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Modeling the Current and future potential distribution of *Arabis alpina* using MaxEnt software in selected mountains of Ethiopia.

Modelado de la distribución potencial actual y futura de Arabis alpina utilizando el software MaxEnt en montañas seleccionadas de Etiopía.

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ABSTRACT

The objective of this study was to model the current and future distributions of the plant species, *Arabis alpina,* using MaxEnt software. Accordingly, a total of 70 locations data were used for this investigation. The occurrence record of this species was obtained from herbarium of Ethiopian Biodiversity Institute and Google Earth version 7 from highland areas of Ethiopia. Climate data with a spatial resolution of 30 s (approximately 1 km^2), was downloaded from world climate database website. The result of this analysis confirmed that the average test of AUC is 0.970. This is an excellent model for the selected variables since the AUC value was more than 0.90. The test of the jackknife indicated the current distribution of *Arabis alpina* was mainly influenced by Annual Mean Temperature (Bio1) and the Min Temperature of Coldest Month (Bio6) that contributed 74.9% and 17.5% to the MaxEnt model respectively. Regarding the future climatic condition the result of this investigation indicated that the average test of AUC was 0.959. The jackknife test was also indicated the future distribution of *Arabis alpina* was mainly influenced by precipitation of wettest Quarter (bio16) that contributed 95.1% to the MaxEnt model. Generally, the picture of the model of current climatic conditions indicated that Arabis *alpina* occurs in most highland areas of Ethiopian but the model for future climatic condition indicated that this plant will be restricted to few areas of the country. This might me due to climate change, anthropogenic degradation and invasive alien species. In addition, from the picture of the model there might be shifting of habitat from the lower altitude to the higher altitude .This may be due to an increase in temperature and decrease in precipitation. Therefore, this study recommends the integration of future climate situation into current restoration and conservation policies to protect ecologically sensitive species of the country.

Key Words: *Arabis alpina,* current and future distributions model, MaxEnt software,

RESUMEN

El objetivo de este estudio fue modelar las distribuciones actuales y futuras de la especie vegetal Arabis alpina utilizando el software MaxEnt. En consecuencia, se utilizaron un total de 70 datos de ubicaciones para esta investigación. El registro de presencia de esta especie se obtuvo del herbario del Instituto de Biodiversidad de Etiopía y la versión 7 de Google Earth de las zonas altas de Etiopía. Los datos climáticos con una resolución espacial de 30 s (aproximadamente 1 km2) se descargaron del sitio web de la base de datos climática mundial. El resultado de este análisis confirmó que la prueba promedio de AUC es 0.970. Este es un modelo excelente para las variables seleccionadas ya que el valor de AUC fue superior a 0,90. La prueba de la navaja indicó que la distribución actual de Arabis alpina estuvo influenciada principalmente por la temperatura media anual (Bio1) y la temperatura mínima del mes más frío (Bio6) que contribuyeron con un 74,9 % y un 17,5 % al modelo MaxEnt, respectivamente. En cuanto a la condición climática futura el resultado de esta investigación indicó que la prueba promedio de AUC fue de 0.959. La prueba de navaja también indicó que la distribución futura de Arabis alpina estuvo influenciada principalmente por la precipitación del trimestre más húmedo (bio16) que contribuyó con el 95,1% al modelo MaxEnt. En general, la imagen del modelo de las condiciones climáticas actuales indica que Arabis alpina se encuentra en la mayoría de las zonas montañosas de Etiopía, pero el modelo de las condiciones climáticas futuras indica que esta planta estará restringida a unas pocas áreas del país. Esto podría deberse al cambio climático, la degradación antropogénica y las especies exóticas invasoras. Además, según la imagen del modelo, podría haber un cambio de hábitat desde la altitud más baja a la altitud más alta. Esto puede deberse a un aumento de la temperatura y una disminución de la precipitación. Por lo tanto, este estudio recomienda la integración de la situación climática futura en las políticas actuales de restauración y conservación para proteger las especies ecológicamente sensibles del país.

