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Ecological niche modeling for stingless bees (genus Melipona) in Waghemira and North Wollo zones of Amhara Regional State, Ethiopia

Ayalew Assefa[a,*], Meressa Lemma[b]

[a] Woldia University, Department of Veterinary Medicine, Merssa, Ethiopia
[b] Sekota Dryland Agricultural Research Center, Sekota, Ethiopia

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ABSTRACT

Ethiopia has excellent potential for the existence of different stingless bee species. However, these species are wild and are facing extinction danger due to destructive harvesting and environmental degradations. To support the domestication and protection of these species, we developed a habitat suitability model for Waghemira and Lasta area (North Wollo Zone). A survey of stingless bees was carried out in Sekota, Dehana, Ziquala, Abergelle, Sehala seyemt, Tsagbji and Gazgibla from the Waghemira zone; and Gidan, Lalibela and Bugna from North Wollo zone (Lasta area) between 2016 and 2017. Environmental variables that are known to determine the site selection habit of stingless bees were used to develop the model. Multicollinearity between environmental variables was checked and maximum entropy model was used with maxent software. The accuracy of the model was assessed with the receiver operating characteristic curve (ROC) and was found to be 0.91. Variables like Water vapor pressure (35%), precipitation seasonality (25.1%), elevation (12.3%), temperature annual range (11.7%), wind speed (7.4%) contributed the highest share in the model. The predicted suitable areas are located in mid and higher altitudes of the Waghemira and North Wollo zone (Lasta area). Sekota district was very suitable. Besides, Lalibela, Gazgibla, Bugna, and Dehana were also reasonably suitable districts for stingless bees. However, the lowlands of the Waghemira zone, i.e., districts of Abergele, Ziquala and Sehala Seyemt, were found unsuitable for stingless bees. This study can be used as a basis for future intervention activities related to bee collection, domestication and commercialization in the study area and similar agroecology in Ethiopia.

Introduction

Stingless bees (Hymenoptera, Apidae: Meliponini) are a diverse group of social bees of the tropics and subtropics [15]. They are eusocial insects living in persistent colonies [17]. Stingless bees provided a vital small-scale economy with honey,

* Corresponding author.
E-mail address: hayall2020@gmail.com (A. Assefa).

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cerumen and resins. Honey production in stingless bees is species-specific; they all have unique and characteristic honey, a highly valued medicinal honey compared to *Apis melifera* honey [7].

The domestication of stingless bees in Africa and Ethiopia is not as advanced as in the Neotropical regions and is not comparable to the advances seen in apiculture. Only six species of stingless bees are known from Ethiopia. While there is a long tradition of honey collection from wild stingless bees by different communities, meliponiculture is not well-practiced [5].

Stingless bee honey is common honey in Ethiopia with a long history of consumption for medicinal purposes and achieving high market demand. The honey production system is traditional and destructive. Due to this reason, the stingless bee native species become endangered; the honey quality remains very poor and adulterated [13].

In Ethiopia, projects on bee rearing have exclusively focused on Apis honey bees and are promoted in rural communities as a sustainable development activity to improve livelihoods. Waghemira zone and North Wollo zone (Wag-Lasta area hereafter) are known for enormous potential in honey production. The local community collects stingless bee honey only from the wild. However, recently, there has been an advancement to domesticate the species to utilize the resource. Preserving and utilizing these stingless bee species in the study area through meliponiculture will significantly contribute to conserving the species in their natural habitats and generate income through honey, resins, and cerumen production and provide effective crop production pollination in small scale farming systems. The efficient utilization of stingless bees starts with the wild stingless bees, which can be done by collecting and putting them at a suitable location.

To facilitate the collection and suitable habitat selection of stingless bees, ecological niche modeling (species distribution modeling) plays an irreplaceable role [4]. SDM is a methodology based on core ecological and biogeographical concepts about the relationship between species distributions (or other biotic response variables describing aspects of biodiversity) and the physical (abiotic) environment. SDMs are quantitative, empirical models typically developed using species location data for species-environment relationships and those environmental variables thought to affect species distributions [9]. SDM has been applied to address conservation issues, including evaluating species representation within naturally protected area networks and identifying optimal values of key environmental variables that favor species survival at broad [1,8,18]. Species potential distribution models have also been used to draw geographic limits for taxonomically problematic species and understand speciation patterns. Many factors influence the selection of sites by a stingless bee. Rainfall, precipitation, daily temperature, and many other factors are being the major ones.

