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SHORT COMMUNICATION

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Modelling the potential distribution of the common impala (*Aepyceros melampus melampus*) across Africa's changing climate

Simbai Mutematemi[1] | Henry Ndaimani[1] | Justice Muvengwi[2]

[1]Department of Geography, Geospatial Sciences and Earth Observation, University of Zimbabwe, Harare, Zimbabwe

[2]School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Johannesburg, South Africa

Correspondence
Justice Muvengwi, School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Private Bag 3, Johannesburg 2050, South Africa.
Email: justice.muvengwi@wits.ac.za; justicemuvengwi@gmail.com

Abstract

The common impala (*Aepyceros melampus melampus*), a medium-sized herbivore in Eastern and Southern African savannahs, faces challenges from climate change. Using a species distribution model, we found temperature of the driest quarter (30.32%) and wettest month precipitation (20.36%) as the most influential factors. Surprisingly, land cover change had less impact (0.25%). Projections suggest a significant habitat reduction for impalas by 2050, with estimated losses of 18.12% (SSP-126) and 25.62% (SSP-585). These findings highlight climate change and land cover alterations as potential threats to impala survival, impacting crucial resources like forage and water. This research guides conservation efforts for common impala.

Resume

L'impala commun (*Aepyceros melampus melampus*), herbivore de taille moyenne des savanes d'Afrique orientale et australe, connaît des difficultés liées au changement climatique. Grâce à un modèle de distribution des espèces, nous avons constaté que la température du trimestre le plus sec (30,32 %) et les précipitations du mois le plus humide (20,36 %) étaient les facteurs les plus influents. Fait surprenant, les modifications de l'occupation des sols ont eu moins d'impact (0,25 %) sur l'environnement. Selon les projections, l'habitat des impalas sera considérablement réduit d'ici 2050, avec des pertes estimées à 18,12 % (SSP-126) et 25,62 % (SSP-585). Ces résultats soulignent que le changement climatique et les modifications de l'occupation des sols constituent des menaces potentielles pour la survie de l'impala, car ils ont un impact sur des ressources cruciales telles que le fourrage et l'eau. Ces recherches orientent les efforts de conservation de l'impala commun.

1 | INTRODUCTION

Evidence of climate change has already been felt across the world. Climate change has started showing its impacts on plant and animal distribution (IPCC, 2022). Developing an understanding of how different species are going to be affected by climate change is one of the priorities in conservation. Species distribution modelling (SDM) has been shown to help predict habitat suitability under climate change (Gábor et al., 2022; Harishchandra et al., 2022). The utilisation of SDMs, which possess the capability to forecast the future distribution of species, presents conservation managers with a valuable tool to proactively tackle the adverse consequences of climate change. The SDMs are built on climate and gas emission scenarios to assess

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current and future spatial patterns of occurrence due to climate change (Rosentrater, 2010).

For a long time, SDM research has been intensified on, Near Threatened (NT), Vulnerable (VU), Endangered (EN) and Critically Endangered (CR) species, while there is less interest in species that are regarded as of least concern. This bias in research efforts has led to a lack of preparedness in conservation of least concern species and calls for more work. Indeed, it becomes especially significant in the Anthropocene era, where changes in the abundance of dominant species can serve as an early warning sign for future shifts within communities and ecosystems (Pau & Dee, 2016). The projected increase in anthropogenic global temperatures by 2°C by the end of the century threatens various species, including those currently considered of least concern by the IUCN (IPCC, 2022).

The common Impala (*Aepyceros melampus melampus*), a medium-sized antelope, serves as an indicator species due to its central role in food chains (Mramba, 2021) and is considered as a least concern species under the IUCN red list. The conversion of natural habitats into agricultural land in Africa raises concerns about the extent to which this is going to impact species distribution (Dejene et al., 2021). To address these challenges, SDM is used to forecast changes in species distribution and map suitable habitats (Dejene et al., 2021; Guisan et al., 2017; Zurell, 2020). Thus, in this study, we aim to assess the potential changes in the suitable habitat and range of the common impala under future climate change scenarios. Specifically, we investigate two contrasting scenarios (reduced emissions: SSP-126 and high greenhouse gas emissions: SSP-585) to determine the extent of range decline by 2050.