Palabras clave: Arabis alpina, modelo de distribuciones actual y futuro, software MaxEnt

INTRODUCTION

MaxEnt is a software package for displaying species distributions from presence-only species records (Elith *et al*., 2010). Species distribution models (SDMs) guess the association between species records at sites and the environmental characteristics of individuals sites which are extensively used for numerous purposes in biogeography, conservation biology and ecology (Elith, and Leathwick, 2009, Franklin, 2009). There have been many progresses in the field of species distribution modeling and manifold methods are now available. A main difference among methods is the kind of species data they use. When species data have been collected systematically – for instance, in formal biological surveys in which a set of sites are surveyed and the abundance of species at each site are recorded – regression methods are familiar to most ecologists such as Generalized Linear or Additive Models or random forests or Boosted Regression Trees are used (Elith *et al*., 2010).

Although species records are available in the form of recent survival records in herbarium and museum databases, systematic biological survey data tend to be limited or rare in coverage for most regions. Several of these databases denote well over a century of public and private investment in biological science and are enormously essential source of species existence data. MaxEnt's is one such method in which its projecting performance is consistently competitive with the highest performing methods and becoming available since 2004 that has been developed widely for modeling species distributions (Elith *et al.*, 2006).The major section of MaxEnt modeling is the data preparation that requires the understanding of several other software and file formats including Microsoft Excel and ESRI ArcGIS. It uses two types of files to perform its calculations: Comma-Separated Values (.csv), and ESRI ASCII GIS (.asc) files (Young *et al*., 2011).

Hence, this study aimed at the modeling of current and future distribution of the plant species, *Arabis alpina. Arabis alpina* is a perennial herb, 5-60 cm tall, forming loose tufts or mats by rooting and branching in the basal parts, all parts covered with stellate hairs. It occurs in most Ethiopian regions. The specific objectives of this study are: - to identify the effect of each bioclimatic variables to the given species distribution model, to estimate the predictive ability of the generated model using AUC of the Receiver Operating Characteristic (ROC), to identify the suitable habitat of the given species and to distinguish the most influencing bioclimatic variable for the current and future distribution of *Arabis alpina* using MaxEnt software.

MATERIAL AND METHODS

Arabis alpina: *Arabis alpina.*L. is the perennial herb in the family Brassicaceae. *Arabis alpina.L.* is distributed in the Northern hemisphere and found at elevations going from few meters above sea level in Northern region to several thousand meters in African mountains. Generally, it is found in many mountains of East Africa, Atlas Mountains, Macaronesia, Europe, North America and Asia. In Ethiopia it is found in Rocky slopes in forests and afro-alpine zone; 2000-4350 m in Gondar, Arsi, Bale, Hararge, Shewa upland, Tigray and Wello of high land areas (Sebsebe Demissew, and Hedberg, 2000).

Environmental Variables and Species Occurrence Data: This study addressed modeling the potential current and future distribution of the *Arabis alpina.*L through MaxEnt software. Climate data with a spatial resolution of 30 s (approximately 1 km^2) was downloaded from world climate database website (WorldClim-Global Climate Database (http:// worldclim.org/) following (Kigen,*et al*.,2013). MaxEnt involves all the bioclimatic variables be in raster format and to have the strict identical cell size, level and projection system so as to perform a model. There are nineteen most important bioclimatic variables that have been reported for modeling potential species distribution of the given species (Molloy *et al*., 2014).

The occurrence data was sourced from the study areas. It was applied a species distribution model to detect where appropriate habitats occur in current and projected climatic scenarios using bio-climatic variables following (Ouko *et al*., 2020, and Yikunoamlak Gebrewahid *et al*., 2020). A total of 70 locations (occurrence data) of *Arabis alpina.*L were obtained from Ethiopian Biodiversity Institute Herbarium which was collected from different areas of the country as well as from Google earth version 7.0 within 3000-4000 m.a.s.l altitudinal ranges. With the help the information on Flora of Ethiopia and Eritrea , the occurrence data were recorded from different mountain areas of the country such as Bale, Chilalo,Abuna yosef, Guna, Anca,Amba farit,Ioll,Bada,Choka, Kecha Terara, Megezet and Tata Yetera chaf via Google earth version 7.0. In accordance with the requirements of MaxEnt software, the distribution records of the given species were organized and entered into Microsoft Excel and saved as format "CSV."

