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Current and future predicting potential areas of *Oxytenanthera abyssinica* (A. Richard) using MaxEnt model under climate change in Northern Ethiopia

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Abstract

Introduction: Climate change will either improve, reduce, or shift its appropriate climatic habitat of a particular species, which could result in shifts from its geographical range. Predicting the potential distribution through MaxEnt modeling has been developed as an appropriate tool for assessing habitat distribution and resource conservation to protect bamboo species.

Methods: Our objective is to model the current and future distribution of *Oxytenanthera abyssinica* (A. Richard) based on three representative concentration pathways (RCP) (RCP2.6, RCP4.5, and RCP8.5) for 2050s and 2070s using a maximum entropy model (MaxEnt) in Northern Ethiopia. For modeling procedure, 77 occurrence records and 11 variables were retained to simulate the current and future distributions of *Oxytenanthera abyssinica* in Northern Ethiopia. To evaluate the performance of the model, the area under the receiver operating characteristic (ROC) curve (AUC) was used.

Results: All of the AUCs (area under curves) were greater than 0.900, thereby placing these models in the "excellent" category. The jackknife test also showed that precipitation of the coldest quarter (Bio19) and precipitation of the warmest quarter (Bio18) contributed 66.8% and 54.7% to the model. From the area of current distribution, 1367.51 km^2 (2.52%), 7226.28 km^2 (13.29%), and 5377.26 km^2 (9.89%) of the study area were recognized as high, good, and moderate potential habitats of *Oxytenanthera abyssinica* in Northern Ethiopia, and the high potential area was mainly concentrated in Tanqua Abergele (0.70%), Kola Temben (0.65%), Tselemti (0.60%), and Tsegede (0.31%). Kafta Humera was also the largest good potential area, which accounts for 2.75%. Compared to the current distribution, the total area of the high potential regions and good potential regions for *Oxytenanthera abyssinica* under the three RCPs (RCP2.6, RCP4.5, and RCP8.5) would increase in the 2050s and 2070s. However, the total area of the least potential regions under the three RCPs (RCP2.6, RCP4.5, and RCP8.5) in 2050s and 2070s would decrease.

Conclusion: This study can provide vital information for the protection, management, and sustainable use of *Oxytenanthera abyssinica*, the resource to address the global climate challenges.

Keywords: *Oxytenanthera abyssinica*, MaxEnt model, Climate change

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Introduction

Bamboo plants grow in the tropical and temperate regions, with predominance in Southeast Asia (Banik 1985). There are more than 1500 species of bamboo in the globe (Ohrnberger 1999), covering more than 14 million ha of land. About 40 of these species occur naturally or have been introduced in Africa, with an area of more than 1.5 million ha of land (Kigomo 1988), and two of these species are indigenous to Ethiopia: *Oxytenanthera abyssinica* (A. Richard) (lowland bamboo) and *Arundinaria alpina* (K. Schum.) (highland bamboo). The natural forest of bamboo in Ethiopian covers around 1 million ha, about 7% of the total forest cover of bamboo in the world and 67% of African bamboo forest area (Embaye 2003). About 130,000 ha of *Arundinaria alpina* and about 850,000 ha of *Oxytenanthera abyssinica* are found scattered in the northern, south, south-west, and central parts of Ethiopia. They were in natural forest conditions that were more or less pure, completely distributed. However, for agricultural land expansion, they are being cleaned at an accelerating rate, burned to promote more tender grass growth for grazing and destroy supposedly damaging insects. Large plantations of coffee and tea and metropolitan expansion also emerge as actual and potential threats (Embaye 2003). Sustained availability and utilization can be ensured by proactive bamboo cultivation (Shanmughavel and Francis 1995).

Bamboo is important for socio-economic growth potential (Baghel et al. 1998, Perez et al. 1999) and environmental protection (Bystriakova et al. 2004). It can be also used as an agroforestry species, for house building, for animal feed, for human consumption (Christanty et al. 1997), for soil fertility maintenance (Gebrewahid et al. 2019), as a source of cash revenue, and as a medicine for the treatment of many disease types (Yuming et al. 2004). The forest of bamboo is also a source of wood for furnishings, pulp, particleboard, and bioenergy (Embaye 2000).

In order to know the overall distribution trends and to protect *Oxytenanthera abyssinica* species, it is important to examine important environmental variables affecting their natural distribution. This data can then be used to determine appropriate places to protect the habitat. Our objective was therefore to define the potential distribution of *Oxytenanthera abyssinica* and environmental constraints using MaxEnt in Northern Ethiopia. This research concentrated primarily on the following strategy: (1) *Oxytenanthera abyssinica*'s dominant environmental factors were selected to develop a model, (2) identification of the present potential regions for cultivation and conservation of *Oxytenanthera abyssinica* by current bioclimatic factors, and (3) model-based predictions were predicted for potential distributions of *Oxytenanthera abyssinica* under multiple future climate scenarios.

Materials and methods

Study species

Oxytenanthera abyssinica (Poaceae) is prominent in river basins and locally on the western part of the central highlands in dry and moist Kolla agroclimatic areas of Benishagul Gumuz and Western Tigray from 1200 to 1800 m above sea level (Bekele-Tesemma and Tengnäs 2007). The species is categorized to tall grass with woody culms and a height of 13 m (Phillips 1995), unusual for a solid stem with a diameter of up to 10 cm at the base (Bekele-Tesemma and Tengnäs, 2007, Bein et al. 1996). The annual rainfall ranges from approximately 700 to 1000 mm, concentrated over a range of 3 to 4 months at an average annual temperature above 30 °C (UNIDO 2009). The species adapts widely to low fertile soils and provides to desert regions as a buffer area (UNIDO 2009). This species flowering happens approximately every 7 years, and then, the clumps disappear but grow up from the rhizomes 1 year later (Bekele-Tesemma and Tengnäs 2007).

Species occurrence and environmental data

A total of 77 locations with *Oxytenanthera abyssinica* occurrence were recorded during 2018–2019 using the Global Positioning System (GPS) and field surveys. All present data have been entered into Microsoft Excel and saved as format "CSV." The most significant factors in identifying environmental niches of species are bioclimatic factors. The 19 bioclimatic variables resulted from the long-term recording of monthly rainfall and temperature value (1950–2000) (Hijmans et al. 2005). The data had a spatial resolution of approximately 1 km^2 (30 s) and was downloaded from the WorldClim dataset (www.worldclim.org). General Circulation Model (GCM) Representative Climate Community Climate System Model version 4 (CCSM4) was used to estimate the impacts of the future climate on *Oxytenanthera abyssinica*. To test *Oxytenanthera abyssinica* habitat suitability ranges in the 2050s (2041–2060) and 2070s (2061–2080), RCP2.6 (the minimum scenario for GHG emissions), RCP4.5 (the intermediate scenario for GHG emissions), and RCP8.5 (the highest scenario for GHG emissions) were used. In total, 19 bioclimatic variables (Bio1–Bio19) and 2 topographical factors (slope and altitude) were used to identify factors with the biggest influences on distribution of

