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Conservation implications of mapping the potential distribution of an Ethiopian endemic versatile medicinal plant, Echinops kebericho Mesfin.

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Abstract

Herbal medicines have served as remedies for both human and livestock ailments for ages. This is continued to be so in developing countries such as Ethiopia where about 80% of the population are still dependent on traditional medicines. However, immense anthropogenic pressure is posing a threat on these invaluable resources. *Echinops kebericho* is a narrow range multipurpose medicinal plant confined to Ethiopia and known for its efficacy to cure several disease such as epilepsy, epistaxis and atrophy. Extracts from *E. kebercho* has antibacterial and anti-leshmanial activities as well as several agricultural and veterinary applications. Currently, intense land use and overharvesting for traditional medicine have resulted in its narrow distributions and *E. kebercho* is among the medicinal plants of Ethiopia with a decreasing population trend. Here we aim to map its potential distribution, which is key to guide conservation efforts and sustainable use. We modeled the potential distribution of this multipurpose medicinal plant using maximum entropy model (MaxEnt) employing twenty-one predictor variables by calibrating the model at two complexity levels and replicating each model 10 times using a cross validation technique. We projected the models into the whole of Ethiopia and produced binary presence-absence maps by splitting the average map from both complexity levels applying three threshold criteria and ensembling the resulting maps into one for the final result. We mapped suitable habitat predicted with high certainty and identified local districts where *E. kebericho* can be cultivated or introduced to enhance its conservation. We estimated that *E.kebercho* has about 137,925 km^2 of suitable habitat, mainly concentrated in the western highlands of the Ethiopian mountains. Our models at both complexity levels had high average performances, AUC values of 0.925 for the complex model and 0.907 for the simpler model. Although *E. kebericho* is locally confined, our models predict that, it has a remarkably wider potential distribution area. We recommend introducing *E. kebericho* to these areas to improve its conservation status and tap its multiple benefits on a sustainable basis. Locally confined threatened plants and animals likely have wider potential distributions than their realized niche and thus similar methodology can be applied for their conservation.

1. Introduction

Biodiversity loss is taking place at an alarming rate, and its concern is currently on top of the global agenda. This is particularly the case in the less developed tropical countries where the majority of the population depends on nature to meet their basic needs (Fedele et al., 2021). Causes of biodiversity loss include land use change, habitat fragmentation, overexploitation, pollution, invasive species, and climate change (Fahrig, 2003; Newbold, 2018; Waldron et al., 2017; Watson et al., 2005; Wilson et al., 2016). Several species are facing extinction as a consequence of this anthropogenic activity (Tilman et al., 2017).

Anthropogenic driven extinction rate during the past 500 years is estimated to be up to 50-fold higher than the natural rate (Barnosky et al., 2011). Over the past 10,000 years, 50% of the ice-free terrestrial surface has been modified by humans (Lambin et al., 2003). This change in land use has highly impacted biodiversity, ecosystem functions and service provisions (García-Vega & Newbold, 2020;

Koellner et al., 2013; Wilson et al., 2016). Land cover land use change affect biodiversity at ecosystem, species, population and gene levels (Baan et al., 2013; Groot et al., 2012).

Exploitation of resources at faster rate than their natural regeneration is becoming the most common challenge of the anthropocene (Hoffmann et al., 2014; Souza & Prevedello, 2020). Overexploitation for different purposes such as for household consumption, trade, recreation and subsistence is one of the factors behind quite large number of the species that are currently listed as threatened or near-threatened in the IUCN red list (Maxwell et al., 2016). Overexploitation decreases population density directly by reducing the number of individuals (Burgess et al., 2017), and it may have indirect impacts by decreasing reproduction (Pillay et al., 2018). It may reduce long-term population viability for these reasons resulting in extinction of populations at different scales (Mora et al., 2007).

Climate change is another factor that results in biodiversity loss causing species range shifts (Scarano & Ceotto, 2015) and redistribution of life on earth (Pecl et al., 2017). Different species have different rate of range shifts in response to climate change and the majority of the species lag behind the shifting climatic zones (Lenoir et al., 2020). This is affecting species assemblage at local and global scales jeopardizing species interactions and deteriorated ecosystem functions and its ability to provide societies with goods and services (Pecl et al., 2017). Though not well studied, the impact of climate change in Africa may be higher when compared with the other parts of the world (Chala et al., 2016; Davis et al., 2019; Malhi et al., 2013; Peters et al., 2019).

Human activity is expected to continue worsening and posing the major threats to African biodiversity (Midgley & Bond, 2015; Sala et al., 2000). Projected population rise and economic growth are expected to exacerbate the loss of biodiversity and put many more species at risk of extinction worldwide (Tilman et al., 2017). Recent studies over a wide geographic scale show that a third of the tropical African flora is potentially threatened with extinction whereas another one third of the species are likely rare, potentially becoming threatened in the near future (Stévart et al., 2019). This calls for the need of immediate intervention.

To mitigate or minimize threats to global biodiversity, greater conservation efforts, as well as dedicated measures such as changes in agricultural practices and better land-use plannings are highly required (Balmford & Bond, 2005; IPCC, 2014). The International Union for the Conservation of Nature's Red List of Threatened Species predicts that 4161 different kinds of species are threatened by climate change, 33% are at risk from climate change-induced habitat shifts and alteration, and 29% are at risk due to drought (Warmenbol & Smith, 2018). Species that need high conservation priority are identified based on the level of threats that is posed on them (Wilson et al., 2016).

E. kebercho is a multipurpose traditional medicinal plant confined to Ethiopia in distribution (Tadesse, 2004; Fig. 1). It is used to treat various infectious diseases, and bioactive extracts of *E. kebericho* have antibacterial activities (Deyno et al., 2021; Fikadu & Melesse, 2014; Tariku & Kebede, 2011; Toma et al., 2015). The extracts of its rootstock cure epilepsy, epistaxis, atrophy, and sudden sickness (Maryo et al., 2015), exhibit high anti-leishmanial activity (Tariku et al., 2011) and can be used to control insect pests of

medical, veterinary, and agricultural values (Hussien et al., 2011). The rootstock of this species is sold in markets in different parts of Ethiopia (Regassa, 2013). Overharvesting and land use change have reduced local populations, inducing local extinctions (Fikadu & Melesse, 2014). The use of roots for traditional medicine is the major cause of the decline of populations compared to the uses of other parts of the plant (Aschale et al., 2018; Gebeyehu et al., 2014; Ragunathan & Abay, 2009). Deforestation (Vivero et al., 2006) and agricultural expansion (Behailu & Temesgen, 2017) are also resulting in diminishing status of local populations of medicinal plants as a whole. This species has been assessed as near threatened (Darbyshire et al., 2021) and was also undergoing local extinctions in its native range.

Mapping the distributions of potential suitable habitats of *E. kebericho* is important for its conservation. Endemic and threatened plant species are critical components of plant biodiversity, and their long-term survival requires immediate human intervention (Bahadur et al., 2015). Predicting and mapping potential suitable habitat for threatened and endangered species is crucial for tracking and conserving declining native populations in their natural habitat (Balmford & Bond, 2005). However, data on the distribution of threatened and endangered species is most often missing (Elith et al., 2006; Engler et al., 2004).

Species distribution modeling tools are gaining popularity in ecology and are being used in many ecological applications (Elith et al., 2006; Peterson, 2008). It is used in conservation biology (e.g., (Gebremedhin et al., 2021; Warren et al., 2014), epidemiology (Cardoso-Leite et al., 2014), invasion biology(Palaoro et al., 2013) and in several fields of biology such as evolution (Chala et al., 2016, 2019; Schmidt-Lebuhn et al., 2015). It is used to understand the relationship between species and their environment and to predict their actual and potential distributions. Various species distribution modeling methods are available with different performances and data type requirements (Elith et al., 2006; Guisan et al., 2007; Guisan & Zimmermann, 2000; Kumar & Stohlgren, 2009). MaxEnt is among the top performing algorithms and it uses presence-only occurrence data (Phillips & Dudík, 2008).

For rare and endangered plant species, relatively few predictive models have been used (Engler et al., 2004). Here we model and quantify the potential suitable habitats of *E.kebericho* in Ethiopia and map areas where it can be cultivated for conservation and medicinal uses.

