Article

Projected Impact of Climate Change on Habitat Suitability of a Vulnerable Endemic *Vachellia negrii* (pic.serm.) kyal. & Boatwr (Fabaceae) in Ethiopia

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Abstract: Species tend to shift their suitable habitat both altitudinally and latitudinally under climate change. Range shift in plants brings about habitat contraction at rear edges, forcing leading edge populations to explore newly available suitable habitats. In order to detect these scenarios, modeling of the future geographical distribution of the species is widely used. *Vachellia negrii* (Pic.-Serm.) Kyal. & Boatwr. is endemic to Ethiopia and was assessed as vulnerable due to changes to its habitat by anthropogenic impacts. It occurs in upland wooded grassland from 2000–3100 m.a.s.l. The main objective of this study is to model the distribution of *Vachellia negrii* in Ethiopia by using Maxent under climate change. Nineteen bioclimatic variables were downloaded from an open source. Furthermore, topographic position index (tpi), solar radiation index (sri) and elevation were used. Two representative concentration pathways were selected (RCP 4.5 and RC P8.5) for the years 2050 and 2070 using the Community Climate System Model (CCSM 5). A correlation analysis of the bioclimatic variables has resulted in the retention of 10 bioclimatic variables for modeling. Forty-eight occurrence points were collected from herbarium specimens. The area under curve (AUC) is 0.94, indicating a high-performance level of the model. The distribution of the species is affected by elevation (26.4%), precipitation of the driest month (Bio 14, 21.7%), solar radiation (12.9%) and precipitation seasonality (Bio15, 12.2%). Whereas the RCP 8.5 has resulted in decrease of suitable areas of the species from the current 4,314,153.94 ha (3.80%) to 4,059,150.90 ha (3.58%) in 2050, this area will shrink to 3,555,828.71 ha in 2070 under the same scenario. As climate change severely affects the environment, highly suitable areas for the growth of the study subject will decrease by 758,325 ha. The study's results shows that this vulnerable, endemic species is facing habitat contraction and requires interventions to ensure its long-term persistence.

Keywords: climate change; endemic; Maxent; range shift; *Vachellia negrii* (Pic.-Serm.) Kyal. & Boatwr.; vulnerable; Ethiopia

1. Introduction

Climate change affects species by pushing them to their ecological limit, resulting in range shifts. Climate change is a key challenge for biodiversity and the functions of ecosystems [1–3]. Various studies elsewhere have shown that climate change results in the redistribution of species [4–7]. Species track suitable habitats at their leading edge [8] and remain in their warm range edge due to phenotypic plasticity [9,10]. In cases where these two options are not available to species, they are destined to extinction [11]. A recent review

of studies on climate change and biodiversity has revealed a taxonomic bias where less than 2% of plants were examined for the effects of climate change [12]. The observed rate of past climate change is slower than the future rate [13] and so are the rates of range shifts [14]. Climate change is not the only factor for species range shift [15–17]. Habitat degradation, loss and invasive species intensify the effects of climate change on species [13,18].

Climate change is part of the history of our planet, and habitat contraction and expansion has been well documented [19]. A recent example is the Pleistocene, where repeated changes in species ranges were recorded [20]. Whereas past environmental change has led to a cycle of species origination (speciation) and extinction, the impact of the current human-driven climate change is unidirectional range shifts [7] whereby species lose their genetic diversity at their rear edge. As a result, local extinctions of populations of species are common, triggering an extinction vortex [21]. On the other hand, leading edge populations tend to occupy novel ranges due to human-driving climate forcing [5]. How and when species under these new physical conditions compensate for the lost segments of their genetic diversity to ensure their long-term persistence is open to question [22,23].

Species of different taxonomic groups respond to climate change differently [1,2]. Butterflies have exhibited faster range shift than birds in Europe [18]. Latitudinal and altitudinal range shift in plants is gradual and this is relatively readily detectable [24,25]. The effects of climate change on range restricted species, e.g., endemics, leads the loss of their habitat due to warming [26–29]. Endemics have narrow geographic ranges and are often linked to a specialized environmental niche, limited dispersal capacities, smaller population sizes and limited adaptive capability [30]. Furthermore, regions with high endemism are more likely vulnerable to climate change at both the species, population and community levels [31,32].
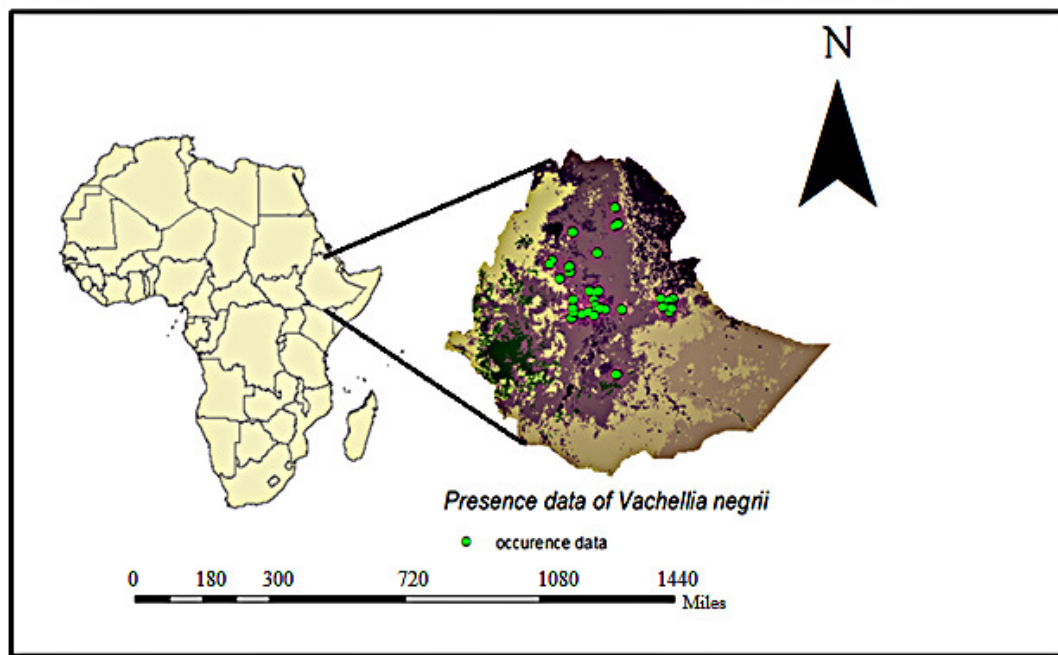
Vachellia negrii (Pic.-Serm.) Kyal. & Boatwr. (Fabaceae) is endemic to Ethiopia and has been assessed as vulnerable due to anthropogenic impacts to its habitat [33]. This tree species has a flat crown and occurs in montane wooded grassland ranging in altitude from 2000–3100 m above sea level (m.a.s.l.) [34,35], as well as church forests [36]. *V. negrii* has a small seed size compared to its pod width [37]. A sample of the seeds of this species has been stored in Svalbard Global Seed Vault (Norway). It does not occur in the protected area network of the country. The species has a wide variety of economic importance such as forage for honeybees, building material for making plows, fuel wood and charcoal. It also improves soil fertility through nitrogen fixation and serves as shade for the domestic animals and people.

