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Research Article

Modelling the Impacts of Climate Change on the Distribution of *Myosorex Varius* and its Genetic Lineages in South Africa, Lesotho and Swaziland

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Abstract: Climate change has been identified as one of the main drivers of biodiversity loss across the globe as it results in alteration of the species habitats. This study investigated the impacts of climate change on a generalist *Myosorex varius* and its genetic lineages endemic to South Africa, Lesotho and Swaziland. The work was based on the changes in climatic variables on the distribution of this species and its genetic lineages; southern and northern lineages in space and time. The current and future distributions of this species and its genetic lineages were determined by Ecological niche modelling using Maxent. Eight bioclimatic variables for current and future projected scenarios by the year 2070 together with locality data from Museums and publications were used to model the current and future distributions. Equal sensitivity and specificity threshold applied to get percentage decrease or increase in range. The current and the future distributions for this species and the lineages were compared to determine the range shifts, extinction risk and range differences. The model results for range shifts revealed that *M. varius* will suffer greater contractions (64.5%) while the northern and southern genetic lineages will suffer minimal (28.4% and 18.4%) range contractions respectively. *Myosorex varius* showed greatest contraction of suitable habitats, consequently, it will experience the highest risk of extinction as a result of global warming associated with climate change by the year 2070. This reveals that climate change is the main factor that affects the distributions of this species and its lineages in South Africa, Lesotho and Swaziland.
Keywords: climate change, *Myosorex varius*, ecological niche modelling, range shifts, extinction risks.

INTRODUCTION

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 [1]. Climatic variations are attributed mainly to natural processes while the observed climate change is due to anthropogenic causes. According to Intergovernmental Panel for Climate change, climate change is primarily caused by increased atmospheric concentration of greenhouse gases (GHGs), due to human activities[1].

Increased concentration of these gases would cause global warming accompanied by a shift in rainfall patterns. According to IPCC 2007 Third Assessment Report, climate change is already happening and will continue to happen even if global greenhouse gas emissions are curtailed significantly in short to medium term. Global increase in mean surface air temperature between 0.3°C and 0.6°C per decade has been experienced since about 1860. According to IPCC, temperature increase of 2-3ºC is likely to trigger substantial changes in biodiversity[1].

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 [2]. Climate change has been reported as a major driver of global biodiversity loss and has been linked to species level extinction [2,34], as it leads to diminishing of climatic suitable habitats and thus may lead to extinction risk [5]. Montane endemic species have limited capacity to shift their ranges across unsuitable habitat to other mountain ranges which could make them vulnerable to extinction due to climate change[6]. Species shift their ranges to suitable climatic environment because most species are adapted to a specific range of environmental conditions. These species are affected by many components of climate that alter these conditions such as rising mean temperature, variability in temperature and rainfall at various scales [6]. Temperature increase and rainfall decrease are the primary causes of habitat loss [7,8]. High temperatures reduce montane species range by forcing them to locate to the upper areas of the mountains and some species may be driven to local or global extinction[6,9]. Highland habitat and especially species that are vulnerable to high temperatures are at risk of extinction[10].

According to the National Climate Change Response White paper [11]), South Africa is vulnerable to impacts of climate change. Under emission scenarios it has been predicted that by 2050, the South African coast will warm by 1 to 2°C and the interior by 3°C. By 2100, warming is projected to reach 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.

The research investigated impacts of climate change on *Myosorex varius* and its lineages focusing on how climatic variables mainly; (temperature and rainfall) impact on species distributions currently and by the year 2070. *Myosorex varius* is a generalist species, widely distributed in most provinces of South Africa, Swaziland, and Lesotho [12]. There are two genetically distinct lineages of *M. varius* namely *M. varius* northern lineage and *M. varius* southern lineage[13]. The northern lineage is distributed within the summer rainfall, grassland and savannah biomes in Mpumalanga, KwaZulu-Natal, Eastern Cape provinces, Lesotho and Swaziland while the southern is distributed in winter rainfall in parts of Western and Eastern Cape provinces of South Africa [13]. *Myosorex varius* and its lineages are endemic to thick moist montane grass, along the river banks and the coastal regions [14].

MATERIALS AND METHODS

The study used modelling approach with two types of data. The model was made with current bioclimatic variables; predicted future climatic scenarios for the year 2070, together with presence data from museum records and published data. Maximum entropy (Maxent)[15] was employed to estimate the relationship between the values of the bioclimatic variables and the point locations defining a species geographic range. The research covered the whole of South Africa, Swaziland and Lesotho (Fig. 1). Swaziland and Lesotho were modelled as part of South Africa.