2. Methods

2.1 Occurrence data

We used 49 occurrence data from three data sources: from the National Herbarium of Ethiopia (11), from our own collections (34) and from Global Biodiversity Information Facility (GBIF.org, 2021; Fig. 2). We additionally generated 10,000 random points in the study area to serve as random pseudoabsence points (see the detail under 2.3).

2.2 Environmental variables

A total of 21 predictor variables (19 bioclimatic variables plus topographic position index and solar radiation index) were used. The bioclimatic variables were obtained from the WorldClim database(Fick & Hijmans, 2017) at 30 arc seconds (~ 1 km) resolution. The topographic data were acquired from www.gscloud.cn using Aster DEM (space-borne thermal emission and reflection radiometer Digital Elevation Model. The solar radiation (SR) data was taken from https://www.worldclim.org/. Topographic variables have a substantial impact on natural resource distribution by restricting hydrological cycle and soil moisture content (Loritz et al., 2019; Mukherjee et al., 2013). Solar radiation, is hypothetically proportional to the amount of direct solar radiation reaching the earth's surface varying along altitude, aspect, slope, and latitude (Keating et al., 2007). Prior to running the models, the multicollinearity of the predictor variables was checked by using pairwise Pearsons correlations. From those variables with a correlation of $r \geq 0.7$, only one variable was selected based on assumed biological importance(Chala et al., 2016; F. Dormann et al., 2007; Kumar & Stohlgren, 2009; Yang et al., 2013a; Table S1). For the final model runs, we retained eleven predictor variables: Bio-1 (annual mean temperature), Bio-3 (isothermally), Bio-4 (temperature seasonality), Bio-7 (temperature annual range), Bio-11 (mean temperature of the coldest quarter), Bio-15 (precipitation seasonality), Bio-17 (precipitation of the driest quarter), Bio-18 (precipitation of the warmest quarter), Bio-19 (precipitation of the coldest quarter), solar radiation index, and topographic position index.

2.3 Modeling procedure

We used Maximum Entropy (MaxEnt) algorithm version 3.4.1(Phillips et al., 2006) to model the potential distribution of *E. kebericho*. The MaxEnt algorithm is one of the best performing algorithms and predicts the possible ranges of species by determining the distribution of maximum entropy.(Peterson, 2008; Phillips et al., 2006). MaxEnt is especially useful for species with limited presence data where false absence in surveys poses a significant risk (Bosso et al., 2013; Vasconcelos et al., 2012). However, its default setting is presented as a complex and its performance may vary with model complexity levels(Halvorsen et al., 2016). Thus, we run the model at two complexity levels (one simple and one complex) to account for this. The complex model was built by setting the regularization multiplier to default (which is 1) and the simpler version built by setting regularization multiplier to 8 (Chala et al., 2016). We used the selected environmental variables along with the random pseudoabsence and presence points in the model by settings the maximum iterations to 500. We run both the simple and complex models 10 times by sub setting the occurrence data and the randomly generated absence points into 10 using cross validation approach. While 9/10 of the subset of the occurrence data were used for model training, the remaining 1/10 was used for model validation at each turn. We used the average result from these 10 runs for reporting. We validated all model runs using the area under ROC curve (AUC). From the final map, we produced binary presence/absence (suitable/unsuitable) maps using three thresholding techniques: 10 percent presence or by omitting the least probabilities values at 10 percent of the presence points; maximum sum training sensitivity plus specifity or the probability values that maximizes the sum of the fraction of correctly predicted presences (sensitivity) and the fraction of correctly predicted absences (specificity) and Maximum sum test sensitivity plus spesficity or a maximum specificity and sensitivity computed on the test data. This means we produced six binary

maps as the three thresholding criteria are applied for both model complexity levels. We overlaid the six binary maps and further classified them into three classes based on the agreements in the number of pixels predicting habitat suitability (Chala et al., 2016b): unsuitable – when 0–30% (one in six) maps predicts habitat suitability; uncertain - when 30–60% (two to three) maps predicts suitability and suitable with certainty - when > 60% (four to six) binary maps predict suitability (Figure.6). A Jackknife analysis was used to determine variable importance's. We overlaid the areas predicted with high certainty with local districts to identify areas where *E. kebericho* can be cultivated for medicinal uses and also to provide practical guide for conservation scientists.

3 Results

3.1 Model performance and variable importance

Both simple and complex models had high performances, AUC values of 0.907 and 0.925, respectively. (Figure.2). The AUC standard deviation among the ten models runs was 0.040 for the complex model and 0.046 for the simple model.

The variable importance computed on a test data indicates that the distribution of *E. kebericho* was mainly influenced by solar radiation, mean temperature of the coldest quarter, precipitation of the coldest quarter, and annual mean temperature contributing 42.5%, 30%, 9.9%, and 6.4%, respectively, to the Maxent model regularization 1 (Table 1). The contributions of these variables to the simple model is a bit different in magnitude but of the same respective order of importance. These variables also have higher permutation importance's.

Table 1
Estimate of average contribution and permutation importance of the environmental variables used in MaxEnt modeling of *Echnops kebericho* (%c = percent contribution and PI = permutation importance) under regularization multiplier 1and 8.

Variables	*Regularization multiplier1.*		*Regularization multiplier 8.*	
	Current		*Current*	
	%C	*PI*	*%C*	*PI*
Annual mean temperature (Bio-1)	*6.4*	9.2	*5.5*	*14.8*
Isothermality (Bio-3)	*1.3*	0.9	*3*	*3.4*
Temperature seasonality (Bio-4)	*1*	17.5	*2.1*	*0.8*
Temperature annual range (Bio-07)	*0.1*	0.9	*0*	*0*
Mean temperature of coldest quarter (Bio-11)	*30*	44.3	*17.1*	*1.9*
Precipitation seasonality (Bio-15)	*0.9*	1.3	*0*	*0*
Precipitation of driest quarter (Bio-17)	*2.7*	0.1	*0*	*0*
Precipitation of warmest quarter (Bio-18)	*2*	1.4	*0.2*	*0*
Precipitation of coldest quarter (Bio-19)	*9.9*	2.8	*8.2*	*5.6*
Solar radiation (Sri)	*42.5*	18.4	*63.3*	*71.5*
Topographic index(tpi)	*6.4*	9.2	*0.7*	*2*

3.2 Potential habitat distribution of E. kebericho

Models of both complexity levels at all the three threshold probability cut-off points consistently showed that the potential suitable habitat of *E. kebericho* is found on the western massifs of Ethiopian highlands (Figs. 3 & 5). The potential distribution patterns didn't show remarkable variations between model complexity levels and among the cutoff thresholds (Fig. 3). However, the simpler model captured a broader distribution area except when the MSSTest threshold is used (Figs. 3 & 4).

From the 10th percentile threshold map (Fig. 5), we identified 139,378.54 km^2 and 207,684.49 km^2 as the suitable geographical distribution of *E. kebericho* at regularization multipliers 1 and 8, respectively. We identified 145,866.14 km^2 and 131,343.49 km^2 as representing the suitable geographical distribution for *E. kebericho* at regularization multipliers 1 and 8, respectively, using the maximum training sensitivity plus specificity threshold map (Fig. 4). Similarly, using maximum test sensitivity plus specificity, we identified 137,506.21 km^2 and 180,159.56 km^2 of the Ethiopian territory as having a suitable geographical distribution for *E. kebericho* at regularization multipliers 1 and 8, respectively (Fig. 4). Assembling the maps showed a total of 132,894.574 km^2 of land in Ethiopia is found to be suitable with

high certainty (Fig. 5). Areas predicted with high certainty are mainly located on the western Ethiopian massifs (Figs. 5 & 6).

4 Discussion

This is the first study to look at the potential suitable habitats of the highly important medicinal plant, *E. kebericho*, which is known for its efficacy to cure several human ailments in Ethiopia where health facilities are not fulfilled. Our findings have significant implications for its conservation and management so that the local communities continue to benefit from it.