Modeling the current and future distributions of *Arabis alpina.*L using MaxEnt Software - The Modeling Approach: MaxEnt modeling is a method for making inferences from incomplete information. It approximates target likelihood distribution for each pixel on a grid map by discovering the likelihood distribution of the highest entropy (most spread out) that is constrained by the statistical response curves between environmental variables and sample points of species occurrence. Pixel is a smallest addressable element in a raster image or one of the tiny dots that make up the representation of an image in a computer's memory. The model was run ten times based on different random partitions of the occurrence data into training and test localities (Elith *et al*., 2010 and, Ouko *et al*., 2020).

To model the current and future distributions of any plant species using MaxEnt software, the first step is Modifying Environmental Layers Using ArcGIS which include loading environmental layers into Arc Map, Modify the 19 Bioclimatic Variables to Arc GIS/Map, Converting Environmental Raster's to ASCII format and generating a CSV file. To run MaxEnt software package all bioclimatic variables must be in ASCII and raster format as well as a need to have the exact same cell size, extent and projection system in order to perform a model.

When geographic coordinates are used in DIVA-GIS, Maxent and other GIS for species distribution modeling programmes, it is preferable to be reported using latitude/ longitude coordinate system and presented in Decimal Degrees (DD) format. Degrees Minutes Seconds (DMS), information should be converted to DD for use in a species distribution modeling. Therefore, the DMS was converted to DD using the given formula: -DD = [(Degrees (°) + Minutes (‘) / 60 + Seconds (“) / 3600)] * H = 1 when the coordinate is in the Eastern (E) or Northern (N) Hemisphere (Ethiopia), H = -1 when the coordinate is in the Western (W) or Southern (S) Hemisphere (Scheldeman and Zonneveld, 2010).

Model Evaluation: Analysis of omission/commission, the Receiver Operating Characteristic (ROC) curve of the model, Jackknife, Species response curve and Pictures of the model was analyzed and evaluated. The accuracy of the models was evaluated by estimating commission and omission. The statistical significance of the models was predicted using binomial statistical tests. Area under Curve (AUC) is a parameter used to evaluate the predictive ability of the generated model (Kigen,*et al*.,2013, Elith *et al*., 2010, Mousazade *et al*., 2019). The specificity (fractional predicted area) on the X-axis of the AUC graph is the fraction of the total study area where the species is predicted present, while the sensitivity (1_Omission Rate) on the Y-axis is the proportion of presence points in the modeled area of occurrence on the total number of actual presence points (Molloy *et al*., 2014). “Jackknife” was also applied to the entire environmental variables to find the most important or the dominant bioclimatic variables that determine the species potential distribution. Species response curve also portrays the correlation between bioclimatic variables and the probability of species existence; they show biological tolerances for target species and habitat preferences. In general, Maxent estimates the habitat suitability under different conditions (Phillips, 2009,and Marcelino and Verbruggen, 2015).

In every statistical analysis it is important to ensure that the independent variables do not confound each other. The correlation between each of the independent variables is not too high. In this proposed study the nineteen bioclimatic variables that were obtained from the global climate data are the independent variable. Hence, if two variables with a bivariate correlation of 0.7 or more in the same analysis, it is probably don’t need to include in the given analysis. In this situation, it may be needed to consider omitting one of the variables or forming a composite variable from the scores of the two highly correlated variables (Pallant, 2011). The bioclimatic variables with correlation coefficient of ≥0.7 were removed so that 8 variables were selected below this threshold to model distribution of *Arabis alpina* (Table 1 and 2).Species response curves were also produced to examine the association among target species habitat suitability and environmental factors. The potential species distribution graph produced had values extending from 0 to 1. The values have been grouped into four suitability classes as: > 0.8 = highly suitable, 0.5 – 0.8 = Suitable, 0.3 – 0.5 = moderately suitable, and < 0.3 = the least suitable.

