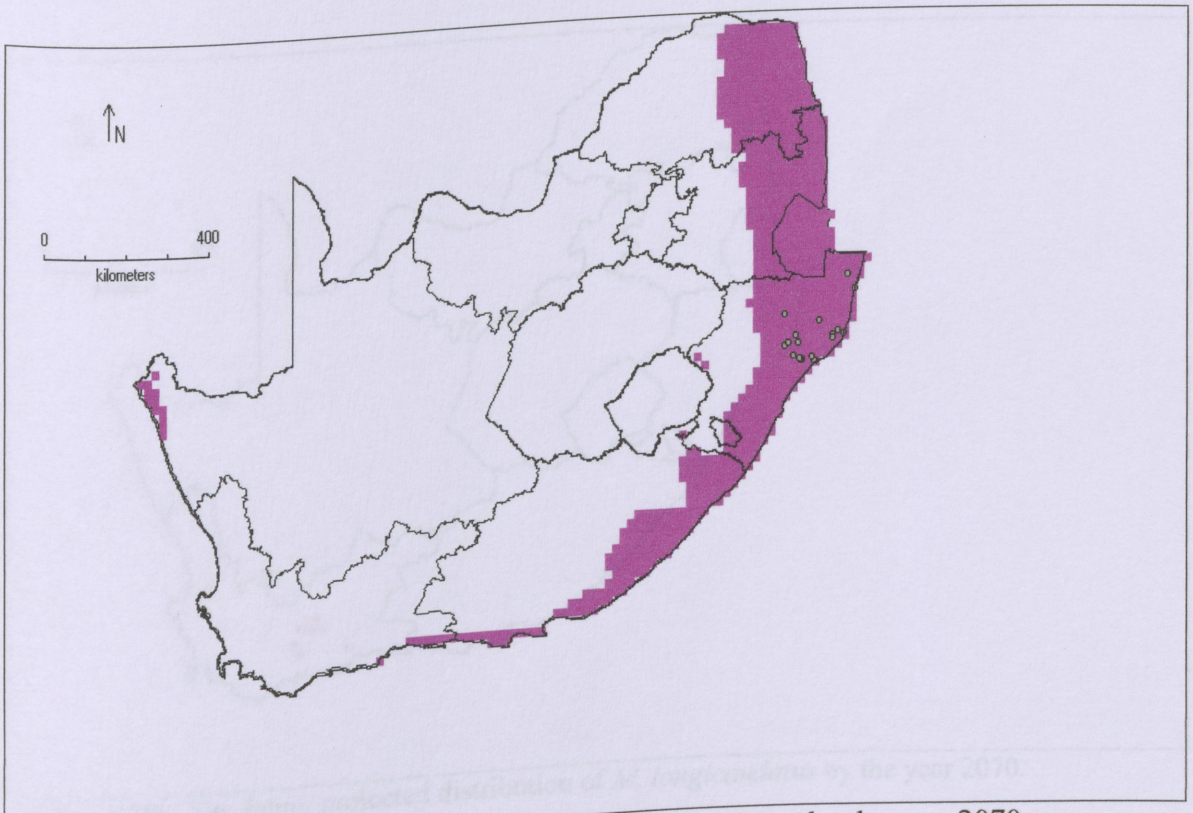


Figure 5.19b: The future projected distribution of *M. sclateri* by the year 2070

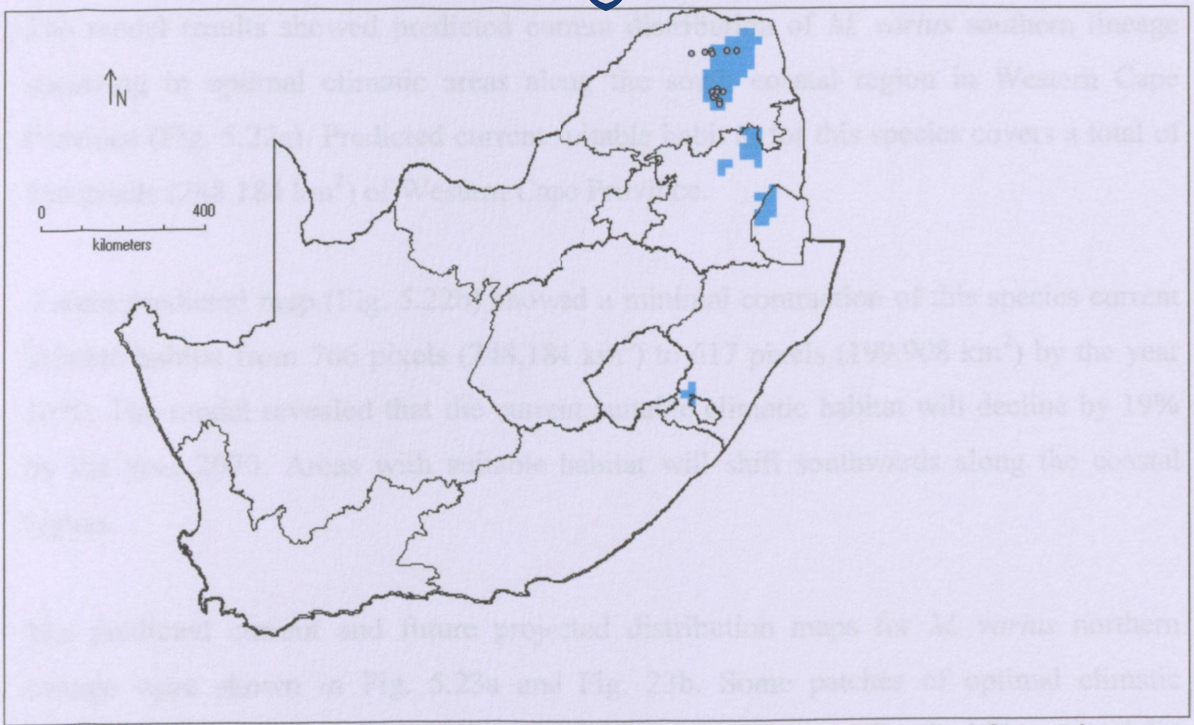


Figure 5.21a: The current predicted distribution of *Myosorex cf. tenius* from Limpopo Province.

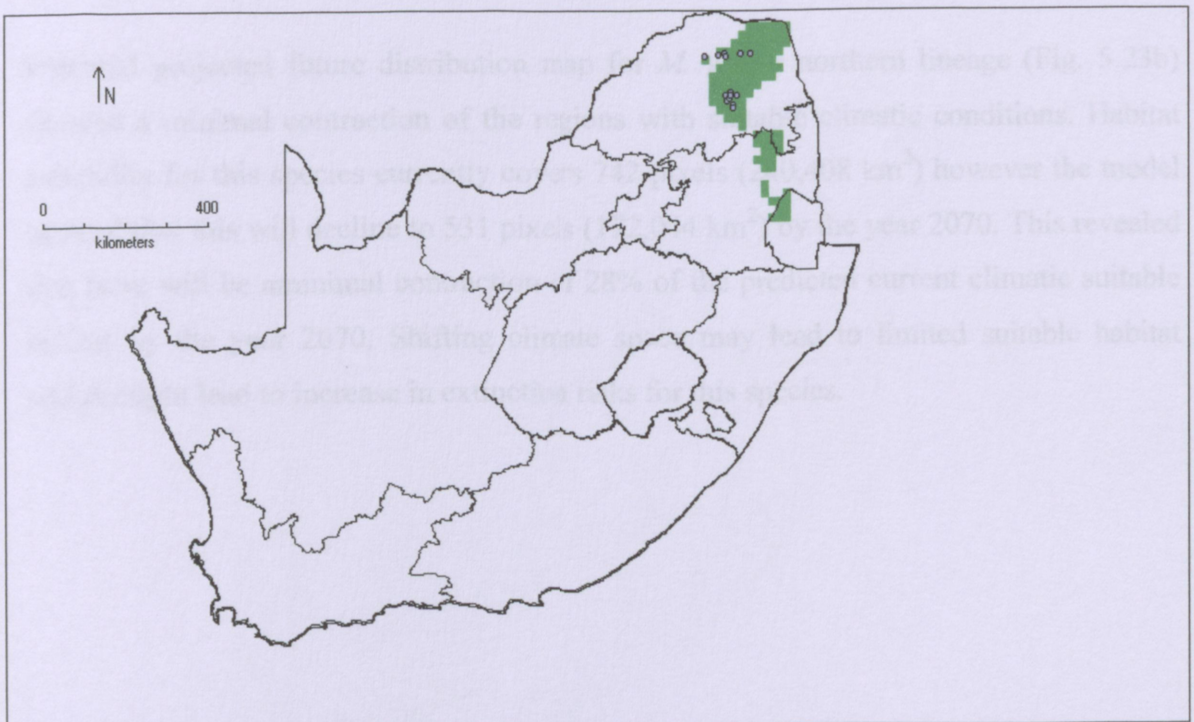


Figure 5.21b: The future projected distribution of *Myosorex cf. tenuis* from Limpopo Province by the year 2070.

The model results showed predicted current distribution of *M. varius* southern lineage occurring in optimal climatic areas along the south coastal region in Western Cape Province (Fig. 5.22a). Predicted current suitable habit at for this species covers a total of 766 pixels (248,184 km^2) of Western Cape Province.

Future predicted map (Fig. 5.22b) showed a minimal contraction of this species current suitable habitat from 766 pixels (248,184 km^2) to 617 pixels (199,908 km^2) by the year 2070. The model revealed that the current suitable climatic habitat will decline by 19% by the year 2070. Areas with suitable habitat will shift southwards along the coastal region.

The predicted current and future projected distribution maps for *M. varius* northern lineage were shown in Fig. 5.23a and Fig. 23b. Some patches of optimal climatic conditions are shown in the southern and northern regions of South Africa especially central Limpopo Province.

Potential projected future distribution map for *M. varius* northern lineage (Fig. 5.23b) showed a minimal contraction of the regions with suitable climatic conditions. Habitat suitability for this species currently covers 742 pixels (240,408 km^2) however the model showed that this will decline to 531 pixels (172,044 km^2) by the year 2070. This revealed that there will be aminimal contraction of 28% of the predicted current climatic suitable habitat by the year 2070. Shifting climate space may lead to limited suitable habitat which might lead to increase in extinction risks for this species.

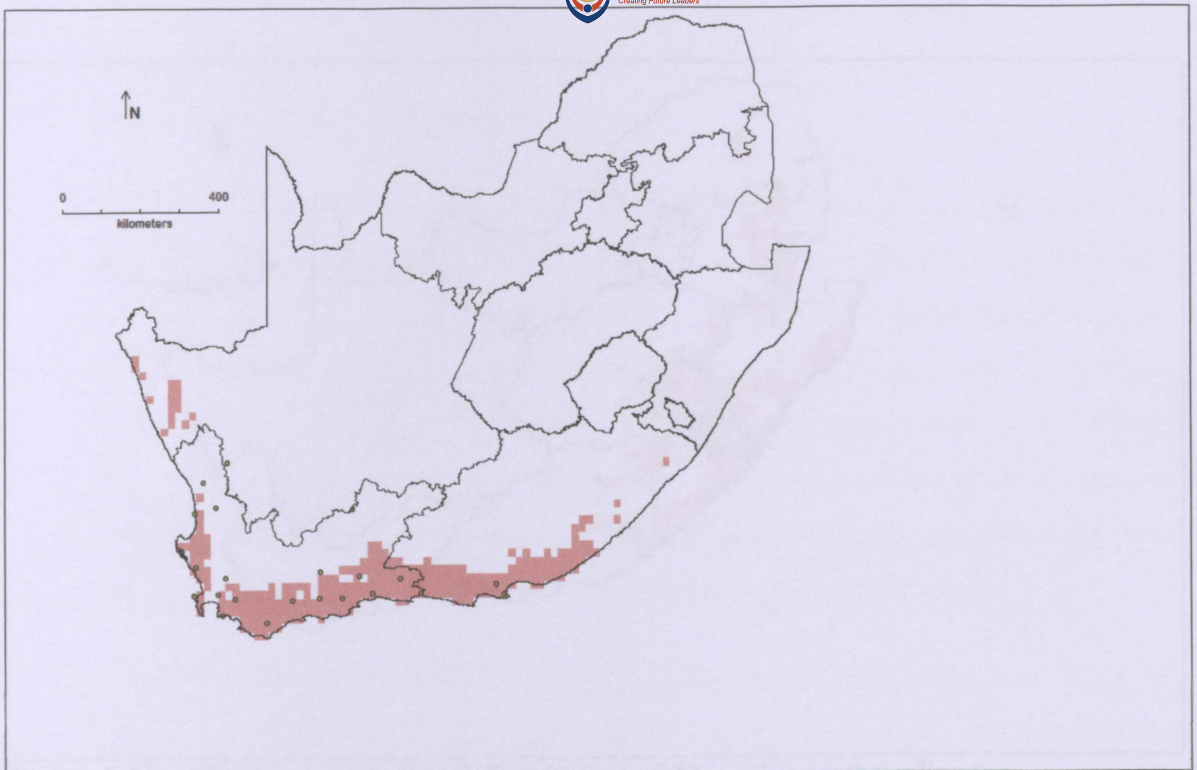


Figure 5.22a: The current predicted distribution of *M. varius* southern lineage

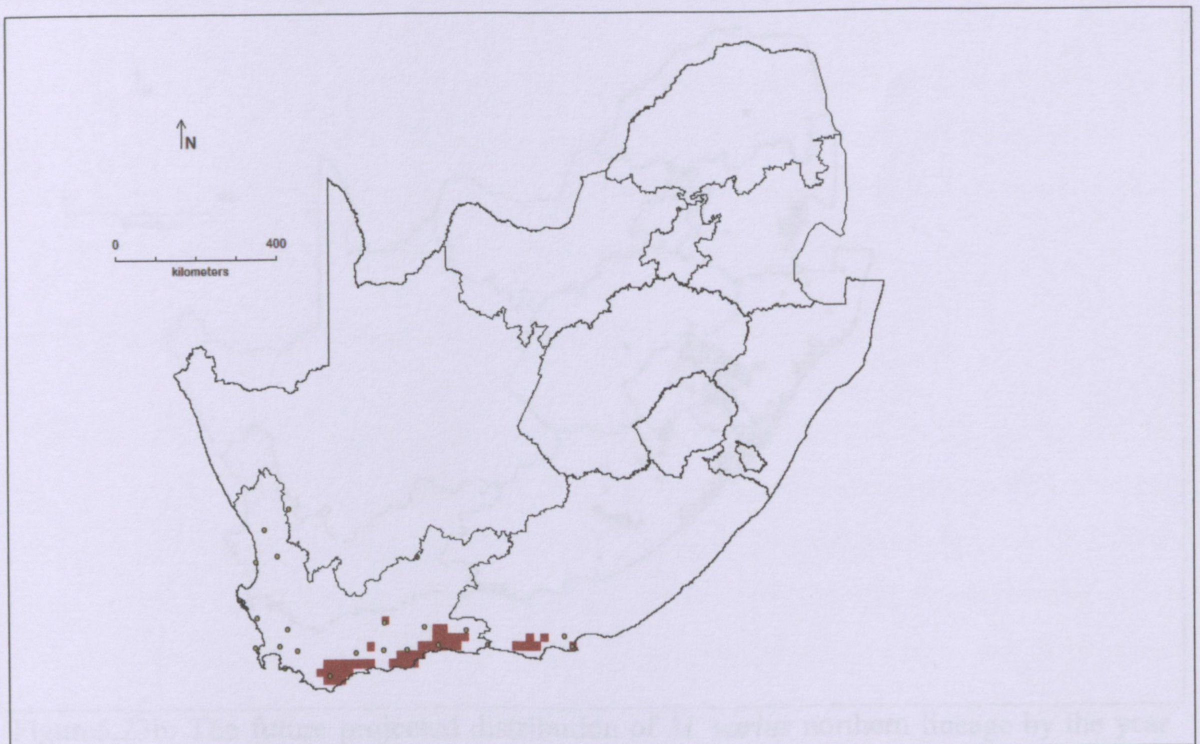


Figure 5.22b: Future projected distribution of *M. varius* sourthern lineage by the year 2070