In this particular study area (wag- lasta area of Ethiopia), the stingless bee species of the genus Melipona are primarily hunted in the wild for honey used for subsistence, traditional medicine and rituals by the rural communities. Even though the production seems abundant, the destructive hunting practice led to the decline of the wild population of these stingless bee species due to the destruction of their habitats. To avoid destructive hunting, and facilitate domestication, we used ecological niche modeling to determine suitable localities.

Material and methods

Description of the study area

The study area accounts for more than 1282,000 hectares and includes ten districts (Fig. 1). Waghimra Zone is one of the 12 administrative zones in Amhara National Regional State that comprises seven districts, including Sekota, Dehana, Ziquala, Abergele, Sehala Seyemt, Tsagbji and Gazgibla. These districts represent three major agroecological zones. These are hot to warm sub-moist agroecology with an altitude of less than 1500 m, moderate or tepid sub-moist agroecology having an altitude of 1500 to1800 meters and cold sub-moist agroecology with altitude ranging from1800 to 2200 m above sea level [2]. Lasta area comprises Gidan, Lalibela, and Bugna districts in the North wollo zone with an altitude of more than 2400 m above sea level. The area's soil type is near vertisol and classified as semi-arid, characterized by land degradation, erratic and unreliable rainfall, water shortage, and periodic famine. The area receives about 772 mm mean annual rainfall with mean annual temperature generally ranging from 13 to 23 °C.

Stingless bee occurrence data

A survey of stingless bees was carried out in the study areas between 2016 and 2017. During this time, 27 colonies were identified with local farmers who have experience in harvesting stingless bee honey. The study area was divided into three agroecological zones (Lowland, midland and highland). From each agroecology, nine stingless bee colonies were searched and collected. The occurrence of a stingless bee was accompanied by recording the GPS coordinates where nests were found. These coordinates were used as presence (occurrence) data in the model development with Maxent.

Environmental variables

Environmental variables known to determine the site selection habit of stingless bees were used to develop a predictive map. The variables have been downloaded from the latest environmental data sources of worldclim 2.1 databases [6]. Initially, a total of 19 bioclimatic variables were proposed but reduced to 12 due to multicollinearity. All variables used in the final model have been depicted in Table 1.