Table 1 Environmental variables used in species distribution modeling process

Variable code	Variable type	Unit
Bio1	Annual mean temperature	℃
Bio2	Mean diurnal range (max temp − min temp) (monthly average)	℃
Bio3	Isothermality (Bio1/Bio7) × 100	℃
Bio4	Temperature seasonality (co-efficient of variation)	℃
Bio5	Max temperature of warmest period	℃
Bio6	Min temperature of coldest period	℃
Bio7	Temperature annual range (Bio5 − Bio6)	℃
Bio8	Mean temperature of wettest quarter	℃
Bio9	Mean temperature of driest quarter	℃
Bio10	Mean temperature of warmest quarter	℃
Bio11	Mean temperature of coldest quarter	℃
Bio12	Annual precipitation	mm
Bio13	Precipitation of wettest period	mm
Bio14	Precipitation of driest period	mm
Bio15	Precipitation seasonality (co-efficient of variation)	mm
Bio16	Precipitation of wettest quarter	mm
Bio17	Precipitation of driest quarter	mm
Bio18	Precipitation of warmest quarter	mm
Bio19	Precipitation of coldest quarter	mm
Elevation	Elevation	m
Slope	Slope	%

Oxytenanthera abyssinica (Table 1). Using ArcGIS software version 10.3, the Advanced Space-borne Thermal Emission and Reflection Radiometer Digital Elevation Model (Aster DEM) information was used to produce slope maps and the Aster DEM variable with 30 m spatial resolution was downloaded from Geospatial Data Cloud (http://www.gscloud.cn/). The Pearson correlation coefficient was used to account for multicollinearity between the bioclimatic (Bio1–Bio19) and topographic (elevation and slope) variable factors (Elith et al. 2006, Stohlgren et al. 2011). In order to determine and exclude extremely correlated variables, removing all the variables with correlation coefficient < 0.8 (Elith et al. 2010) was used as a cutoff limit to minimize the effect of multicollinearity and model overfitting (Wang et al. 2018) and maintain 11 variables below this threshold to simulate *Oxytenanthera abyssinica* current and future outcomes in Northern Ethiopia (Table 2). The contribution percentage and permutation importance are significant factors that assess the environmental variable importance. Permutation importance rather than the path is used in an individual run-up to the final results of the model and therefore is easier for

assessing the significance of a particular variable (Songer et al. 2012).

Data analysis

MaxEnt is now a popular species distribution modeling (SDM) instrument used to predict species distribution (Fourcade et al. 2014) and classified as a background activity technique (presence information only). It uses the maximum entropy algorithm and incidence of species to estimate the likelihood of incidence of species in unidentified event regions (Phillips 2006). This technique is not susceptible to sample size and in comparison to environmental variables can produce species response curves (Khanum et al. 2013). Independent data collected from sites other than those used to train the model are essential to evaluate the predictive performance of the model. Therefore, species occurrence information for model calibration was divided into a training set (75% of total occurrence records) and test set (25% of total occurrence records) for design assessment. All environmental factors have been converted to the same pixel size (30 m) and projection (meter) ASCII raster grids format. The modeling process is

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Table 2 Correlation matrix among environmental variables

Layer	Bio1	Bio2	Bio3	Bio4	bio5	Bio6	Bio7	Bio8	Bio9	Bio10	Bio11	Bio12	Bio13	Bio14	Bio15	Bio16	Bio17	Bio18	Bio19	Elevation	Slope
Bio1	1																				
Bio2	0.755	1																			
Bio3	− 0.282	− 0.331	1																		
Bio4	0.608	0.736	− 0.693	1																	
Bio5	0.990	0.808	− 0.362	0.681	1																
Bio6	0.989	0.683	− 0.228	0.548	0.976	1															
Bio7	0.718	0.935	− 0.637	0.862	0.792	0.638	1														
Bio8	0.985	0.757	− 0.300	0.622	0.977	0.970	0.727	1													
Bio9	0.992	0.718	− 0.248	0.590	0.979	0.991	0.675	0.968	1												
Bio10	0.997	0.783	− 0.324	0.661	0.995	0.981	0.757	0.983	0.988	1											
Bio11	0.998	0.761	− 0.260	0.590	0.987	0.986	0.714	0.978	0.991	0.995	1										
Bio12	0.221	0.204	− 0.088	0.313	0.276	0.277	0.197	0.152	0.277	0.243	0.228	1									
Bio13	0.181	0.360	0.011	0.275	0.236	0.196	0.284	0.099	0.195	0.206	0.209	0.739	1								
Bio14	− 0.432	− 0.441	0.252	− 0.367	− 0.467	− 0.427	− 0.452	− 0.347	− 0.424	− 0.447	− 0.449	− 0.273	− 0.619	1							
Bio15	0.310	0.498	− 0.052	0.253	0.341	0.279	0.421	0.244	0.274	0.325	0.341	0.159	0.729	− 0.845	1						
Bio16	0.381	0.460	− 0.110	0.402	0.432	0.396	0.412	0.283	0.401	0.406	0.404	0.785	0.952	− 0.717	0.716	1					
Bio17	− 0.411	− 0.471	0.235	− 0.350	− 0.448	− 0.396	− 0.468	− 0.330	− 0.388	− 0.427	− 0.430	− 0.219	− 0.645	0.967	− 0.901	− 0.728	1				
Bio18	− 0.416	− 0.244	− 0.121	− 0.096	− 0.372	− 0.414	− 0.152	− 0.360	− 0.442	− 0.402	− 0.420	− 0.026	− 0.138	0.325	− 0.298	− 0.250	0.334	1			
Bio19	0.502	0.397	− 0.148	0.482	0.533	0.537	0.375	0.430	0.548	0.517	0.501	0.674	0.575	− 0.471	0.314	0.697	− 0.441	− 0.378	1		
Elevation	− 0.979	− 0.703	0.286	− 0.554	− 0.963	− 0.970	− 0.678	− 0.961	− 0.972	− 0.973	− 0.976	− 0.175	− 0.105	0.408	− 0.258	− 0.322	0.384	0.427	− 0.458	1	
Slope	− 0.310	− 0.224	0.094	− 0.106	− 0.297	− 0.296	− 0.215	− 0.316	− 0.279	− 0.303	− 0.313	0.121	0.006	0.226	− 0.214	− 0.047	0.241	0.109	− 0.067	0.330	1

chosen for linear and quadratic features. The model generated was evaluated by calculating the AUC of the receiver operating characteristic (ROC) plot (Phillips 2006). The AUC is a model performance measure and ranges between 0 and 1, and perfect discrimination shows a value of 1 (Fielding and Bell 1997). The AUC was an efficient autonomous threshold index capable of evaluating the ability of a model to discriminate presence from absence. AUC scores could be divided into five categories (Swets 1988). AUC < 0.5 describes models that are less than chance and rarely occur in reality. An AUC of 0.5 is a pure guess. Model performance is classified as failing (0.5 to 0.6), bad (0.6 to 0.7), reasonable (0.7 to 0.8), good (0.8 to 0.9), or great (0.9 to 1) (Swets 1988). The jackknife test (systematically excluding each variable) was used to assess the dominant environmental variables that determined the species potential distribution (Yang et al. 2013). Species response curves were created to investigate the relationship between target species habitat suitability and environmental factors. The prospective species distribution chart generated had values ranging from 0 to 1. These values have been grouped into four groups: high potential (> 0.6), good potential (0.4–0.6), moderate potential (0.2–0.4), and low potential (< 0.2) (Yang et al. 2013).

Results

Evaluations of the model and its importance to variables under current climatic condition

The calibration of the model for *Oxytenanthera abyssinica* was satisfactory (AUCmean = 0.903, Fig.