Based on the known sensitivity of species distributions to climate and the projected changes in bioclimatic variables (Barbet-Massin et al., 2012; Hijmans & Elith, 2013), we predict that the potential distribution of the common impala will undergo significant declines in its range. By examining these changes, this research provides valuable insights into the potential consequences of climate change on the distribution of the common impala in Africa, aiding in the development of effective conservation strategies in the face of future environmental challenges.

2 | METHODS AND MATERIALS

2.1 | Collection of presence data

Presence-only records of common impala were downloaded from the Global Diversity Information Facility (GBIF; www.gbif.org/, accessed 25 July 2023). We downloaded only human observations and cleaned the data ($n = 3627$ records) by applying the following criteria: records collected over 10 years ago, data with location accuracy >20 km, as our raster resolution was 20 km, and records without location name (Country and/or Province name) and date of identification were excluded. Subsequently, we performed additional processing in ArcGIS 3.0.1 to eliminate duplicates, and further applied thinning

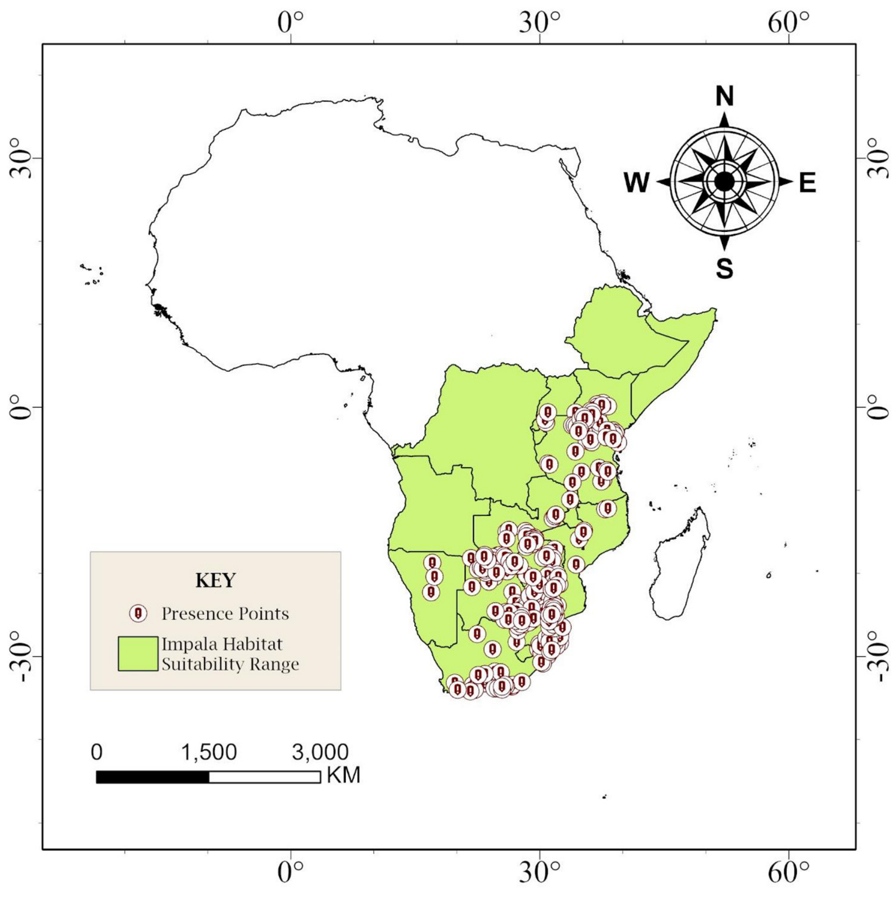

FIGURE 1 Distribution of calibration presence ($n = 310$) and generated absence ($n = 515$) points for species distribution model development.

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to ensure a minimum distance of 20 km between all data points to avoid spatial autocorrelation. After data cleaning, 298 presence-only records were used to build the models predicting the potential distribution of impalas. A set of 300 pseudo-absence points was generated using random sampling (Figure 1; Barbet-Massin et al., 2012; Hijmans & Elith, 2013).