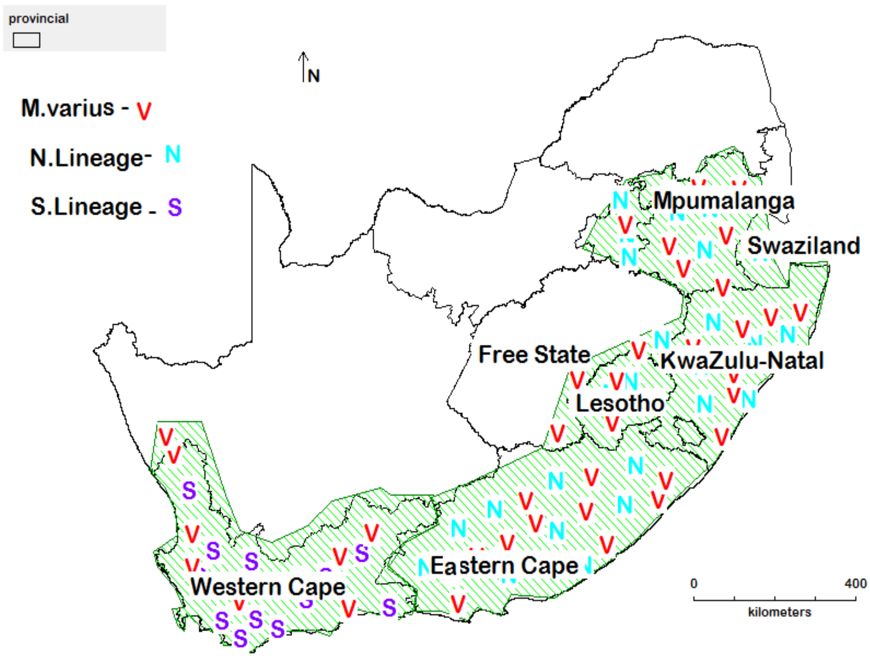

Fig-1: Study area showing locations of *M. varius* and its lineages.

Species presence data

Species presence data are the record localities of *Myosorex varius* specimens from several South African Museums. Data sources include the Ditsong Natural History Museum (formerly Transvaal Museum), Durban Natural Science Museum, Amathole Museum and published data.

Environmental predictor 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). The following were used, Temperature Seasonality (Bio 4); Maximum Temperature of the Warmest Month (Bio 5); Minimum Temperature of the Coldest Month (Bio 6); Annual Precipitation (Bio 12); Precipitation of the Wettest Month (Bio 13); Precipitation of the driest Month (Bio 14) and Precipitation Seasonality (Bio 15).

For future climate scenarios, the same eight bioclimatic variables for the year 2070 were obtained from the same website (http://www.climond.org). Global Change Model (GCM) scenarios with Resolution–10‘(approx 15 x 15 km), CliMond database [16] were used to model historical and future climatic surface. Scenario A2 emission was chosen as it is more radical and 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 high 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[17].

Maxent

Ecological niche modelling was applied to infer ecological requirements from prevailing environmental conditions at locations where species are known to occur and use that to predict areas with suitable habitat [18].

Maxent model version 3.3.3 k [19] was used in this study to model the distribution of *M. varius* and its lineages. 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. Maxent was used because it is the most accurate and popular method which is widely used in comparison with other approaches [18, 20, 21]. Maxent program is regularly updated to catch up with new capabilities and to carter for the increasing number of applicants and also to change the program defaults [21].

To run the model, Maxent was supplied with a file containing eight continuous environmental variables and all the variables were masked with the background which combined South Africa, Lesotho and Swaziland map and a file containing presence localities of *Myosore*x *varius* and its lineages in comma separated value file (csv) format as an input. The model was run 6 times and a total of 6 distribution maps were produced. The models were generated randomly with 70% of presence points as training data with remaining 30% used as testing data for *M. varius* and its lineages. Selection of features was carried out automatically following default rules depending on the number of presence records. Logistic output format was selected which yields continuous values ranging from 0 to 1 which indicate relative environmental suitability for the species [19]. A jackknife test was run to all the models to select variable contributing positively to model quality for species distribution.

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 overall occurrence that is independent of any particular threshold [22]. 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 [19]. 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 present [19]. 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.

Range shift analysis

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. A single Pixel at 10’resolution translates to approximately 18 x 18 km or 324 km square. The numbers of Pixels were counted to get the distribution of the current and projected future range and the percentage of contraction or expansion in range. The produced current and projected future by the year 2070 distribution maps were compared by using suitable and unsuitable habitats [23] to get range shifts. The areas experiencing decline in suitability are interpreted as contraction while the areas experiencing increase in suitability interpreted as expansion. This is based on the assumption that the current species climate relationship remains unchanged under changing climate [24].