Our results indicate that the predicted suitable habitats of *E. kebericho* mainly concentrates on the western Ethiopian massifs, while habitat suitability is generally lower on the eastern part except in some mountainous areas (Fig. 5). Most of the occurrence data we used from modelling were obtained from the western Ethiopian massifs which is congruent to the predicted suitable areas and the distribution areas of *E. kebericho* described in the Flora of Ethiopia and Eritrea (FEE; Tadesse, 2004). However, the predicted suitable habitats cover much wider areas than the areas that are mentioned in the flora. While *E. kerbricho* is described only from three flora regions, Shoa, Gojam and Tigray in FEE (Tadesse, 2004), we show that Wallega, Kaffa, Illubabor, Arsi and Bale highlands are also suitable to *E. kebericho* (Figs. 5 &. S1). This shows there is a mismatch between the actual and potential distributions of *E. kebericho* which is of conservation importance. Particularly high suitability within the western Ethiopian massif confirms the significance of the area to conserve this versatile medicinal plant.

The models run at both complexity levels had high performances and also showed less variations from one run to the other. For species with small sample size or small number of occurrence points simple models are recommended (Merow et al., 2014). We had minor deviation in AUC values for both simple and complex models, standard deviation that ranges from 0.04–0.046, showing the reliability of the occurrence data we used though it was small in size. Consistence with this, the differences among the binary maps and the uncertainty in the final assembled is map was also minor.

Results from our model runs indicated that the distribution of *E. kebericho* was more influenced by precipitation of coldest quarter, solar radiation and two temperature variables (annual mean temperature and mean temperature of the coldest quarter). Solar radiation played a key role in determining the distribution of potential habitats for *E. kebericho*. Precipitation also played a key role in influencing the distribution of the potential geographical area of *E. kebericho*. Geographical locations with high precipitation are unsuitable habitats for *E. kebericho*. As shown in Fig. 6, the western part of Ethiopia has a higher potential suitability than the eastern part of Ethiopia.

Species may use different strategies to adapt to future climate changes through phenological or physiological modification and in-situ adaptation to climate. Species with a diverse habitat can benefit from changing conditions due to distinct phenological or physiological characteristics (Abolmaali et al., 2018). However, species with a narrow geographical distribution are more vulnerable. *E. kebericho* is confined to Ethiopian highlands, to elevation ranging from 1700 to 2900 m (Tadesse,2004). This shows

how it is narrowly distributed and vulnerable to changes as well as the importance of introducing it to all potential suitable areas.

Commercial harvesting and sale of *E. kebericho* roots has impacted local populations and will reduce their adaptability to climate change. This could cause the extinction of overused plants in current and future suitable habitats (Svenning et al., 2009). Species distribution models predict the species' fundamental niche besides of the realized niche (Kumar & Stohlgren, 2009; Pearson et al., 2007; Yang et al., 2013b). In reality, a species might have failed to disperse due to geographical barriers, human disturbance, or associated competitive species (Yang et al., 2013b). *Echniops kebericho* has economic and medicinal values and is exposed to dual pressure due to human disturbance (for example - loss of habitat due to changes in land use and land cover change, and exploitation due to its known medicinal use. Similarly, (Manahlie & Feyissa, 2014) reported that *E. kebericho* was a severely endangered medicinal plant mainly due to commercial harvesting and selling of roots. Furthermore, research done in West Gojam Ethiopia (Chandrodyam, 2016) found that *E. kebericho* was on the verge of extinction as a result of overharvesting of the root for medicinal purposes.

Conservation strategies E. kebericho

The application of results from this research are used in the management and conservation of *E. kebericho*, such as identifying geographical locations for introduction or translocation in natural habitat. According to IUCN/SSC,(2013), species with small populations, in demographic regression or with high extinction probability have priority when deciding or translocating. In *E. kebericho*, the small population size, habitat fragmentation, and overexploitation would lead to extinction if conservation strategy are not well designed and implemented. Several geographical areas predicted to have suitable habitat for *E. kebericho* may already be devoid of population due to land use change, land cover change, and overexploitation for medicinal and economic purposes. A study by (Midgley et al., 2003) proved that the combined effect of future land use, land cover change and climate change will increase unsuitable habitats in the cape floristic region.

According to the findings of this study, much of the suitable habitat for these plants in the country has already been converted to agricultural land. Likewise, research conducted in Ethiopia's Guraghe zone revealed that agricultural expansion threatens 66% of *E. kebericho* population density (Kloos et al., 2014). In addition to pointing to regions where the species will also find suitable habitats under current climates, our study also identified potential key sites that can support re-introduction of the *E. kebercho* outside of its current distribution range. Successful conservation planning and strategy for human-dominated landscapes can be used to address this issue (Urbina-Cardona & Flores-Villela, 2010). In response to the loss of suitable habitats, botanical gardens and field gene banks should be established, and *E. kebercho* should be transplanted for cultivation, genetic resource conservation, and sustainable use. Therefore, the Ethiopian Biodiversity Institute, research institutes, and non-government organizations working on biodiversity conservation should focus on conservation actions such as: suitable area protection, species management (species recovery and propagation), education, and awareness-creation for small-holder

farmers and relevant stakeholders to reduce the risk of *E. kebericho* extinction. To enable the *E. kebricho* occupy the current suitable habitat in Ethiopia, the national green legacy should take the deliberate reintroduction of endangered and nearly extinct medicinal plant species into consideration.

Conclusions

In this study, we predicted the suitable habitats of *E, kebericho* with high certainty. Our results did not vary across model runs, model complexity levels and cutting thresholds. Our results indicate that the suitable habitats of *E. Kebericho* concentrates on the western Ethiopia highland massifs. Though *E. kebericho* is described only from three flora regions of Ethiopia, we showed that its suitable habitats exist in other flora regions as well and *E. kebericho* has much wider potential distribution. We also mapped these potential distribution areas at local district levels. We recommend the importance of introducing *E. kebericho* to those suitable areas to ensure its conservation as well as to benefit indigenous people who are relying on it for herbal medicines and household income. We hypothesise that other locally confined medicinal plants of Ethiopia may also have wider potential distribution and we recommend a similar approach to ensure their conservation for local and global benefits.

Declarations

Authors' contributions

BT conceived of the paper together with TB, BW, SD, SN and DC. BT collected the data and made data analysis with close supervision from DC and SN. BT wrote the manuscript with main contributions from DC, BW and all other coauthors. All coauthors actively involved in reviewing and finalizing the paper.

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Competing Interests

We have no relevant financial or non-financial interests to disclose

Data Availability

The datasets used in this study are freely available from the following sources: Presence records of the 49 studied species are given in Appendices S1 . Bioclimatic data: WorldClim (https://www.world clim.org). *The datasets generated during and the current study is available from the corresponding author on reasonable request*

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References

1. Abolmaali SMR, Tarkesh M, Bashari H (2018) MaxEnt modeling for predicting suitable habitats and identifying the effects of climate change on a threatened species, Daphne mucronata, in central Iran. Ecol Inf 43:116–123. https://doi.org/10.1016/j.ecoinf.2017.10.002
2. Aschale Y, Wubetu M, Reta H (2018) Ethnobotany of Medicinal Plants Used to Treat Leishmaniasis in Ethiopia: A Systematic Review. J Traditional Med Clin Naturopathy 07(02):2–7. https://doi.org/10.4172/2573-4555.1000271
3. de Baan L, Alkemade R, Koellner T (2013) *Land use impacts on biodiversity in LCA: a global approach*. 1216–1230. https://doi.org/10.1007/s11367-012-0412-0
4. Bahadur B, Rajam MV, Sahijram L, Krishnamurthy Kv (2015) Plant biology and biotechnology: Volume II: Plant genomics and biotechnology. In *Plant Biology and Biotechnology: Volume II: Plant Genomics and Biotechnology: Vol. II*. https://doi.org/10.1007/978-81-322-2283-5
5. Balmford A, Bond W (2005) Trends in the state of nature and their implications for human well-being. In *Ecology Letters* (Vol. 8, Issue 11, pp. 1218–1234). https://doi.org/10.1111/j.1461-0248.2005.00814.x
6. Barnosky AD, Matzke N, Tomiya S, Wogan GOU, Swartz B, Quental TB, Marshall C, McGuire JL, Lindsey EL, Maguire KC, Mersey B, Ferrer EA (2011) Has the Earth's sixth mass extinction already arrived? Nature 471(7336):51–57. https://doi.org/10.1038/nature09678
7. Behailu B, Temesgen A (2017) Ethnobotanical value of medicinal plant diversity in Cheha district, Guraghe zone, Southern Nations, Nationalities and Peoples (SNNPR) of Ethiopia. J Med Plants Res 11(28):445–454. https://doi.org/10.5897/jmpr2017.6356
8. Bosso L, Rebelo H, Garonna AP, Russo D (2013) Modelling geographic distribution and detecting conservation gaps in Italy for the threatened beetle Rosalia alpina. J Nat Conserv 21(2):72–80. https://doi.org/10.1016/j.jnc.2012.10.003
9. Burgess MG, Costello C, Fredston-hermann A, Pinsky ML (2017) Range contraction enables harvesting to extinction. *Proc. Natl. Acad. Sci*, *114*, 1–6. https://doi.org/10.1073/pnas.1607551114
10. Cardoso-Leite R, Vilarinho AC, Novaes MC, Tonetto AF, Vilardi GC, Guillermo-Ferreira R (2014) Recent and future environmental suitability to dengue fever in Brazil using species distribution model. Trans R Soc Trop Med Hyg 108(2):99–104. https://doi.org/10.1093/trstmh/trt115
11. Chala D, Brochmann C, Psomas A, Ehrich D, Gizaw A, Masao CA, Bakkestuen V, Zimmermann NE (2016a) Good-bye to tropical alpine plant giants under warmer climates? Loss of range and genetic diversity in Lobelia rhynchopetalum. Ecol Evol 6(24):8931–8941. https://doi.org/10.1002/ece3.2603
12. Chala D, Roos C, Svenning JC, Zinner D (2019) Species-specific effects of climate change on the distribution of suitable baboon habitats – Ecological niche modeling of current and Last Glacial