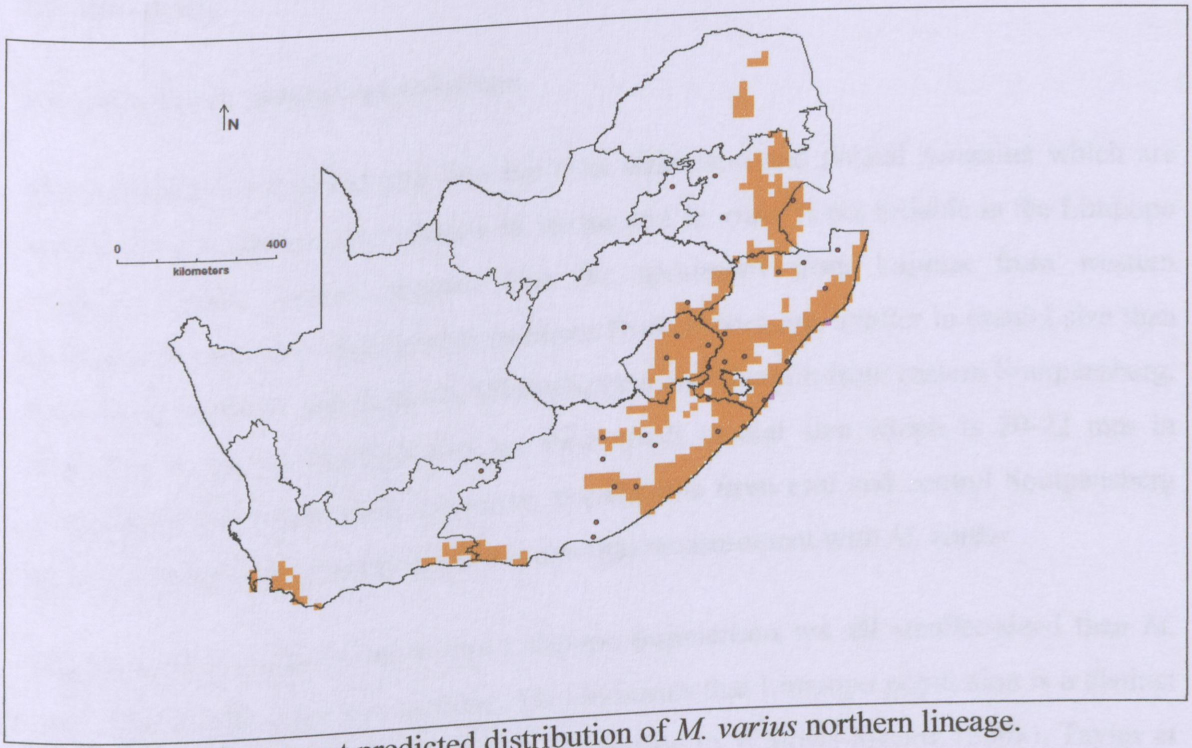


Figure 5.23a: The current predicted distribution of *M. varius* northern lineage.

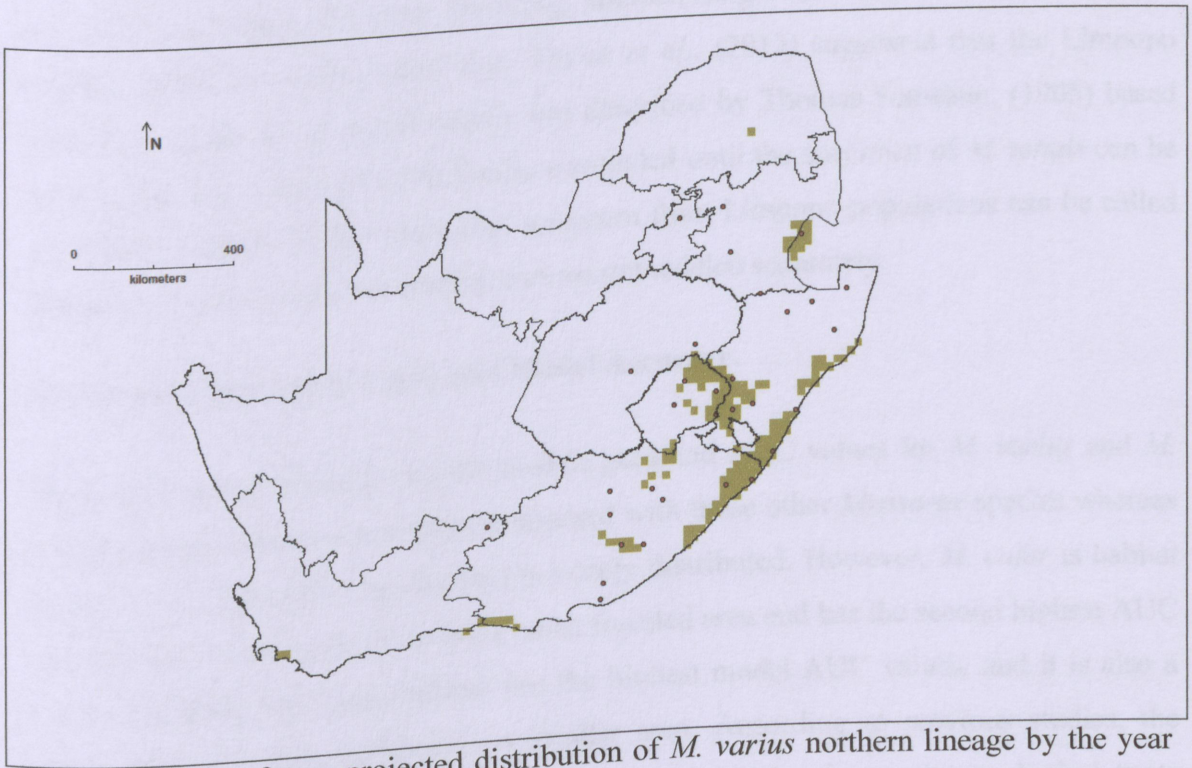


Figure5.23b: The future projected distribution of *M. varius* northern lineage by the year 2070.

5.6. Discussion

5.6.1 Status of Limpopo populations

Morphological results indicate that the skin characters and palatal foramina which are usually used to distinguish between *M. varius* and *M. cafer* is not reliable in the Limpopo samples. Cranial results showed that the specimens from Lajuma from western Soutpansberg and Woodbush from northern Drakensberg are smaller in cranial size than those from Entabeni, Buzzard Mt, Middelfontein and Hanglip from eastern Soutpansberg. They can be easily distinguished by their small cranial size which is 20-22 mm in condylo-incisive length (CI). However, populations from east and central Soutpansberg are larger in size and overlap in cranial external measurement with *M. varius*

Morphological analyses show that Limpopo populations are all smaller-sized than *M. cafer* even though some are variable. This indicates that Limpopo population is a distinct lineage based on the small cranial size. According to Willows-Munro, (2008); Taylor *et al.,* (2013), Limpopo Province including Soutpansberg Mountains is a distinct genetic lineage. Based on small cranial size, Taylor *et al*., (2013) suggested that the Limpopo specimens might be *M. tenuis* which was described by Thomas Schwann, (1905) based on its small size. This cannot be finally concluded until the specimen of *M. tenuis* can be genetically studied. In the meantime, specimen from Limpopo populations can be called *Myosorex cf. tenuis*. For this reason, they were modeled separately.

5.6.2 Species Ecological Traits and Model Accuracy.

The model results showed that the models gain and AUC values for *M. varius* and *M. varius* northern lineage were lower compared with those other *Myosorex* species whereas *M. varius* is a generalist species and is widely distributed. However, *M. cafer* is habitat specialist and more confined to thick moist forested area and has the second highest AUC values. Although *M. longicaudatus* has the highest model AUC values, and it is also a habitat specialist and confined to a smaller area. According to previous studies, the accuracy of the species distribution models is affected by the species ecological traits (Philips *et al*., 2006; Evangelista *et al.,* 2008; Franklin *et al.,* 2009). Evangelista *et al.,*

(2008) demonstrated that models for wide ranging species have lower accuracy than those generated for species with small range size. This was attributed to the generalist species' ability to persevere in wide range of environmental conditions that is not discriminated by the model. Specialist species such as *M. cafer, M. longicaudatus and M. sclateri* have well defined niche and environmental barrier that can be easily discriminated by the models.

According to Stockwell and Peterson, (2002) and Hernandez *et al*. (2006), local ecological adaption can reduce the accuracy of the models generated by general species. This may be due to the fact that the wide spread species display regional variations in ecological characteristics that may result to local subpopulations of the same species (lineage) with varying habitat preferences in different parts of the species range.

In this study *M. varius* is a generalist species, widely distributed in all the Provinces of South Africa. According to Willows-Munro and Matthee, (2011), there are two genetically distinct lineages of *M. varius* namely *M. varius* northern lineage and *M. varius* southern lineage. The model results (Table 5.5) showed *M. varius* southern lineage has a higher AUC than *M. varius* northern lineage. This indicates that these lineages are vaying in habitat preferences. All models in this study have high AUC value indicating that the models are accurate.

5.6.3 Climate Change and Species Range Shifts

The distribution model results showed habitat contraction that will occur in the afro-temperate species *M. cafer, M. varius, M. longicaudatus* and *M. varius* lineages; however *M. sclateri* and *M. cf. tenuis* from Limpopo Province which are subtropical species will increase the range of suitable habitats by the year 2070. The models revealed changes in the size and the location of suitable habitat within the distribution.

These afro-temperate species are shifting towards the east coastline at different contraction rates of suitable habitat (*M. varius* northern 28.4% and southern lineage 19.4%, *cafer* 59.8%, *varius* 64.5%, and *longicaudatus* 91%). This supports the view that species ecological traits such as habitat and dietary specialization influence their response to climate change and vulnerability to local extinction. The traits of vulnerability falls under categories such as specialized habitat, narrow environmental tolerances, depending on the specific environment which is likely to be interfered by the climate change and poor ability to disperse. A ccording to Coetzee *et al*., 2009, a full dispersal assumption is that the species will be able to disperse to all cells that become suitable in future and for no dispersal, the species is only able to survive in cells that are currently suitable and that remain suitable in future.

In this study, *M. longicaudatus* revealed the highest amount of decrease (91%) in areas of suitable habitat by the year 2070 which may lead to severe increase in extinction risk for this species in southern South Africa. Extinction risk is likely to be affected by a bility of species to disperse to new areas that become suitable (Coetzee *et al*,. 2009). The modeling assumption is that the species can only remain in currently suitable habitat and will migrate to all suitable climatic areas in future (Coetzee *et al*,. 2009). The future of this species looks bleak given the already restricted range, large decrease in the amount of area with high environmental suitability due current and future predicted climate change. This species occurs in a small area of occurrence in five localities at higher elevations in Western Cape and Eastern Cape Provinces (Meester and Dippenaar, 1995), and habitat in neighbouring area is arid and unsuitable for this moist habitat species. The status of this species by IUCN is vulnerable and this study recommends change to Endangered due to almost complete disappearance of suitable pristine fynbos habitat.

The future of habitat specialist *M. cafer* is threatened with 59.8% decrease by the year 2070 in predicted suitable habitat which falls under both protected and unprotected areas. The species status in South Africa by IUCN is Near Threatened and this study recommends change to Vulnerable due to extent of habitat contraction predicted due to climate change, and current habitat transformation along the KwaZulu-Natal coast (Driver *et al*., 2011), this combines with limited dispersal ability. The contracted range for this species by the year 2070 in southern KwaZulu-Natal is in areas where transformation has left no remaining natural habitats.

Generalist *M. varius* occurs in a number of protected areas. The areas predicted to have high environmental suitability for this species will have moderate (64.5%) decrease by the year 2070. Moderate decrease in the amount of high environmental suitability may lead to consequences of increase in extinction risk of this species. This species by IUCN is Listed Least Concern in South Africa however, this study recommend change to Near Threatened due to extent of habitat contraction predicted due to climate change, and current habitat transformation in three provinces and the existence of cryptic species as northern and southern lineage. This species comprises distinct southern and northern genetic lineage recognized by Willows-Munro and Matthee (2009). Some of the affected habitats are under protected areas.

The result showed that both southern and northern lineage of *M. varius* will experience minimal range shift in predicted current and future suitable habitat (19.4% and 28.4%) by the year 2070 (Fig. 5.22 and Fig. 23). This indicates that the lineages will be affected a little by climate change by the year 2070. The results indicate that these lineages have varying preference niche.

Subtropical *M. sclateri* and *M. cf. tenuis* from Limpopo Province will increase in range of suitable habitats but due to low dispersal rates and habitat transformation and these increases in range will probably not be realised. Given that both species have restricted ranges. They typically require pristine wetland habitats and there is no forest in the new suitable habitats, and they are endemic to single South African Provinces therefore they should be flagged for conservation concern as Near Threatened.

Small distributions are linked to low abundance of species and highly special habitat (Brown, 1984). In this study, the abundance was not directly measured. The suitable habitat predicted by Maxent has been shown to correlate with species abundance in such a way that where the habitat suitability is low, species abundance is expected to be low and where the habitat suitability is high, species may range from high to low (VanDerval *et al*., 2009). Contraction in habitat suitability may indicate that the species is likely to decrease in abundance by the year 2070.

5.6.4 Limitations of the study

There are other factors that were not considered in this study that may limit the distribution of these species such as dispersal abilities, biological interactions and evolution adaptions (Guisan and Zimmermann, 2000; Araujo *et al.,* 2005; Araujo and Pearson, 2006). The biotic interactions between species such as competition and predators were not considered even though they were known to limit species distribution (Pearson and Dawson, 2003). An evolutionary adaptation of species to changing climate that may lead to species persistence in an area was not considered (Pearson and Dawson, 2003). The future projection for species was also made with an assumption that the current species climatic niche will remain unchanged under changing climate (Fitzpatrick *et al.,* 2008: Coetzee *et al*., 2009). This assumption make one assumes that species can only remain in currently climatic suitable environment and will disperse to all suitable climatic habitat in future (Coetzee *et al*,. 2009).

Databases from museums may have also some areas that are over sampled, whereas others are under sampled and some areas may not have been sampled yet have the potential habitat for the species thus, gives inaccurate distribution in modeling. This was not considered in this study as the used were from the Museums and new collection from Soutpansberg in Limpopo Province.

CHAPTER SIX: CONCLUSION AND RECOMMENDATION

6.1. Conclusion

Climate change has been reported as the driver of global biodiversity patterns by causing range shifts and redistribution of species and linked to extinction risks of species (Pounds, 1999; Araujo *et al*., 2006; Thuiller *et al.,* 2008; Monadjem *et al*., 2012). The magnitude of such shifts was evaluated by Maxent to predict current and projection future distribution of *Myosorex* species using current and future climatic variables the year 2070. The results showed that future climate is an important factor that cause predicted range shifts and affect the distribution of *Myosorex* species and lineages of *M. varius* in South Africa, Swaziland and Lesotho. Other non-climatic factors that were not included in the model such as biotic interaction, and dispersal abilities may influence distribution (Aruajo *et al*., 2005).

The results showed that radical habitat contraction will occur in the three afro-temperate species, *M. cafer*, *M. longicaudatus* and *M. varius* which will be further compounded by current climate change and habitat transformation. *M. longicaudatus* showed greatest contraction of suitable habitats by the year 2070. Consequently, in the event of adverse climate change resulting in global warming by the year 2070, *M. longicaudatus* will experience highest risk of extinction. *M. varius* will experience higher contraction than the lineages. This revealed that *M. varius* and the lineages do not have same the ecological niche.

The results of the two subtropical *M. sclateri* and *M. cf. tenuis* from Limpopo Province showed that there will be an increase range of suitable habitats but due to low dispersal rates and habitat transformation, these increase in rate may not realized given that both species have restricted ranges. They typically require pristine wetland habitats and are endemic to single South African Provinces. Hence the results revealed that species habitat requirements can influence their response to climate change and vulnerability to local extinction. The result showed that climate change is real and has potential to cause range shifts and affecting the distribution of *Myosorex* species in South Africa. As expected, Afro-temperate species of *Myosorex* are good model to warn of the potential impacts of future climate change on biodiversity as climate change has the potential to cause range shifts in their distributions. The result is important for conservation strategies and for revising the IUCN Redlist status of all *Myosorex* species.