Species reach their ecological limits under continued climate change and either respond to survive or perish [11]. Modelling future potential suitable ranges under different climate change scenarios is useful to foster conservation and long-term persistence of species [1]. Maxent is a useful and widely used tool for predicting the current and future distribution of species and the performance of the model can be statistically evaluated [38–41]. The main aim of this study is to predict the current and future distribution the endemic *Vachellia negrii* (Pic.-Serm.) Kyal. & Boatwr. in Ethiopia under climate change.

2. Materials and Methods

Species Occurrence and Environmental Data

Presence data of *Vachellia negrii* (Pic.-Serm.) Kyal. & Boatwr. were collected from the field observation in northern Wollo, the National Herbarium of Ethiopia, using published and unpublished materials. Forty-eight occurrence points were used in this study (Figure 1).

Figure 1. Map of Africa and Ethiopia showing localities of *Vachellia negrii* (Pic.-Serm.) Kyal. & Boatwr. occurrences.

The 19 bioclimatic variables downloaded from Worldclim (www.worldclim.org, accessed on 20 May 2021) with 30 s (~1 km^2) from the observation data version 2.1 and 3 topographic layers were used in this study (Table 1). To predict the future distribution of this species, the General Circulation Model (GCM) Community Climate System Model (CCSM ver.5) was used. The intermediate greenhouse gas scenario (RCP 4.5) and the highest emission scenario (RCP 8.5) from the fifth Report of the Intergovernmental Panel on Climate Change (IPCC5) were used. Furthermore, solar radiation data was downloaded from the www.worldclim.org (accessed on 20 May 2021) with the standardized tiff formats [42–44]. Topographic factors (altitude and slope) were downloaded from Aster DEM (space born thermal emission and reflection radiometer Digital Elevation Model) from www.gscloud.cn (accessed on 24 May 2021) [45].

Table 1. Bioclimatic and topographic variables used in the species distribution modeling.

Variable	Variable Type	Unit
Bio 1	Annual Mean Temperature	°C
Bio 2	Mean Diurnal Range (Mean of monthly (max temp–min temp))	°C
Bio 3	Isothermality (BIO2/BIO7) (×100)	°C
Bio 4	Temperature Seasonality (standard deviation ×100)	°C
Bio 5	Max Temperature of Warmest Month	°C
Bio 6	Min Temperature of Coldest Month	°C
Bio 7	Temperature Annual Range (BIO5-BIO6)	°C
Bio 8	Mean Temperature of Wettest Quarter	°C
Bio 9	Mean Temperature of Driest Quarter	°C
Bio 10	Mean Temperature of Warmest Quarter	°C
Bio 11	Mean Temperature of Coldest Quarter	°C
Bio 12	Annual Precipitation	°C
Bio 13	Precipitation of Wettest Month	Mm
Bio 14	Precipitation of Driest Month	Mm
Bio 15	Precipitation Seasonality (Coefficient of Variation)	Mm
Bio 16	Precipitation of Wettest Quarter	Mm
Bio 17	Precipitation of Driest Quarter	Mm
Bio 18	Precipitation of Warmest Quarter	Mm
Bio 19	Precipitation of Coldest Quarter	Mm
Elevation	Altitude	M
Solar radiation	Solar radiation	
Slope	Slope	%

Bioclimatic variables downloaded in TIFF file format and converted to Asci format by using SDM toolbox of ArcGIS version 10.5 [44]. In order to identify the multicollinearity among the 19bioclimatic and topographic variables, Pearson's correlation was used [43]. A correlation among the bioclimatic and topographic variables was assessed using the ENM tool in R package [46]. A cut-off point of <0.8 was used to exclude variables with high correlation from further analysis to minimize the effect of multicollinearity and model overfitting [47]. Out of the 22 environmental variables, 13 were considered for further analyses in this study.

3. Data Analysis

Maxent software version 3.4.4 was downloaded from http://www.cs.princeton.edu/schapire/MaxEnt/ (accessed on 30 May 2021) and used for modeling the current and future distribution of the species. Maxent is not disposed to sample size and can produce species response curves. All environmental layers have been converted and overlaid onto the same pixel size of 30 m and projected as an ASCII raster grid format. The generated model was evaluated by calculating the AUC of ROC graph [48,49]. The data for species distribution classified as training and test data with proportion of 75% and 25% for the total occurrence record data.

AUC is an effective and efficient independent threshold index with the capacity of assessing the model's capacity to distinguish the presence and absence. AUC values are categorized in to five different classes based on performance [50,51]. The performance classes are failing (0.5 to 0.6), bad (0.6 to 0.7), reasonable (0.7 to 0.8), good (0.8 to 0.9) and great (0.9 to 1). Models with values less than 0.5 indicates that the occurrence in the real-life scenario is rare or can be considered as a guesstimate [52] Jackknife was run to systematically exclude each variable or evaluate the leading bioclimatic or topographic variables. Jack knife evaluates the leading variables in determining the potential distribution of species [53]. The relationship between the environmental and topographic factors and the potential habitat for the species is determined from the created response curve from the model [54,55].