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Table 1.Correlation Matrix for current Bioclimatic variables

Layer	Bio1	Bio2	Bio3	Bio4	Bio5	Bio6	Bio7	Bio8	Bio9	Bio10	Bio11	Bio12	Bio13	Bio14	Bio15	Bio16	Bio17	Bio18	Bio19
Bio1	1	0.986	0.984	-0.632	-0.618	-0.329	0.168	-0.601	-0.368	-0.545	-0.318	-0.458	-0.533	0.414	0.96	0.961	-0.049	0.971	0.97
Bio2	0.985	1	0.946	-0.595	-0.557	-0.343	0.157	-0.538	-0.383	-0.575	-0.274	-0.42	-0.629	0.553	0.979	0.918	0.065	0.952	0.95
Bio3	0.984	0.946	1	-0.613	-0.607	-0.304	0.206	-0.596	-0.348	-0.516	-0.311	-0.466	-0.393	0.255	0.912	0.976	-0.167	0.947	0.97
Bio4	-0.632	-0.595	-0.613	1	0.858	0.571	-0.314	0.913	0.568	0.441	0.779	0.366	0.385	-0.21	-0.608	-0.633	0.078	-0.724	-0.522
Bio5	-0.618	-0.557	-0.607	0.858	1	0.213	0.119	0.984	0.178	0.235	0.722	0.46	0.343	-0.106	-0.554	-0.645	0.198	-0.713	-0.551
Bio6	-0.329	-0.343	-0.304	0.571	0.214	1	-0.673	0.265	0.974	0.469	0.301	0.109	0.294	-0.257	-0.358	-0.293	-0.104	-0.335	-0.236
Bio7	0.168	0.157	0.206	-0.314	0.119	-0.673	1	0.01	-0.751	-0.353	-0.097	0.034	0.088	-0.047	0.162	0.182	-0.045	0.153	0.102
Bio8	-0.601	-0.538	-0.596	0.913	0.984	0.266	0.01	1	0.238	0.256	0.783	0.442	0.314	-0.081	-0.539	-0.634	0.205	-0.707	-0.52
Bio9	-0.368	-0.383	-0.348	0.568	0.178	0.974	-0.751	0.238	1	0.523	0.264	0.137	0.295	-0.264	-0.389	-0.339	-0.076	-0.367	-0.276
Bio10	-0.545	-0.575	-0.516	0.442	0.235	0.47	-0.353	0.257	0.524	1	0.121	0.289	0.409	-0.385	-0.535	-0.514	-0.012	-0.492	-0.534
Bio11	-0.318	-0.274	-0.311	0.779	0.722	0.301	-0.096	0.783	0.264	0.121	1	0.223	0.189	-0.026	-0.307	-0.342	0.082	-0.452	-0.196
Bio12	-0.458	-0.42	-0.466	0.366	0.46	0.109	0.034	0.442	0.137	0.289	0.223	1	0.404	-0.054	-0.264	-0.633	0.708	-0.507	-0.477
Bio13	-0.533	-0.629	-0.393	0.385	0.343	0.294	0.089	0.314	0.295	0.411	0.189	0.404	1	-0.875	-0.626	-0.421	-0.356	-0.56	-0.463
Bio14	0.414	0.553	0.255	-0.21	-0.106	-0.257	-0.047	-0.081	-0.265	-0.385	-0.026	-0.054	-0.875	1	0.582	0.232	0.631	0.409	0.343
Bio15	0.96	0.979	0.912	-0.608	-0.554	-0.358	0.162	-0.539	-0.389	-0.535	-0.306	-0.264	-0.626	0.582	1	0.856	0.222	0.93	0.907
Bio16	0.961	0.918	0.976	-0.633	-0.645	-0.293	0.182	-0.634	-0.339	-0.514	-0.342	-0.632	-0.421	0.232	0.856	1	-0.314	0.945	0.948
Bio17	-0.049	0.065	-0.167	0.077	0.198	-0.104	-0.045	0.205	-0.076	-0.012	0.082	0.708	-0.356	0.631	0.222	-0.314	1	-0.076	-0.123
Bio18	0.971	0.952	0.947	-0.724	-0.713	-0.335	0.153	-0.707	-0.367	-0.492	-0.452	-0.507	-0.56	0.409	0.93	0.945	-0.076	1	0.914
Bio19	0.97	0.95	0.969	-0.522	-0.551	-0.236	0.102	-0.521	-0.276	-0.534	-0.196	-0.477	-0.463	0.343	0.907	0.948	-0.123	0.914	1