6.2. Recommendations

- Future researchers should reduce uncertainties in projections by including other factors that may have significant influence in the distribution of species such as biotic interactions, dispersal abilities and multiple future scenarios in modeling process.

- Further research is needed for identification of *Myosorex* species in Limpopo Province as this study has identified them as adistinct species, may be *Myosorex cf. tenuis*. The previous researchers identified them as *M. cafer*, and *M. varius* (Friedmann and Daly 2004: Willows-Munro, 2009 and 2011) while Roberts (1951): Jenkins, (2013), and Taylor *et al.* (2013) identified species from Woodbush and Entabeni from Limpopo Province as *M. cf. tenuis.*

- *Myosorex* species should be used as indicator for climate change for afro- montane small mammals to assist the management of Afromontane small mammals' conservation.

REFERENCES

Anderson, R.P. and Raza, A. (2010). Effect of extent of study region on GIS models of species geographic distributions and estimates of niche evolution: Preliminary tests with montane rodents (genus Nephelomys) in Venezuala. *Journal of Biogeography*, 37, pp 1378-1393.

Andrew, L.M. (2009). Predicting the effects of climate change on Melanesian bird populations: the constraints of too many variables and too few data. *Bishop Museum Technical Report,* 9, 42 pp.

Araujo, M.B., and Pearson, R.G. (2005). Equilibrium of species' distributions with climate. *Ecography*, 28, pp 693-695.

Araujo, M.B. Whittaker, R.J. Ladle, R.J. and Erhard, M. (2005). Reducing uncertainity in projections of extinction risk from climate change. Global Ecology and Biogeography, 14, pp 529-538.

Araujo, M.B., Thuiller, W., and Pearson, R.G. (2006) Climate warming and decline of amphibians and reptiles in Europe. *Journal of Biogeography*, 33, pp 171-217.

Barnard, C.J. (1984). Shrews. *The Encyclopedia of mammals*. New York, pp 758-763.

Baxter, R.M. (2005). Variation in aspects of the population dynamics of the endemic forest shrew *Myosorex varius* in South Africa. In Merritt, J.J., Churchfield, S. and Shefttel, B. (eds) Advances in the Biology of shrews ll. Special Publication of the Carnegie Museum of National History, pp 181-190.

Baxter, R.M. (2008a). *Myosorex cafer*. In: IUCN 2012. IUCN Red List of Threatened species. Version 2010.4.www.iucnredlist.org. Downloaded on 29 Dec 2012.

Baxter, R. M. (2008b). *Myosorex longicaudatus*. In: IUCN 2012. IUCN Red List of Threatened species. Version 2010.4. www.iucnredlist.org. Downloaded on 29 Dec 2012.

Baxter, R.M. (2008c). *Myosorex sclateri.* In: IUCN 2012. IUCN Red List of Threatened species. Version 2010.4.www.iucnredlist.org. Downloaded on 29 Dec 2012.

Baxter, R.M. (2008d). *Myosorex varius*. In: IUCN 2012. IUCN RedList of Threatened species. Version 2010.4.www.iucnredlist.org. Downloaded on 29 Dec 2012.

Baxter, R.M. and Dippenaar, N.J. (2013a). *Myosorex cafer* (Sundevall). Dark footed Forest shrew. In: Happold M, Happoid DCD, eds. *Mammals of Africa,* York, Bloomsbury, NewYork, 4.pp, 152-153.

Baxter, R.M. and Dippenaar, N.J. (2013b). *Myosorex varius* (Smuts). Forest shrew.In: Happold M, Happoid DCD, eds. *Mammals of Africa,* York, Bloomsbury, Newyork, 4, pp 161-163.

Beaumont, L.J., Hughes, L and Pitman, A.J. (2008). Climate warming and the decline of amphibians and reptiles in Europe, *Journal of Biogeography*, 33, pp 1712-1728.

Brown, C.R., Hunter, E.M., Baxter, R.M. (1997). Metabolism and Thermoregulation in forest shrews, *Myosorex varius* (Soricidae: Crocidurinae) *Comparative Biochemistry. Physiology*, 118, pp 1285-1290.

Brown, J.H. (1984). On the relationship between abundance and disribution of species. *America Naturalist*. 124; pp 255-279.

Butler, P.M. and Hopwood, A.T. (1957). *Insectivora and Chiroptera from the Miocene rocks of Kenyan colony, no. 13 of fossil mammals of Africa*: London, British Museum, 13, pp 1-35.

Canadell, J.G., Corinne L.Q, Michael R., Christopher, B., Field, E.T. Buitehuis, P. C, Thomas J. C., Houghton, R.A. (2007). Contrintribution of accelerating atmospheric CO_2 growth from economic activity, carbón intensity and efficiency of natural sinks. *Proceedings of National Academy of science of United States of America*, 104, pp 18866-18870.

Chen, 1.C., Shiu, H.J., Benedick, S., Holloway, J.D., Chey, V.K., Barlow, H.S., Hill, J.K, Thomas, C.D. (2009). Elevation increase in Moth assemblage over 42 years on tropical mountain, *Science,* 10, pp 103-1073.

Chen, I.C., Hill, J.K, Ohlemu'ller, R., Roy, D.B., Thomas, C.D. (2011). Rapid range shifts of species associated with high levels of climate warming. *Sciences* 333, pp 1024-1026.

Coetzee, B.W.T., Robertson, M.P., Erasmus, B.F.N., van Rensburg, B.J. and Tuiller, W. (20009). The impact of climate change on the southern African Important Bird Areas network. Global Ecology and Biogeography, pp 18, 701-710.

Colwell, R.K., Briham, G.B., Cardellus, R.K., Gilman, A.C., Longino, J.T. (2008). Global warming elevation range shifts and lowland biotic attrition in the wet tropics, *Science*, 322, pp 261-268.

Churchfield, S. (1990). The natural history of shrew. *Comstock Publishing Associate,* New York, 178 pp.

Churchfield, S. (2013). Family Soricidaein Happold, M. Happold, D.C.D (eds) : Mammals of Africa, Bloombury, New York, 4, pp 43-55.

Dippenaar, N. J. (1977). Variation in *Crocidura mariquensis* (A. Smith, 1844) in Southern Africa, Part 1 (Mammalia, Soricidae). *Annales, Transvaal Museum*, 30, pp163-206.

Dippenaar, N.J, Meester, J., Rautenbach, I.L and Wolhuter, D.A. 1983. The status of southern African mammals taxonomy. Annales, *Muse'e royal de l'Afrique centrale, Science zoologiques,* 237, pp 103-107.

Dippenaar, N.J. (1995). Geographic variation in *Myosorex longicaudatus* (Soricidae) in the southern Cape Province, South Africa. *Journal of Mammalogy*, 76 (4), pp1071- 1087.

Driver A., Sink, K.J., Nel, J.N., Holnes, S., Van Niekerk, L., Daniel, F., Jonas, Z., Majiedt, P.A., Harris, L. and Maze, K. (2011). National Biodiversity Assessment of South Africa biodiversity and Ecosystems, Synthesis Report. South African National Biodiversity Institute and Department of Environmental Affairs Pretoria, 110 pp.

Elith, J, Graham, C.H, Anderson, R.P, Dudik, M., Ferrier, S., Guisan,A. Hijamans, R.J, Huettmann, F. Lethwick, J.R, Lehmann, A., Li, J., Lohmann, J.G., Loiselle, B.A., Manion, G,, Moritz, C., Nakamura, M., Nakazawa Y., Mc, C, J., Overton, A., Sobéron, J., Williams, S., Wisz, M.S. and Zimmermann, N.E. (2006). Novel methods improve prediction of species' distributions from occurrence data. *Ecography*, 29, pp 129-151.

Elith, J., Kearney, M., and Philips, S. (2010). The art of modelling range shifting species. Methods in Ecology and Evolution, 1, pp 330-342.

Elith, J., Phillips, S.J., Hastie, T., Dudik, M., Cheee, Y.E and Yates, C.J. (2011). A statistical Explanation of Maxent for Ecologist. *Diversity and Distributions*, 17, pp 43-57.

Enquist, (2002). Predicted regional impacts of climate change on the geographical distribution and diversity of tropical forest in Costa Rica. *Journal of Biogeography*, 29, pp 519-534.

Evangelista P.H., Kumar, S., Stohlgren, T.J., Jarnevich, C.S., Crall, A., Norman Li, J.B. and Barnett, D.T. (2008). Modeling invasion for a habitat generalist and a specialist plant species. *Diversity and Distributions*, 14, pp 808-817.

Franklin, J., Wejnert, K.E., Hathaway, S.A., Rochester, C.J. and Fisher, R.N. (2009). Effects of species rarity on the accuracy on the species distribution models for reptiles and amphibians in southern California. *Diversity and Distributions,* 15, pp 167-177.

Fielding, A.H. and Bell, J.F. (1997). A review of methods for the assessment of prediction errors in conservation presence models. *Environmental Conservation*, 24, pp 38-49.

Fitzpatrick, M.C., Gove, A.D., Sanders, N.J. and Dunn, R.R. (2008). Climate change plants migration and range collapse in global biodiversity hotspot. The Banksias of Western Austrialia, *Global Biology* 14, pp 1337-1352.

Friedmann, Y, and Daly, B. (editors) (2004) Red Data book of the mammals of South Africa. A conservation assessment CBSC, Conservation Breeding specialist Group. (SSC (IUCN) , Endangered Wildlife Trust, South Africa, 179 pp.

Foord, S.H., Mafadza, M.M., Dippenaar-Schoeman, A.S., Van Rensburg, B.J. (2008). Micro-scale heterogeneity of spiders (Arachnida: Araneae) in the Soutpansberg, South Africa: *A* comparative survey and inventory in representative habitats, *Journal African: Zoology society in South Africa* 43, pp 156-174.

Furio, M., Santos-Cubedo, A., Raef, R. (2007). Evolutionary history the African Soricidae *Myosorex* out of Africa.Vertebrate Journal. *Palaeontol,* 27, pp 108-1032.

Gasner, M.R., Jankwoski, J.T., Ciecka, L.A., Kyle, K.O, Rabenold, K.N. (2010). Projecting the local impacts of climate change on central American montane avian community. *Biological Conservation*, 143, pp 1250-1258.

Gibson, L.A., Wilson, B.A., Cahill, D.M. and Hill, J. (2004). Spatial prediction of rufous bristlebird habitat in a coastal heat land. A GIS-based approach. *Journal of Applied Ecology,* 41, pp 213-223.

Government of the Republic of South Africa, (2011). National Climate Change Response White Paper. Government of South Africa, Department of Environmental Affairs, Pretoria, 47 pp.

Guisan, A. and Zimmermann, N.E. (2000). Predictive habitat distribution models in ecology, Ecological modeling, 135, pp 147-186.

Hannah, L., Midgley, G., Andelman, S., Araujo, M.B., Hughes, G., Martinez-Meya, E., Pearson, R., Williams, p. (2007). Protected areas needa changing climate. *Frontiers Ecological Environment*, 5, pp 131-138.

Heim de Balsac, H. (1967). Faits nouveaux concernant less Myosorex (Soricidae) de l'Afrique orientale, *Mammalian*, 31, pp 610-638.

Hernandez, P.A., Graham, C.H. Master, L.L., and Albert, D.L. (2006). The effects of sample size and species characteristics on performance on different species distributional modeling methods. *Ecography*, 29, pp 773-7885.

Hewitson, B.C. (1998). South African National Assessment for the framework convention for climate change, Climate change scenarios, Http// tie.egs.uct.za.

Hof, C., Levinsky, M.B., Araujo, and Rahbek, C. (2011).Rethinking species ability to cope with rapid climate.*Global Change Biology*, 17, pp 2987-2990.

Hole, D.G., Willis, S., Pain, D.J., Fishpool, L.D., Butchart, S.H.M., Collingham, Y.C., Rahbek, C. and Huntley, B. (2009).Projected impacts of Climate Change on continent-wide protected area nectwork.*Ecology Letters*, 12, pp 420-431.

Huey, R.B., Deutsch. C.A., Tewksbury, J.J., Vitt, L.J. Hertz, P.E., Perez, H.J.C., Garland,T. (2009). Why tropical lizards are vulnerable to climate warming. *Proceedings of the Royal Society of London B, Biological Sciences,* 276, 1939-1948 pp.

Hughes, L. (2000). Biological consequences of global warming; Is the signal already Apparent? *Trends in Ecology and Evolution*. 15, pp 56-61.

Hutterer, R. (2005). Order Soricomorpha.In: Wilson D.E., Reeder, D.M. eds. *Mammal species of the world: a taxonomic and geographic reference*, third edition. Baltimore, M.D., Johns Hopkins Universiy press, pp 220-311.

Hutterer, R. (2013). *Myosorex* Forest shrews. In Happold M, Happold DCD, eds. Mammals of Africa. New York, Bloomsbery, 153-154 pp.

IPCC (1996) Climate change 1995, the science of Climate Change. Contribution of Working Group 1 to the second.Assessment report of the IPCC. *Cambridge University Press, New York*.

IPCC (2007) Climate change 2007, Synthesis Report contribution of Working Group 111, the fourth assessment report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland.

IUCN (2001) Red List categories and criteria version 3.1. Gland, Switzerland; *Species Survival Commission,* pp 34-35.

IUCN (2012) IUCN Red list of Threatened Species. Version 2012. 1www.iucnredlist.org.

Isaack, J.L., Williams, S.E. (2007). Climate change and extinctions In. Levin S (ed) Encyclopadia of biodiversity. *Academic press, San Diego, CA,* pp 67-72.

Jenkins, P.D, Churchfield, S. (2013). *Myosorex tenuis*. Thin mouse shrew (Transvaal Forest shrew). In: Happold M, Happold D.C.D, (eds). Mammals of Africa, New York: *Bloomsbury*, 4, pp 160-161.

Jimenez-Valverde, A., Lobo, J.M. and Hortal, J. (2008). Not as good as they seem: The importance of concepts in species distribution modeling. *Diversity Distributions*, 14, pp 885-890.

Jimenez-Valverde, A., Diniz, F., de Azevedo, E.B. and Borgers, P. A.V. (2009). Species distribution model do not account for abundance. The case of earthropods on Terceira island. *Annales Zoologici Fennici*, 46, pp 451-464.

Jones, G., David, S.J., Thomas, H.K., Michael, R.C. (2009). The impotance of bats as bioindicators, 8, pp 93-115.

Kearney, T. C. (1993). A craniometric analysis of three taxa of *Myosorex* from Natal and Transkei. M. Sc. Thesis. University of Natal.

Kingdon, J. (1997). The Kingdon field guide to mammals, Academic Press London, 69 pp.

Kriticos, D. J., Webber, B.L., Leriche, A., Ota., N., Macadam, I., Bathols, J., Scott, J.K. (2012). Climond: Global high- resolution historical and future scenario climate surfaces for bioclimatic modelling, *Methods in Ecology and Evolution,* 3, pp 53-64.

Lamb, J.M., Ralph, T.M., Goodman, S.M., Bates, P.J., Eger, J., Benda, P., Taylor, P.J. (2008). Phylogeography and predicted distribution of African-Arabian and Malagasy populations of giant mastiff bats, *Otomops*, 10, pp 21-40.

Lawler J.J., Shfer, S.L., White, D., Kareiva, P. Maurer, E.P., Blaystein, A.R. Blaysteinand, P.J. (2009). Projected climate induced fauna change in the western Hemisphere. *Ecology,* 90, pp 588-597.

Li, J., D. Hilbert, T.,Parker, Williams, S. (2009). How do species respond to climate change along an elevational gradient? A case study of the grey headed Robin *(Heteromyias albispcularis).Global Change Biology,* 15, pp 255-267.

Lobo, J.M., Jimenez-Velverde, A. and Real, R. (2007). AUC is a misleading measure of performance of predictive distribution models. *Global Ecology and Biogeography*. 17, pp 145-151.