Maximum conditions. J Hum Evol 132:215–226. https://doi.org/10.1016/j.jhevol.2019.05.003

13. Chandrodyam S (2016) Studies on traditional medicinal plants in Ambagiorgis area of Wogera District, Amhara Regional State, Ethiopia. Int J Pure Appl Bioscience 4(2):38–45. https://doi.org/10.18782/2320-7051.2240
14. Darbyshire et al (2021) *Echinops kebericho The IUCN Red List of Threatened Species 2021. 8235*. https://dx.doi.org/10.2305/IUCN.UK.2021-3.RLTS.T147865429A155799140.en
15. Davis AP, Chadburn H, Moat J, O'Sullivan R, Hargreaves S, Lughadha EN (2019) High extinction risk for wild coffee species and implications for coffee sector sustainability. Sci Adv 5(1):1–10. https://doi.org/10.1126/sciadv.aav3473
16. Deyno S, Mtewa AG, Hope D, Bazira J, Makonnen E, Alele PE (2021) Antibacterial Activities of Echinops kebericho Mesfin Tuber Extracts and Isolation of the Most Active Compound, Dehydrocostus Lactone. Front Pharmacol 11(January):1–13. https://doi.org/10.3389/fphar.2020.608672
17. Elith J, Graham H, Anderson CP, Dudík R, Ferrier M, Guisan S, Hijmans AJ, Huettmann R, Leathwick FR, Lehmann J, Li A, Lohmann JG, Loiselle LA, Manion B, Moritz G, Nakamura C, Nakazawa M, Overton YMcCM, Townsend Peterson J, Zimmermann A…E, N (2006) Novel methods improve prediction of species' distributions from occurrence data. Ecography 29(2):129–151. https://doi.org/10.1111/j.2006.0906-7590.04596.x
18. Engler R, Guisan A, Rechsteiner L (2004) An improved approach for predicting the distribution of rare and endangered species from occurrence and pseudo-absence data. J Appl Ecol 41(2):263–274. https://doi.org/10.1111/j.0021-8901.2004.00881.x
19. Dormann F, McPherson CM, Araújo JB, Bivand M, Bolliger R, Carl J, Davies GG, Hirzel R, Jetz A, Daniel Kissling W, Kühn W, Ohlemüller I, Peres-Neto RR, Reineking P, Schröder B, Schurr BM, F., Wilson R (2007) Methods to account for spatial autocorrelation in the analysis of species distributional data: A review. Ecography 30(5):609–628. https://doi.org/10.1111/j.2007.0906-7590.05171.x
20. Fahrig L (2003) Effects of Habitat Fragmentation on Biodiversity. Annu Rev Ecol Evol Syst 34:487–515. https://doi.org/10.1146/annurev.ecolsys.34.011802.132419
21. Fedele G, Donatti CI, Bornacelly I, Hole DG (2021) Nature-dependent people: Mapping human direct use of nature for basic needs across the tropics. Glob Environ Change 71:102368. https://doi.org/10.1016/j.gloenvcha.2021.102368
22. Fick SE, Hijmans RJ (2017) WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. Int J Climatol 37(12):4302–4315. https://doi.org/10.1002/joc.5086
23. Fikadu E, Melesse M (2014) Endemic plant species composition and their status in Boda Dry Evergreen Montane Forest, West Showa, Ethiopia. Int J Biodivers Conserv 6(7):563–569. https://doi.org/10.5897/ijbc2014.0724
24. García-Vega D, Newbold T (2020) Assessing the effects of land use on biodiversity in the world's drylands and Mediterranean environments. Biodivers Conserv 29(2):393–408. https://doi.org/10.1007/s10531-019-01888-4

25. GBIF.org (2021) Available from https://doi.org/10.15468/dl.sdjjes [20 October 2021]
26. Gebeyehu G, Asfaw Z, Enyew A, Raja N (2014) Ethnobotanical study of traditional medicinal plants and their conservation status in Mecha Wereda. Int J Pharmaceuticals Health Care Res 02(03):137–153
27. Gebremedhin B, Chala D, Flagstad Ø, Bekele A, Bakkestuen V, van Moorter B, Ficetola GF, Zimmermann NE, Brochmann C, Stenseth NC (2021) Quest for New Space for Restricted Range Mammals: The Case of the Endangered Walia Ibex. *Frontiers in Ecology and Evolution*, *9*. https://doi.org/10.3389/fevo.2021.611632
28. de Groot R, Brander L, van der Ploeg S, Costanza R, Bernard F, Braat L, Christie M, Crossman N, Ghermandi A, Hein L, Hussain S, Kumar P, Mcvittie A, Portela R, Rodriguez LC, van Beukering P (2012) Global estimates of the value of ecosystems and their services in monetary units. Ecosyst Serv 1(1):50–61. https://doi.org/10.1016/j.ecoser.2012.07.005
29. Guisan A, Graham CH, Elith J, Huettmann F, Dudik M, Ferrier S, Hijmans R, Lehmann A, Li J, Lohmann LG, Loiselle B, Manion G, Moritz C, Nakamura M, Nakazawa Y, Overton JMC, Peterson AT, Phillips SJ, Richardson K, …, Zimmermann NE (2007) Sensitivity of predictive species distribution models to change in grain size. Divers Distrib 13(3):332–340. https://doi.org/10.1111/j.1472-4642.2007.00342.x
30. Guisan A, Zimmermann NE (2000) Predictive habitat distribution models in ecology. Ecol Model 135(2–3):147–186. https://doi.org/10.1016/S0304-3800(00)00354-9
31. Halvorsen R, Mazzoni S, Dirksen JW, Næsset E, Gobakken T, Ohlson M (2016) How important are choice of model selection method and spatial autocorrelation of presence data for distribution modelling by MaxEnt? Ecol Model 328:108–118. https://doi.org/10.1016/j.ecolmodel.2016.02.021
32. Hoffmann M, Brooks TM, Butchart SHM, Carpenter KE, Chanson J, Self-sullivan C, Shi Y, Shoemaker A, Short FT, Snoeks J, Stattersfield AJ, Symes AJ, Taber AB (2014) *The Impact of Conservation on the Status of the World ' s Vertebrates*. *1503*(2010). https://doi.org/10.1126/science.1194442
33. Hussien J, Urgessa K, Regassa F, Jemal A, Abajebel S, Hussien N (2011) Antihelmentic effects of the essential oil extracts of selected medicinal plants against Haemonchus contortus. Int J Agricultural Res 6(3):290–298. https://doi.org/10.3923/ijar.2011.290.298
34. IPCC (2014) Climate Change 2014: Synthesis Report. Contribution. In *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*
35. IUCN/SSC (2013) *Guidelines for Reintroductions and Other Conservation Translocations. Version 1.0. Gland, Switzerland: IUCN Species Survival Commission, viiii + 57 pp.*
36. Keating KiA, Gogan PJP, Vore JM, Irby LR (2007) A Simple Solar Radiation Index for Wildlife Habitat Studies. J Wildl Manage 71(4):1344–1348. https://doi.org/10.2193/2006-359
37. Kloos H, Menberu T, Tadele A, Chanie T, Debebe Y, Abebe A, Zealiyas K, Tadele G, Mohammed M, Debella A (2014) *Traditional medicines sold by vendors in Merkato, Addis Ababa: Aspects of their utilization, trade, and changes between 1973 and 2014*