Table 2.Correlation Matrix for Future Bioclimatic variables

Layer	Bio1	Bio2	Bio3	Bio4	Bio5	Bio6	Bio7	Bio8	Bio9	Bio10	Bio11	Bio12	Bio13	Bio14	Bio15	Bio16	Bio17	Bio18	Bio19
Bio1	1	0.109	0.077	0.497	-0.492	-0.669	-0.575	-0.302	-0.566	-0.599	-0.624	-0.665	-0.578	0.538	0.262	0.701	-0.517	0.291	0.754
Bio2	0.109	1	0.266	0.183	-0.086	-0.153	-0.218	0.109	-0.402	-0.138	-0.254	-0.235	-0.225	0.760	0.742	0.239	-0.018	0.801	0.178
Bio3	0.077	0.266	1	0.273	-0.167	-0.025	-0.352	0.675	-0.263	-0.207	-0.185	-0.187	-0.150	0.258	0.477	-0.106	0.358	0.415	-0.119
Bio4	0.497	0.183	0.273	1	-0.888	-0.528	-0.318	-0.521	-0.498	-0.382	-0.454	-0.555	-0.324	0.402	0.238	0.455	-0.160	0.254	0.459
Bio5	-0.491	-0.085	-0.166	-0.889	1	0.458	0.231	0.543	0.375	0.281	0.353	0.475	0.196	-0.296	-0.129	-0.345	0.074	-0.149	-0.347
Bio6	-0.668	-0.153	-0.025	-0.5284	0.458	1	0.89	0.381	0.923	0.935	0.968	0.981	0.941	-0.570	-0.447	-0.526	0.369	-0.451	-0.570
Bio7	-0.575	-0.218	-0.353	-0.3184	0.232	0.895	1	-0.071	0.925	0.958	0.957	0.934	0.962	-0.586	-0.603	-0.368	0.197	-0.576	-0.408
Bio8	-0.302	0.1093	0.675	-0.522	0.543	0.381	-0.071	1	0.146	0.104	0.181	0.258	0.111	-0.060	0.250	-0.413	0.419	0.185	-0.429
Bio9	-0.565	-0.402	-0.262	-0.499	0.375	0.923	0.925	0.146	1	0.917	0.969	0.961	0.945	-0.725	-0.691	-0.457	0.234	-0.688	-0.481
Bio10	-0.599	-0.138	-0.207	-0.3824	0.281	0.935	0.958	0.104	0.916	1	0.972	0.955	0.971	-0.548	-0.526	-0.412	0.239	-0.500	-0.451
Bio11	-0.625	-0.254	-0.185	-0.455	0.353	0.9686	0.958	0.181	0.967	0.972	1	0.990	0.985	-0.646	-0.594	-0.482	0.289	-0.582	-0.516
Bio12	-0.665	-0.235	-0.186	-0.555	0.475	0.981	0.934	0.257	0.961	0.955	0.99	1	0.955	-0.640	-0.561	-0.509	0.296	-0.553	-0.544
Bio13	-0.577	-0.225	-0.150	-0.324	0.196	0.941	0.962	0.110	0.945	0.971	0.985	0.955	1	-0.609	-0.575	-0.452	0.309	-0.560	-0.491
Bio14	0.538	0.761	0.258	0.408	-0.296	-0.570	-0.586	-0.060	-0.725	-0.547	-0.646	-0.640	-0.609	1	0.862	0.598	-0.339	0.917	0.583
Bio15	0.263	0.743	0.478	0.238	-0.129	-0.447	-0.034	0.250	-0.691	-0.527	-0.595	-0.561	-0.575	0.862	1	0.246	0.082	0.982	0.203
Bio16	0.701	0.239	-0.105	0.455	-0.345	-0.526	-0.368	-0.413	-0.457	-0.412	-0.482	-0.509	-0.452	0.598	0.246	1	-0.676	0.304	0.963
Bio17	-0.517	-0.018	0.358	-0.160	0.0742	0.367	0.197	0.419	0.233	0.239	0.288	0.295	0.309	-0.339	0.081	-0.676	1	-0.027	-0.763
Bio18	0.292	0.801	0.415	0.254	-0.149	-0.450	-0.575	0.185	-0.687	-0.501	-0.582	-0.553	-0.560	0.917	0.982	0.304	-0.027	1	0.266
Bio19	0.755	0.179	-0.118	0.4597	-0.347	-0.570	-0.408	-0.429	-0.48	-0.451	-0.515	-0.543	-0.491	0.583	0.204	0.963	-0.763	0.267	1