2.2 | Environmental variables

The model utilised bioclimatic data from the WorldClim database (http://www.worldclim.org, accessed 15 June 2023) for both current and future analyses. In addition to the bioclimatic variables, we used 1 km^2 resolution land cover change (LC) data for near-present (year = 2010) and A2 future (year = 2050) scenarios from http://geosimulation.cn/GlobalLLUCCProduct.html. The variables were evaluated for multi-collinearity using variance inflation factors (VIFs). VIF values with Pearson's $|r| > 0.7$ suggested a multi-collinearity problem, so they were excluded from the model. Only nine of the 20 variables did not pose the multi-collinearity problem (Table S1), and these were used to build the SDMs for impala.

2.3 | Species distribution model

Our modelling structure was constructed using four SDM algorithms from the R package *Biomod2*, as described by Thuiller et al. (2021). We used an ensemble model to combine the predictions of four different algorithms: generalised linear model (GLM), Multivariate Adaptive Regression Splines (MARS), random forest (RF) and boosted regression tree (GBM). This approach is supported by previous studies using ensemble GLM, FDA, MARS and RF models for flood and erosion susceptibility mapping (Mosavi et al., 2020). We selected 70% of the sample for the calibration of models and the remaining 30% of the sample for model validation.

We assessed the accuracy of our model using several statistical measures, including Cohen's Kappa (Kappa) value and True Skill Statistic (TSS). Kappa and TSS values ranging from 0.8 to 1 indicate excellent model performance (Thuiller et al., 2010). The importance of a variable was determined by measuring the decrease in model accuracy when that variable was shuffled (Kwon et al., 2018). A higher value signifies a more significant influence of the variable on the model.

2.4 | Species range change

The change in species range size was quantified using the BIOMOD_RangeSize function in *Biomod2* package using the following equation (Thuiller et al., 2021):

$$\text{proj.future} - 2 \times \text{proj.current} \quad (1)$$

The resulting output from this function comprises four distinct categories: (1) areas predicted to be lost, (2) areas predicted to remain occupied, (3) areas predicted to remain unoccupied and (4) areas predicted to be gained.

3 | RESULTS

3.1 | Potential distribution of the common impala

3.1.1 | Model performance

As we modelled the potential distribution of the common impala in Africa, all the models performed well as they had Kappa and TSS values greater than 0.65. The Kappa score for GLM and MARS were the lowest of the four models; therefore, the two models were excluded from the ensemble model (Figure S1). RF and GBM were finally incorporated for modelling the potential distribution of common impala using climate variables because they exhibited excellent model performance according to their TSS and Kappa values (Figure S1).

3.1.2 | Variable importance

The mean temperature of the driest quarter (Bio 9) contributed most to the ensemble model (30.32%), followed by the precipitation during the wettest month (Bio13: 20.36%) and precipitation of the warmest month (Bio 18: 13.70%; Figure S1).

The predicted habitat suitability for the common impala under current climate and environmental conditions shows that areas of high suitability are present in Angola, Zimbabwe, South Africa and Zambia though the species is found in East and Southern Africa (Figure 2).

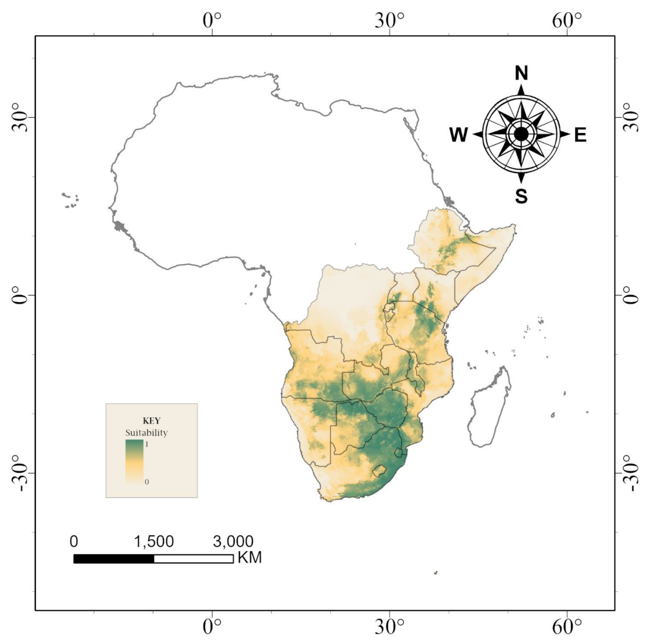

FIGURE 2 The predicted habitat suitability for common impala under current climate and land cover conditions.