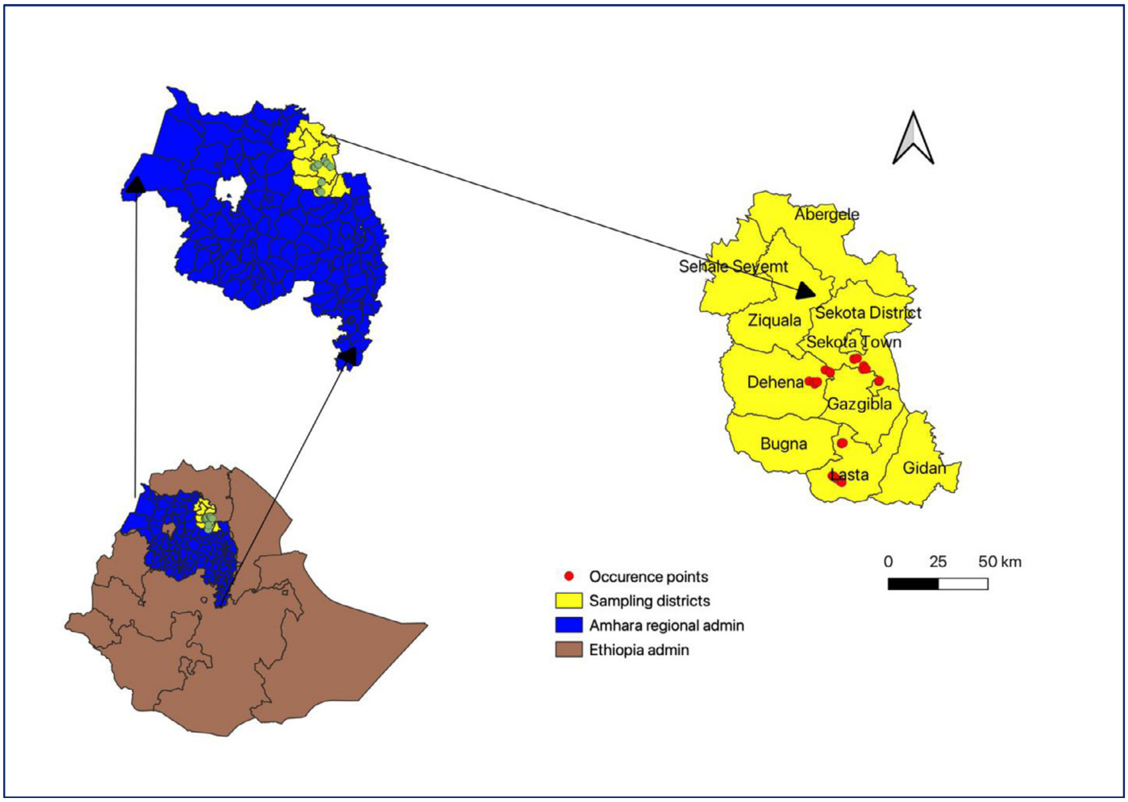

Fig. 1. Location map of the study area and sampling points.

Table 1
Variables used to model the suitability for Genus melipona in waglasta area.

Variable Code	Variable Name
Vapor	Water vapor pressure
wc2.1_2.5m_bio_2	Precipitation seasonality (cv)
wc2.1_2.5m_elev	Elevation
wc2.1_2.5m_bio_7	Temperature annual range (bio5-bio6)
Wind	Wind
Tmax	Annual maximum temperature
wc2.1_2.5m_bio_18	Precipitation of warmest quarter
wc2.1_2.5m_bio_14	Precipitation of driest month
Prec	Annual precipitation
wc2.1_2.5m_bio_13	Precipitation of wettest month
wc2.1_2.5m_bio_19	Precipitation of coldest quarter
Tmin	Annual minimum temperature

Data management and model development

The maximum entropy model was used with the maxent software program [14]. Environmental variables downloaded were processed in the SDM package of the ArcGIS software program [11]. First, they were clipped to the study area location and further processed to bring them to the same projection system, cell size and resolution. Besides, variables in GeoTIFF formats were converted to ASCI grid formats. Multicollinearity between environmental variables was checked with the VIF procedure of the USDM package of R software program [12]. Variables that have a multicollinearity coefficient of more than 0.7 were eliminated.

Most of the default settings of maxent were retained except few features. The number of replicates maximized to ten so that the maxent gets enough time to converge and avoid overfitting. Relative contributions of the environmental variables for the model were measured by estimating the first estimate; in each iteration of the training algorithm, the increase in regularized gain is added to the contribution of the corresponding variable or subtracted from it if the change to the absolute value of lambda is negative. For the second estimate, for each environmental variable, in turn, the values of that