MacDonald, D.W. (2006). The Encylopedia of mammals, oxford, 24, pp 267-271.

MacKinney, M.L. (1997). Extinction vulnerability and selectivity; combining ecological and paleontological views. *Animal revolution and ecological Systems*, 28, pp 495-516.

Maddalena, T. and Bronner, G. (1992). Biochemical systematics of the endemic African genus *Myosorex* Grey, 1838 (Mammal , Soricidae). *Israel Journal of Zoology*, 38, pp 245-252.

Manne, L., and Pimm, S.L. (2001). Beyond eight forms of rarity; which species are threatened and which will be next? *Animal Conservation*, 4, pp 221-229.

Meester, J., (1958). Variation in the shrew genus *Myosorex* in southern Africa.*Journal of Mammalogy*, 39, pp325-339.

Meester, J. (1963). A systematic revision of the shrew genus *Crocidura* in southern Africa. *Memoirs of the Transvaal Museum*, 13, pp 1-126.

Meester, J., and Dippenaar, N. J. (1978). A new species of *Myosorex*from Knysna, South Africa (Mammalia; Soricidae) *Annals of the Transvaal Museum*, 31, pp 29-42.

Meester, J., Rautenbach, I.L., and Baker, C.M. (1986). Classification of southern African mammals. *Transvaal Museum Monographs*, 5, pp 1-359.

Midgley, G.F., Chapman, R.A., Mukheibir, P., Tadross, M., Hewitson, B., Wand, S.J.E., Knowles, A., Abayomi, A., Ziervogel, G., Cullis, R., Theron, A. (2007). Assessing impacts, vulnerability and adaptation in key SouthAfrican sector: A background study for the long term mitigation scenarios assessment. *Energy Research Centre*, Cape Town.

Millenium Ecosystem Assessment. (2005). Ecosystem and human well being. Biodiversity Synthesis. *World Resources Institute*, Washington, DC, 10 (2), 19 pp.

Monadjem, A., Munir, Z., Colin, J., and April. R. (2012). Rapid decline and future distribution and predicted for the endanged Sokoke Scops Owl *OTUs ireneae* due to climate change. *Birds Conservation International*, pp 1-12.

Mucina, L., and Rutherford, M.C. (2006). The vegetation of South Africa, Lesotho and Swaziland. South African National,Biodiversity Institute Pretoria, 807 pp.

Myers, P., R. Espinosa, C.S., Parr, T. Jones, G.S., and Dewey, H.T. (2013). The animal Diversity web (on line).Accesssed at www.http:// *animal diversity organization*. Downloaded on 14 March 2013.

Nagorsen, D.W and Peterson L.R. 1980.Mammal collector's manual. A guide for collecting, documenting and preparing mammal specimens for scientific research.Life sciences miscellaneous publications.Royal Ontario museum, Toronto, 79 pp.

Parmesan, C.D. and Yohe, G. (2003). A globally coherent finger print of climate change impacts across natural systems. *Nature*, 421, pp 37-42.

Parmesan, C.D. and Yohe, G. (2004). Extinction from Climate Change, *Nature*, 427, pp 145-148.

Parmesan, C.D.(2006). Ecological and Evolutionary responses to recent climate change.*Annual Review of Ecology Evolution and Systematics*, 37, pp 637-669.

Pearson, R.G. and Dawson, T.P. (2003).Predicting the impacts of climate change on the distribution of species. *Global Ecology and Biogeography*, 12, pp 361-371.

Pearson , R,G., Raxworthy, CJ., Nakamura, M. and Peterson, A.T. (2007). Predicting species distributions from small numbers of occurrence records.A test case using cryptic geckos in Madagascar. Journal of*Biogeography*, 34, pp 102-117.

Phillips, S.J., Dudik, M.,Schapire, R.E. (2004).A maximum Entropy Machine learning, proceedings of the 21st International Conference on Machine learning, ACM, *Press New York.*

Phillips, S.J., Anderson, R.P. and Schapire, R.E. (2006). Maximum entropy modelling of geographic distributions. *Ecological Modelling*, 190, pp 231-259.

Phillips, S.J. and Dudik, M. (2008).Modeling of species distribution with Maxent; new extensions and a comprehension evaluation, *Ecography* 31, pp161-175.

Pimm, S.L, (2008). Biodiversity: Climate change or Habitat loss- Which will kill more species? *Current Biology*, 18, pp 117-119.

Pounds, J.A., Fogden, M.P.L. and Campbell, J. (1999). Biological response to climate change on a tropical mountain, *Nature*, 398, pp 611-615.

Pounds, J.A., Bustamante, M.R., Coloma, L.A., Consuegra, J.A., Fogden, M.P.L.,Foster, P.N.(2006).Widespread amphibian extinctions from epidemic disease driven by global warming.*Nature*, 439, pp 161–167.

Price, J. (2000). Modeling the potential impacts of climate changes on the summer distribution of Massachusetts.*Birds's Observer*, 28 (4), pp 224-230.

Raxworthy, C.J., Ingram, C.M., Rabibisoa, N. and Pearson, R. G. (2007). Applications of ecological niche modeling for species delimitation. A review and empirical evaluation using day geckos from Madagascar. *Systematic Biological*, 56, pp 907-923.

Roberts, A. (1951). The mammals of South Africa, 1st. Endernsm, Cape Town: The Trustees of The Mammals of South Africa Book Fund, Central News Agency, 4, pp 339-350.

Robertson, M.P., Cumming, G.S. and Erasmus, F.N. (2010). Getting the most out of atlas data. Ajournal of conservation Biogeography, 1, pp 1-13

Rowe-Rowe, D.T and Meester, J. (1982). Habitat references and abundances relations of small mammals in the Natal Drakensberg. *South Africa Journal Zool*, 17, pp 202-209.

Rowe-Rowe, D.T., Meester, J. (1985). Biology of *Myosorex varius* in an African montane region.*Acta.Zoological Fennica*, 173, pp 271-2 73.

Schmidt- Nielsen, K. (1990). Animals physiology,Adaptation and Environmental. Fourth edition, *Cambridge UniversityCity press,* 1553 pp.

Sekercioglu, C.H., Schneider, S.H., Fay, J.P. and Loarie, S.R. (2008). Climate Change, elevational range shifts, and bird extinctions. *Conservation Biology*, 22, pp 140-150.

Sekercioglu, C.H. (2011). Functional extinction of birds pollination cause declines. *Science*, 331, pp 1019-1020.

Skinner, J.D., Chimimba, C.T. (2005). *The mammals ofthe southernAfrican subregion*.third edition. Cambridge University press, 814 pp.

Smithers R.H.N. 1983. *The mammals of the southern African subregion*. 1stedition Pretoria,University of Pretoria , pp 736.

Sodhi, N.S., Koh, L.P., Brook, W.B. (2004). South East Asia biodiversity, an impending disaster. *Trends Ecological Evolution*, 19, pp 654-660.

Sodhi, N.S., Bickford, D., Diesmos, A.C, Lee, T.M., Koh, L.P., Brook., B.W., Sekercioglu, C.H., and Broadshaw, C.J.A. (2008). Meaning the meltdown drivers of global amphibians extinction and decline, *PloS One*, 3, 1636 pp.

Stanley, S.M. (1986). Anatomy of a regional mass extinction: Plio-Pleistocene decimation of the Western Atlantic bivalve fauna, *Palaios* 1, pp 17-36.

Stanley, W.T., and Hutterer, R. (2000). A new species of *Myosorex* Gray, 1832, (Mammal: Soricidae) from the Eastern Arc Mountain, Tanzania, *Bonner Zoologische Beitrage,* 49, pp 19-20.

Stockwell, D.R. and Peterson, A.T. (2002). Effects of Sample Size on occurrence of species distribution models. *Ecological modeling*, 148, pp 1-13

Suarez-Seone,S., Garcia de la Morena, E.L., and Morales Prieto, M. B., Osborn, P.E., and de Juana, E. (2008). Maximum entropy niche-based modeling in seasonal changes in little bustard distribution. *Ecological Modeling*, 219, pp 17-29.

Taylor, P.J. (1998). The small mammals of KwaZulu-Natal.*University of Natal Press, Pietermarizburg,* 144 pp.

Taylor, J.P., Kearney, T.C., Peterhans, J.C., Baxter, R.M., Willows-Munro, S. (2013). Cryptic diversity in forest shrews of the genus *Myosorex* from southern Africa, with the description of a new species and comments on *Myosorextenuis*, *Zoological Journal of the Linnan Society,* 169, pp 881-902.

Thomas, O. and Schwann, H. (1905). On mammals from the wakkerstroom District, Transvaal. *Proceedings of the Zoological Society, London*, 32pp.

Thomas, C.D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L.J., Collingham, Y. C., Erasmus, B.F., De Siqueira, M., Grainger, A., Hannah. (2004). Extinction risk from climate change.*Nature,* 427, pp 145-148.

Thuiller, W., Albert, C.H., Araujo, M.B., Berry, P.M., Cabeza, M., Guissan, G., Hickler, T., Midgley, G.F., Paterson, J., Schurr, F.M., Sykes, M.T., Zimmermann, N.E., (2008). Predicting global change impacts on plant species distributions: future challenges. *Perspectives in Plant Ecology*, *Evolution and Systematics*, 9, pp 137-152.

Tracy, C.R. (1977). Limits endothermic.*Science,* 198, pp 034-035.

VanDerWal, J., Shoo, L.P., Johnson, C.N. and Williams, S.E. (2009). Abundace and environmental niche, environmental suitability estimated from niche models predicts the upper limit of local abundance. *American. Nauralist*. 174, pp 282-291.

Williams, S.E., Bolitho, E.E. and Fox, S. (2003). Biodiversity and climate change in the tropical montane forests of Northern Austrialia. InGreen, R.E., Hardley, M., Miles, L., Scharlemann, J., Watkinson, A., Watts, O. (eds): *Global Change Biodiversity*, pp 20-21,

Williams, C.J., Kniveton, D.R., Layberry, R. (20I0). Assessment of climate model to reproduce rainfall variability and extremes over Southern Africa.*Theorical Climate*,pp 10-25.

Willows-Munro, S. (2008).The molecular Evolution of African Shrews (Family sorcidae). Thesis. Chapt 6. Stellenbosch University, South Africa, *Unpublished Ph.D.*

Willows-Munro, S. and Matthee, C.A. (2009). The evolution of the southern African members of the shrew genus *Myosorex.* Understanding the origin and diversification of a morphologically cryptic group. *Molecular Phylogenetics and Evolution*, 51, pp 394-398.

Willows-Munro, S. and Matthee, C.A. (2011).Linking lineage diversification to habitat heterogeneity, phylogeography of the southern African shrew *Myosorex varius*. *Journal of Biogeography*, 38, pp 1976-1991.

Wilson, D.E. and Reeder, D.M. (2005). Mammal species of the world. A Taxonomic and Geographic Reference (3rd Ed), Johns Hopkins University Press.

Wisz, M.S., Hijmans, R. J., Li, J., Peterson, A.T., Graham, C.H., Guisan, A., Elith, J., Dudik, M., Ferrier, S.,Huettmann, F., Leatherwick, J.R., Lehmann, A., Lohmann, L., Loiselle, B.A., Mannion, s.j., Richardson, K.S., Scachetti-Pereira, R., Schapire, R.E., Soberon.J., Williams, S.E., and Zimmermann, N. E. (2008). Effects of samples size on performance of species distribution models. *Diversity and Distributions*, 14, pp 763-773.

APPENDIX A-K

Appendix –A: New Field and Museums Collections from Limpopo Province

Species	Place name	Coordinates		Source
Myosorex cf. tenuis	Lajuma: wetland	29.4276	-23.0357	This study
Myosorex cf. tenuis	Lajuma: Ian's barn	29.4408	-23.038	This study
Myosorex cf. tenuis	Lajuma: Wilderness Camp	29.4494	-23.0392	This study
Myosorex cf. tenuis	Lajuma: 1200m SA	29.4505	-23.0402	This study
Myosorex cf. tenuis	Lajuma: 1600m SA	29.434	-23.0225	This study
Myosorex cf. tenuis	Lajuma: 1747m SA	29.429	-23.0249	This study
Myosorex cf. tenuis	Buzzard Mt: 1600m	29.7536	-22.9997	This study
Myosorex cf. tenuis	Middelfontein Farm	29.9366	-22.9771	This study
Myosorex cf. tenuis	Entabeni	30.25	-22.9833	Museum
Myosorex cf. tenuis	Hanglip	29.8833	-22.9833	Museum
Myosorex cf. tenuis	Tate Vondo	30.483	-22.9667	Museum
Myosorex cf. tenuis	Woodbush	30.0167	-23.75	Museum

Appenndix B: Details of specimens used in morphological analysis

Species	Place name	Latitude	Longitude	Source
cafer	Transkei: Port St. Johns	-31.6333	29.55	DM: 156-158
cafer	Pirie	-32.77	27.25	DM: 159
cafer	Hillcrest	-29.77	30.75	DM: 778
cafer	Ngome	-27.8333	31.4	DM: 1003
cafer	Farm_Clearwater	-31.033	30.1667	DM: 1121
cafer	Umtamvuna_Reserve	-31.0667	30.1667	DM: 1124
cafer	Renishaw	-30.2667	30.7556	DM: 1851
varius	Karkloof	-29.3333	30.1833	TM: 41824-6; 43838
varius	Drakensberg, Cathedral_Peak	-28.9333	29.23333	TM: 42213; 42215
varius	Dargle, Kilgobbin	-29.4667	30.05334	TM: 42229
varius	Hluhluwe Game Reserve	-28.0333	32.1167	TM: 44400-44401; 44383
cf. tenuis	Hanglip, Soutpansberg	-22.9833	29.8833	DM: 7279-80; 7301-2; 7305; 7308
cf. tenuis	Entabeni State Forest, Soutpansberg	-22.9833	30.25	TM: 25843-46; 25858-61; 25868; 25870-71; 25873; 30473-75
cf. tenuis	Woodbush Forest Reserve	-23.75	30.0167	TM: 30079-87; 30089-30099; 30101; 30104-30111
cf. tenuis	Buzzard Mt Retreat, Soutpansberg	-22.9997	29.7536	PT2011-5; 7
cf. tenuis	Lajuma Mountain Reserve, Soutpansberg	-23.0357	29.4276	PT2010-11; PT2010-18; PT2010-19; PT2010-20; AM11; AM33; AM34; AM35; SN02; SN03; NT04
cf. tenuis	Lajuma Mountain Reserve, Soutpansberg	-23.0357	29.4276	PT2010-11; PT2010-18; PT2010-19; PT2010-20; AM11; AM33; AM34; AM35; SN02; SN03; NT04
cf. tenuis	Farm Middelfontein, Soutpansberg	-22.9754	29.9521	PT2012-41; PT2012-42

APPENDIX C: Details of measurement of specimens from Limpopo province (*Myosorex cf. tenuis*) and M. varius from Durban Museum used for analysis. The specimens are from Entabeni, Hanglip, Lajuma, Buzzard and woodbush.