1). The findings indicated that *Oxytenanthera abyssinica* current distribution characterized by the selected variables is excellent. The test of the jackknife indicates the distribution of *Oxytenanthera abyssinica* was mainly influenced by the coldest quarter precipitation (Bio19) and warmest quarter precipitation (Bio18) and contributed 42.0% and 24.8% to the MaxEnt model (Fig. 2). The species habitat model was also collectively contributed by nine other layers of environmental factors of 32.3% and two topographic factors of 6.5% (Fig. 2 and Table 3). In consideration of the permutation importance, precipitation of the coldest quarter (Bio19) had the highest impact on the habitat model and contributed 33.3%, while precipitation of the warmest quarter (Bio18) and isothermality (Bio3) together contributed 32.9% (Table 3). Species response curve depicts the relationship between environmental variables and the probability of species incidence; they show biological tolerances for target species and habitat preferences. Based on the species response curves acquired, *Oxytenanthera abyssinica* prefers the coldest quarter precipitation ranges from 700 to 780 mm, warmest quarter precipitation ranges from 10 to 45 mm, isothermal ranges from 76 to 77 °C, driest quarter precipitation ranges from 80 to 150 mm, and seasonal precipitation ranges from 145 to 155 mm (Fig. 3).

Current potential distribution of *Oxytenanthera abyssinica*

Species distribution maps indicated that 2.52%, 13.29%, and 9.89% of the study area respectively
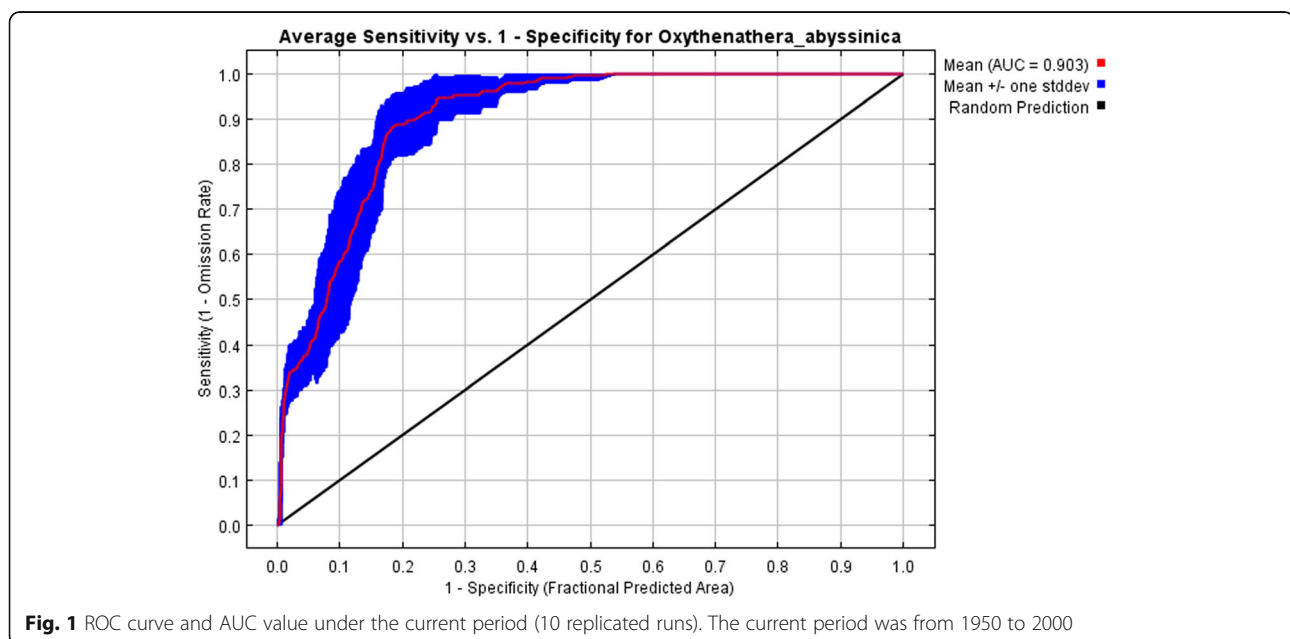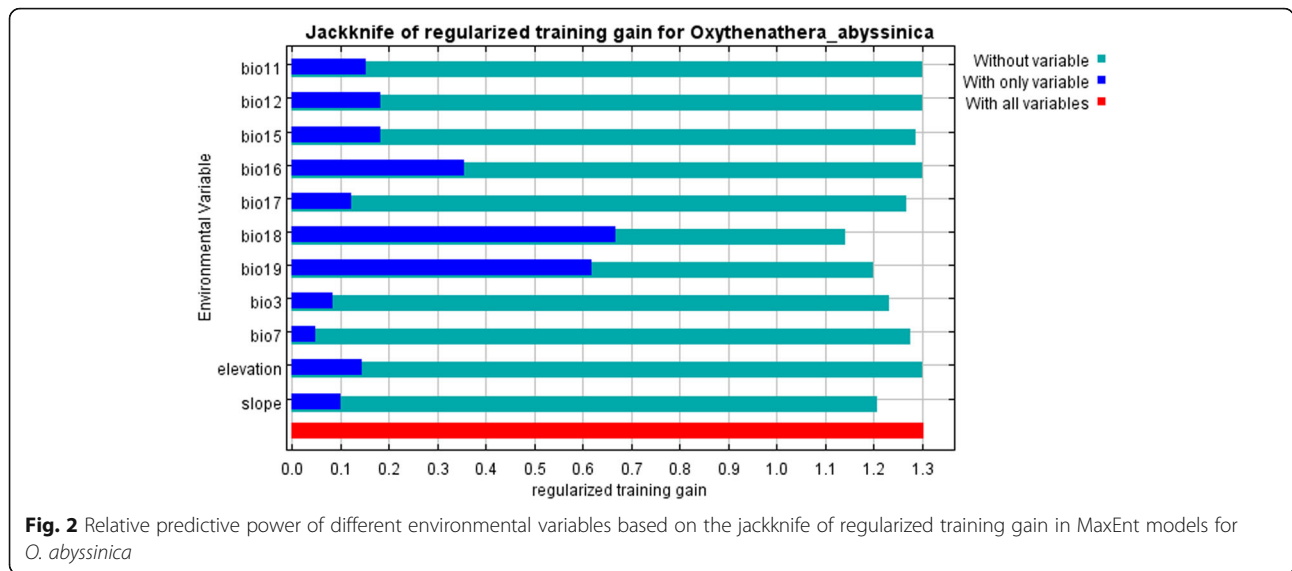

Fig. 1 ROC curve and AUC value under the current period (10 replicated runs). The current period was from 1950 to 2000