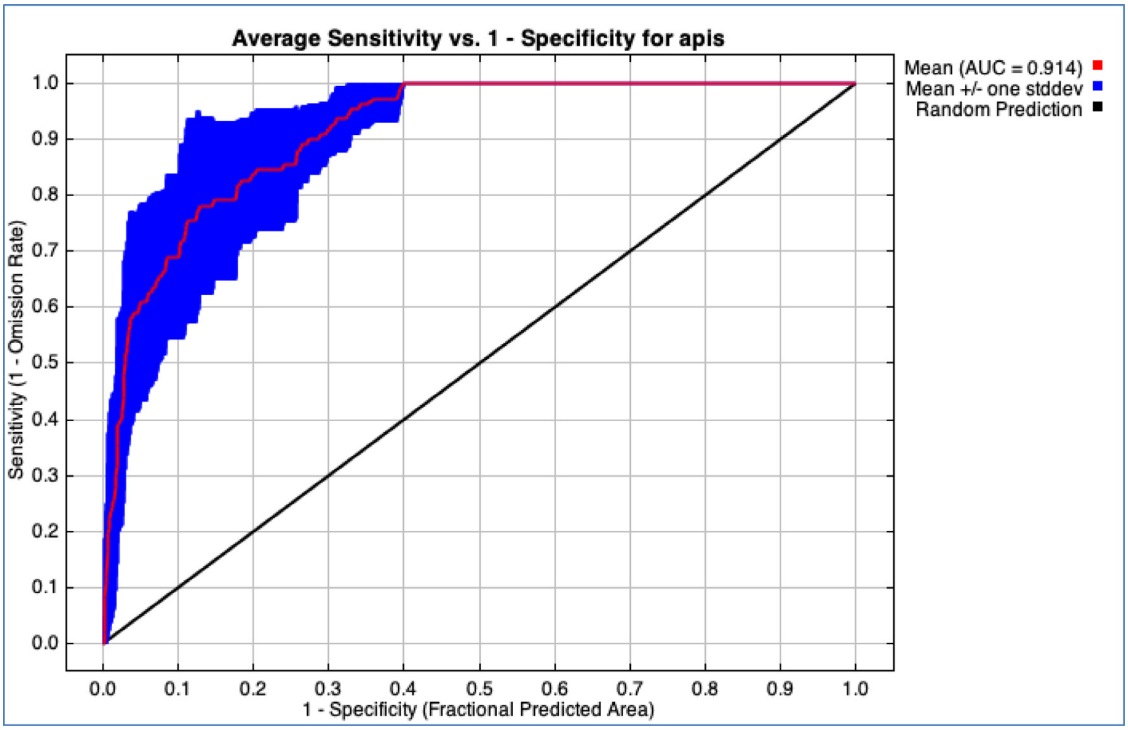

Fig. 2. The area under the curve (AUC) of the receiver operating characteristic (ROC) measures the performance of the model.

Table 2
Percent variable contribution of variables used in the model.

Variable Code	Variable Name	Percent contribution
Vapor	Water vapor pressure	35
wc2.1_2.5m_bio_2	Precipitation Seasonality (bio-2)	25.1
wc2.1_2.5m_elev	Elevation (Altitude)	12.3
wc2.1_2.5m_bio_7	Temperature Annual Range (bio-7)	11.7
Wind	windspeed	7.4
Tmax	Annual Maximum Temperature	3.2
wc2.1_2.5m_bio_18	Precipitation of Warmest Quarter (bio-18)	3
wc2.1_2.5m_bio_14	Precipitation of Driest Month (bio-14)	1.1
Prec	Annual Precipitation	0.6
wc2.1_2.5m_bio_13	Precipitation of Wettest Month (bio-13)	0.3
wc2.1_2.5m_bio_19	Precipitation of Coldest Quarter (bio-19)	0.2
Tmin	Annual Minimum Temperature	0.2

variable on training presence and background data are randomly permuted. The model is re-evaluated on the permuted data [14].

Accuracy assessment was performed by calculating the area under the curve (AUC) of the receiver operating characteristic (ROC), which evaluates commission vs. omission errors). An AUC value of $\leq$ 0.5 indicates that the model performed no better than random. In contrast, an AUC of 1 indicates a perfect performance, and an AUC of $\geq$ 0.7 reflects an acceptable model.

Results

Model evaluation and variable contributions

The accuracy of the model was 0.91, indicating our model was an excellent fit, much better than a random model (Fig. 2).

The model's training omission rate and predicted area as a function of the cumulative threshold averaged over the replicate runs are depicted in Fig. 3.

Variables that hugely contributed to the model were water vapor pressure, annual precipitation, precipitation, seasonality (cv) and elevation, temperature annual range, and wind speed. The percent contribution of all variables used has been depicted in Table 2.