38. Koellner T, de Baan L, Beck T, de Souza DM, Müller-wenk R (2013) *UNEP-SETAC guideline on global land use impact assessment on biodiversity and ecosystem services in LCA*. 1188–1202. https://doi.org/10.1007/s11367-013-0579-z
39. Kumar S, Stohlgren TJ (2009) *Maxent modeling for predicting suitable habitat for threatened and endangered tree Canacomyrica monticola in New Caledonia*. *1*(4), 94–98
40. Lambin EF, Geist HJ, Lepers E (2003) Dynamics of land-use and land-cover change in tropical regions. *Annual Review of Environment and Resources*, *28*(January 2003), 205–241. https://doi.org/10.1146/annurev.energy.28.050302.105459
41. Lenoir J, Bertrand R, Comte L, Bourgeaud L, Hattab T, Murienne J, Grenouillet G (2020) Species better track climate warming in the oceans than on land. Nat Ecol Evol 4(8):1044–1059. https://doi.org/10.1038/s41559-020-1198-2
42. Loritz R, Kleidon A, Jackisch C, Westhoff M, Ehret U, Gupta H, Zehe E (2019) A topographic index explaining hydrological similarity by accounting for the joint controls of runoff formation. Hydrol Earth Syst Sci 23(9):3807–3821. https://doi.org/10.5194/hess-23-3807-2019
43. Malhi Y, Adu-Bredu S, Asare RA, Lewis SL, Mayaux P (2013) African rainforests: Past, present and future. Philosophical Trans Royal Soc B: Biol Sci 368(1625). https://doi.org/10.1098/rstb.2012.0312
44. Manahlie B, Feyissa T (2014) Micropropagation of Kebericho: An Endandered Ethiopian Medicinal Plant. Am J Plant Sci 05(26):3836–3847. https://doi.org/10.4236/ajps.2014.526402
45. Maryo M, Nemomissa S, Bekele T (2015) An ethnobotanical study of medicinal plants of the Kembatta ethnic group in Enset-based agricultural landscape of Kembatta Tembaro (KT) Zone, Southern Ethiopia. Pelagia Res Libr Asian J Plant Sci Res 5(7):42–61 www.pelagiaresearchlibrary.com
46. Maxwell SL, Fuller RA, Brooks TM, Watson JEM (2016) The ravages of guns, nets and bulldozers. Nature 536:143–145. https://doi.org/10.1038/536143a
47. Merow C, Smith MJ, Edwards TC, Guisan A, Mcmahon SM, Normand S, Thuiller W, Wüest RO, Zimmermann NE, Elith J (2014) What do we gain from simplicity versus complexity in species distribution models? Ecography 37(12):1267–1281. https://doi.org/10.1111/ecog.00845
48. Midgley GF, Bond WJ (2015) ecosystems under anthropogenic climate change. Nat Publishing Group 5(9):823–829. https://doi.org/10.1038/nclimate2753
49. Midgley GF, Hannah L, Millar D, Thuiller W, Booth A (2003) Developing regional and species-level assessments of climate change impacts on biodiversity in the Cape Floristic Region. Biol Conserv 112(1–2):87–97. https://doi.org/10.1016/S0006-3207(02)00414-7
50. Mora C, Metzger R, Rollo A, Myers RA (2007) Experimental simulations about the effects of overexploitation and habitat fragmentation on populations facing environmental warming. *Proc. R. Soc. B Biol. Sci.*, *274*(February), 1023–1028. https://doi.org/10.1098/rspb.2006.0338
51. Mukherjee S, Mukherjee S, Garg RD, Bhardwaj A, Raju PLN (2013) Evaluation of topographic index in relation to terrain roughness and DEM grid spacing. J Earth Syst Sci 122(3):869–886. https://doi.org/10.1007/s12040-013-0292-0

52. Newbold T (2018) Future effects of climate and land-use change on terrestrial vertebrate community diversity under different scenarios. *Proceedings of the Royal Society B: Biological Sciences*, *285*(1881). https://doi.org/10.1098/rspb.2018.0792
53. Palaoro Av, Dalosto MM, Costa GC, Santos S (2013) Niche conservatism and the potential for the crayfish Procambarus clarkii to invade South America. Freshw Biol 58(7):1379–1391. https://doi.org/10.1111/fwb.12134
54. Pearson RG, Raxworthy CJ, Nakamura M, Townsend Peterson A (2007) Predicting species distributions from small numbers of occurrence records: A test case using cryptic geckos in Madagascar. J Biogeogr 34(1):102–117. https://doi.org/10.1111/j.1365-2699.2006.01594.x
55. Pecl GT, Araújo MB, Bell JD, Blanchard J, Bonebrake TC, Chen IC, Clark TD, Colwell RK, Danielsen F, Evengård B, Falconi L, Ferrier S, Frusher S, Garcia RA, Griffis RB, Hobday AJ, Janion-Scheepers C, Jarzyna MA, Jennings S, …, Williams SE (2017) Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being. Science 355(6332). https://doi.org/10.1126/science.aai9214
56. Peters MK, Hemp A, Appelhans T, Becker JN, Behler C, Classen A, Detsch F, Ensslin A, Ferger SW, Frederiksen SB, Gebert F, Gerschlauer F, Gütlein A, Helbig-Bonitz M, Hemp C, Kindeketa WJ, Kühnel A, Mayr AV, Mwangomo E, …, Steffan-Dewenter I (2019) Climate–land-use interactions shape tropical mountain biodiversity and ecosystem functions. Nature 568(7750):88–92. https://doi.org/10.1038/s41586-019-1048-z
57. Peterson AT (2008) *Modeling ecological niches and predicting geographic distributions: A test of six presence-only methods Designing Biodiversity Inventories Across the Hutchinsonian Duality View project Epidemiological views of infectious diseases View project*. https://www.researchgate.net/publication/230709975
58. Phillips SJ, Dudík M (2008) Modeling of species distributions with Maxent: New extensions and a comprehensive evaluation. Ecography 31(2):161–175. https://doi.org/10.1111/j.0906-7590.2008.5203.x
59. Phillips S, Aneja SB, Kang VP, D., Arya SP (2006) Modelling and analysis of the atmospheric nitrogen deposition in North Carolina. Int J Global Environ Issues 6(2–3):231–252. https://doi.org/10.1016/j.ecolmodel.2005.03.026
60. Pillay R, Hua F, Loiselle BA, Bernard H, Jr RJF (2018) Multiple stages of tree seedling recruitment are altered in tropical forests degraded by selective logging. Ecol Evol 8(May):1–12. https://doi.org/10.1002/ece3.4352
61. Ragunathan M, Abay SM (2009) Ethnomedicinal survey of folk drugs used in Bahirdar Zuria district, Northwestern Ethiopia. Indian J Traditional Knowl 8(2):281–284
62. Regassa R (2013) Assessment of indigenous knowledge of medicinal plant practice and mode of service delivery in Hawassa city, southern Ethiopia. J Med Plants Res 7(9):517–535. https://doi.org/10.5897/JMPR12.1126