4. Result

4.1. Correlation among the Environmental Variables

The Pearson's correlation has resulted in the removal of Bio 5, Bio 6, Bio 8, Bio 10, Bio 11, Bio 13 and Bio 16 from further analysis due to their high multicollinearity (Table 2).

4.2. Model Evaluation

Validation guarantees the reliability of modeling results. In this study, the AUC value showed that the Maxent model performed well (AUC = 0.940) under the current scenario (Figure 2). The distribution of *Vachellia negrii* (Pic.-Serm.) Kyal. & Boatwr. under the current climatic conditions is highly influenced by elevation, Bio 14 (precipitation of the driest month), Bio 1 Annual Mean Temperature, Bio 15 (precipitation seasonality) and solar radiation (Table 3). Furthermore, the contributions of these variables are higher than the others.

Table 2. Correlation result of bioclimatic and topographic variables.

layer	Sri	Bio1	Bio2	Bio3	Bio4	Bio5	Bio6	Bio7	Bio8	Bio9	Bio10	Bio11	Bio12	Bio13	Bio14	Bio15	Bio16	Bio17	Bio18	Bio19	Elv	Asp
Sri	1	0.25	−0.15	0.33	−0.49	0.13	0.34	−0.41	0.29	0.23	0.13	0.35	−0.45	−0.44	−0.23	0.36	−0.47	−0.23	−0.035	−0.36	−0.31	−0.25
Bio1		1	−0.45	−0.53	0.41	**0.96**	**0.96**	−0.04	**0.97**	**0.97**	**0.98**	**0.98**	−0.63	−0.618	−0.32	0.16	−0.60	−0.36	−0.54	−0.31	**−0.96**	−0.43
Bio2			1	0.40	−0.05	−0.26	−0.63	0.70	−0.50	−0.47	−0.42	−0.46	0.36	0.46	0.10	0.03	0.44	0.13	0.28	0.22	0.58	0.22
Bio3				1	−0.87	−0.62	0.42	−0.35	−0.56	−0.46	−0.62	0.39	0.38	0.34	0.29	0.08	0.31	0.29	0.41	0.18	0.45	0.15
Bio4					1	0.58	0.23	0.63	0.40	0.34	0.53	0.25	−0.21	−0.10	−0.25	−0.04	−0.08	0.137	0.28	−0.02	−0.28	−0.04
Bio5						1	0.85	0.22	**0.93**	**0.90**	**0.97**	**0.91**	−0.60	−0.55	−0.35	0.16	−0.54	0.29	0.41	−0.30	**−0.89**	−0.38
Bio6							1	−0.31	**0.94**	**0.94**	**0.91**	**0.97**	−0.633	−0.64	−0.29	0.18	−0.63	−0.38	−0.38	−0.341	**−0.96**	−0.43
Bio7								1	−0.07	−0.12	0.06	−0.16	0.077	0.19	−0.10	−0.04	0.20	−0.33	−0.53	0.08	0.19	0.11
Bio8									1	**0.91**	**0.952**	**0.94**	−0.72	−0.71	−0.33	0.15	−0.70	−0.07	−0.012	−0.45	**−0.94**	−0.44
Bio9										1	**0.95**	**0.96**	−0.52	−0.55	−0.23	0.10	−0.52	−0.36	−0.49	−0.19	**−0.94**	−0.39
Bio10											1	0.94	−0.59	−0.55	−0.34	0.15	−0.53	−0.27	−0.53	−0.27	**−0.93**	−0.39
Bio11												1	−0.63	−0.60	−0.30	0.20	−0.59	−0.38	−0.51	−0.31	**−0.97**	−0.44
Bio12													1	**0.85**	0.57	−0.31	**0.91**	−0.34	0.44	0.77	0.61	0.35
Bio13														1	0.12	0.11	**0.98**	0.56	0.23	0.72	0.63	0.37
Bio14															1	−0.67	0.26	0.177	0.46	0.30	0.30	0.24
Bio15																1	0.01	0.974	−0.35	−0.09	−0.14	−0.09
Bio16																	1	−0.75	0.25	0.78	0.61	0.35
Bio17																		1	0.52	0.26	0.33	0.26
Bio18																			1	0.12	0.49	0.21
Bio19																				1	0.33	0.23
Elv																					1	0.46
Asp		1																				1

Note: The bold once are auto correlated variables need to be removed from the model inorder to avoid over fitting of model.
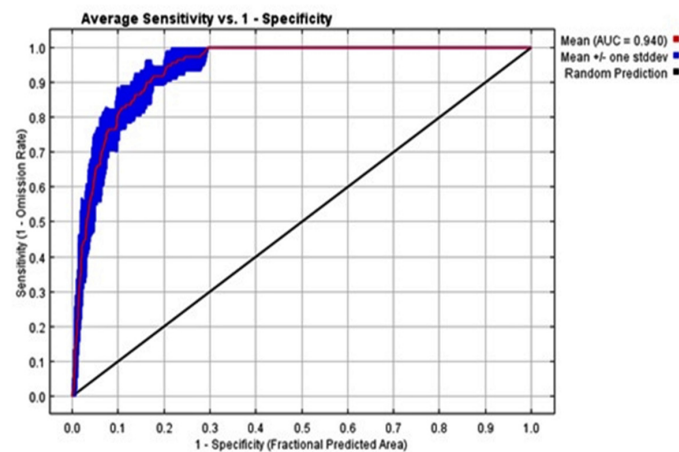
Figure 2. The Receiver Operating Characteristic (ROC) curve result of the Maxent modelling.

Table 3. Percent contribution of variables and species response to different climatic scenarios (%c = percent contribution and PI = permutation importance).