Fig. 2 Relative predictive power of different environmental variables based on the jackknife of regularized training gain in MaxEnt models for *O. abyssinica*
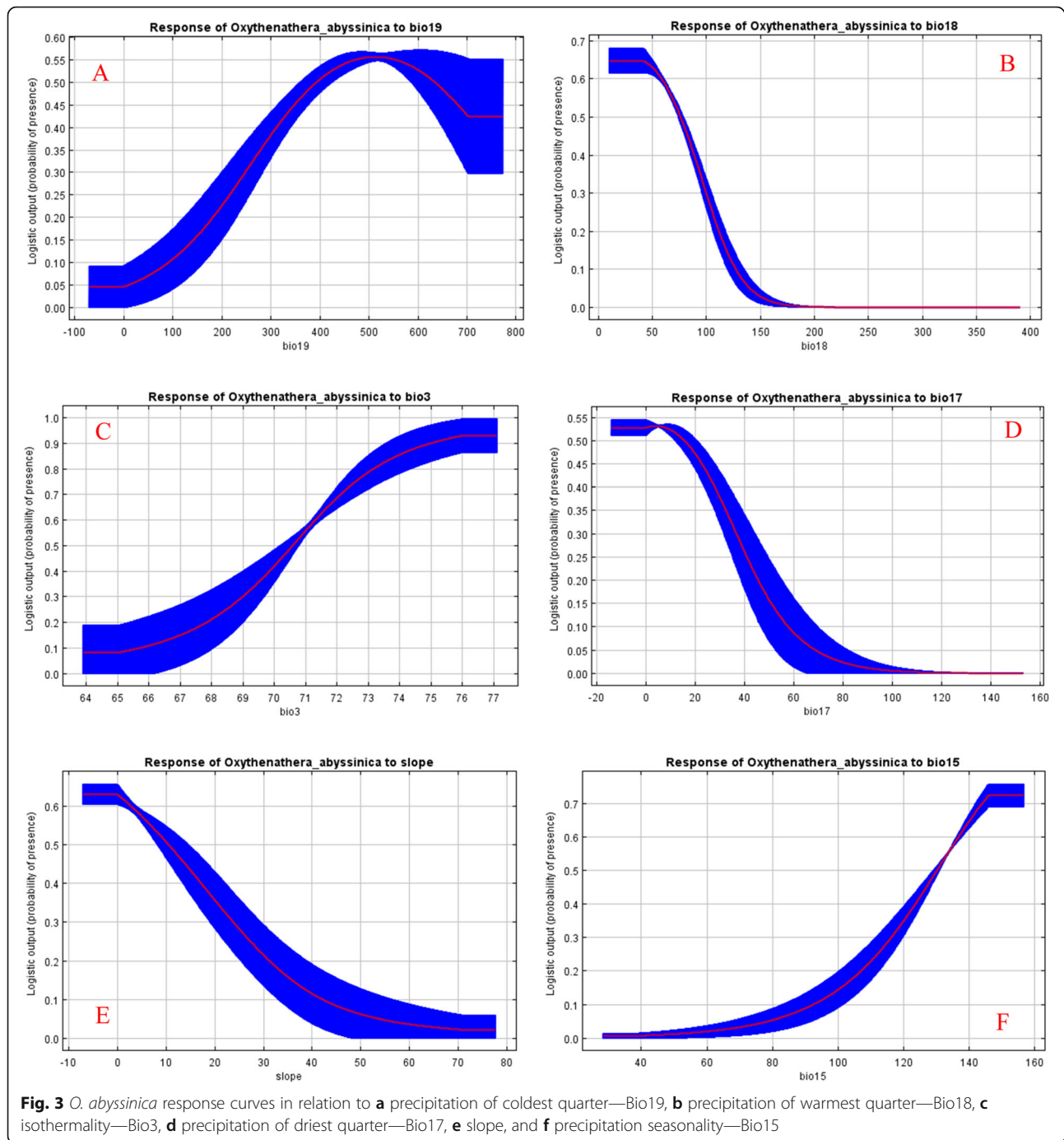
were identified as high, good, and moderate potential habitats of *Oxytenanthera abyssinica* in Northern Ethiopia (Table 4 and Fig. 4). Apparently, mainly in Central and Northwestern Tigray were identified as the high distribution areas. In addition, *Oxytenanthera abyssinica*'s ecologically good distribution areas were mainly situated in lowland areas of West and Northwest of Tigray. The average of *Oxytenanthera abyssinica*'s high distribution region was estimated 1367.51 km² (2.52%), while the good and moderate distributed regions were about 7226.28 (13.29%) and 5377.26 km² (9.89%).

Model evaluations and its importance to variables under different scenarios

The AUC values for 2050s RCP 2.6, 2070s RCP 2.6, 2050s RCP 4.5, 2070s RCP 4.5, 2050s RCP 8.5, and 2070s RCP 8.5 were respectively 0.887, 0.892, 0.915, 913, 0.908, and 0.924, indicating that the expected findings were very accurate. By selecting the option "Do jackknife to measure important variable" (Jackknife), the percentage contribution values of each ecological factor (Table 3) were obtained, which were defined only heuristically and depended on the specific path used by the MaxEnt code to obtain the

Table 3 Estimates of relative contributions and permutation importance of the predictor environmental variables to the MaxEnt model

Time	RCPs	Variable	Bio3	Bio7	Bio11	Bio12	Bio15	Bio16	Bio17	Bio18	Bio19	Elevation	Slope
Present time		Percent contribution	11.1	2.3	0.8	0.1	5.3	0.1	7.0	24.8	42.0	0.1	6.4
		Permutation importance	11.5	6.2	0.6	3.1	8.3	2.3	8.8	21.4	33.3	0.7	3.8
2050	2.6	Percent contribution	11.8	2.2	2.4	2.0	6.1	4.8	5.2	3.0	50.6	2.5	9.4
		Permutation importance	3.9	2.2	8.3	7.1	8.3	34.7	13.7	3.2	4.8	11.8	1.9
	4.5	Percent contribution	18.6	5.8	1.9	–	5.4	10.0	4.6	3.6	40.1	2.4	7.4
		Permutation importance	8.0	1.9	6.5	–	6.1	30.6	10.2	17	7.6	7.8	4.2
	8.5	Percent contribution	10.1	1.1	4.1	–	6.9	14.4	5.8	4.7	38.7	5.7	8.3
		Permutation importance	1.0	1.6	12.3	–	9.8	39.0	13.7	3.9	7.2	9.0	2.5
2070	2.6	Percent contribution	7.0	1.5	1.2	1.9	7.6	7.3	7.9	12.8	41.6	3.9	7.4
		Permutation importance	1.3	2.2	7.6	14.3	15.6	18.4	12.1	7.4	7.4	10.6	3.2
	4.5	Percent contribution	13.8	3.6	4.6	3.1	7.2	6.7	3.7	1.6	44.0	3.8	7.9
		Permutation importance	4.9	0.1	11.7	18.1	15.6	19.8	10.8	2.1	3.5	10.0	3.3
	8.5	Percent contribution	7	0.9	2.3	–	7.5	14.4	3.1	0.9	45.2	9.4	9.3
		Permutation importance	2.5	0.7	2.8	–	3.8	46.0	5.6	3.0	16.1	15.1	4.6

Fig. 3 *O. abyssinica* response curves in relation to **a** precipitation of coldest quarter—Bio19, **b** precipitation of warmest quarter—Bio18, **c** isothermality—Bio3, **d** precipitation of driest quarter—Bio17, **e** slope, and **f** precipitation seasonality—Bio15

optimal solution. The model also referred to the impact of environmental factors in determining the optimal parameters of the environment (Fig. 5). The jackknife test reveals that the distribution of *Oxytenanthera abyssinica* was mainly influenced by the coldest quarter precipitation (Bio19) in all predictions which contributed 50.6%, 40.1%, 38.7%, 41.6%,

44%, and 45.2% for 2050s RCP 2.6, 2050s RCP 4.5, 2070s RCP 2.6, 2070s RCP 4.5, and 2070s RCP 8.5, respectively, to the MaxEnt model (Fig. 5). According to the species response curves obtained, *Oxytenanthera abyssinica* prefers precipitation coldest-quartered habitats which ranges from 700 to 860 mm, 730 to 900 mm, 650 to 870 mm, 810 to 910

Table 4 Predicted potential distribution areas for *O. abyssinica* under current climatic conditions