63. Sala OE, Chapin FS, Armesto JJ, Berlow E, Bloomfield J, Dirzo R, Huber-Sanwald E, Huenneke LF, Jackson RB, Kinzig A, Leemans R, Lodge DM, Mooney HA, Oesterheld M, Poff NLR, Sykes MT, Walker BH, Walker M, Wall DH (2000) Global biodiversity scenarios for the year 2100. In *Science* (Vol. 287, Issue 5459, pp. 1770–1774). https://doi.org/10.1126/science.287.5459.1770
64. Scarano FR, Ceotto P (2015) Brazilian Atlantic forest: impact, vulnerability, and adaptation to climate change. Biodivers Conserv 24(9):2319–2331. https://doi.org/10.1007/s10531-015-0972-y
65. Schmidt-Lebuhn AN, Knerr NJ, Miller JT, Mishler BD (2015) Phylogenetic diversity and endemism of Australian daisies (Asteraceae). J Biogeogr 42(6):1114–1122. https://doi.org/10.1111/jbi.12488
66. de Souza AC, Prevedello JA (2020) The importance of protected areas for overexploited plants: Evidence from a biodiversity hotspot. Biol Conserv 243(February):108482. https://doi.org/10.1016/j.biocon.2020.108482
67. Stévart T, Dauby G, Lowry P, Blach-Overgaard A, Droissart V, Harris DJ, Mackinder AB, Schatz GE, Sonké B, Sosef MSM, Svenning JC, Wieringa J, Couvreur TLP (2019) A third of the tropical African flora is potentially threatened with extinction. Sci Adv 5(11). https://doi.org/10.1126/sciadv.aax9444
68. Svenning JC, Harlev D, Sørensen MM, Balslev H (2009) Topographic and spatial controls of palm species distributions in a montane rain forest, southern Ecuador. Biodivers Conserv 18(1):219–228. https://doi.org/10.1007/s10531-008-9468-3
69. Tadesse M (2004) Flora of Ethiopia and Eritrea. Volume 4, Part 2: Asteraceae (Compositae). In *The Biodiversity of African Plants* (Vol. 4)
70. Tariku Y, Hymete A, Hailu A, Rohloff J (2011) In vitro evaluation of antileishmanial activity and toxicity of essential oils of Artemisia absinthium and Echinops kebericho. Chem Biodivers 8(4):614–623. https://doi.org/10.1002/cbdv.201000331
71. Tariku Y, Kebede T (2011) *Natural Products screening project View project n vitro antifungal effect of crude extracts and solvent fractions of Croton macrostachyus Hochst. ex Del. and Vernonia amygdalina Del. against fungi isolated from formalin fixed cadavers View project*. https://www.researchgate.net/publication/236590639
72. Tilman D, Clark M, Williams DR, Kimmel K, Polasky S, Packer C (2017) Future threats to biodiversity and pathways to their prevention. In *Nature* (Vol. 546, Issue 7656, pp. 73–81). https://doi.org/10.1038/nature22900
73. Toma A, Deyno S, Fikru A, Eyado A, Beale A (2015) In vivo antiplasmodial and toxicological effect of crude ethanol extract of Echinops kebericho traditionally used in treatment of malaria in Ethiopia. Malar J 14(1). https://doi.org/10.1186/s12936-015-0716-1
74. Urbina-Cardona JN, Flores-Villela O (2010) Ecological-niche modeling and prioritization of conservation-area networks for Mexican herpetofauna. Conserv Biol 24(4):1031–1041. https://doi.org/10.1111/j.1523-1739.2009.01432.x
75. Vasconcelos TS, Rodríguez M, Hawkins BA (2012) Species distribution modelling as a macroecological tool: A case study using New World amphibians. Ecography 35(6):539–548. https://doi.org/10.1111/j.1600-0587.2011.07050.x

76. Vivero JL, Kelbessa E, Demissew S (2006) *The Red List of Endemic Trees & Shrubs of Ethiopia and Eritrea*. *January 2015*, 28. https://doi.org/10.13140/2.1.3139.6168
77. Waldron A, Miller DC, Redding D, Mooers A, Kuhn TS, Nibbelink N, Roberts JT, Tobias JA, Gittleman JL (2017) Reductions in global biodiversity loss predicted from conservation spending. Nature 551(7680):364–367. https://doi.org/10.1038/nature24295
78. Warmenbol C, Smith M (2018) International union for conservation of nature (IUCN). *The Wetland Book: I: Structure and Function, Management, and Methods*, 665–669. https://doi.org/10.1007/978-90-481-9659-3_110
79. Warren DL, Wright AN, Seifert SN, Shaffer HB (2014) Incorporating model complexity and spatial sampling bias into ecological niche models of climate change risks faced by 90 California vertebrate species of concern. Divers Distrib 20(3):334–343. https://doi.org/10.1111/ddi.12160
80. Watson RT, Scientist C, Bank W, Arico S, Bridgewater P, Tschirley J, Valentini R, Almeida F, Barnard P, Invasive G, Camac-ramirez E, Rica C, Fortier F, Peoples I, Schei PJ, Mooney HA (2005) *E COSYSTEMS AND H UMAN W ELL - BEING. World Health*
81. Wilson MC, Chen XY, Corlett RT, Didham RK, Ding P, Holt RD, Holyoak M, Hu G, Hughes AC, Jiang L, Laurance WF, Liu J, Pimm SL, Robinson SK, Russo SE, Si X, Wilcove DS, Wu J, Yu M (2016) Habitat fragmentation and biodiversity conservation: key findings and future challenges. Landscape Ecol 31(2):219–227. https://doi.org/10.1007/s10980-015-0312-3
82. Yang XQ, Kushwaha SPS, Saran S, Xu J, Roy PS (2013a) Maxent modeling for predicting the potential distribution of medicinal plant, Justicia adhatoda L. in Lesser Himalayan foothills. Ecol Eng 51:83–87. https://doi.org/10.1016/j.ecoleng.2012.12.004
83. Yang XQ, Kushwaha SPS, Saran S, Xu J, Roy PS (2013b) Maxent modeling for predicting the potential distribution of medicinal plant, Justicia adhatoda L. in Lesser Himalayan foothills. Ecol Eng 51:83–87. https://doi.org/10.1016/j.ecoleng.2012.12.004

Figures



Figure 1

Echinops kebericho(A) growing on a grazing land, (B) growing in home garden. Photos: Bedilu Tafesse

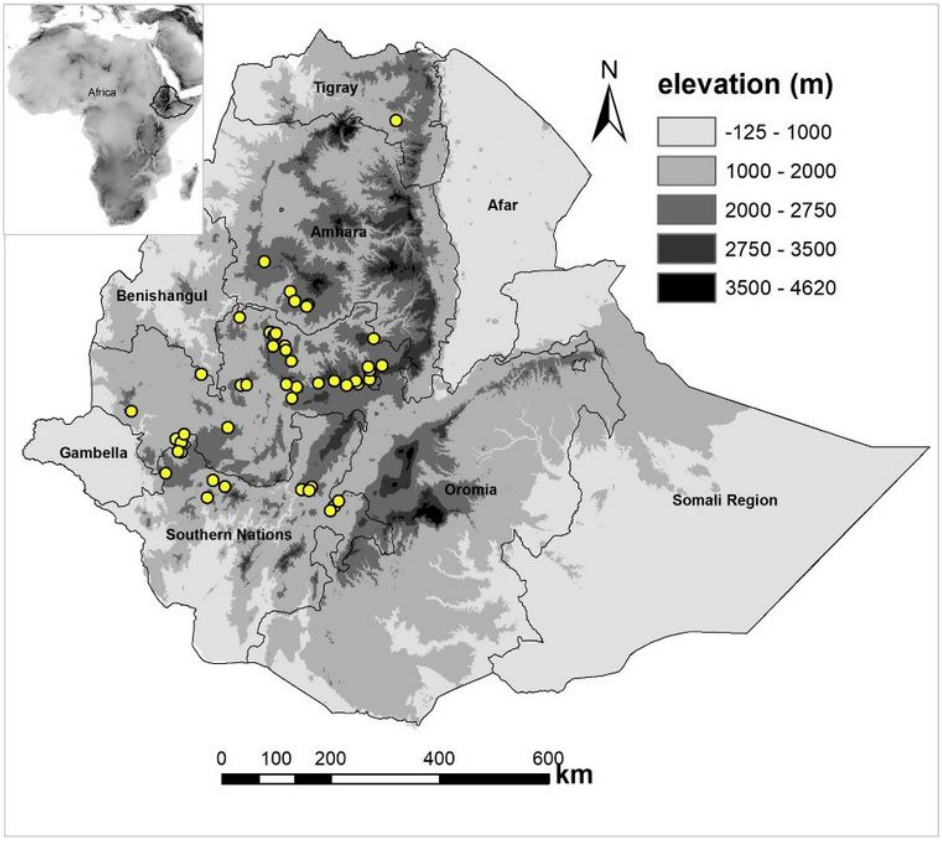


Figure 2

Map of study area; occurrence points ofEchnops kebericho are presented in yellow points.