Variables	Code	Current		2050 RCP 4.5		2050 RCP 8.5		2070 RCP 4.5		2070 RCP 8.5	
		%c	PI	%c	PI	%c	PI	%c	PI	%c	PI
Annual Mean Temperature	Bio 1	0.2	0.9	0	4.5	0	0.8	0	4.7	0	2.2
Mean Diurnal Range (Mean of monthly (max temp–min temp))	Bio 2	2.9	2.1	0	0.4	0	9.5	0	0	0	0
Isothermality (P2/P7) × (100)	Bio 3	0.1	0.1	0	5.5	0	3.7	0	0	0	0
Temperature Seasonality (standard deviation × 100)	Bio 4	4.6	13.9	0	16.7	0.2	0	0	7.5	0	3.7
Temperature Annual Range (P5–P6)	Bio 7	0.1	0.2	0	6.3	0	3.8	0	7.1	0.8	4.7
Annual Precipitation	Bio12	0.1	2.4	0	2.5	0	0	0	4.1	0	2.7
Precipitation of Driest Month	Bio 14	21.7	27.2	3	2.1	1	0.9	0	10.3	2	6.8
Precipitation of Seasonality (Coefficient of Variation)	Bio 15	12.2	6.8	2.0	11.6	1	1.1	0	12.7	2	33.9
Precipitation of Warmest Quarter	Bio 18	12.7	6.5	3.0	24.7	1	14.1	0	1	0	2.1
Precipitation of Coldest Quarter	Bio 19	4	1.1	0	2.3	2	10.6	0	12.2	2	2.4
Elevation	Elev	26.4	30.4	50	17.1	60	22.4	79.4	21.1	70	27.4
Solar radiation	Sr	12.9	6.8	29.2	3.7	32.8	32.3	16.1	17.2	16	10.5
Slope	Slp	2.1	1.5	12.8		2	0.9	4.5	2	6.7	3.7

4.3. Response Curves of Bioclimatic Variables

The response curves show the relationships of probability of occurrence of *Vachellianegrii* (Pic.-Serm.) Kyal. & Boatwr. and each environmental variable (Figure 3). The species response curve describes the relationship between the topography and bioclimatic factors and species occurrence probability (Figure 3). Elevation, precipitation of the driest month (Bio 14), 26.4 percent and 21.7 percent, respectively, contributed the most to the spread of the species. The relevance of the bioclimatic and topographic variables of elevation and precipitation of the driest month (Bio 14) contribute the greatest percentages (30.4 and 27.2, respectively), followed by temperature seasonality (Bio 15), contributing13.9 in permutation (Table 3). The response curves for the important variables show that they have a greater influence on the distribution of *Vachellianegrii* (Pic.-Serm.) Kyal. & Boatwr. (Figure 4). The suitability for growth increases as the altitudinal range increases, and ideally fits in the range of 2000 to 3000 m, where the rainfall of the driest month is adequate for the species' survival and growth ranges from 5 to 10m^3 during the driest season.

Figure 3. Importance of environmental variables for distribution of *Vachellianegrii* (Pic.-Serm.) Kyal. & Boatwr.
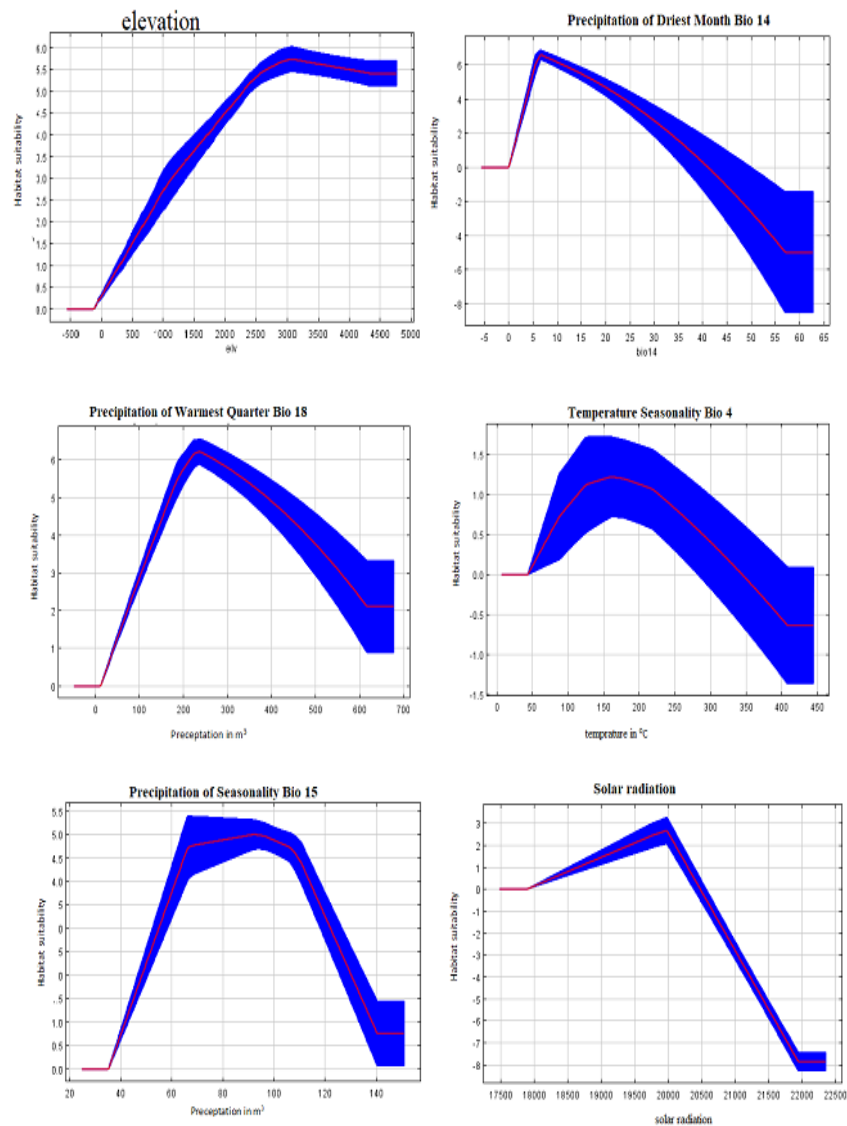
Figure 4. Response curve of the major bioclimatic and topographic factors influencing the distribution of *Vachellianegrii* (Pic.-Serm.) Kyal. & Boatwr.