Number	Wereda	Zone name	Moderate potential (ha)	Good potential (ha)	High potential (ha)	Percentage of moderate potential	Percentage of good potential	Percentage of high potential
1	Abiy Adi Town	Central	14.67	71.73	2225.07	0.0003	0.0013	0.0409
2	Asgede Tsimbla	North Western	58,997.61	47,796.30	3018.33	1.0854	0.8791	0.0555
3	Degua Temben	South Eastern	482.04	311.94	1220.85	0.0089	0.0057	0.0225
4	Kafta Humera	Western	150,599.16	149,431.68	–	2.7707	2.7484	0.0000
5	Kola Temben	Central	9586.44	19,007.55	35,447.04	0.1764	0.3496	0.6522
6	Medebay Zana	North Western	11,628.54	22,066.11	3695.76	0.2139	0.4059	0.0680
7	Naeder Adet	Central	13,576.14	21,789.36	2888.10	0.2498	0.4008	0.0531
8	Saharti Samre	South Eastern	8500.32	1476.09	534.24	0.1564	0.0271	0.0098
9	Tahtay Adiyabo	North Western	582.39	108.18	–	0.0107	0.0020	0.0000
10	Tahtay Koraro	North Western	2347.74	812.97	13.32	0.0432	0.0150	0.0002
11	Tahtay Maychew	Central	2641.77	4532.13	22.68	0.0486	0.0834	0.0004
12	Tanqua Abergele	Central	8953.20	6991.47	38,082.60	0.1647	0.1286	0.7007
13	Tsegede	Western	45,753.93	193,899.69	16,805.88	0.8418	3.5663	0.3092
14	Tselemti	North Western	68,990.31	122,974.47	32,595.57	1.2693	2.2618	0.5997
15	Welkait	Western	155,072.34	131,358.60	201.60	2.8530	2.4160	0.0037
	Total area		537,726.60	722,628.27	136,751.04	9.89	13.29	2.52

mm, and 850 to 960 mm for 2050s RCP 2.6, 2070s RCP 2.6, 2070s RCP 4.5, 2050s RCP 8.5, and 2070s RCP 8.5 climate projections, respectively.

Future prediction potential distribution of *Oxytenanthera abyssinica*
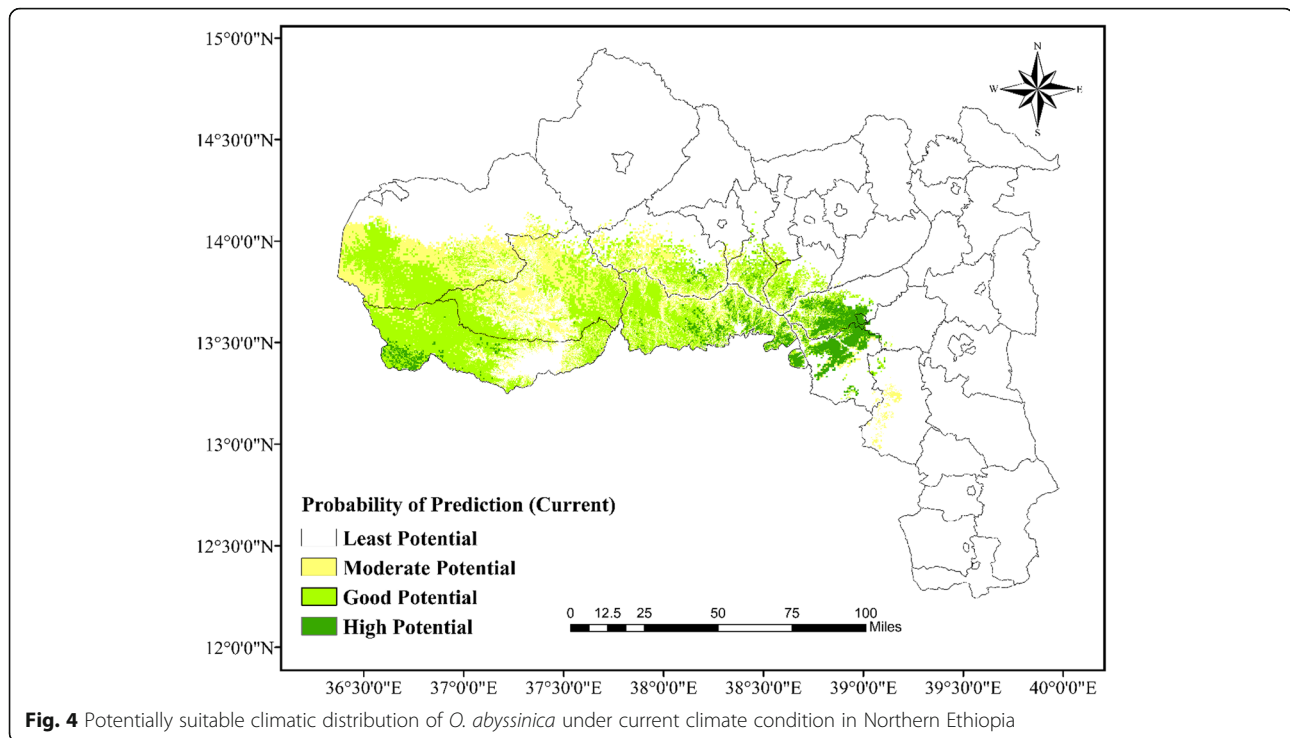
Species distribution maps revealed that in the mid-century (2050), projections of RCP 2.6, RCP 4.5, and RCP 8.5 scenarios of the study area were identified as high potential habitats for *Oxytenanthera abyssinica* which were 3.21%, 5.52%, and 5.61% respectively (Table 7 and Fig. 6), and projections for high potential habitats of *Oxytenanthera abyssinica* in the end century (2070) scenarios of RCP 2.6, RCP 4.5, and RCP 8.5 were 3.68%, 5.79%, and 6.70%, respectively. MaxEnt's average future predictions for 2050 and 2070 (CCSM4 emission scenario) revealed an increment in suitable habitats of *Oxytenanthera abyssinica* in lowland sites of Central, Western, Northwestern, and Western areas of Tigray (Tables 5 and 6). In the mid-century (2050), the highest potential distribution area for *Oxytenanthera abyssinica* was dominated in Tanqua Abergele, Tsegeda, and Tselemti area in all RCP's (Table 5), and in the end century (2070), Tanqua Abergele was the highest potential distribution area for *Oxytenanthera abyssinica* in all RCP's, whereas Teselemti and Asgede Tsimbla have the highest potential in RCP 2.6, Tselemti and Tsegedea have the highest

potential in RCP 4.5, and Tsegede and Welkait have the highest potential in RCP 8.5 for distribution of *Oxytenanthera abyssinica* (Table 6). Future scenarios increase over the current distribution of *Oxytenanthera abyssinica* by 21.5% in 2050s RCP 2.6, 31.5% in 2070s RCP 2.6, 54.3% in 2050s RCP 4.5, 56.5% in 2070s RCP 4.5, 55.1% in 2050s RCP 8.5, and 62.4% in 2050s RCP 8.5 (Table 7).

Discussion
Oxytenanthera abyssinica habitat suitability and their important environmental variables

Climate modeling of tree distribution has shown that future global climate change will have important effects on forest ecosystems (Hamann and Wang 2006, Wang et al. 2011). Discrepancies exist between varying climate modeling models (Cheaib et al. 2012), but the strategy still acts as a significant study tool to assess and predict future changes in the distribution of species (Iverson and McKenzie 2013). *Oxytenanthera abyssinica* is a threatened plant, and its population in its native areas has been steadily declining due to numerous human-induced threats, primarily habitat fragmentation and illegal harvesting (Embaye 2003). In addition, economically significant species such as *Oxytenanthera abyssinica* are considered as an indication of environmental integrity and play a crucial part in the restoration of Northern Ethiopia's degraded ecosystem, and hence, its

Fig. 4 Potentially suitable climatic distribution of *O. abyssinica* under current climate condition in Northern Ethiopia

conservation is of the highest significance in the context of Northern Ethiopia's future predicted warming climate. Research showed a more detailed survey on the suitable habitat of *Oxytenanthera abyssinica* in Northern Ethiopia using the MaxEnt ecological niche modeling software that will help as a significant first stage in the development of strategies and policies to manage and use this important forest tree.