RESULTS

Models results for training and testing data for the Area under the Curve

The results showed that all the models have good fit for the potential distribution for *M. varius* and the two lineages according to training data Area under the curve values (AUC) and test AUC. *Myosorex varius* southern lineage emerged with the best results of Area Un der the Curve training and test with 0.951 and 0.951; *M. varius* northern lineage 0.868 and 0.868; and *M. varius* 0.864 and 0.882 (Fig. 2). The ability of the model is assessed by comparing the AUC of ROC thus the AUC values represent a threshold independent measure of productivity[25]. AUC values provide an overall assessment of how well the model of each species predicts localities [25]. 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 [26].

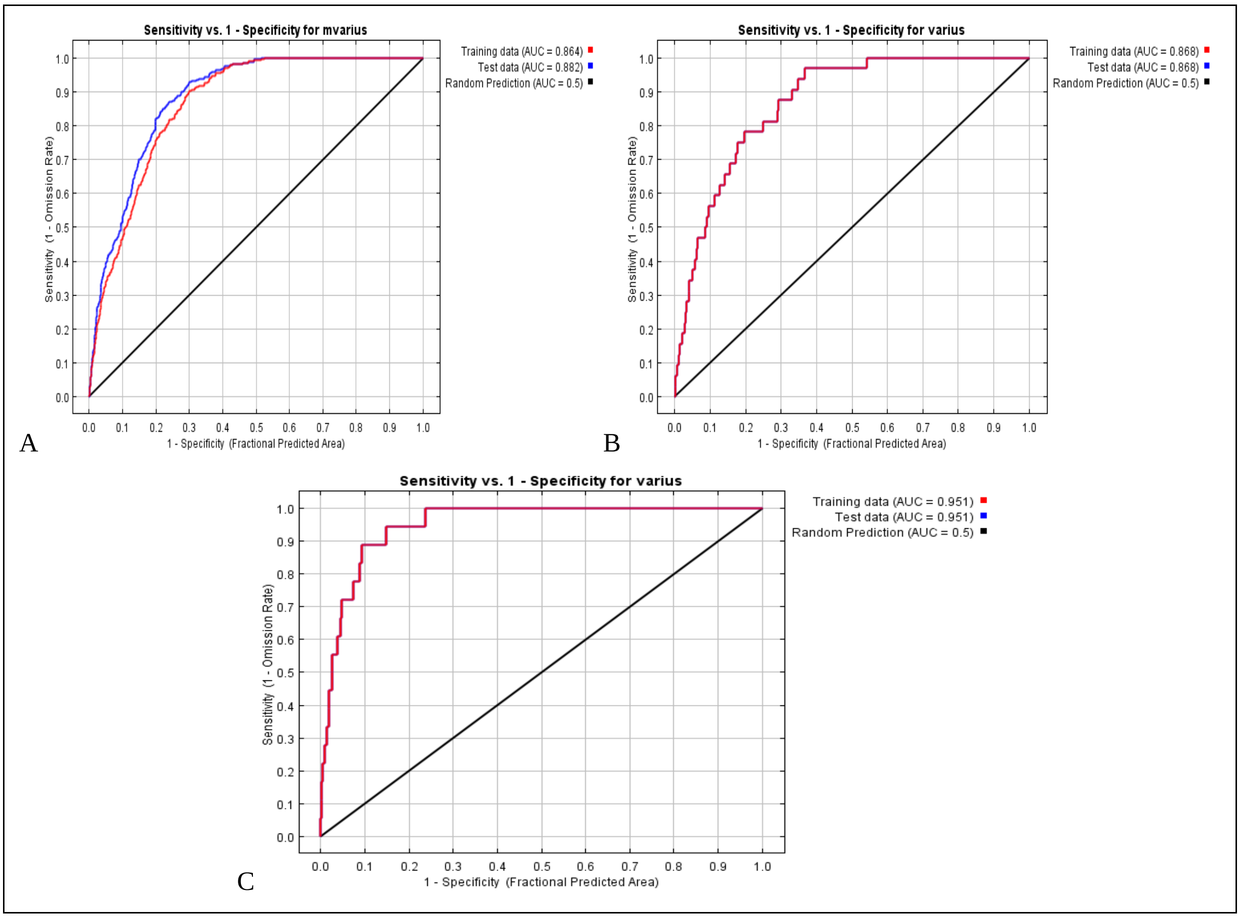

Fig-2: Results of AUC for *M. varius* (A), *M. variu*s northern lineage (B) and *M. varius* southern lineage (C).