4.4. Potential Distribution of Vachellia negrii

　　　　Modelling the potential distribution *Vachellia negrii* (Pic.-Serm.) Kyal. & Boatwr. shows that it occurs on both sides of the Rift Valley (Figure 5). It has a relatively higher range on the north and northwestern highlands of Ethiopia than on the southeastern highlands. In the latter, its highly suitable habitats are confined to the Bale Mountain range and Gara Muleta and its surroundings. In north and northwestern Ethiopia, highly suitable areas for this species are in moist and dry Afromontane forests. Moderately suitable habitats of this species occur at the fringes of the highly suitable areas and are much more extensive (Table 4).
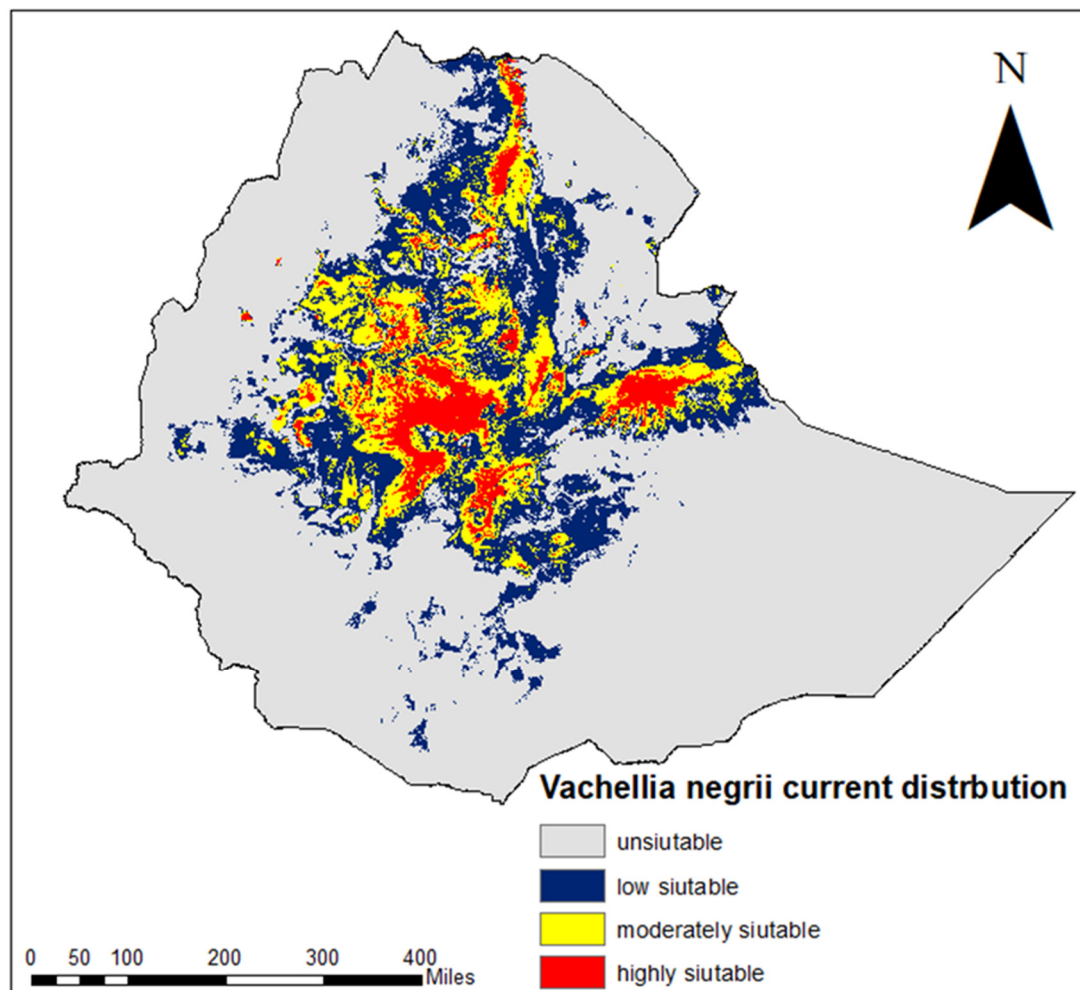
Figure 5. Potential distribution of *Vachellia negrii* (Pic.-Serm.) Kyal. & Boatwr.in Ethiopia.

Table 4. Suitable areas for the distribution of *Vachellia negrii* (Pic.-Serm.) Kyal. & Boatwr.

Climatic Period	RCP	Classes of Suitable Habitats							
		Highly Suitable		Moderately Suitable		Low Suitable		Unsuitable	
		Hectares	%	Hectares	%	Hectares	%	Hectares	%
Current		4,314,153.941	3.80	9,394,670.699	8.29	18,423,842.68	16.26	81,177,180.2	71.64
2050	RCP 4.5	4,059,150.901	3.58	8,491,245.863	7.49	17,529,132.28	15.47	83,230,318.48	73.45
	RCP 8.5	3,745,769.595	3.3	7,303,036.612	6.45	16,657,887.62	14.28	85,603,153.7	75.97
2070	RCP 4.5	3,555,828.711	3.13	6,675,597.149	5.89	14,063,493.76	12.41	89,014,927.9	78.55
	RCP 8.5	2,676,601.245	2.36	10,035,562.54	8.85	14,171,535.86	12.50	86,426,147.87	76.27