Table 5a: Skull Measurements of specimens from Hanglip

CI	PPL	UTR	LIW	BW	GW	LTR	M3L	M3W	P4-M3
22	9.89	9.67	4.39	6.56	10.43	9.21	1.62	0.92	5.61
22.2	10.2	9.55	4.58	6.87	10.8	8.36	1.57	0.95	5.69
23.2	10.8	9.49	4.61	6.96	11.1	8.87	1.58	0.93	5.78
22	9.85	9.31	4.61	6.76	10.6	8.67	1.6	0.85	5.57
22	10.06	9.22	4.59	6.63	10.6	8.54	1.6	0.85	5.6
22.1	10.1	9.14	4.41	6.96	10.7	8.5	1.68	0.75	5.63

Table 5b: Skull Measurements of specimens from Entabeni

CI	PPL	UTR	LIW	BW	GW	LTR	M3L	M3W	P4-M3
21.8	10.2	9.46	4.39	6.81	10.9	8.66	1.54	0.87	5.48
22.72	9.89	9.66	4.68	6.87	11.11	8.82	1.59	0.93	5.79
22.32	9.77	9.71	4.37	6.77	10.62	8.9	1.58	0.89	5.74
22.54	10.32	9.67	4.54	6.97	10.66	8.71	1.57	0.91	5.73
22.58	10.18	9.68	4.45	6.65	10.72	8.77	1.45	0.86	5.6
22.1	9.63	9.3	4.41	6.36	10.59	8.65	1.54	0.75	5.59
22.6	10.38	9.67	4.31	6.79	10.53	8.77	1.5	0.87	5.69
22.18	9.9	9.34	4.45	6.73	10.49	8.61	1.58	0.82	5.48
22.25	10.19	9.57	4.73	6.81	10.89	8.67	1.47	0.9	5.62
21.92	9.84	9.45	4.35	6.72	10.93	8.51	1.58	0.86	5.52
22.27	9.81	9.14	4.51	6.66	11	8.25	1.51	0.75	5.39
22.86	10.25	9.67	4.59	6.76	10.92	8.79	1.47	0.84	5.67
21.6	9.47	9.28	4.28	6.48	10.71	8.52	1.53	0.9	5.56
22.6	10.02	9.71	4.56	6.79	10.86	8.8	1.49	0.85	5.73
22.24	9.42	9.56	4.29	6.91	10.61	8.71	1.55	0.9	5.57

Table 5.1c: Skull Measurements of Specimens from Buzzard Mt and Middelfontein

CI	PPL	UTR	LIW	BW	GW	LTR	M3L	M3W	P4-M3
22.03	10.06	9.83	4.45	6.58	10.28	8.7	1.5	0.95	5.5
22.5	10.54	9.4	4.67	6.67	10.7	8.58	1.65	0.95	5.52
22.3	9.82	9.5	4.68	6.79	11	8.62	1.6	0.9	5.54
22.4	9.76	9.55	4.76	6.77	10.9	8.69	1.6	0.9	5.56

Table 5.1d: Skull Measurements of Specimens from Lajuma

CI	PPL	UTR	LIW	BW	GW	LTR	M3L	M3W	P4-M3
21	9.2	9.1	4.41	6.43	10.3	8.4	1.47	0.88	5.29
21.2	9.48	9.13	4.48	6.43	10.3	8.44	1.54	0.82	5.17
21.5	9.61	9.19	4.44	6.48	10.5	8.3	1.41	0.82	5.35
20.9	9.29	8.87	4.46	6.43	10.1	8.14	1.53	0.77	5.13
21.4	9.84	8.97	4.56	6.5	10.4	8.2	1.33	0.81	5.36
21.1	9.31	8.85	4.31	6.46	10.3	8.43	1.42	0.85	5.4
21.1	9.56	8.72	4.4	6.45	10.4	7.98	1.45	0.87	5.08
21.3	9.69	8.96	4.49	6.41	10.4	8.48	1.48	0.8	5.23
21.3	9.53	9.19	4.6	6.33	10.57	8.22	1.48	0.85	5.31
21.6	9.83	9.26	4.47	6.54	10.5	8.14	1.54	0.8	5.42
21.1	9.52	9.08	4.31	6.24	10.29	8.3	1.47	0.88	5.24

Table 5.1e: Skull Measurements of *M. varius* from Durban Museum

CI	PPL	UTR	LIW	BW	GW	LTR	M3L	M3W	P4-M3
22.49	9.98	9.5	4.27	6.69	10.75	8.52	1.64	0.97	5.51
22.34	10.23	9.58	4.26	6.74	11.21	8.71	1.59	0.91	5.49
22.97	10.08	9.82	4.52	6.73	11.45	8.9	1.63	0.96	5.75
21.3	9.72	8.66	4.15	6.42	10.49	7.77	1.39	0.81	5.09
21.94	9.64	9.45	4.36	6.58	10.3	8.59	1.65	0.85	5.53
22.6	10.23	9.36	4.41	6.62	10.66	8.46	1.59	0.88	5.42
23.18	10.38	9.92	4.19	6.9	11.22	8.93	1.65	0.99	5.73
21.86	9.65	9.43	4.05	6.78	10.4	8.36	1.44	0.94	5.81
21.99	10.03	9.35	4.39	6.95	10.43	8.51	1.53	0.82	5.51
21.85	9.7	9.57	4.42	7.1	10.48	8.64	1.64	0.9	5.81

Table 5.1g: Skull Measurements of Specimens from Woodbush

CI	PPL	UTR	LIW	BW	GW	LTR	M3L	M3W	P4-M3
20.8	9.55	8.98	4.2	6.14	10.2	8.13	1.55	0.96	5.2
21.5	9.62	9.25	4.57	6.66	10.3	8.25	1.5	0.96	5.36
21.1	9.69	8.82	4.21	6.07	10.1	7.97	1.68	0.78	5.2
21.5	9.86	8.98	4.32	6.34	10.26	8.15	1.44	0.8	5.34
20.87	9.27	8.54	4.16	6.22	10.37	7.87	1.5	0.8	5.02
21.56	9.87	8.93	4.28	6.37	10.86	8.19	1.44	0.81	5.22
21.4	9.84	8.97	4.24	6.4	10.57	8.12	1.41	0.84	5.18
21.55	9.95	9.05	4.29	6.4	10.54	8.27	1.53	0.81	5.35
20.87	9.51	8.82	4.25	6.2	10.15	8.09	1.44	0.79	5.11
21.31	9.98	8.83	4.25	6.42	10.41	8.08	1.64	0.83	5.27
20.87	9.56	8.8	4.4	6.42	10.61	8.02	1.46	0.81	5.15
21.64	9.72	9.12	4.31	6.33	10.6	8.22	1.47	0.85	5.33
21.73	9.87	8.88	4.38	6.45	10.77	8.05	1.45	0.75	5.09

20.96	9.29	8.9	4.96	6.49	10.45	8.06	1.5	0.83	5.21
20.9	9.2	8.78	4.1	6.16	10.34	8.16	1.46	0.81	5.23
20.79	9.21	8.79	4.06	6.17	10.22	8.01	1.46	0.79	5.18
21.37	9.55	8.97	4.37	6.42	10.53	8.19	1.54	0.8	5.21
21	9.44	8.85	4.13	6.06	10.23	8.07	1.47	0.77	5.19
20.87	9.47	8.79	4.26	6.3	10.21	8.04	1.42	0.76	5.13
21.39	9.77	9.02	4.35	6.34	10.28	8.18	1.6	0.86	5.33
21.4	9.71	9.07	4.37	6.18	10.93	8.33	1.58	0.82	5.33
21.07	9.59	8.78	4.25	6.19	10.59	8	1.43	0.8	5.06
21.35	9.69	8.86	4.27	6.47	10.47	7.99	1.51	0.89	5.45
21.15	9.57	8.8	4.33	6.16	10.59	8	1.53	0.88	5.36
21.25	9.66	8.85	4.15	6.39	10.45	8.04	1.39	0.79	5.22
21.07	9.32	9.08	4.07	6.31	10.39	8.37	1.6	0.87	5.34
21.46	9.31	9.12	4.23	6.14	10.45	8.31	1.56	0.76	5.28
21.57	9.53	9.11	4.23	6.37	10.56	8.3	1.53	0.84	5.35
21.57	9.48	9.34	4.23	6.41	10.61	8.48	1.5	0.86	5.43
22.11	9.52	9.39	4.33	6.32	10.64	8.51	1.5	0.89	5.43
21.42	9.62	8.99	4.08	6.43	10.5	8.2	1.58	0.82	5.32
21.57	9.58	9.09	4.01	6.36	10.48	8.36	1.61	0.87	5.26
21.83	9.98	9.12	4.43	6.53	10.65	8.3	1.39	0.8	5.41
21.18	9.5	9	4.33	6.3	10.6	8.21	1.48	0.82	5.26

Appendix D-J: Details of Data from Museums and Published data for *Myosorex* species used in Modeling. TM- Transvaal Museum, DM- Durban Museum, W-M- Willows-Munro, AM-Amatole Museum and BR- Mr. Rod Baxter.

Appendix D- Details of *Myosorex cafer*

	Place name	Longitude	Latitude	Source
487	Kilgobin	30.1000	-29.4667	TM 2406
488	Mshwati River Valley	30.3833	-29.2833	TM 43828
489	Port St Johns	29.5500	-31.6333	TM 806
490	Ngqeleni	29.0333	-31.6667	TM 838
491	Town Bush Cave Area	30.3833	-29.6000	TM 32406
492	Lebanon Sappi Plantation	30.1910	-29.2919	TM 47116
493	Oribi Gorge Nature Reserve	30.2667	-30.7167	TM 43353
494	Karkloof Forest	30.3833	-29.2833	TM 43807
495	Kilgobbin	30.1000	-29.4667	TM 2406
496	Between Hilton And Pmb	30.3833	-29.5833	TM 29042
497	Hilton	30.3833	-29.6000	TM 34398
498	Pietermritzburg	30.3833	-29.58333	TM 34397
499	Dargle State Forest	30.1167	-29.4667	TM 34458
500	Hilton	30.3833	-29.6000	TM 34519
501	Blinkwater Nature Reserve	30.4333	-29.2333	DM 5804
502	MONDI - Linwood Estate	30.0944	-29.5639	DM 6004
503	Hilton - 32 Acutt Road	30.3333	-29.4833	DM 6015
504	Queen Elizabeth Park	30.3056	-29.5653	DM 6320
505	Blinkwater Road	30.7561	-29.4006	DM 6321
506	Blinkwater Nature Reserve	30.7625	-29.3961	DM 6322
507	Stainbank N.R.	30.9333	-30.0000	DM1629
508	Port St Johns Pondoland	29.5333	-31.6167	DM 155
509	Farm Clearwater, Port Edward	30.1667	-31.0333	DM 1124
510	Umtamvuna RSV Pont Caravan	30.1667	-31.0667	DM 1228
511	Umtamvuna RSV Port Edward	30.1667	-31.0667	DM 1146
512	Karkloof Forest	30.2167	-29.3333	DM 1630
513	Renishaw, South Coast	30.7556	-30.2667	DM 2194
514	Alice, South Africa	26.8300	-32.7800	W-M

515	Boston, South Africa	29.9700	-29.6700	W-M
516	Dargle, South Africa	29.9700	-29.4800	W-M
517	Hillcrest, South Africa	30.7500	-29.7700	W-M
518	Hogsback, South Africa	26.9000	-32.5200	W-M
519	Howick, South Africa	30.2000	-29.4500	W-M
520	Ixopo, South Africa	30.0500	-30.1500	W-M
521	Stutterheim, South Africa	27.4200	-32.5500	W-M
522	Umtwalume, South Africa	30.3800	-30.2900	W-M
523	Umzinto, South Africa	30.6500	-30.3000	W-M
524	Msikaba river mouth	29.9594	-31.2278	AM 31203
525	Msikaba river mouth	29.9586	-31.2608	AM 31204
526	Msikaba river mouth	29.9964	-31.2733	AM 31205
527	Msikaba river mouth	29.9564	-31.2900	AM 31206
258	Msikaba river mouth	29.9744	-31.3033	AM 31207
259	Msikaba river mouth	29.9619	-31.3064	AM 31208
260	Msikaba river mouth	29.9769	-31.3064	AM 31210
261	Stutterheim	27.1706	-32.6728	AM 31801

Appendex E: Data from Museums and published data for *Myosorex varius*. RB-Rod Baxter; WM- Willows-Munro; DM-Durban Museum, TM-Transvaal Museum and AM-Amatole Museum.

Identification Number	Place name	Coordinates		Source
3	GHT, Gowies Kloof	26.5167	-33.2833	RB
4	GHT, Drostdy	26.5167	-33.3000	RB
5	Leliefontein, Ezelfontein	18.0833	-30.3000	RB
6	GHT, Orinway Farm	26.4833	-33.3167	RB
7	GHT, Gov. Plot	26.5167	-33.3167	RB
8	Lidney Farm	26.0000	-33.6667	RB
9	Alexandria F. R. dunes	26.0000	-33.6833	RB
10	Alexandria, WSW	25.8500	-33.7167	RB
11	Rhodes, Tenahead Farm	28.1333	-30.6833	RB
12	Rhodes, Carlisle's Hoek	27.9500	-30.7333	RB
13	Rhodes, Tushielaw	27.9500	-30.7833	RB
14	Rhodes Village	27.9667	-30.7833	RB
15	Maclear, Lehana's Pass	28.1333	-30.7000	RB
16	Bathhurst, Caxton	26.9667	-33.4167	RB
17	Kasouga	26.7333	-33.6333	RB
18	Bedford	26.1000	-32.6833	RB
19	Bedford, Chestnut Grove	26.0500	-32.6000	RB
20	Cathcart, Lowestoffe	26.9000	-33.2833	RB
21	Hankey	24.8833	-33.8167	RB
22	Kareedouw	24.1167	-33.9667	RB
23	Kareedouw, WitEls F.R.	24.1167	-33.9833	RB
24	Plettenberg Bay	23.7167	-33.9167	RB
25	Plett, Lottering F. R.	23.7333	-33.9500	RB
26	Kei Road, Gleniffer	27.5667	-32.7000	RB
27	KWT, Pirie	27.2500	-32.7667	RB
28	KWT, Yellowoods	27.4500	-32.8667	RB
29	Kirkwood, Dunbody Estates	25.7167	-33.4667	RB
30	Lusikisiki, Nkambati River	29.9500	-31.2500	RB
31	Lusikisiki, Msikaba Mouth	29.9667	-31.2667	RB
34	Molteno, Glen Cave	26.5000	-31.3500	RB
35	Molteno, Rondavel	26.5167	-31.3500	RB
36	PE, Schoenmakerskop	25.5333	-34.0333	RB
37	Port St Johns	30.4667	-30.7333	RB
38	Seymour	26.6833	-32.4833	RB
37	Port St Johns	30.4667	-30.7333	RB
38	Seymour	26.6833	-32.4833	RB

39	Stutterheim, Amabele	27.5333	-32.6500	RB
40	Kei Road, Wriggleswade	27.5500	-32.5667	RB
41	Stutterheim, Qacu Forest	27.5000	-32.4000	RB
42	Stutterheim, Peninsula Farm	27.7000	-32.5500	RB
43	Isidenge Forest	27.1667	-32.6667	RB
44	Tarkastad, Quagga's Kerk	26.2333	-32.3167	RB
45	Dordrecht, Carlton Farm	27.0833	-31.3500	RB
46	Dordrecht	27.0333	-31.3833	RB
47	Zwelitsha, Izeleni Plantation	27.4167	-32.6833	RB
48	Hlabisa, Lake Eteza	32.1667	-28.4833	RB
49	Underberg	29.5000	-29.5833	RB
50	Frazerburg, Ayesfontein	21.6333	-32.0333	RB
51	Kamiesberg, Ezelfontein	18.1000	-30.3833	RB
52	Ficksburg, Franschoek	27.8667	-28.8667	RB
53	Beaufort West, Karoo N. P.	22.5833	-32.2500	RB
54	Beaufort West	22.5833	-32.3500	RB
55	Bredasdorp, De Hoop N. R.	20.3833	-34.4167	RB
56	Bredasdorp, De Hoop N. R.	20.4167	-34.4833	RB
57	Bredasdorp, Berghoek	19.9500	-34.5333	RB
58	Bredasdorp, Haze Vlakte	19.8500	-34.6167	RB
59	Napier, Hagelkraal	19.5500	-34.7000	RB
60	Kleinmond Bot. Res.	18.9167	-34.3333	RB
61	Betty's Bay	18.8833	-34.3500	RB
62	Ceres, Rietvallei	19.5000	-32.8500	RB
63	Ceres, Beukesfontein	19.7333	-32.8667	RB
64	Touwsrivier, Bokke Rivier	19.8333	-33.3333	RB
65	Citrusdal, Hex River	18.9833	-32.4667	RB
66	Citrusdal	19.0167	-32.6000	RB
67	Clanwilliam, Kliphuis	18.9500	-32.1333	RB
68	Lamberts Bay, Compagniesdrift	18.4500	-32.1167	RB
69	Clanwilliam, Pakhuis Pass	19.0333	-32.1333	RB
70	George	22.5333	-33.9500	RB
71	Knysna	23.0333	-34.0333	RB
72	Knysna, Goukamma N. R.	22.9333	-34.0500	RB
73	Knysna, Coney Glen	23.0500	-34.0667	RB
74	Harkerville F. R.	23.2167	-34.0833	RB
75	Darling, Doornfontein	18.3167	-33.4000	RB
76	Darling, Rondeberg	18.2833	-33.4167	RB
77	Murraysburg,	23.9500	-32.1667	RB
78	Piketberg, Rocherpan N.R.	18.3000	-32.5833	RB
79	Piketberg, Rocherpan N.R.	18.3000	-32.6000	RB
80	Piketberg, Rocherpan N.R.	18.2833	-32.6000	RB
81	Elandsbaai, Bonteheuwel	18.4000	-32.3167	RB
82	Elandsbaai, Grootedrift	18.4667	-32.3833	RB