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3.2 | Future distribution under climate change scenarios

The findings indicate that under SSP-126 and SSP-585 scenarios, the unsuitable area for common impala is projected to increase by 8.16% and 7.72%, respectively by 2050 (Table 1, Figure 3c,d). For the year 2050, the projected suitable area for common impala was predicted to be lost by 18.12% and 25.62% under both SSP-126 and SSP-585 scenarios, respectively (Table 1, Figure 3c,d). For both climate change scenarios (SSP-126 and SSP-585) for 2050, the suitable area for common impala potential distribution was predicted to decrease in Southern and East Africa.

TABLE 1 Suitability changes the percentage of the total change between current climate conditions and climate change scenarios (SSP-126 and SSP-585) for the year 2050.

Scenario	Gain (%)	Loss (%)	Range change
SSP-126	8.99	23.39	−14.41
SSP-585	8.11	31.41	−23.30

4 | DISCUSSION

Our research findings confirmed our prediction that the habitat suitable for impala is going to decline. The modelling technique proved effective, with RF and GBM (Boosted Regression Trees) models performing exceptionally well. Findings further demonstrate that climate change (Thuiller et al., 2005) and human interference through land

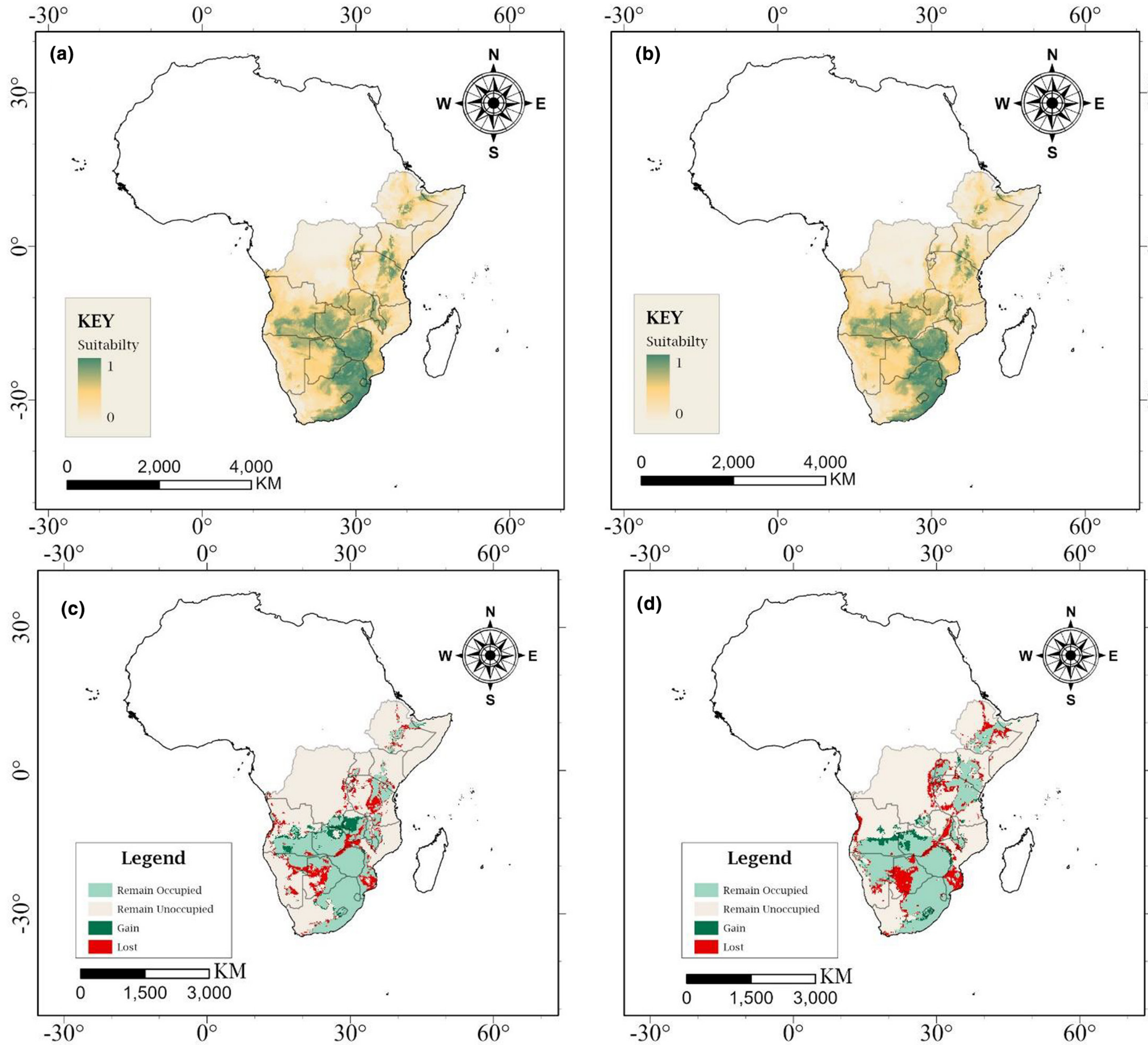

FIGURE 3 Projected change in common impala habitat suitability by 2050 under (a) SSP-126, (b) SSP-585 climate change scenarios and land cover, and the projected range size change by the year 2050, considering both the (c) SSP-126 and (d) SSP-585 climate change scenarios, in conjunction with the influence of land cover change.

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cover changes are indeed the primary drivers of habitat loss for the Impala population. The results from this study showed that the current potential distribution of the common impala spans across multiple African countries. Future projections, however, indicate a decrease in suitable habitats by 2050 under both SSP-126 and SSP-585 climate change scenarios. This is alarming, as these scenarios represent a range of potential global greenhouse gas emissions (Riahi et al., 2017).

Our study revealed a substantial reduction in suitable habitats for common impala due to increasing temperatures, particularly influenced by the global mean temperature of the driest quarter (Figure S2). These findings align with previous research that indicates a positive correlation between hot, dry months and higher lamb mortality rates, suggesting a scarcity of food and water (Ogutu, 2012). Moreover, female impalas experience elevated mortality rates during hot, wet