4.5. Important Environmental Variables for Future Geographic Distribution of Vachellia negrii

The importance of environmental variables for the prediction of the distribution of *Vachellia negrii* (Pic.-Serm.) Kyal. & Boatwr for in the scenarios (RCP 4.5 and 8.5) are different for mid-century and for2070 (Figure 6). There is also a within-scenarios variation. The distribution of this species is mainly determined by elevation, precipitation of the driest month (Bio 14) and precipitation of the warmest month (Bio 18) for RCP 4.5 in 2050. For RCP 4.5 in 2070, Bio 14 and elevation are the main factors restricting the distribution of this species. Whereas Bio 18 is the main limiting factor for RCP 8.5 in 2050, Bio 14 limits the distribution of this species. Elevation determines the distribution of *Vachellia negrii* (Pic.-Serm.) Kyal. & Boatwr. in both 2050 and 2070 for RCP 8.5.
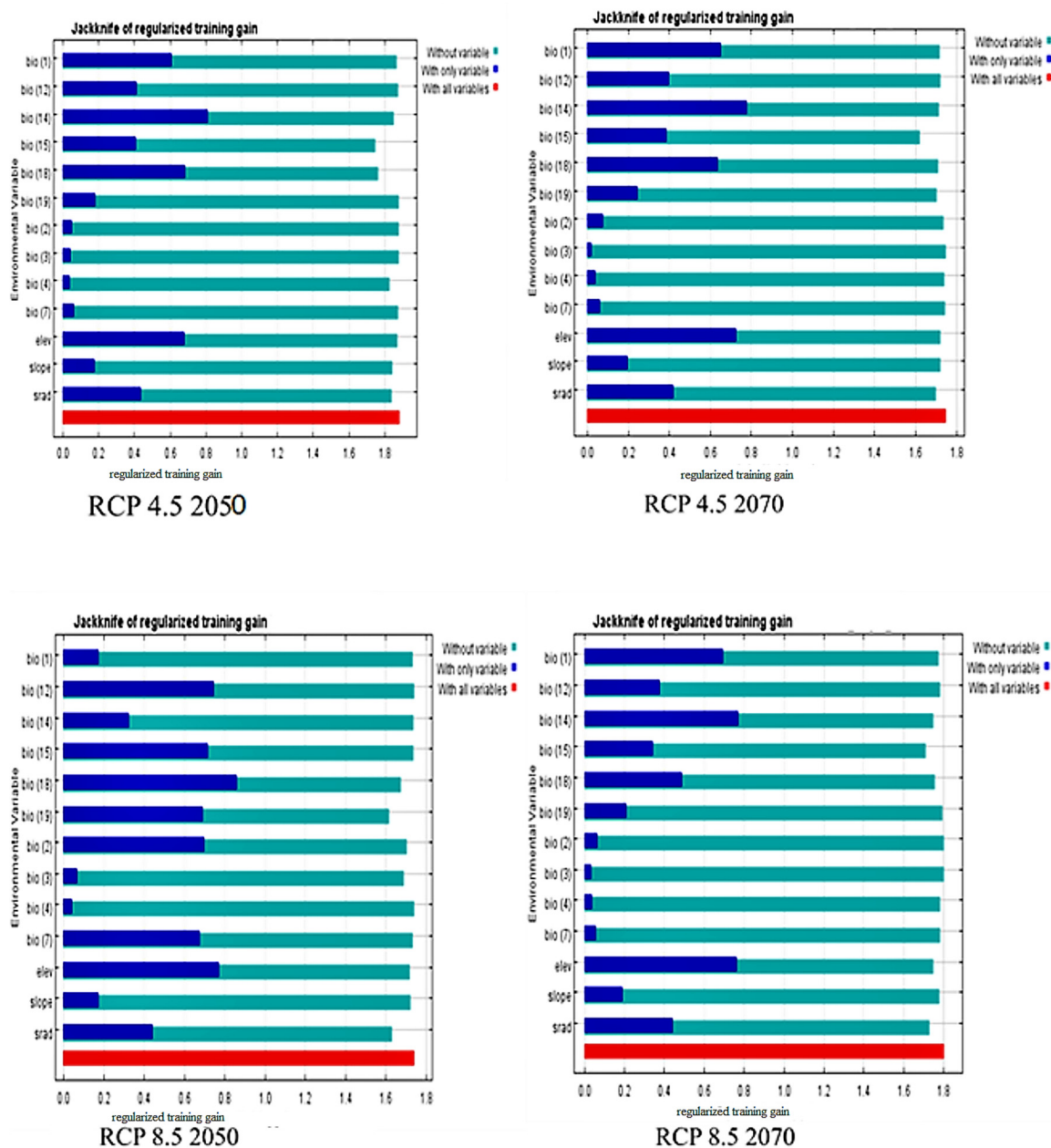
Figure 6. Importance of environmental variables for predicting the distribution of *Vachellia negrii* (Pic.-Serm.) Kyal. & Boatwr. under different climate change scenarios.