83	Elandsbaai, Bonteheuwel	18.4667	-32.4000	RB
84	Elandsbaai, Wittedrift	18.5167	-32.4500	RB
85	Piketberg, Het Kruis	18.7500	-32.5833	RB
86	Piketberg, Mouton's Valley	18.6833	-32.7500	RB
87	Piketberg, Mouton's Valley	18.7000	-32.7500	RB
88	Piketberg, Mouton's Valley	18.7167	-32.7667	RB
89	Redelinghuis	18.5333	-32.4833	RB
90	Swartberg Forest R.	22.0000	-33.3333	RB
91	Swartberg Forest R.	21.9000	-33.3333	RB
92	Swartberg Forest R.	21.9333	-33.3333	RB
93	Swartberg Forest R.	21.9667	-33.3333	RB
94	Swartberg Forest R.	21.9333	-33.3500	RB
95	Swartberg Pass, Top of	22.0500	-33.3167	RB
96	Albertinia, De Groote Fontein	21.5833	-34.2333	RB
97	Riversdale, Garcia F. R.	21.2167	-33.9500	RB
98	Riversdale, Corente River	21.1500	-33.9833	RB
99	Riversdale, Koppies Kraal	21.1667	-33.9833	RB
100	Riversdale, Garcia F. R.	21.2167	-34.0000	RB
101	Riversdale, Garcia F.R.	21.2167	-34.0167	RB
102	Stellenbosch, Jonkershoek	18.9333	-33.9667	RB
103	Stellenbosch, Jonkershoek	18.9167	-33.9667	RB
104	Uniondale	23.1667	-33.6167	RB
105	Vredendal, Ebenzer Colony	18.2167	-31.5833	RB
106	Vredendal, Papendorp	18.2000	-31.7000	RB
107	Knysna, Diepwalle F.R.	23.1667	-33.9500	RB
111	Clanwilliam, Algeria S.Forest	19.0500	-32.3667	RB
112	Lemoenshoek, Boosmansbos	20.8833	-33.9333	RB
113	Nature's Valley, De Vasselot	23.6833	-33.9667	RB
114	Uitenhage, Groenendal	25.3167	-32.7167	RB
115	Uniondale, Kammanassie	22.9000	-33.6167	RB
116	Storm's River	23.8833	-33.9667	RB
117	Mossel Bay, Ruitersbos	22.0333	-33.8833	RB
118	Karoo NP	22.5500	-33.3333	RB
119	Ceres, Lot B	19.5667	-33.3333	RB
120	Noupoort	25.2000	-31.1167	RB
121	George, Saasveld	22.3833	-33.9667	RB
122	Hout Bay	18.3667	-34.0667	RB
123	Cape Town, Plumstead	18.4667	-34.0167	RB
124	Silvermine	18.4333	-34.1167	RB
125	Raubenheimer Dam	22.3167	-33.4000	RB
126	Ngome Forest,	31.4333	-27.8167	RB
127	Ngome Forest,	31.4167	-27.8333	RB
128	Duku Duku	32.3500	-28.3667	RB
129	Stutterheim, Kologha	27.2667	-32.5167	RB

130	Nature's Valley	23.5500	-33.9833	RB
131	Stellenbosch, Jonkershoek	18.9667	-34.0000	RB
132	Piketberg, Rocherpan N.R.	18.3000	-32.6333	RB
133	Heidelberg WC, Grootvaders	20.7833	-34.0167	RB
134	Langebaan	18.0833	-33.1500	RB
135	Louwsburg, Itala G.R.	31.3500	-27.5167	RB
136	Kamberg	29.6667	-29.4000	RB
137	Hluhluwe	32.1167	-28.0333	RB
138	Van Reenen	29.4333	-28.4167	RB
139	Simonstown	18.4333	-34.2000	RB
140	Dargle	30.1000	-29.4667	RB
141	Cathedral Peak	29.2500	-28.9333	RB
142	Nottingham Road	30.0000	-29.3500	RB
143	Golden Gate	28.6333	-28.4667	RB
144	Wakkerstroom	30.3167	-27.3000	RB
145	Middelburg	29.6000	-26.0500	RB
146	Badplaas	30.7500	-25.8667	RB
147	Pilgrim's Rest	30.8333	-24.9167	RB
148	Nooitgedacht	30.0333	-25.9500	RB
149	Bethal	29.4833	-26.1000	RB
149	Ermelo	29.9833	-26.5167	RB
151	Dullstroom, Verloren Vallei	30.1333	-25.3000	RB
152	Wakkerstroom	30.2667	-27.2833	RB
153	Irene	28.2833	-25.8833	RB
154	Belfast	30.0667	-25.5667	RB
155	Swaziland, Mlilwane	31.1333	-26.4500	RB
156	Swaziland, Malalotja	31.1167	-26.1333	RB
157	Swaziland, Ncabaneni	31.1333	-26.6167	RB
158	Blyde River	30.9167	-24.7833	RB
159	Dullstroom	30.1000	-25.4167	RB
160	Ermelo	29.8833	-26.4333	RB
161	Harrismith	29.1333	-28.2833	RB
162	Clarkson, Hoffmansbosch	24.3667	-34.0167	RB
163	Rietfontein, Jo'burg	28.0667	-26.0500	RB
164	Pietermaritzburg	30.3833	-29.6167	RB
165	Pietermaritzburg, QEP	30.3167	-29.5667	RB
166	Royal Natal NationalPark	28.9167	-28.6667	RB
167	Tokai Retreat	18.4167	-34.0667	RB
168	Blyderiviers Poort	30.8000	-24.5167	RB
169	Nelspruit	31.0167	-25.4500	RB
170	Lydenburg	30.4667	-25.1167	RB
171	Gaika's Kop	26.9500	-32.5500	RB
172	Wolsley	19.1833	-33.4167	RB
173	Eendekuil	18.8667	-32.6833	RB

174	Worcester, De Wet	19.5167	-33.6167	RB
175	La Motte	19.0833	-33.8833	RB
176	Ngqeleni	29.0333	-31.6500	RB
177	Midmar	30.1667	-29.5333	RB
178	Giant's Castle	29.5167	-29.2667	RB
179	Nkandla	31.0833	-28.6167	RB
180	Qudeni	31.0833	-28.6167	RB
181	St Lucia	32.4167	-28.2833	RB
182	Ashburton	30.4667	-29.6333	RB
183	Umfolozi	31.2333	-28.2333	RB
184	Thornville	30.3833	-29.7333	RB
185	Sani Pass	29.3000	-29.6000	RB
186	Karkloof	30.1833	-29.3333	RB
187	Lidgetton	30.1167	-29.4500	RB
188	Oribi Gorge	30.2333	-30.7000	RB
189	Rietvlei Dam	28.2833	-25.8833	RB
190	Krugersdorp, Uitkomst	27.7500	-25.9167	RB
191	Koster	26.9000	-25.8667	RB
192	Randfontein	27.6667	-26.1833	RB
193	Mbabane	31.1333	-26.3000	RB
194	Barberton	31.0000	-25.8000	RB
195	Lesotho, Maluti	27.6667	-29.3333	RB
196	Blinkwater	30.4500	-29.2333	RB
197	Durban	31.0000	-29.8667	RB
198	Fort Nottingham	29.9000	-29.4000	RB
199	Highmoor	29.6167	-29.3167	RB
200	Hillcrest	30.7667	-29.7667	RB
201	Hilton	30.3000	-29.4833	RB
202	Krantzkloof	30.8333	-29.7667	RB
203	Clearwater Farm	30.1667	-31.0333	RB
204	Hlatikulu Vlei	29.6833	-29.2833	RB
205	Kilgobbin Farm	30.0500	-29.4667	RB
206	Kalkoenkrantz 189	26.8000	-31.5333	RB
207	Kalkoenkrantz	26.6833	-31.3167	RB
208	Robertson	19.8667	-33.3167	RB
209	Venture	26.5667	-30.9333	RB
210	Town Bush	30.3500	-29.5500	RB
211	Kevitts Hoek	27.8167	-31.5667	RB
212	Winterskloof	30.2667	-29.5833	RB
213	Redlands	29.7167	-30.6000	RB
214	Mbabane	31.1333	-26.2833	RB
215	Snowhill	27.0667	-31.5667	RB
216	Goodstone	27.3167	-31.5667	RB
217	Heimat	27.5667	-31.4333	RB

218	Darvill	30.3833	-29.6000	RB
219	Sxwaleni Forest	28.8667	-31.8833	RB
220	Aberfeldy	28.8500	-28.2167	RB
221	Donkerhoek Farm	29.7167	-27.6333	RB
222	Willbrook	29.8667	-29.1333	RB
223	Umbilo	31.0000	-29.8333	RB
224	Mposa	32.0833	-28.6500	RB
225	Wakkerstroom	30.1333	-27.2167	RB
226	Rocky Park	28.3167	-31.3167	RB
227	Mispa	27.4167	-29.1833	RB
228	Carnarvon	26.8500	-31.5667	RB
229	Umfolozi Flats	31.8667	-28.3333	RB
230	Bosch Hoek SANDF	30.1000	-29.2833	RB
231	Garden Castle	29.2500	-29.7500	RB
232	Bosch Hoek	30.1000	-29.3500	RB
233	Rooiberg	21.5000	-33.6667	RB
234	Waterfall	29.3167	-28.3167	RB
235	Mooi River	30.0000	-29.2167	RB
236	Drakensberg Gardens	29.2500	-29.7667	RB
237	Ncabaneni	31.1333	-26.6333	RB
238	Umdoni Park	30.6833	-30.4000	RB
239	Hogsback	26.9500	-32.6333	RB
240	Umtamvuna	30.2000	-31.0333	RB
241	Kambula	30.7167	-27.6833	RB
242	Krugersdorp, Danielsrust	27.7167	-25.9667	RB
243	Nova	27.3833	-29.0333	RB
244	Boshoek	28.3833	-28.3833	RB
245	Fernkloof NR	19.3167	-34.3833	RB
246	Blyde Forest Reserve	30.8500	-24.8667	RB
247	Ngome	31.4333	-27.8000	RB
248	Uitkyk & Paranie PNR	31.1167	-25.6000	RB
249	Sussanaskop	28.6667	-27.7000	RB
250	Castle View	29.4167	-29.8333	RB
251	Allemansgras	29.1333	-28.3833	RB
252	Vernon Crooks NR	30.5833	-30.2833	RB
253	Karkloof Forest	30.2167	-28.3000	RB
254	Eagles Crag	27.8333	-30.7500	RB
255	Alice	26.8667	-32.8000	RB
256	Hogsback	26.9167	-32.5500	RB
257	Happy Hills Farm	30.1167	-29.4500	RB
258	Halstone	27.7667	-30.6833	RB
259	Gwaliweni	32.0833	-27.3333	RB
260	Port Edward	30.2500	-31.0333	RB
261	Drumbo	27.7000	-30.7000	RB

262	Umtwalume	30.6333	-30.4833	RB
263	Milton	28.3167	-30.6833	RB
264	Golden Gate	28.3833	-28.6333	RB
265	Mfongozi	30.8000	-28.7167	RB
266	Injasuti NR	29.3667	-29.1167	RB
267	Phallang	27.9333	-29.8167	RB
268	Umhlanga	31.0833	-29.7333	RB
269	Helvellyn	27.2833	-30.6833	RB
270	Roodekraal	27.9333	-31.3167	RB
271	Denorbin	27.6833	-31.1833	RB
272	Ben Becula	28.0667	-31.3167	RB
273	Modderfontein	26.6833	-31.0667	RB
274	Lake Sibayi	32.7500	-27.3333	RB
275	Cape Flats	18.6167	-33.9833	RB
276	Mgeni Vlei	29.8000	-29.4833	RB
277	Sehlabathebe	29.6833	-29.9333	RB
278	Hluhluwe	32.0333	-28.0667	RB
279	Mlilwane	31.1333	-26.9500	RB
280	Golden Gate	28.1333	-28.8833	RB
281	Sehlabathebe	29.0667	-29.4333	RB
282	Alice	26.8333	-32.8000	RB
283	Botha's Hill	30.7500	-29.7500	RB
284	Risler	28.3167	-30.8167	RB
285	Hluhluwe GR	32.0333	-28.0833	RB
286	Malutizicht	28.1333	-28.6333	RB
287	Virginia Farm	29.9500	-29.6667	RB
288	Umdoni Park	30.6833	-30.4000	RB
289	Marakabei	28.1167	-29.5333	RB
290	Ossa	27.9333	-30.8167	RB
291	Hamilton	28.0667	-30.9333	RB
292	Ben Voirlich	27.9333	-31.1833	RB
293	Twee Zusters	27.5000	-31.0333	RB
294	Highfield	28.4333	-31.0667	RB
295	Rooipoort	27.8167	-31.3167	RB
296	Cape Point	18.4333	-34.2833	RB
297	Golden Gate	28.6500	-28.9833	RB
298	Koeberg	28.6000	-28.5667	RB
299	Lejone	28.4333	-29.0667	RB
300	Lepaquoa	28.4000	-29.0833	RB
301	Brucedell	27.9333	-30.9333	RB
302	Shamrock	28.0667	-31.0667	RB
303	Glen Gyle	27.6500	-30.7167	RB
304	Bokong	28.5667	-29.3167	RB
305	Mateanong	29.2333	-29.3333	RB

306	Bokong	28.4333	-29.3167	RB
307	Champagne Castle	29.2500	-29.0500	RB
308	Clarendon	30.3833	-29.6000	RB
309	Malalotja	31.1167	-26.1333	RB
310	Carter's Nursery	30.3833	-29.6167	RB
311	Ski Chalet	28.5333	-28.8667	RB
312	Mothae	28.7833	-28.8833	RB

Identification Number	Place name	Coordinates		Source
479	Pretoria	28.2700	-25.7000	W-M
426	Vedendal	18.5000	-31.6500	W-M
427	Clanwilliam	18.8000	-32.1500	W-M
428	Elandsbaai	18.3000	-32.2800	W-M
480	Middelburg	29.2800	-25.4900	W-M
430	Saldanha	17.9300	-33.0000	W-M
431	Darling	18.3200	-33.3700	W-M
432	Wellington	19.0300	-33.6000	W-M
433	Stellenbosch	18.8300	-33.9300	W-M
434	Cape Town	18.2800	-33.9500	W-M
435	Villiersdorp	19.2500	-34.0200	W-M
436	Betty's Bay	18.9500	-34.3500	W-M
437	Bredasdorp	19.9800	-34.5200	W-M
438	Grootvadersbos	20.5900	-34.0600	W-M
439	Riversdal	21.2200	-34.0100	W-M
440	Basemfontein	21.2500	-33.4800	W-M
441	Herbertsdale	21.7500	-34.0300	W-M
442	Doringrivier	22.4800	-33.9300	W-M
443	Oudtshoorn	22.1700	-33.5700	W-M
444	Prince Albert	22.0100	-32.2000	W-M
445	Naturé's Valley	23.6200	-33.9300	W-M
446	Uniondale	23.1300	-33.6500	W-M
447	Port Elizabeth	25.5700	-33.9500	W-M
448	Utenhage	25.3800	-33.7500	W-M
449	Murraysburg	23.7500	-31.9500	W-M
450	Alexandria	26.4100	-33.6500	W-M
451	Grahamstown	26.4700	-33.3000	W-M
452	Hogsback	26.9000	-32.5200	W-M
453	Stutterheim	27.4200	-32.5500	W-M
454	Tarkastad	26.6200	-31.8700	W-M
455	Molteno	26.6200	-31.3700	W-M
456	Dodracht	27.6200	-31.3700	W-M
457	Halane	27.8700	-31.6200	W-M
458	Port St John's	29.3300	-31.3800	W-M