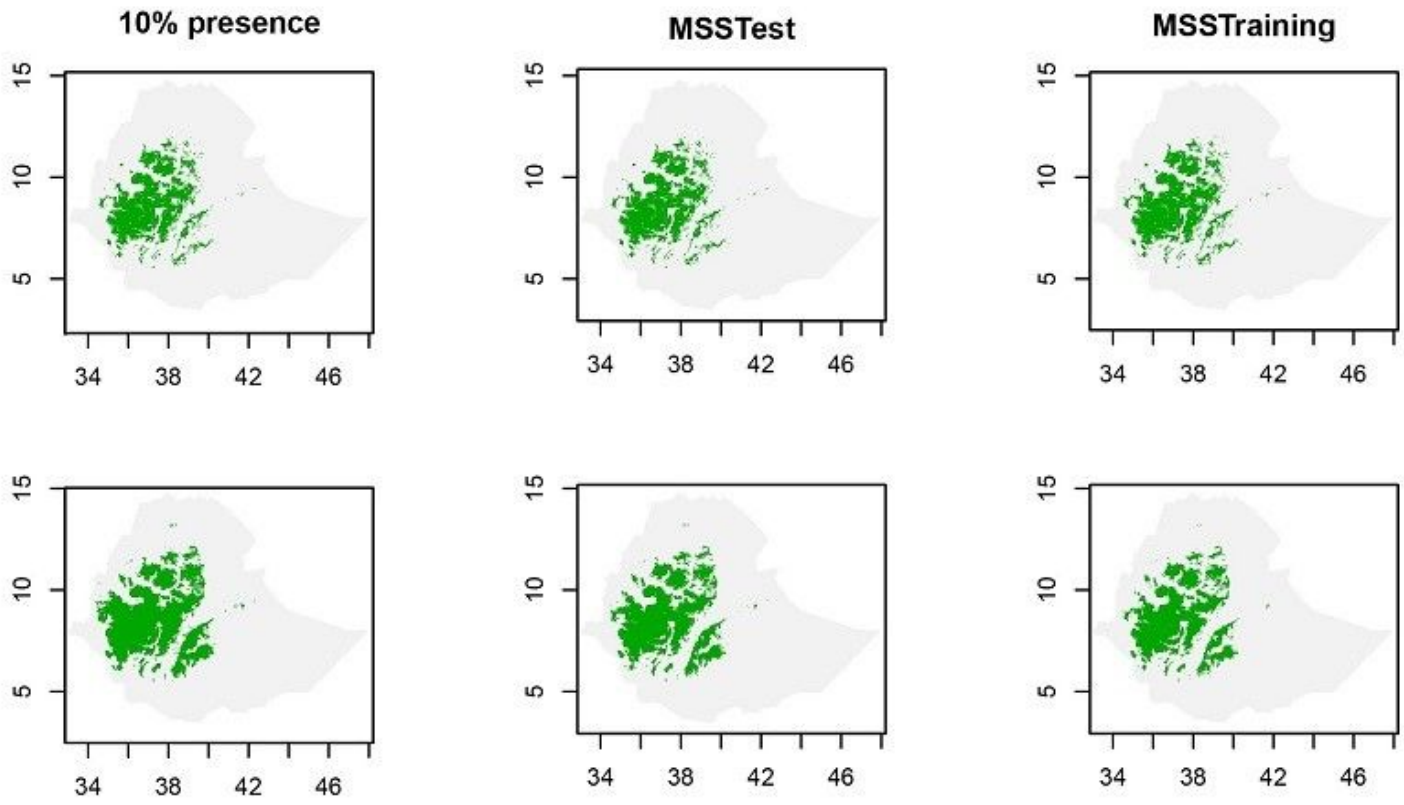


Figure 3

Binary habitat suitability maps produced using two model complexity levels (regularization multiplier 1 – upper row and regularization multiplier 8 – lower row) and three threshold criteria (10% presence – at 10% training data omission; MSSTest – maximum sum sensitivity and specificity computed on test data; MSSTrain - maximum sum sensitivity and specificity computed on training data).

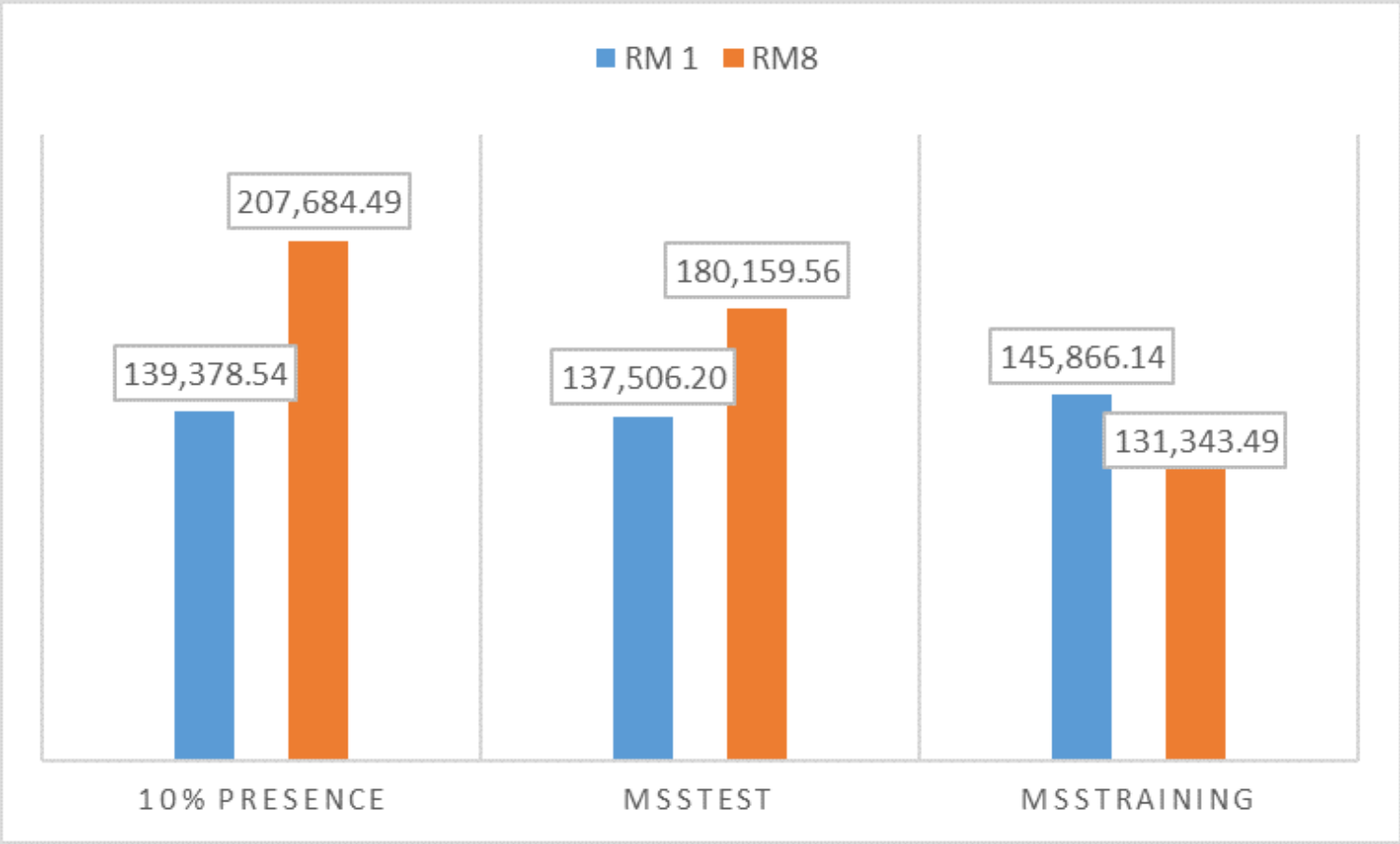


Figure 4

Habitat suitability at three thresholds using two model complexity levels (regularization multipliers 1 (RM1) and 8 (RM8)). MSSTest – maximum sum sensitivity and specificity computed on test data, MSSTraining- Maximum training sensitivity plus specificity,10%presence- 10 percentile training presence.