4.6. Predicted Distribution of Vachellia negrii (Pic.-Serm.) Kyal. & Boatwr.

The predicted distribution of highly suitable habitats for *Vachellia negrii* (Pic.-Serm.) Kyal. & Boatwr. decreases for both climate change scenarios (Figure 7). The species loses its northern range of highly suitable areas, and the southeastern range is more or less limited to Gara Muleta and its surroundings. Highly suitable habitats for this species decrease by 5.9% under RCP 4.5. in 2050 and 13.2% for RCP 8.5 in 2070 (Table 4). The decline of highly suitable habitats for this species is dramatic for RCP 8.5 in 2050 and 2070, i.e., 17.6% in 2050 and 38% in 2070. A similar trend was observed for moderately and low suitable habitats. An exception is a slight increase in moderately suitable habitats for RCP 8.5 in 2070.
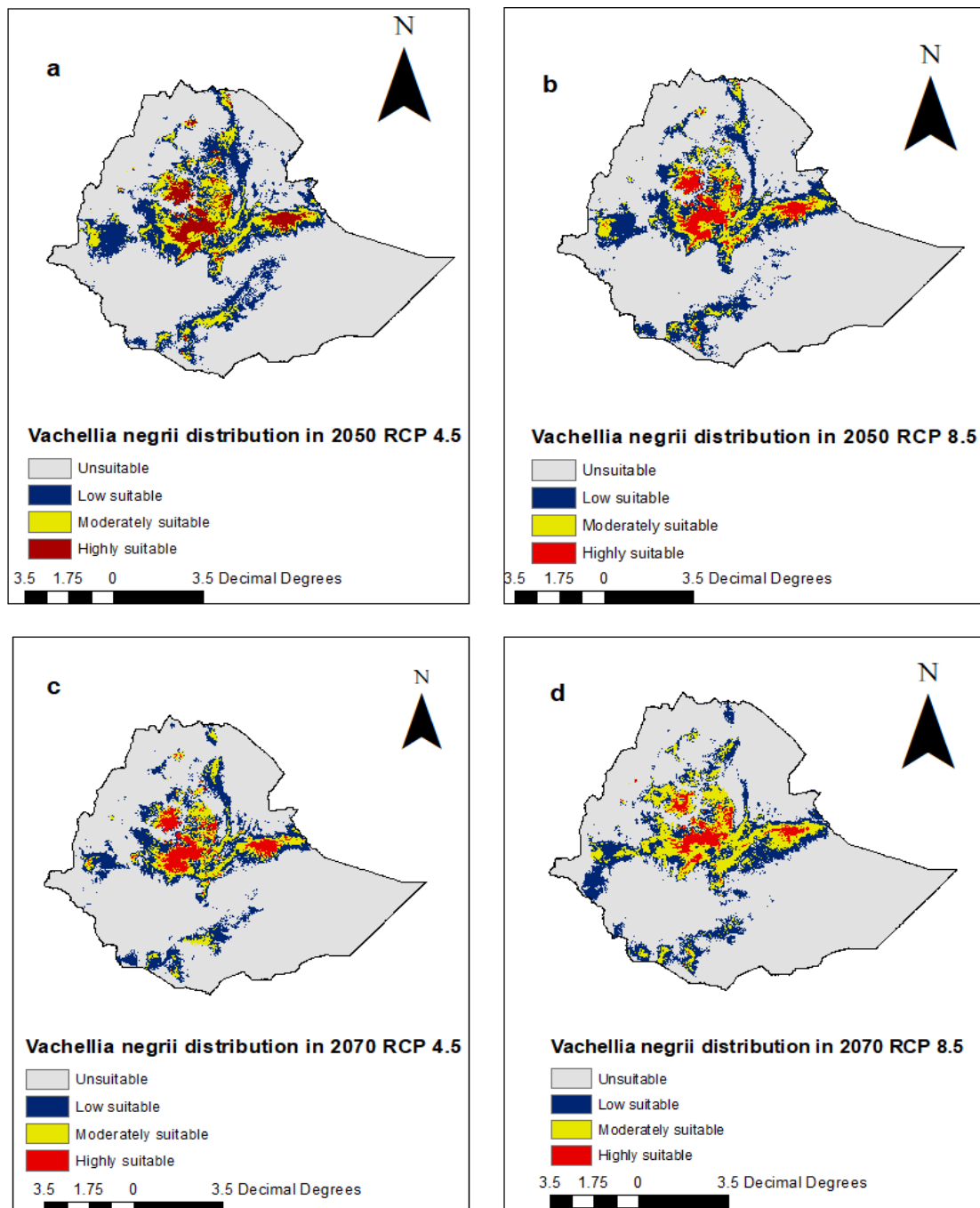
Figure 7. Predicted distribution of *Vachellia negrii* (Pic.-Serm.) Kyal. & Boatwr. (**a**). RCP 4.5 in 2050 (**b**). RCP 8.5 in 2050 (**c**). RCP 4.5 in 2070 and (**d**). RCP 8.5 in 2070 under different climatic change scenarios.

5. Discussion

Forecasting the future of climate change and its influence on species distribution is essential due to the wide range of climate simulation findings [56,57]. The distribution and well-being of forest ecosystems will be altered in either a positive or negative way by future global warming. In Ethiopia, the spread of *Vachellia negrii* (Pic.-Serm.) Kyal. & Boatwr. is now threatened. This vulnerable species is affected by both anthropogenic and climatic forces. The current impacts of climate change are affecting the whole world, especially in developing countries due to extreme population growth and illegal poaching [58]. Maxent modeling will have an effect on allocating the areas and the species which are endangered and in need of conservation [57].

5.1. Model Performance and Percent Contribution of Variables

According to Pearson et al., an AUC greater than 0.75 is a clear illustration of the strength and efficiency of a good species distribution (niche) model (2007). The model's AUC of 0.94 indicates that it is within the acceptable limits [57,59]. Because AUC values greater than 0.75 are considered informative [50], our results show that the model performed well in distinguishing between true and false positives [60]. The exclusion of variables owing to autocorrelation resulted in a flawless model outcome, according to references [61,62]. The topographic and climatic factors were shown to be autocorrelated, resulting in (Table 2) topographic variables (elevation and slope), precipitation (Bio 12, Bio 14, Bio 15, Bio 18 and Bio 19), temperate (Bio 1, Bio2, Bio3, Bio4 and Bio7) and solar radiation. Elevation has a significant role in determining the range of a species' habitat. As seen in Figure 4, the most suitable areas are found at elevations of 2500 m.a.s.l. When predicting the distribution of organisms, elevation is one of the most essential factors to consider [16].

5.2. Current Distribution

The species' present distribution is limited to the highlands of Tigray, Amhara, Oromia and Dire Dawa. The spread of *Vachellia negrii* (Pic.-Serm.) Kyal. & Boatwr is constrained by elevation. Even a small number of bioclimatic factors [63,64] affects the distribution. Bioclimatic variables that were employed to anticipate the distribution of suitable land did not adequately determine microclimates [57,65–67]. Although elevation is the most important factor in the distribution model, solar radiation also has a role in the species' future and current spread. Elevation influences the species' microclimate, which has a direct impact on distribution [67,68].

Growing may also be possible at various elevations around the country [68–70]. Other variables that influence distribution, such as Bio14 and Bio15, also have a role. The temperature during the dry season and the precipitation throughout the dry and rainy seasons have an impact on species survival and recruitment. Because water is involved in all of the physiological activities of the species, the availability of water throughout the dry season promotes flowering and seed dispersal [71].