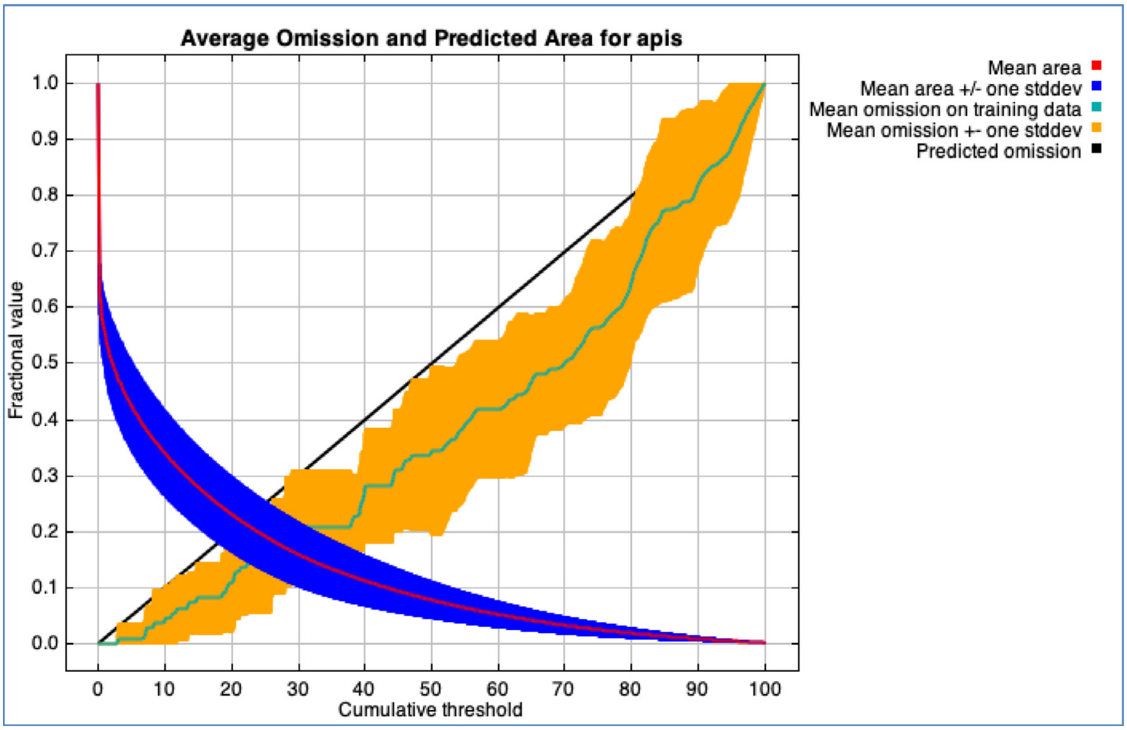

Fig. 3. The training omission rate and predicted area as a function of the cumulative threshold averaged over the replicate runs.

Variable importance was evaluated using the Jackknife variable removal approach. Jackknife removes a variable and evaluates the effect of variable removal on the model. The environmental variable with the highest gain, when used in isolation, is precipitation seasonality (bio-2). Therefore, it appears to have the most useful information by itself. The environmental variable that decreases the gain when it is omitted is precipitation seasonality (bio-2). Therefore, it appears to have the most information that is not present in the other variables. Values shown are averages over replicate runs. The jackknife test of variable importance has been depicted in Fig. 4.

Response curves were generated to understand the probability of a species presence at a location due to these parameters used. Besides, these curves show how each environmental variable affects the Maxent prediction and how the predicted probability of presence changes as each environmental variable is varied, keeping all other environmental variables at their average sample value. The response curves of all variables used have been depicted in Fig. 5.

Predicted suitable habitats

The predicted suitable areas were primarily located in mid and higher altitudes of the Waghemira zone and Lasta area (North Wollo Zone). Sekota area was very suitable, while Lalibela, Gazgibla, Bugna, and Dehana districts were medium-level suitable. However, the lowlands of Waghemira zone, i.e., districts of Abergele, Ziquala and Sehala Seyemt were found unsuitable. The mean suitability level is depicted in Fig. 6.

Discussion

To the best of our knowledge, this stingless bee (genus Melipona) suitability model is the first of its kind in Ethiopia. Such suitability models would contribute to the nest collection and domestication process in the country. The model is reasonably better than a random model, as its accuracy was 0.91. Even though the occurrence points were few, we have an excellent model as maxent can perform great with fewer occurrence points. Studies showed that it is possible to do ENMs with occurrence points, even less than 10. Besides, there is an argument that states small sample size can result in accurate models provided that the sample is not biased and accurately represents the geographic extent of the species [18].