459	Mkambati	29.9500	-31.2800	W-M
460	Kokstad	29.1200	-30.6200	W-M
461	Oribi Gorge	30.4500	-30.7000	W-M
462	Durban	30.9700	-29.8300	W-M
463	Boston	29.9700	-29.6700	W-M
464	Underberg	29.5000	-29.7800	W-M
465	Sehlabathebe	29.1200	-29.8700	W-M
466	Giant's Castle	29.1200	-29.3700	W-M
467	Mooiriver	29.5000	-29.1300	W-M
468	Semonkong	28.1200	-29.6200	W-M
469	Moletsane	28.3700	-29.1200	W-M
470	Bethlahem	28.6200	-28.3700	W-M
471	Excelsior	27.1200	-28.8700	W-M
472	Hlabisa	31.8700	-28.1700	W-M
473	Mfongosi	32.1700	-27.3000	W-M
474	Boshoek	31.3500	-27.5700	W-M
475	Vryheid	30.7800	-27.7500	W-M
476	Wakkerstroom	30.1500	-27.3500	W-M
477	Bethal	29.4500	-26.4500	W-M
478	Mbabane	31.1200	-26.1200	W-M
422	Caledon Bett's Bay	18.9278	-34.3483	AM 30429
423	Caledon Bett's Bay	18.9250	-34.3531	AM 30430
424	Bredasdorp	20.4206	-34.4964	AM 30827
394	Stellenbosch	18.9219	-33.9681	AM 30828
395	Hankey	24.7167	-33.8203	AM 21158
396	Rhodes Village	28.3344	-30.7964	AM 22964
397	Stutterheim	27.5056	-32.4083	AM 22965
398	Seymour Highland	26.6883	-32.4861	AM 24932
399	Rhodes Farm	28.1442	-30.6958	AM 24981
400	Rhodes Farm	28.1569	-30.7056	AM 24998
401	Rhodes Carlisl	28.1886	-30.7436	AM 24999
402	Rhodes Farm	27.9636	-30.7911	AM 25002
403	Molteno	26.5214	-31.3564	AM 25012
404	Alexandria	26.0033	-33.6703	AM 25388
405	Kareedouw Humansdorp	24.1242	-33.9936	AM 12956
406	Plettenberg Bay Lotteri	23.7461	-33.9650	AM 25967
407	Msikaba river mouth	29.9642	-31.2617	AM 31211
408	Msikaba river mouth	29.9964	-31.2733	AM 31212
409	Kei Road	27.5647	-32.5942	AM 31290
410	Stutterheim	27.1706	-32.6728	AM 31802
411	Alexandria	25.8650	-33.7172	AM 31971
412	Pirie Forest	27.2500	-32.7667	AM 32493
413	Grahamstown	26.5167	-33.2833	AM 32494
414	George	22.5386	-33.9567	AM 25954

415	Bredasdorp	20.3986	-34.4306	AM 26300
416	Bredasdorp Npier Farm	19.5500	-34.7000	AM 26301
417	Knysna	22.9417	-34.0583	AM 26302
418	Stellenbosch	18.9342	-33.9669	AM 26303
419	Breadasdorp farm	19.9533	-34.5464	AM 30426
420	Breadasdorp farm	19.8636	-34.6247	AM 30427
421	Caledon Harold Porter	18.9258	-34.3469	AM 30428
386	Bulwer Mountain	29.7358	-29.8206	DM 6315
352	Monks Cowl, Hlathikulu F	29.3875	-29.0371	DM 8769
353	Lotheni Nature reserve	29.4785	-29.4152	DM 8770
354	Monks Cowl, Hlathikulu F	29.3930	-29.0373	DM 8772
355	Dargle, Lemonwood Farm	30.0533	-29.4865	DM 8867
356	Anagwe forest	32.1189	-28.6056	DM 8884
357	Port edward Clearwater	30.1667	-31.0333	DM 1241
358	Joostenberg Vlakte	18.7833	-33.7667	DM 1242
359	Umhlanga Rocks	31.0833	-29.7167	DM 657
360	Durban	31.0000	-29.8333	DM 776
361	Boschoek ladysmith	30.0333	-28.2167	DM 777
362	Pungashe'sHilton	31.0511	-28.3486	DM 9160
363	Ngome	31.3833	-27.8333	DM 1145
364	Umtamvuna Reserve	30.1667	-31.0000	DM 1167
365	Kuilsriver	18.3000	-33.9333	DM 1247
366	Kranzkloof N.R.	30.8333	-29.7667	DM 1628
367	Garden Castle N.R.	30.2167	-29.7556	DM 2478
368	Royal Natal NationalPark	28.9333	-28.6833	DM 2716
369	Cathedra Peak	29.2667	-28.9833	DM 2745
370	Kamberg NR	29.6667	-29.0444	DM 3350
371	Boschoek farm	30.1000	-29.3500	DM 3353
372	Fort Nottingham	29.9167	-29.4167	DM 3354
373	Crane Hlatikulu vlei	29.6833	-29.2833	DM 3446
374	Mgeni Vlei	29.8889	-29.4833	DM 34.50
375	Pmb.13, Winterskloof	30.3333	-29.5833	DM 3505
376	Ugie, Khulu forest	28.1898	-31.0703	DM 8762
377	Ugie	28.2556	-31.1833	DM 4030
378	Winterskloof	30.2833	-29.5833	DM 4152
379	8km SE Algeria	19.0833	-32.4333	DM 4183
380	Impendle district farm	29.9556	-29.6833	DM 4843
381	Oribi	30.2333	-30.7778	DM.5178
382	Blinkwater Nature Reserve	30.4500	-29.2333	DM 5179
383	Reins Nature Reserve	21.7556	-34.3667	DM 5704
384	Groenvlei	30.2556	-27.4333	DM 5710
385	MONDI - Linwood Estate	30.0833	-29.5556	DM 6229
393	Monks Cowl, Hlathikulu F	29.3885	-29.0381	DM 8564
387	Bulwer Mountain	29.7528	-29.8181	DM 6316

388	Bulwer Mountain	29.7522	-29.8267	DM 6317
389	Bulwer Mountain	29.7528	-29.8231	DM 6318
390	Bulwer Mountain	29.7508	-29.8200	DM 6323
391	Blinkwater Nature Reserve	30.7628	-29.8294	DM 7045
392	Highmoor Nature Reserve	29.6228	-29.3194	DM 7101
351	Bdyderiviersproot NRSV	30.9167	-24.7833	TM 40819
323	Baberton	31.0500	-25.7833	TM 29748
324	Mareipskop	30.8934	-24.5637	TM 47963
325	Diepwalle Forest RSV	23.1667	-33.9556	TM 32287
326	Clanwilliam Algeria forest	19.0556	-32.3667	TM 28306
327	De Vasselot Forest Reserve	30.1000	-25.4167	TM 23755
329	Farm Groenvlei, No.353	30.1167	-25.6333	TM 4094
330	Kamanassie m.c.a	22.9000	-33.6167	TM 29649
331	Ruitersbos S.Forest	22.0333	-33.8833	TM 32018
332	C. 40km E Ceres, Lot B	19.7167	-33.3333	TM 33826
333	Algeria State Forest	19.1333	-32.2333	TM 35056
334	Algeria State Forest	19.1333	-32.4000	TM 35063
335	Algeria Forest Station	19.0333	-32.3667	TM40598
336	Natures valley village	23.5583	-33.9833	TM 40517
337	Rocherpan Nature Reserve	18.3000	-32.6333	TM 40586
338	Knysna	23.0500	-34.0333	TM 753
339	Port St Johns	29.5500	-31.6333	TM 760
340	Utenhage, Groendal forest	25.3167	-32.7167	TM 28546
341	Kologha Forest	27.2667	-32.5083	TM 40488
342	Rietvlei Dam	28.2833	-25.8833	TM 41071
343	Veryheid Tygerskloof	31.3410	-27.8554	TM 46489
344	Midmar Dam	30.2333	-29.5000	TM 31838
345	Pietermaritzburg	30.3833	-29.6000	TM34441
346	Kamberg, Mooi River	29.6653	-29.3819	TM 38617
347	Ngome Forest RSV	31.4000	-27.8333	TM 39117
348	Cathedral Peak Forest	29.2500	-28.9333	TM 29400
349	Piet Retief Commonage	30.8000	-27.0000	TM 19011
350	Nelspruit, Uitkyk NRSV	31.1167	-25.6000	TM 20128

Appendix F: Details of *Myosorex sclateri* used in Modeling (Willows-Munro, 2008), and from Musems.

ID	Place name	Coordinates		Source
575	Lake Eteza	32.1667	-28.4833	DM 2299
576	Eshowe, S of Rutledge Park	31.3333	-28.4500	DM 3528
577	Umlalazi Nature Reserve	31.7806	-28.9458	DM 3529
579	Umlalazi Nature Reserve	31.7667	-28.9333	DM 3978
580	Eshowe, Dlinza Forest Nature Rsv.r	31.4667	-28.9000	DM 4002
581	Eshowe	31.4500	-28.8833	DM 4379
582	Eshowe - 8 Residency Road	31.4583	-28.9042	DM 7562
583	Sodwana Bay: Lake Mgobelezeni	32.6605	-27.5355	DM 8886
584	De waal, Hilton daisy site	31.0897	-28.0153	DM 8888
585	Springvale, SOL site, Melmoth	31.3767	-28.5767	DM 6319
586	Ngome	31.3833	-27.8333	DM 1029
587	Dukuduku Indigenous Forest	32.2833	-28.3667	TM 43312
588	Mapelane Resort	32.4167	-28.4000	TM 37167
589	Kologha Forest	32.5083	-27.2667	TM 43830
590	Ngoye Hills	31.6833	-28.8500	TM 790
591	Veryheid, Tygerskloof	31.3410	-27.8554	TM 46488
592	Kologha Forest	32.5083	-27.2667	TM 43830
593	Kwamagwaza Mission Melmoth	31.1667	-28.5833	DM 4641
594	Ngome Forest Reserve	31.4000	-27.8333	TM 39103
595	Ngome South Africa	31.2700	-27.4700	W-M
596	Entumeni	31.2700	-28.8300	W-M
507	Esowe South Africa	31.4200	-28.8700	W-M
598	Hlabisa South Africa	31.8700	-28.1700	W-M
599	Melmoth South Africa	31.4000	-28.5800	W-M
600	Mtinzizi South Africa	31.7500	-28.9500	W-M
6001	Nkandla forest, South Africa	31.0800	-28.6200	W-M

Appendix G: Details *M. varius* southern lineage used in modeling (Willows-Munro, 2008)

Identification Number	Place name	Coordinates X	y	Source
623	Utenhage	25.3800	-33.7500	W-M
611	Betty's Bay	18.9500	-34.3500	W-M
612	Bredasdorp	19.9800	-34.5200	W-M
613	Groootvadersbos	20.5900	-34.0600	W-M
614	Riversdal	21.2200	-34.0100	W-M
615	Basemfontein	21.2500	-33.4800	W-M
616	Herbertsdale	21.7500	-34.0300	W-M
617	Doringrivier	22.4800	-33.9300	W-M
618	Oudtshoorn	22.1700	-33.5700	W-M
619	Prince Albert	22.0100	-32.2000	W-M
620	Naturé's Valley	23.6200	-33.9300	W-M
621	Uniondale	23.1300	-33.6500	W-M
622	Port Elizabeth	25.5700	-33.9500	W-M
600	Niewoudsville	19.0700	-31.2300	W-M
601	Vedendal	18.5000	-31.6500	W-M
602	Clanwilliam	18.8000	-32.1500	W-M
603	Elandsbaai	18.3000	-32.2800	W-M
604	Saldanha	17.9300	-33.0000	W-M
605	Darling	18.3200	-33.3700	W-M
607	Wellington	19.0300	-33.6000	W-M
608	Stellenbosch	18.8300	-33.9300	W-M
609	Villiersdorp	19.2500	-34.0200	W-M

Appendix H: Details of *Myosorex varius* Northern lineage used in modeling (Willows-Munro, 2008)

Identification Number	Place name	Coordinates x	y	Source
656	Middelburg	29.2800	-25.4900	W-M
634	Mkambati	29.9500	-31.2800	W-M
635	Kokstad	29.1200	-30.6200	W-M
636	Oribi Gorge	30.4500	-30.7000	W-M
637	Durban	30.9700	-29.8300	W-M
638	Boston	29.9700	-29.6700	W-M
639	Underberg	29.5000	-29.7800	W-M
640	Sehlabathebe	29.1200	-29.8700	W-M
641	Giant's Castle	29.1200	-29.3700	W-M
643	Mooiriver	29.5000	-29.1300	W-M
644	Semonkong	28.1200	-29.6200	W-M
645	Moletsane	28.3700	-29.1200	W-M
646	Bethlahem	28.6200	-28.3700	W-M
647	Excelsior	27.1200	-28.8700	W-M
648	Hlabisa	31.8700	-28.1700	W-M
649	Mfongosi	32.1700	-27.3000	W-M
650	Boshoek	31.3500	-27.5700	W-M
651	Vryheid	30.7800	-27.7500	W-M
652	Wakkerstroom	30.1500	-27.3500	W-M
653	Bethal	29.4500	-26.4500	W-M
654	Mbabane	31.1200	-26.1200	W-M
655	Pretoria	28.2700	-25.7000	W-M

Appendix I: Details of *Myosorex cf.* from Limpopo Province used in Modeling

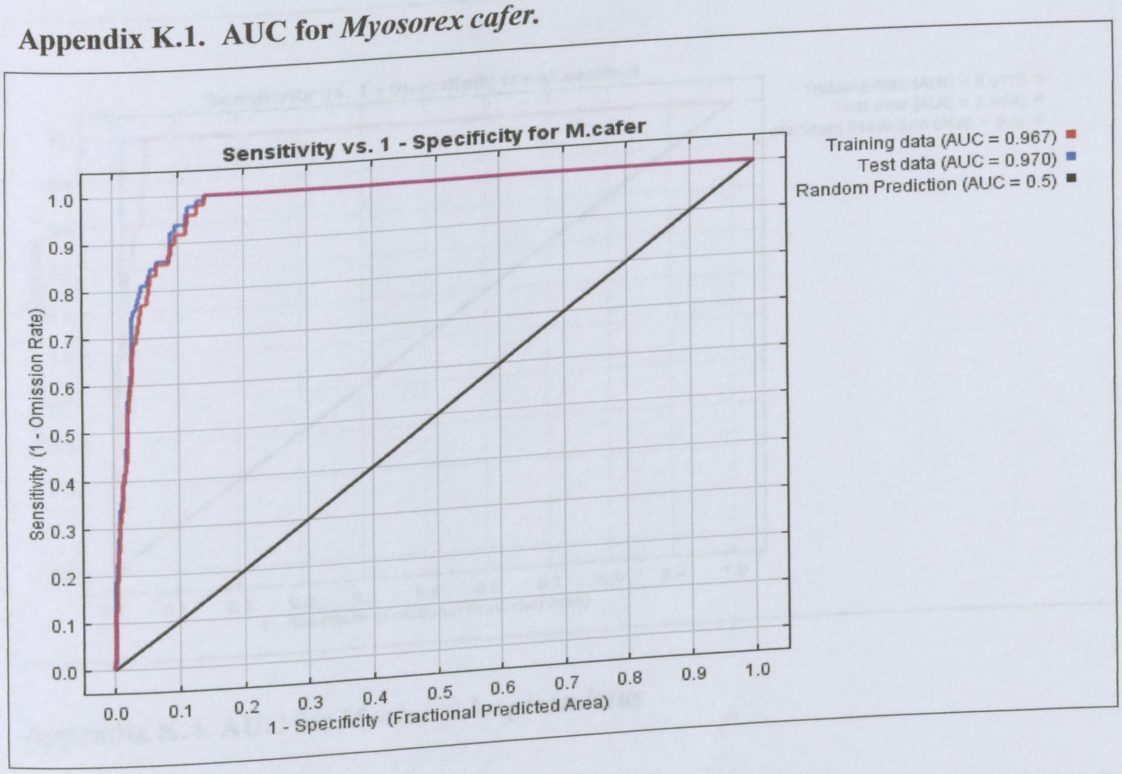
Identification	Place name	Coordinates		Source
8001	Tate Vondo Sibasa	30.4833	-22.9667	TM 42369
8002	Entabeni State Forest	30.2500	-22.9833	TM 6800
8003	De Hoek Forest	30.0167	-23.2800	TM 40767
8004	Buzzard Mt	29.7611	-23.0083	TM41650
8005	Wolkberg Wilderness	30.0667	-24.0167	TM 1428
8006	Tzaneen Estate	30.1667	-23.8000	TM 974
8007	Ebenezar Dam	29.9500	-23.9167	TM 42471
8008	Haenertburg	29.9500	-23.9167	TM 10435
8009	New Agatha Forest	30.0667	-24.0167	TM 23641
8010	Woodbush Forest Station	30.0167	-23.7500	TM 29042
8011	Woodbush Forest Reserve	29.900	-23.8166	TM 3391
8012	Louis Trichardt	29.9200	-23.0300	W-M
8013	Letaba	31.5700	-23.8500	W-M
8014	Magoebaskloof	30.0000	-23.8667	TM 44636
8015	Lajuma Wetland	29.4228	-23.0356	W-M
8016	Old Farm Klipdraai	30.0833	-24.0500	TM 40763
8017	DeHoek Fores Reserve	30.0167	-23.8166	TM 42122