Our models achieved AUC values of 0.903 which for models to be considered strong are within the acceptable range. Swets (1988), Elith (2000), and Pearce and Ferrier (2000) stated that AUC values above 0.75 might be helpful and appropriate in evaluating the performance of a niche model. After removing auto-correlated parameters (Table 1), MaxEnt stated that three factors of precipitation (Bio17, Bio18, and Bio19), slope, and one temperature (Bio3) had 91.3% more contribution to the current distribution of *Oxytenanthera abyssinica* (Table 3). The main role in determining the potential distribution habitats of *Oxytenanthera abyssinica* is played by precipitation and temperature (Zhong et al. 2010).

Changes in the distribution of *Oxytenanthera abyssinica* in the future

Future model projections from the 2050s and 2070s obtained from the IPCC climate change scenario

indicated that climate change would significantly affect this species distribution, but the particular impacts will differ from one location to another. Overall, in response to global warming, the model predicted that highly and good suitable habitats would be expanded in most areas, but these more suitable habitats will effectively reduce in a few particular places. In addition, in response to the predicted climate changes, the overall locations of the most favorable habitats would significantly shift in most woredas. Global warming promotes the growth of vegetation (Cao et al. 2004, Xu et al. 2015), and a simulation of the warming climate in Northern Ethiopia's hilly area found that temperature had a positive impact on the mountain steppe by accelerating the growing season's alpine process. However, a continuous increase in temperature had an adverse impact on plants (Xu and Xue 2013). The moderate, good, and high potential of the overall landscape and areas with habitats suitable for *Oxytenanthera abyssinica*'s survival in the RCP8.5 scenario was higher than in RCP2.6 and RCP 4.5 in both mid-century (the 2050s) and end-century (the 2070s). Therefore, an increase in temperature might be a cause shifting their habitat from the lower elevation to the higher elevation, and this leads to an increase in *Oxytenanthera abyssinica*'s distribution in those
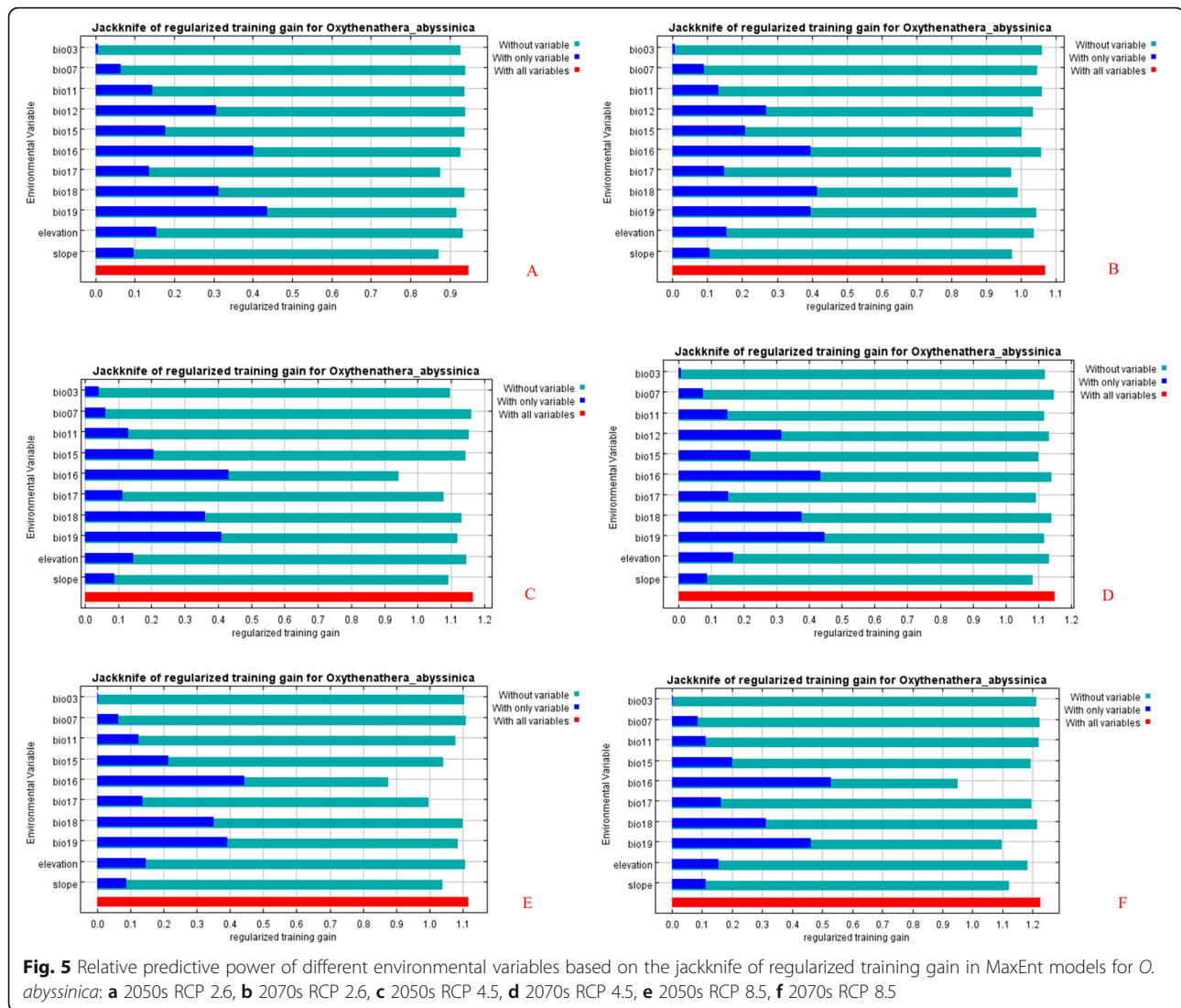
Fig. 5 Relative predictive power of different environmental variables based on the jackknife of regularized training gain in MaxEnt models for *O. abyssinica*: **a** 2050s RCP 2.6, **b** 2070s RCP 2.6, **c** 2050s RCP 4.5, **d** 2070s RCP 4.5, **e** 2050s RCP 8.5, **f** 2070s RCP 8.5

sites over time and especially towards the end of the century.

If the establishment or expansion of the current areas is not viable due to financial, political, or cultural constraints, this study suggests that in such vulnerable environmental regions, collaborative *Oxytenanthera abyssinica* habitat conservation programs should be developed and implemented with grassroot assistance. Through some exemplary efforts, such as area closure programs, Tigray regional state is regarded as a leader in human-oriented conservation practice in the global arena. Rainfall is the main factor of *Oxytenanthera abyssinica* distribution, and such collaborative programs aimed at soil and water conservation will increase the habitat of *Oxytenanthera abyssinica* and support *Oxytenanthera abyssinica* in changing potential warming

impacts. This not only helps *Oxytenanthera abyssinica* but also other economically important species in areas that are similarly vulnerable and may lose their habitat due to such unexpected warming. An appropriate strategy in this sense could be to implement socio-ecological frameworks for landscape planning and conservation that link human beings and their socio-culture and ecological mechanisms (Virapongse et al. 2016, Lamsal et al. 2017, Martín-López et al. 2017).