Stingless bee species are greatly endangered due to a lack of proper harvesting, environmental degradation and lack of domestication practice in Ethiopia. Harvesters usually search in the wild, and when they locate the nest, they dig and collect the honey and scatter the bees without considering sustainability. Hence, a well-organized domestication program and awareness creation for harvesters should be planned. This study can be used as a basis in the domestication and commercialization of meliponiculture in the study area and related agroecological localities of the country.

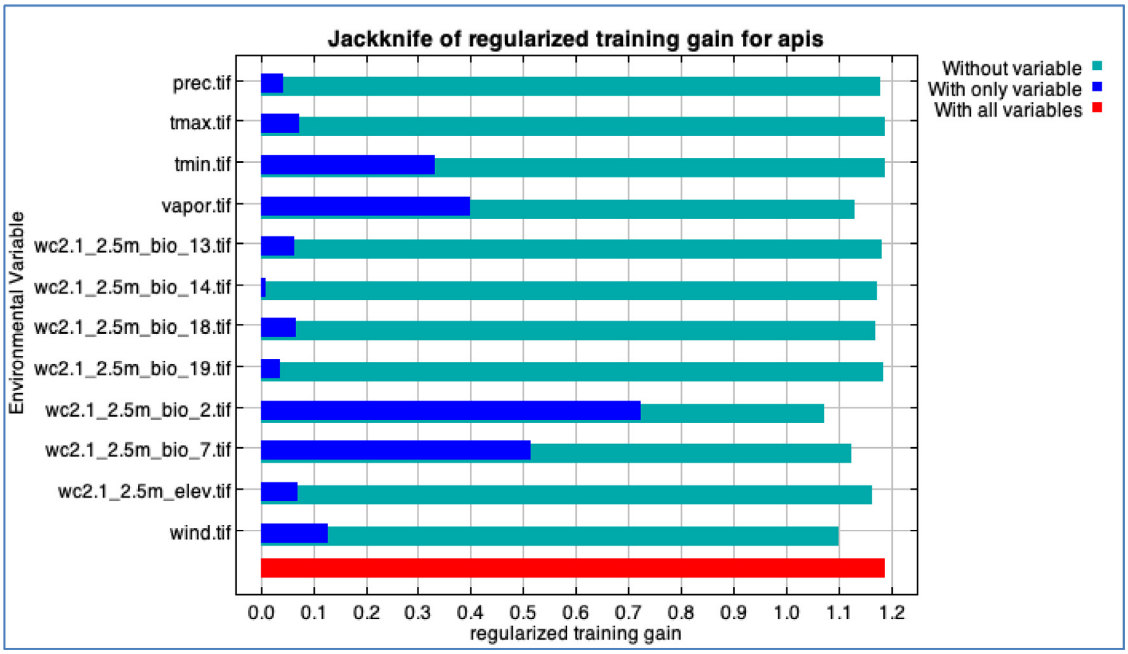

Fig. 4. The jackknife test of variable importance.