5.3. Future Distribution

Climate change has a significant impact on the geographic range of *Vachellia negrii* (Pic.-Serm.) Kyal. & Boatwr. according to the IPCC climate change scenario. Highly suitable, moderately suitable, low suitable and unsuitable are the four categories of appropriate regions predicted by the model. Climate change would have a negative influence on the niche of the species [28,72]. As a result, the suitable habitat range decreases (Figure 8). References 43, 52 and 66 predict that the species will make a significant shift to a more appropriate habitat. Climate change is the most significant factor, although habitat degradation, invasive species invasions, biodiversity loss and land conversion also contribute to the species' decreasing land mass [9,10].
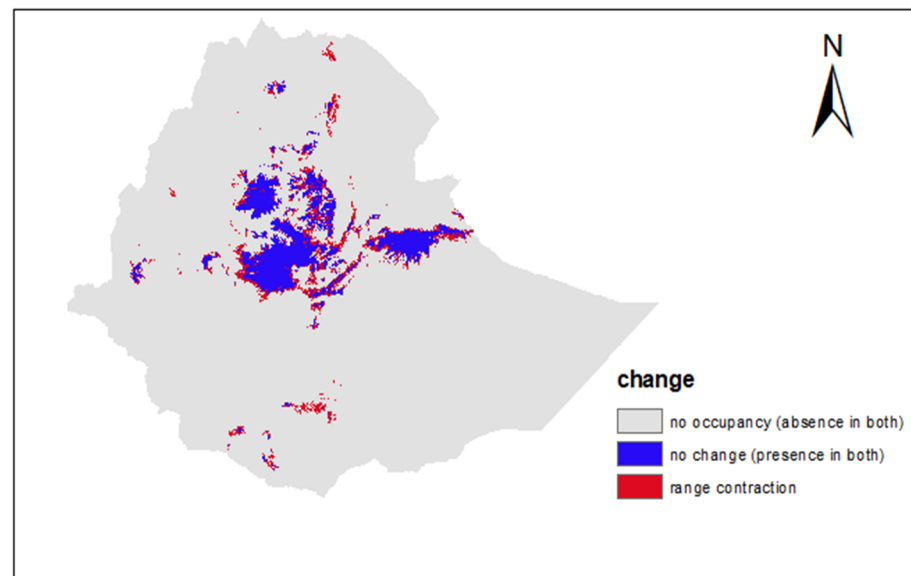
Figure 8. Change in the occupancy of *Vachellia negrii* (Pic.-Serm.) Kyal. & Boatwr.

Vachellia negrii (Pic.-Serm.) Kyal. & Boatwr. thrives in environments that are ideal for its distribution, which decrease by 73.86% in 2050 of RCP 4.5 and 7% in 2070of RCP 4.5. The species' habitat suitability decreases in 2050 based on RCP 8.5, but increases in 2070 based on RCP 8.5. The Ethiopian highlands, similar to all other highlands, are undergoing climate change, which has a beneficial impact on species growth [67]. If the temperature rises on a regular basis, it will alter the seasonal growth of species [73,74].

Highly suitable areas for distribution of *Vachellia negrii (Pic.-Serm.) Kyal. & Boatwr.* decreases by 73.86% in 2050 of RCP 4.5 and an increase in 7% in 2070of RCP 4.5. The projection of the species in 2050 based on RCP 8.5 shows a decrease in the moderately suitable areas, but in the case of 2070 RCP 8.5, there is an increase in the habitat suitability. Ethiopian highlands, similar to any other highlands, are facing change in temperature, which affects the species growth positively [67]. The increase in temperature would also affect the seasonal growth of species if it occur son a continuous basis [73,74].

5.4. Range Shift

The moderate, low and high potentials from the landscape and regions with adequate habitats for growth and survival showed a decline in both the mid-century (2050s) and the end-of-century (2070s) periods (Figure 8). As a result, a rise in temperature may compel their habitat to move from a lower to a higher elevation, causing habitat contraction and expansion, in this case, contraction [57,75,76]. In addition, invading species tend to decrease and alter the distribution of native species in the region [21,71,77,78]. According to the findings, the species range decreases from the total land mass of 104,429,094.6 ha with no occupancy, whereas 5,753,201.233 ha is deemed as an appropriate habitat in both situations, but climate change has caused 2,915,668.9450000003 ha to be lost. Several new studies on climate change and global warming demonstrate that variations in temperature have an impact on biodiversity distribution [78,79].

5.5. Conservation Strategy

In forest and land management, the ultimate goal of species distribution modeling (SDM) is to create future information about species distribution. The (SDM's) findings will encourage conservationists to develop and use coping mechanisms. The suitable region of the species' geographical range has shifted, according to the current research. Environmental plans must be based on research findings and recommendations. The species should be included in a list that may be planted during the country's yearly green movement, increasing the availability of the species in the country's high lands [55]. During

the country's yearly greening, these designated appropriate regions would be used for planting. The government and stakeholders must focus on planting rare and endemic endangered species since the allocated sites for yearly plantation are ideal habitats for the species. In addition to the *Vachellia negrii* (Pic.-Serm.) Kyal. & Boatwr. plantation, the closure area would have an effect on safeguarding other treated plants and facilitating the establishment of additional species from seed banks [80,81].

6. Conclusions

Climate change is affecting the geographic distribution of *Vachellia negrii* (Pic.-Serm.) Kyal. & Boatwr. according to the present research. The model clearly demonstrates that the range of appropriate habitat for the species is shrinking. This has long-term consequences for the survival of the species. As a result, yearly tree-planting activities in Ethiopia should take into account predicted climatic conditions as well as the planting of *Vachellia negrii* (Pic.-Serm.) Kyal. & Boatwr. in appropriate habitats. For the Ethiopian government's annual plantation, the central highlands are now the most favored planting regions. Because these areas have been recognized as appropriate, it is suggested that these species be introduced. It is advised that these plants be planted on the hilltops since these areas have been designated as suitable. Efforts to conserve these severely endangered species should be made in general. Other endangered plant species, in addition to *Vachellia negrii* (Pic.-Serm.) Kyal. & Boatwr., should be conserved, therefore seed banks, botanical gardens and other insitu conservation techniques should be prioritized. To assist in the rescue of these species from extinction in the wild, further physiological, ecological, and microclimate research should be conducted.

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