There is uncertainty in the modeling of the distribution of species, primarily due to several basic assumptions of the model and gaps in potential changes in greenhouse gases (GHG) emissions. It should be observed that while MaxEnt is efficient in modeling species habitat niche with small occurrence data and restricted ecological information, the climate factors
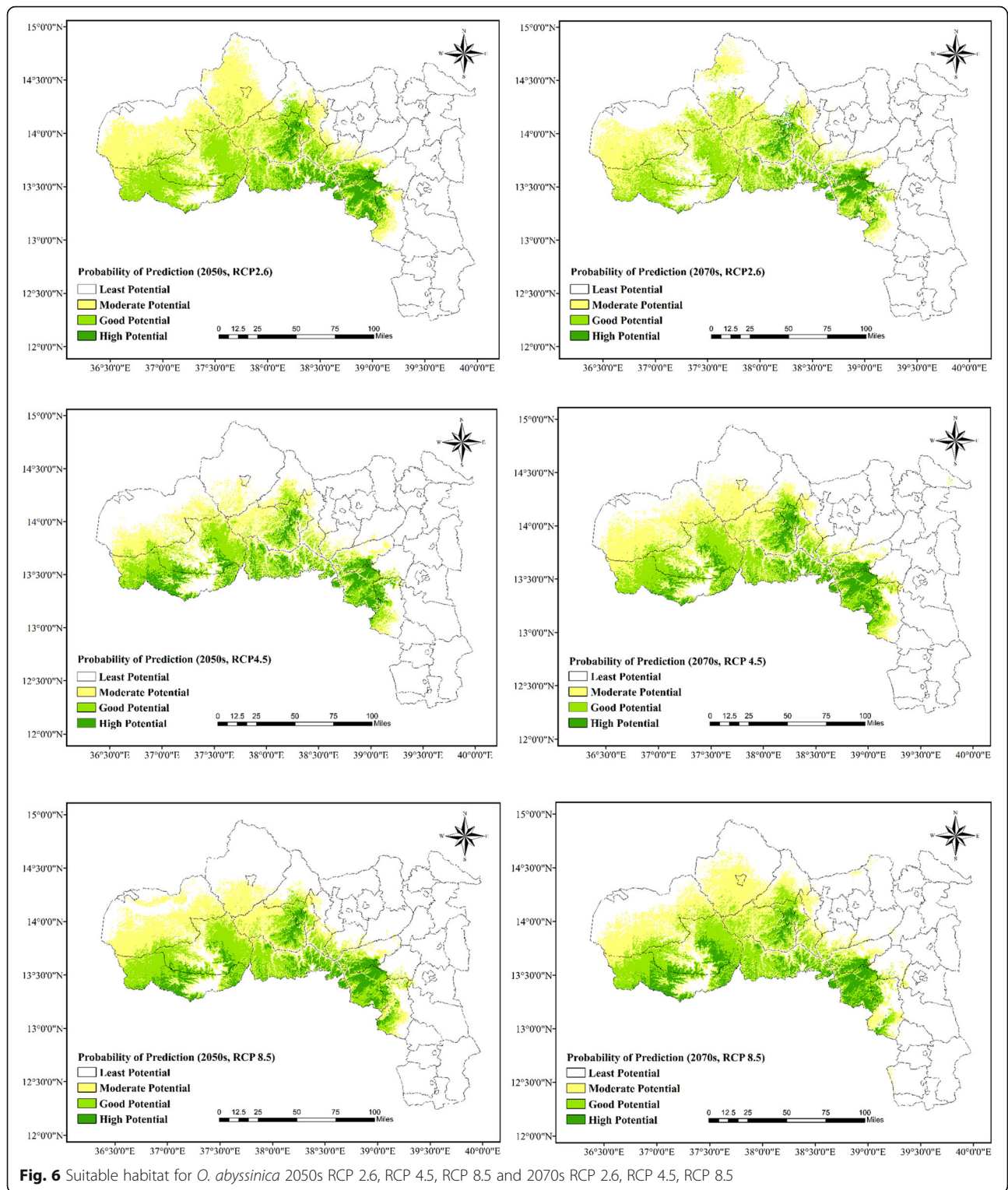
Fig. 6 Suitable habitat for *O. abyssinica* 2050s RCP 2.6, RCP 4.5, RCP 8.5 and 2070s RCP 2.6, RCP 4.5, RCP 8.5

used in this model may not adequately clarify the current and future distribution of species. Non-climatic factors such as biotic interaction, species dispersal mode and ability, potential land-cover changes, and other anthropogenic factors have not been used

in the model that might influence the results, and this is a limitation of the research. Although these species distribution models have many assumptions and uncertainties, such species distribution models still remain a critical data source for future suitability

Table 5 Predicted potential distribution areas (ha) for *O. abyssinica* under mid-century (2050) climatic conditions

Number	Wereda	Zone name	RCP 2.6 2050			RCP 4.5 2050			RCP 8.5 2050		
			Moderate	Good	High	Moderate	Good	High	Moderate	Good	High
1	Abiy Adi Town	Central	113.04	239.31	2106.54	190.08	390.69	1808.64	164.70	232.02	2014.74
2	Asgede Tsimbla	North Western	153,098.73	33,914.43	1205.28	121,047.48	52,065.99	21,710.52	125,224.65	70,094.97	28,562.04
3	Degua Temben	South Eastern	1760.94	1209.78	1018.89	8480.79	3379.05	1027.44	8738.82	3106.80	972.27
4	Enderta	South Eastern	–	–	–	806.85	88.83	–	2750.13	271.89	–
5	Hintalo Wejirat	South Eastern	–	–	–	218.79	–	–	1060.02	46.53	–
6	Shire E/slasie	North Western	38.16	–	–	126.63	468.99	827.01	125.01	425.25	908.64
7	Kafta Humera	Western	213,494.85	26,362.53	161.55	193,515.03	19,947.06	26.19	337,298.58	30,420.72	11.25
8	Kola Temben	Central	24,499.71	22,668.21	25,020.99	36,023.49	18,737.19	16,313.49	32,066.82	21,380.94	24,939.18
9	Laelay Adiyabo	North Western	34,040.61	827.19	0.54	39,772.17	15,071.94	633.69	28,703.61	9823.50	12.87
10	Medebay Zana	North Western	30,996.72	10,459.08	894.78	32,846.76	9948.60	507.51	33,153.12	16,629.66	1132.02
11	Mereb Leke	Central	536.85	–	–	298.71	–	–	–	–	–
12	Naeder Adet	Central	22,076.91	8422.02	1431.18	16,612.83	3846.51	204.39	23,180.94	9462.60	1169.10
13	Saharti Samre	South Eastern	3328.56	6266.16	3396.87	40,876.74	32,882.76	17,304.03	54,186.21	37,633.23	15,473.07
14	Setit Humera	Western	–	–	–	–	–	–	109.26	–	–
15	Sheraro Town	North Western	4853.88	120.33	–	1677.06	–	–	710.46	–	–
16	Tahtay Adiyabo	North Western	167,333.67	9154.44	5.94	56,276.10	741.78	–	102,337.11	854.37	–
17	Tahtay Koraro	North Western	15,425.01	1140.57	30.42	21,951.99	20,994.21	9579.33	20,795.76	24,345.54	11,317.50
18	Tahtay Maychew	Central	3787.74	228.24	2.07	2128.59	55.89	–	2986.56	9.09	–
19	Tanqua Abergele	Central	35,066.88	34,704.36	37,769.13	20,353.50	47,425.41	66,125.70	14,743.62	59,302.62	65,454.39
20	Tsegede	Western	77,785.29	142,710.84	38,023.65	61,549.29	134,058.51	72,459.90	44,726.49	169,935.57	62,889.93
21	Tselemti	North Western	70,210.17	106,794.27	48,831.75	68,623.11	94,649.58	57,604.86	58,702.59	126,758.70	55,584.54
22	Welkait	Western	135,116.46	133,982.82	14,791.41	107,497.89	159,727.05	34,056.27	102,131.64	190,745.01	34,532.82
23	Werei Leke	Central	456.93	5.13	0.09	2705.85	23.49	–	3514.95	13.32	–
Total area			994,021.11	539,209.71	174,691.08	833,579.73	614,503.53	300,188.97	997,411.05	771,492.33	304,974.36