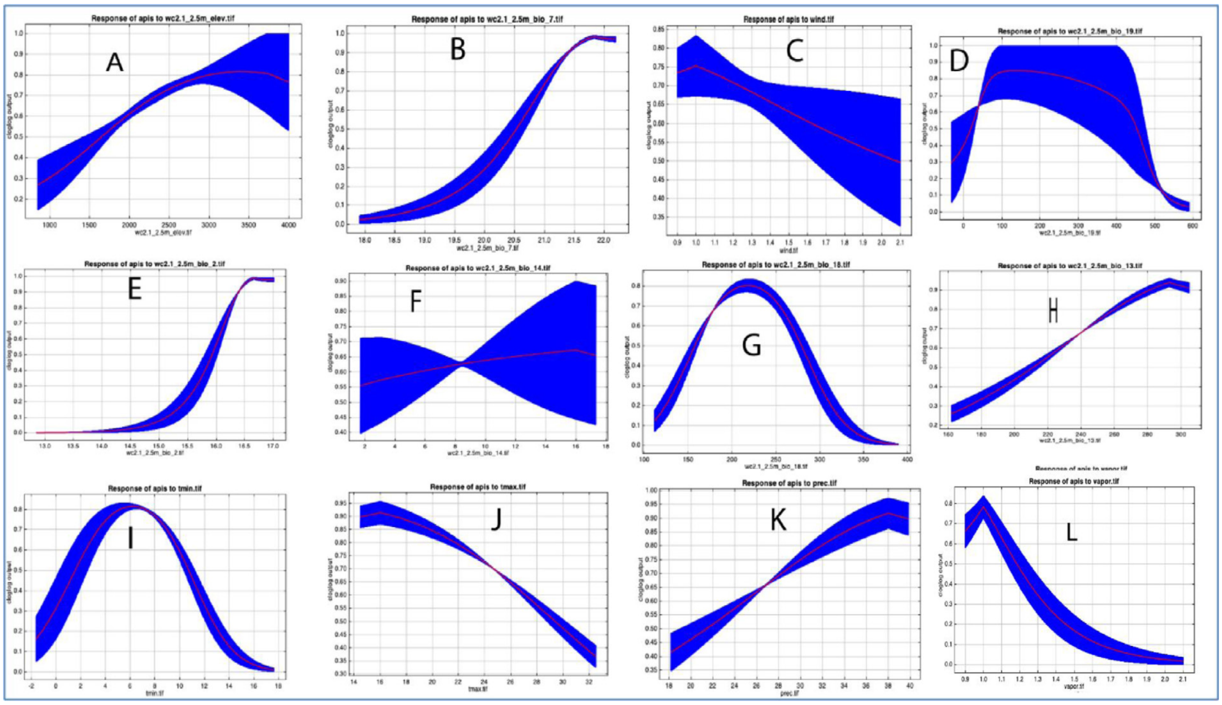

Fig. 5. Response of Melipona to variables used. A, Altitude B, bio 7 C, wind D, bio 19 E, bio 2 F, bio 14 G, bio 18 H, bio13 I, tmin, J, tmax K, precipitation L, vapor.

Water vapor pressure contributed the highest share in the model. It alone contributed more than 33%. This variable is known to affect the survival of insects in moist deficit areas like Wag-Lasta of Ethiopia. Studies suggest that humidity influences the survival of insects, mainly by affecting their water content [3]. Besides, as communication in stingless bees is based on volatile compounds, water vapor and temperature can affect their signaling and communication, i.e., affecting their site selection [16]. Exposure to dry or humid conditions may not be harmful if humidity can be kept within certain limits. Insects are capable of maintaining a stable water balance by searching for a suitable environment. The study area