Current and future range shift analysis

The results of Maxent models for *M. varius* and its lineages 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. A single pixel at 10'resolution translates to approximately 18 x 18 km or 324km^2

The current distribution of *M. varius* showed that suitable habitats are found in Swaziland a Lesotho and almost in all the provinces in South Africa except North West Province (Fig.3a). 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 64.5% in the case of the pixels with current high suitable habitats by the year 2070 (Fig. 3b). In the case of northern lineage, the predicted current map has high habitat suitability along the south eastern coastal and eastern part of the country, central Lesotho and western Swaziland (Fig. 4a). 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 a minimal contraction of 28.4% of the predicted current climatic suitable habitat by the year 2070 (Fig 4b). Shifting climate space may lead to limited suitable habitat which might lead to increase in extinction risks for this species. 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. 5a). Predicted current suitable habitat for this species covers a total of 766 pixels (248,184 km^2) of Western Cape Province. Future predicted map (Fig. 5b) 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 19.4% by the year 2070. Areas with suitable habitat will shift southwards along the coastal region.

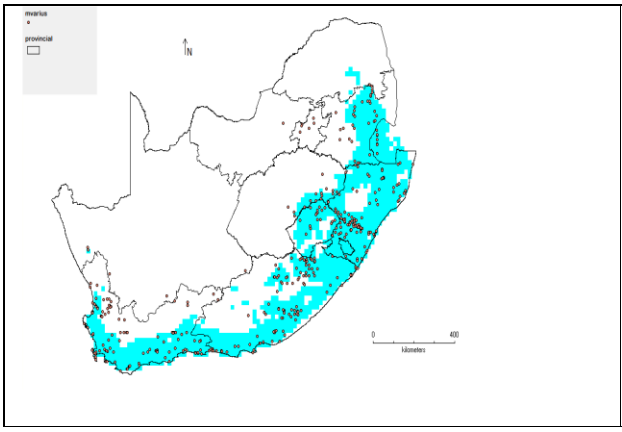

Fig-3a: Current distribution of *M. varius*

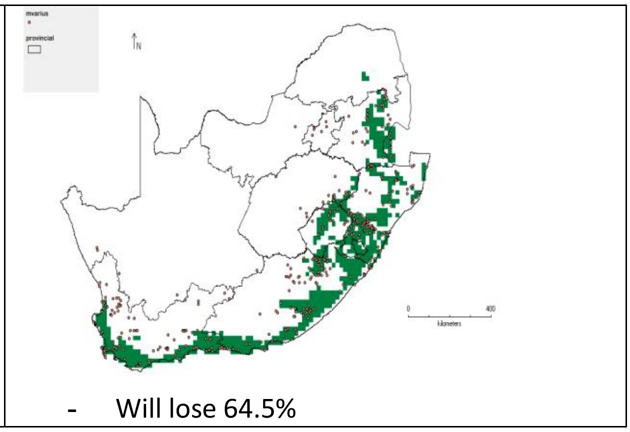

Fig-3b: Future distribution of *M. varius*-2070.

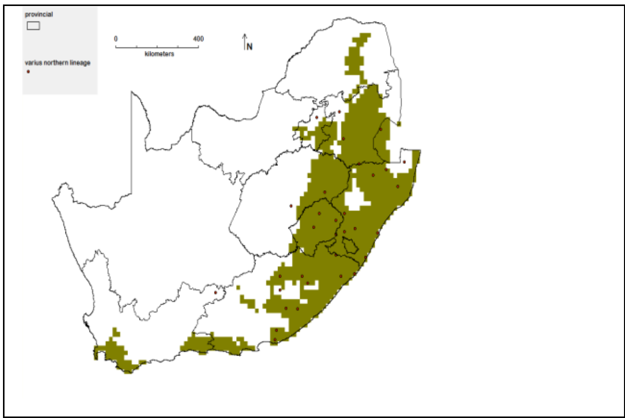

Fig-4a: Current distribution of northern lineage.