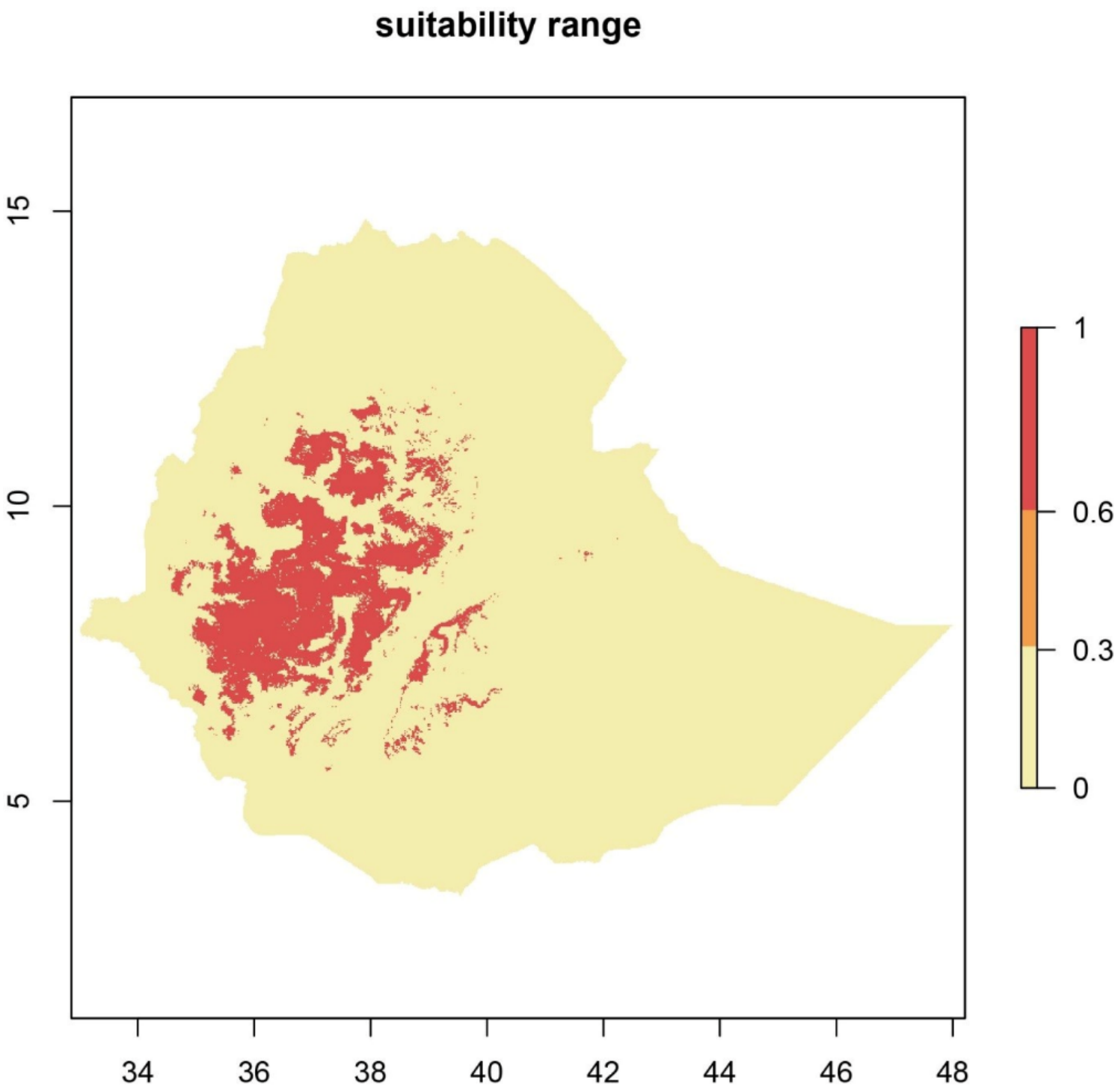


Figure 5

Current habitat suitability of *Echinops kebericho* produced by combining six binary maps produced employing two model complexity levels of MaxEnt, and three cutoff threshold criteria (2 * 3). 0 – 0.3 shows where none or only one of the six binary maps predicts suitability; 0.3 – 06 shows where 2 – 3 of the six binary maps predict suitability and 0.6 - 1 shows where 4 – 6 of the six binary maps predict habitat suitability

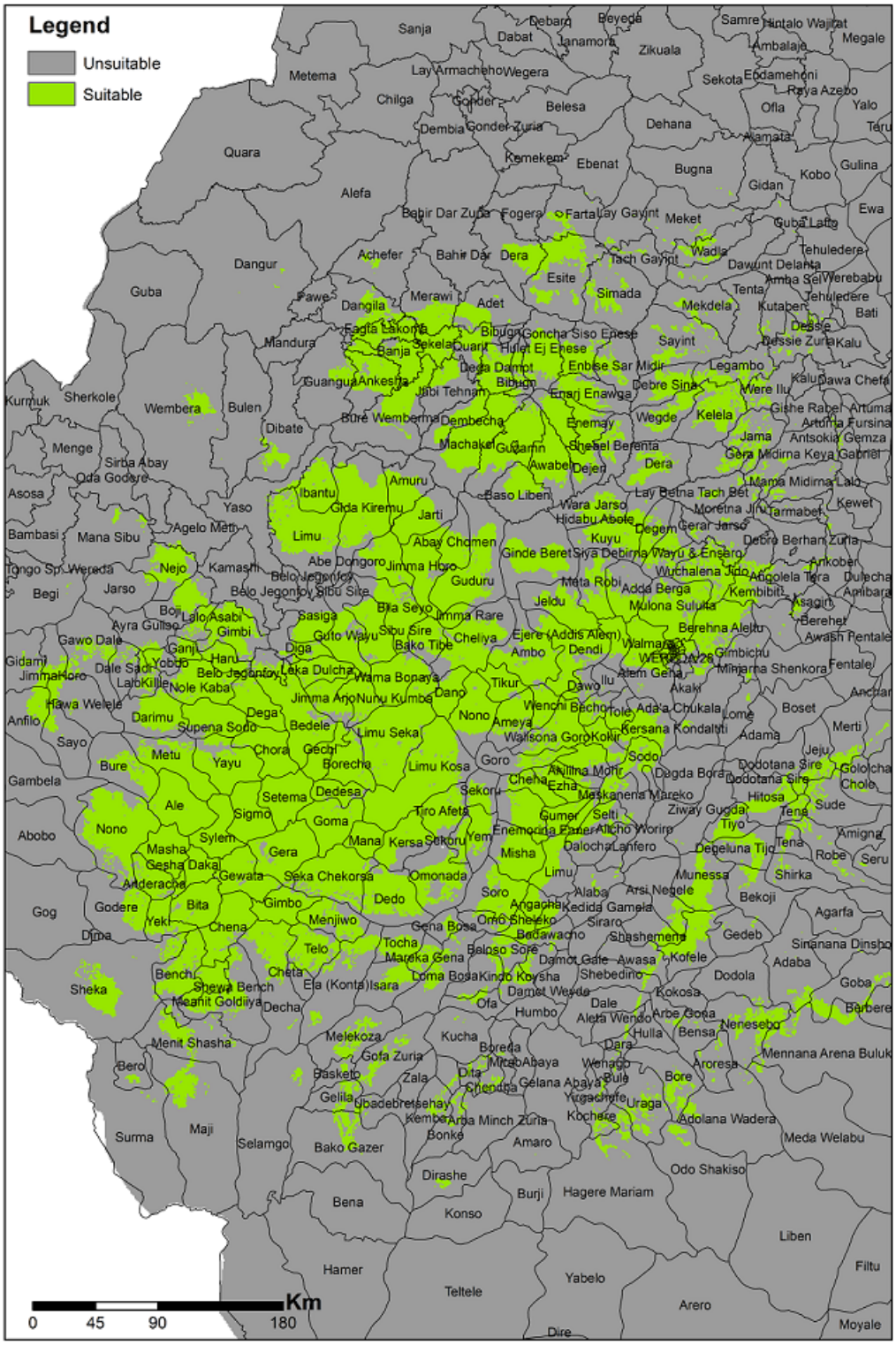


Figure 6

local districts where habitat suitability is predicted with high certainty.

Supplementary Files

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