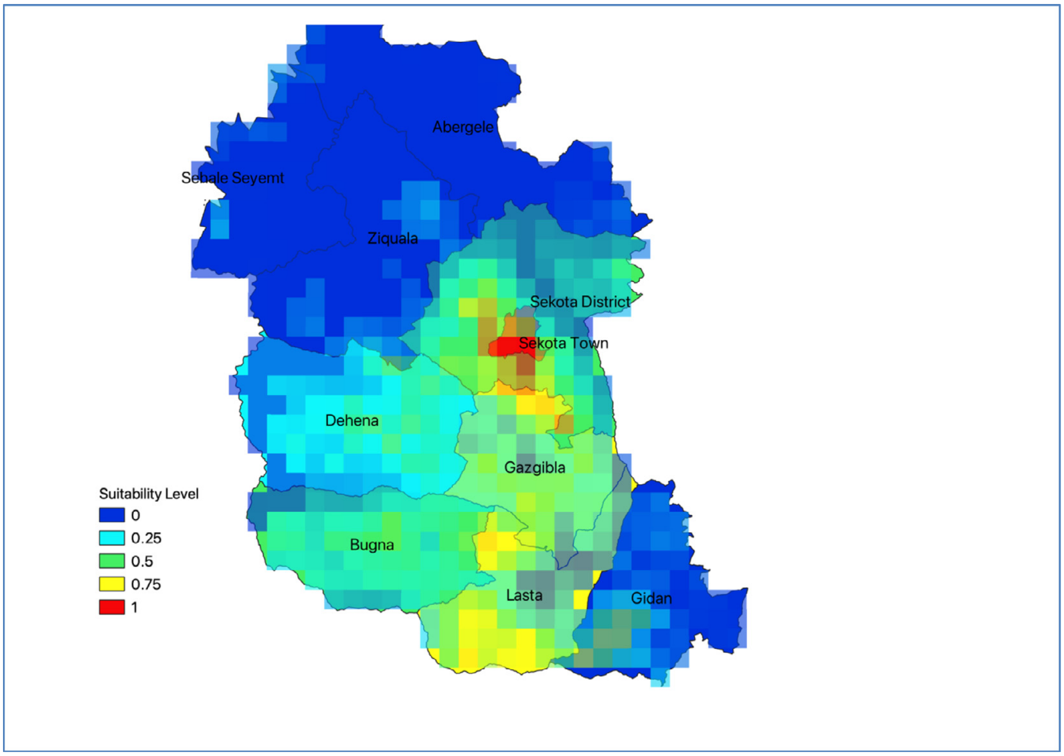

Fig. 6. Mean suitability map depicting suitable niches in the Wag-Lasta area. warmer colors indicate ideal suitability, while the cooler one (blue area) depicts unsuitable locations.

depicted as suitable has better humidity than the lowland deserts of Abergelle, Sahala Seyemt, and Ziquala, indicating the lowlands are not suitable for the melipona species.

Precipitation variables (annual average precipitation and precipitation seasonality) also contributed a significant share of variable importance in the model. Previous studies have shown that these variables affect species richness in a particular area [19]. The precipitation level in areas identified as suitable is much higher than that of unsuitable areas. Besides, altitude was also the other contributing variable for the model with an 11% share. Areas identified as suitable are characterized as mid-altitude with a relatively higher vegetation cover than the unsuitable lowland areas. Melipona species prefer midlands to lowland and highland areas. The districts of Sekota Lalibela and Dehana are characterized primarily as midlands. These areas are very suitable for the occurrence of these species, according to the model. The model showed potential distribution in Sekota, Lalibela, Gazgibla, Dehana, and Sekota, the most suitable districts, while the lowland arid areas were identified as unsuitable. These districts include Abergele, Ziquala and Sehala, characterized as dry arid areas with average annual rainfall less than 750 mm.

Nevertheless, these areas' climatic and environmental variables are reported as suitable with this study and accepted elsewhere as the determinant variables for these species.

The shortcoming of the study is that we developed a model for the genus Melipona without species identification. Even though species identification was not carried out, a study showed that only six species of the genus exist in Ethiopia. Namely; *Meliponula beccarii* (Gribodo, 1879), *Liotrigona bottegoi* (Magretti, 1895), L. *baleensis* sp. *nov*., *Hypotrigona gribodoi* (Magretti, 1884), *H. ruspolii* (Magretti, 1898) *and Plebeina armata* [10]. Hence, we believe the model developed at the genus level can represent these species found in Ethiopia.

Conclusion

This study is the first of its kind in Ethiopia to map suitable territories for stingless bees. The study area has ten districts, namely Sekota, Dehana, Ziquala, Abergele, Sehala, Tsagbji and Gazgibla from Waghemira zone; and Gidan, Lalibela and Bugna from the North Wollo zone (Lasta area). Among the districts, Sekota and Dehana from the Wag area; Lalibela from the Lasta were found highly suitable for stingless bees. On the other hand, the lowland districts of Abergelle, Ziquala and Sahala Seyemnt were unsuitable. Variables including Water vapor pressure (35%), precipitation seasonality (25.1%), elevation (12.3%), temperature annual range (11.7%) and wind speed (7.4%) contributed the highest share in the model. This study can be a supportive tool for stingless be collection, domestication and commercialization in the study area and similar agroecology in the country. We urge extending the study's extent to a national or sub-regional level with more occurrence data; species identification and characterization of the genus melipona is highly advised.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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Author contribution

AA, managed the data, developed the model and wrote the manuscript; ML designed the study and collected data. All authors read and approved the final manuscript

Data Availability

The data used can be found upon request to the corresponding author

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