prediction in order to evaluate scientific adaptation strategies for offsetting future warming impact on biota at species, community, and ecosystem levels (Wiens et al. 2009, Ackerly et al. 2010).

Conclusion

This study efficiently modeled *Oxytenanthera abyssinica*'s habitat suitability for current and future climate change scenarios. The spatial resolution also made it much easier for the model to predict suitable habitats accurately. This research suggests that *Oxytenanthera abyssinica*'s habitat suitability will increase for 2050 and 2070 under the moderate climate change scenario. In order to protect shifting from their niche, this study suggests incorporating future climate scenario into current restoration and conservation policies to protect ecologically sensitive species in the current habitat. In addition, the

Table 6 Predicted potential distribution areas (ha) for *O. abyssinica* under end century (2070) climatic conditions

Number	Wereda	Zone name	RCP 2.6 2070			RCP 4.5 2070			RCP 8.5 2070		
			Moderate	Good	High	Moderate	Good	High	Moderate	Good	High
1	Abiy Adi Town	Central	88.65	154.53	2227.05	138.51	237.24	2040.30	171.90	378.72	1863.18
2	Ahferom	Central	–	–	–	–	–	–	1773.72	–	–
3	Emba Alaje	Southern	–	–	–	–	–	–	197.55	–	–
4	Raya Alamata	Southern	–	–	–	–	–	–	134.73	0.18	–
5	Asgede Tsimbla	North Western	109,642.50	76,012.83	30,546.90	117,949.59	68,397.12	34,813.08	108,565.29	96,704.64	24,733.08
6	Degua Temben	South Eastern	5350.23	2478.60	2553.57	8243.28	3870.63	1616.40	11,704.41	4199.85	1268.10
7	Enderta	South Eastern	873.81	5.31	–	2174.94	50.31	–	4029.39	481.50	–
8	Erob	Eastern	–	–	–	1282.23	224.73	17.28	–	–	–
9	Hawzen	Eastern	–	–	–	–	–	–	1071.81	–	–
10	Hintalo Wejirat	South Eastern	478.44	2.07	–	637.92	13.14	–	2064.15	196.47	–
11	Shire E/slasie	North Western	89.19	207.00	648.09	68.22	149.13	1245.96	96.75	442.62	922.05
12	Kafta Humera	Western	294,316.74	44,757.99	54.90	316,111.05	27,410.76	101.88	295,633.98	50,295.24	191.61
13	Kola Temben	Central	29,489.85	22,450.41	27,532.62	34,826.49	22,267.89	23,066.37	36,557.82	23,453.73	21,186.36
14	Laelay Adiyabo	North Western	22,199.76	8883.27	687.78	44,139.33	20,131.02	1831.95	64,028.70	25,018.83	261.81
15	Laelay Maychew	Central	221.49	–	–	–	–	–	–	–	–
16	Medebay Zana	North Western	42,060.24	22,767.66	2800.17	39,885.48	18,405.27	2815.29	48,081.87	17,315.19	994.77
17	Mereb Leke	Central	478.26	–	–				3643.83	–	–
18	Naeder Adet	Central	23,630.58	8188.20	1766.97	23,531.85	9384.66	1421.10	26,689.32	9031.50	1040.04
19	Ofla	Southern	–	–	–	–	–	–	3029.04	64.26	–
20	Saharti Samre	South Eastern	44,580.42	23,725.35	7872.66	46,426.14	42,991.47	16,013.34	54,043.20	29,079.81	14,324.94
21	Sheraro Town	North Western	2105.46	351.81	–	3194.91	–	–	6457.77	–	–
22	Tahtay Adiyabo	North Western	145,803.42	47,532.33	72.00	127,992.51	2142.54	–	213,054.57	10,017.72	0.27
23	Tahtay Koraro	North Western	13,286.79	22,361.94	13,938.66	14,744.16	22,447.44	20,742.30	17,640.27	27,776.34	13,290.57
24	Tahtay Maychew	Central	5600.79	873.36	1.08	4182.12	234.63	–	4142.16	169.20	–
25	Tanqua Abergele	Central	35,247.24	42,407.55	50,317.92	13,671.18	53,093.97	71,920.17	11,258.73	44,586.54	84,779.19
26	Tsegede	Western	111,551.49	138,778.74	7535.07	75,103.29	161,790.03	41,992.83	46,519.29	154,742.13	77,900.58
27	Tselemti	North Western	74,550.51	100,692.63	45,239.13	62,196.57	113,990.85	57,201.03	61,676.91	126,238.41	52,597.26
28	Welkait	Western	126,173.88	162,407.70	6092.82	109,423.80	189,419.13	37,986.75	86,657.04	181,556.73	68,622.93
29	Werei Leke	Central	1679.58	60.93	–	4479.21	63.09	0.36	5989.86	141.84	3.33
	Total area		1,089,499.32	725,100.21	199,887.39	1,050,402.78	756,715.05	314,826.39	1,114,914.06	801,891.45	363,980.07

Table 7 Predicted suitable areas for *O. abyssinica* under current and future climatic conditions

Category		Least potential (< 0.2)	Moderate potential (0.2–0.4)	Good potential (0.4–0.6)	High potential (> 0.6)
Current	Area (ha)	4,040,197.65	537,942.96	722,737.44	136,804.05
	Cover (%)	74.30	9.89	13.29	2.52
RCP 2.6 2050	Area (ha)	3,729,556.17	994,087.98	539,276.31	174,761.64
	Cover (%)	68.59	18.28	9.92	3.21
RCP 2.6 2070	Area (ha)	3,422,752.29	1,089,782.19	725,219.19	199,928.43
	Cover (%)	62.95	20.04	13.34	3.68
RCP 4.5 2050	Area (ha)	3,689,079.57	833,703.48	614,636.55	300,262.50
	Cover (%)	67.84	15.33	11.30	5.52
RCP 4.5 2070	Area (ha)	3,315,410.10	1,050,499.71	756,836.28	314,936.01
	Cover (%)	60.97	19.32	13.92	5.79
RCP 8.5 2050	Area (ha)	3,363,330.24	997,675.65	771,619.68	305,056.53
	Cover (%)	61.85	18.35	14.19	5.61
RCP 8.5 2070	Area (ha)	3,156,399.090	1,115,199.000	802,022.220	364,061.790
	Cover (%)	58.047	20.509	14.749	6.695

findings of this research may contribute to a better understanding of the environmental factors affecting *Oxytenanthera abyssinica*'s current distributions. However, the validation of this model requires further field research on the distribution of *Oxytenanthera abyssinica*.

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