Appendix J: Details of *Myosorex longicaudatus* from Ditsong National Museum of Natural history, (formerly Transvaal) Museum used in Modeling

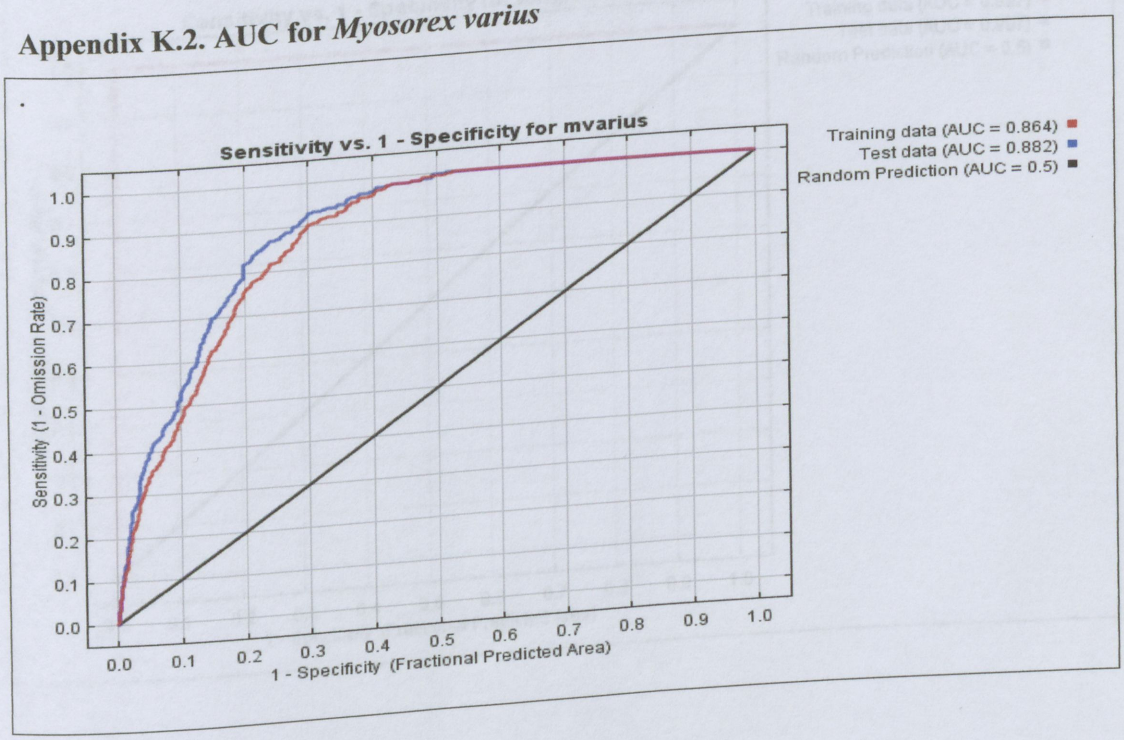
ID	Place name	Longitude	Latitude	Source
600	Knysna	23.5000	-34.0333	TM 917
601	Diepwwalle forest	23.1667	-33.9500	TM 26255
602	Lemoenshoek Boosmansbos	20.8833	-33.9333	TM 28683
603	Ruitersbos state forest	22.0333	-33.8833	TM 30953

Appendix K: Model Results for Area under Curve.

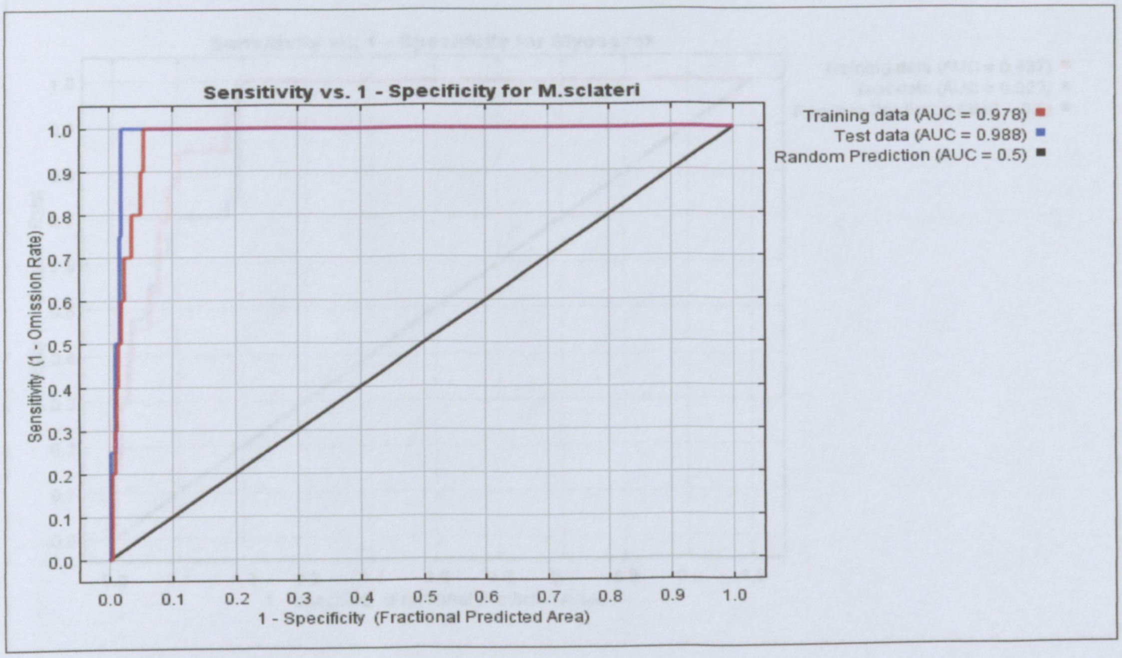
Appendix K.1. AUC for *Myosorex cafer.*



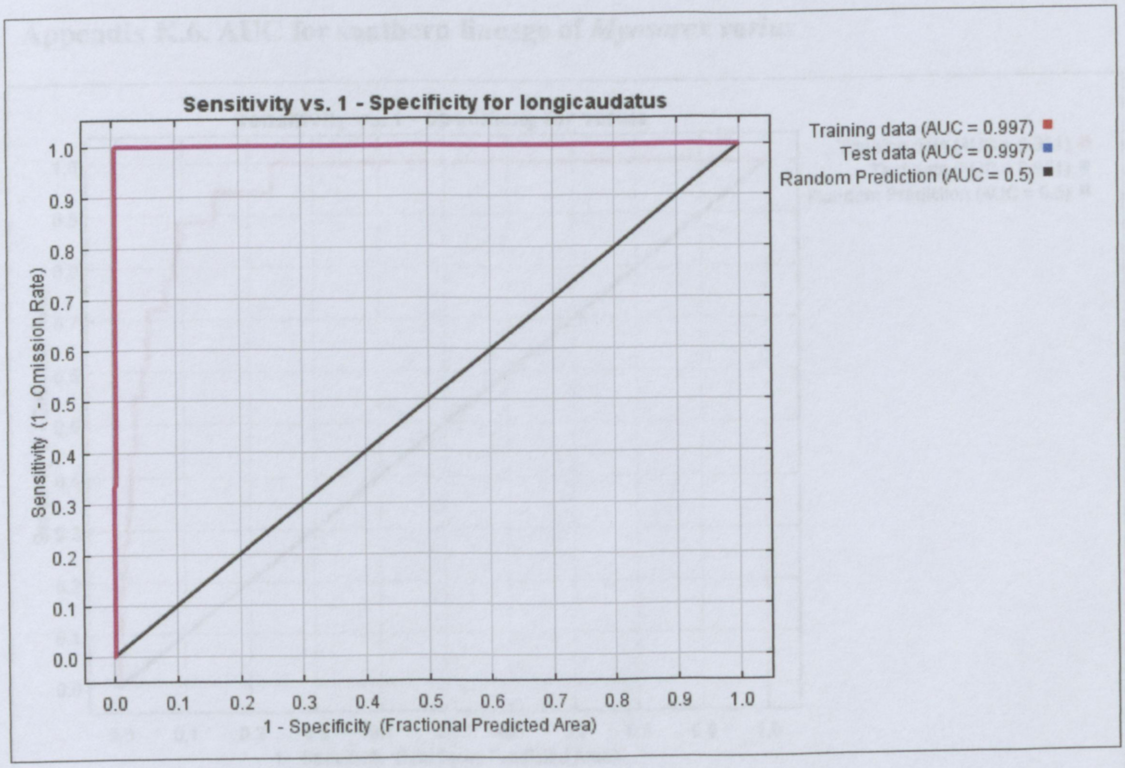
Appendix K.2. AUC for *Myosorex varius*



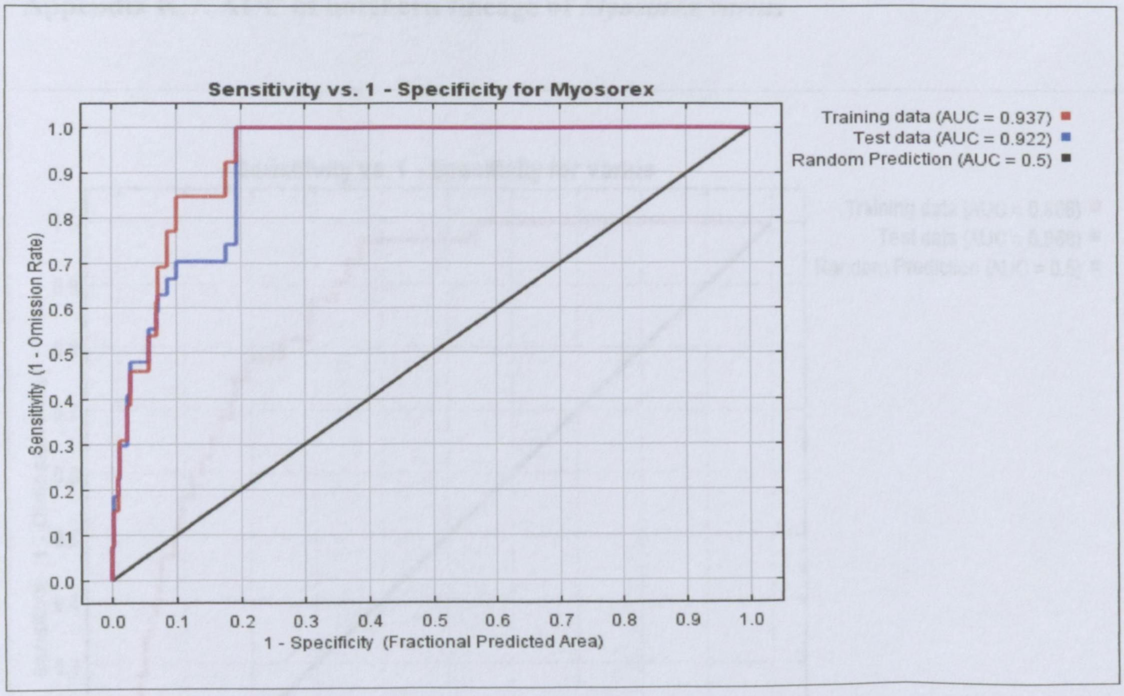
Appendix K.3. AUC for *Myosorex sclateri*



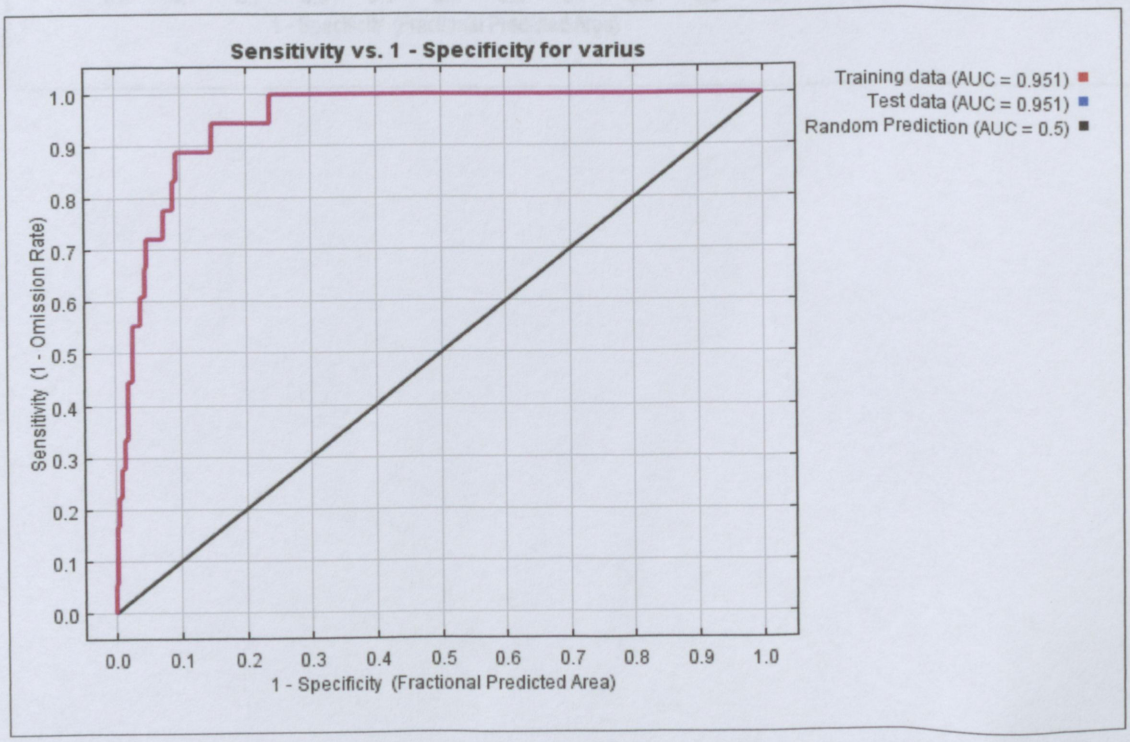
Appendix K.4. AUC for *Myosorex longicaudatus*



Appendix K.5. AUC for *Myosorex* from Limpopo Province



Appendix K.6. AUC for southern lineage of *Myosorex varius*



Appendix K.7. AUC of northern lineage of *Myosorex varius*