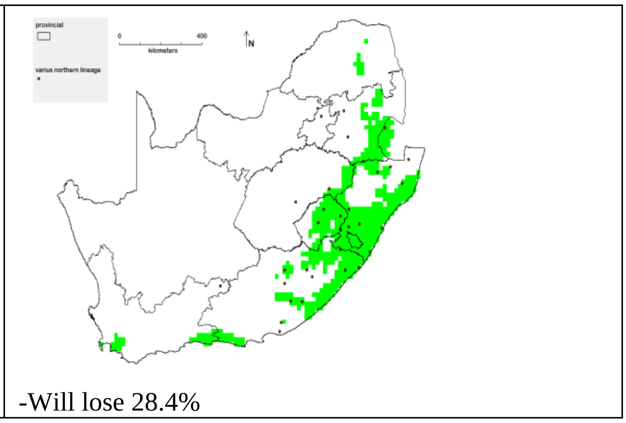

Fig-4b: Future distribution of northern lineage-2070

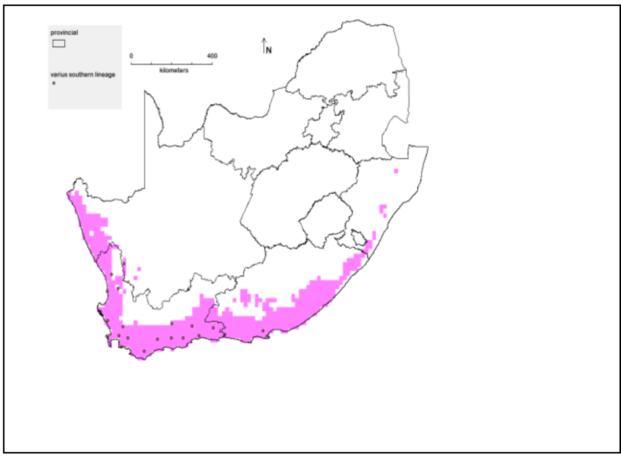

Fig-5a: Current distribution of southern Lineage.

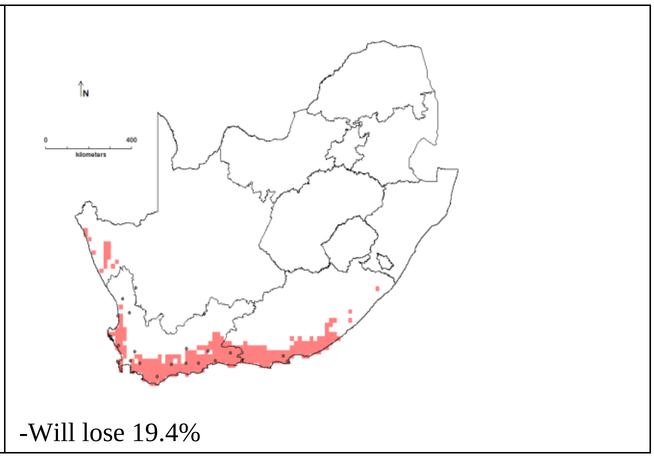

Fig-5b: Future distribution of distribution of southern lineage-2070.

DISCUSSION

Model accuracy

The model results showed that *M. varius* has the highest model AUC values. *M. varius* southern lineage has a higher AUC than *M. varius* northern lineage. This indicates that these lineages are varying in habitat preferences. All models in this study have high AUC value indicating that the models are accurate. According to Hernandez *et al.* [28], 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.

Current and future projection

The results from the distribution model showed that *M. varius* will have a greater decrease of the current climatic suitable habit by 64.5% whereas southern and northern lineage will suffer minimal contraction (19.4% and 28.4% respectively) by the year 2070. The model revealed also changes in the size and the location of suitable habitat within the distribution. The results is based on modelling assumption that the species can only remain in currently suitable habitat and will migrate to all suitable climatic areas in future [28]. 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 [28]. *Myosorex varius* and its lineages may not disperse to cells that will be suitable in future due to their low dispersal rate. This may lead to consequences of increase in extinction risk of *M. varius*. Greater decrease in the amount of high environmental suitability may increases the possibility of extinction risk of this species. Currently, this species in IUCN Redlist category 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 the existence of cryptic species as northern and southern lineage.

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 [27]. However, the result showed that both southern and northern lineage of *M. varius* will experience minimal range contraction in predicted current and future suitable habitat by the year 2070 (Figs. 2 and 3). This revealed that the impacts of climate change on the distribution of lineages may be less. The results revealed that these lineages will not have the same rate of impacts of climate change on their distributions.

CONCLUSION

Climate change is responsible for species range contraction and shifts**.** The results showed that future climate change is the main factor that will affect the distribution of *M. varius* and its lineages in South Africa, Lesotho and Swaziland. *Myosorex varius is* most vulnerable to climate change as it showed greatest contraction of current suitable habitats consequenly will experience the highest risk of extinction as a result of global warming associated with climate change by the year 2070. There are other non-climatic factors that were not included in the model such as biotic interaction, and dispersal abilities that may influence distribution [23, 26]. The result is important for conservation strategies and for revising the IUCN Redlist status of *M. varius*. *Myosorex varius* should be used as an indicator for climate change for all afro-montane *Myosorex* species in this region to assist the management and conservation in implementing strategies for conservation.

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