seasons, likely due to increased vulnerability to diseases and pathogens in humid and warm conditions (Ogutu, 2012). The projected future temperature increases are anticipated to exacerbate the frequency and intensity of extreme weather events, such as droughts and wildfires, further endangering the distribution of common impala (IPCC, 2022). Changes in precipitation patterns, particularly an increase in global droughts, may significantly impact forage availability and consequently the suitable habitat for the common impala in sub-Saharan Africa (Ayebare et al., 2018). Additionally, our study highlights the critical role of land cover changes in shaping the distribution of common impala. These results align with studies by Midgley et al. (2002) and Thuiller et al. (2006) which also forecast a decrease in suitable habitat for African fauna due to climate change. The loss and alteration of natural habitats have been widely recognised as leading causes of biodiversity loss (Foley et al., 2005). Habitat degradation resulting from land use alterations reduces forage availability and disrupts migratory corridors, adversely affecting impala and other migratory species (Beier & Loe, 1992; Bender et al., 1998; Kitina Nyamasyo & Odiara Kihima, 2014; Maitima et al., 2009).

The findings of this study hold significant implications for conservation strategies. Firstly, they highlight the need for proactive, climate change-informed conservation planning. Secondly, they underscore the importance of transboundary conservation efforts, given the cross-country distribution of the common impala's suitable habitats.

4.1 | Limitations of the study

We used data from GBIF, which might not have exhaustive occurrence records. Furthermore, our model does not account for biotic interactions and historical factors that may have affected the impala distribution.

5 | CONCLUSION

This study estimates the habitat suitability for common impala under both current and future climates using SDMs. Common impala population is affected by a change in temperature and precipitation changes, which may lead to population decline due to a reduction in suitable habitat. Our study proves that not only endangered species will become a victim of climate change, but also species that fall on the IUCN least concern species list will be affected by climate change.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this study.

DATA AVAILABILITY STATEMENT

Data are available on request from the authors.

ORCID

Henry Ndaimani https://orcid.org/0000-0002-8237-8140
Justice Muvengwi https://orcid.org/0000-0001-9117-1865

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