RESULT AND DISCUSSIONS

Evaluations of the model under current climatic condition- Analysis of omission/commission: The result of this analysis indicated that the omission on training samples (blue line) is close to Predicted omission (black line).The closer the omission on training samples line is to the Predicted omission, the more accurate the generated model (Kigen *et al*., 2013).On the other hand, if the blue line (omission on training samples) is well below the black line (predicted omission), this might indicate some over-fitting because of dependence between presence points (Scheldeman, and Zonneveld,2010). In this instance (*Arabis alpina)*, this was not happen, although very few blue line (omission on training samples) are below black line (predicted omission). The result of this analysis also indicated that the omission on test samples is a virtuous match to the projected omission rate (figure 1).

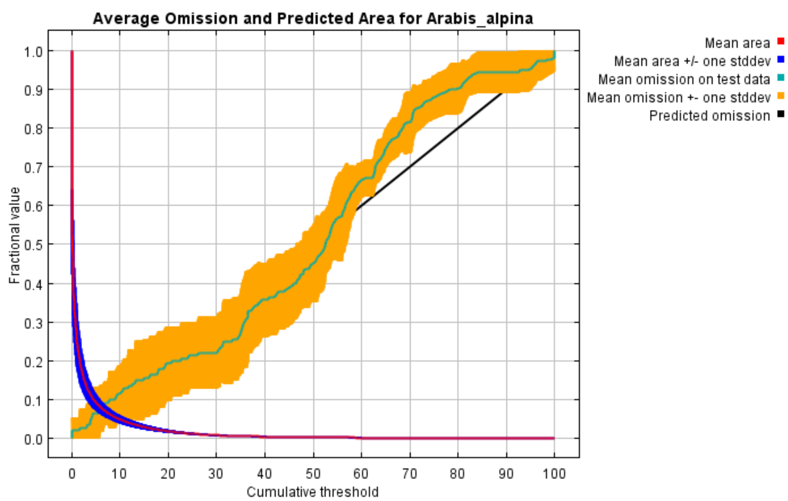

Fig1. Average omission and predicted areas of current climatic condition for *Arabis alpina* (10 replicas)

The ROC curve of the model under current climatic condition

A parameter used to evaluate the predictive ability of the generated model is referred to as Area under Curve (AUC) of the Receiver Operating Characteristic (ROC) Curve. The AUC value provided by Maxent measures the probability that a arbitrarily designated occurrence point is situated in a raster cell with a higher likelihood value for species existence than a randomly selected nonappearance point. The AUC can assume values between 0 and 1. Values between 0.7 and 0.9 correspond to a model of average useful application, and values above 0.9 indicate the highest accuracy of the model (Phillips *et al*., 2006).

In MaxEnt, presences are split in to training and test data. Each replica of training and test data has its own AUC value. Training data are used to create the predictive model while test data are used to assess the model accuracy. The result of this analysis confirmed that the average test of AUC for the 10 replicate runs is 0.970 with a random prediction AUC of 0.5 or the average sensitivity vs.1- specificity of the model for *Arabis alpina* was excellent (AUC mean = 0.970) for current distribution. As reported by Araujo *et al*.(2005) this is an excellent model since the AUC is more than 0.90(figure 2).

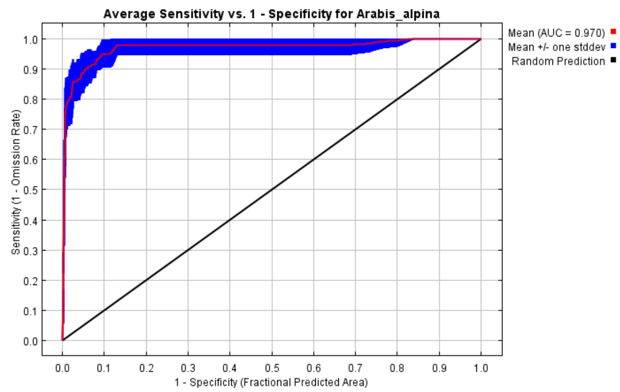

Figure 2: The ROC Curve of the model for *Arabis alpina* under current climatic condition

Jackknife and Species response curve of the model under recent climatic situation

The jackknife test indicated the current distribution of *Arabis alpina* was predominantly influenced by Annual Mean Temperature (Bio1) and the Min Temperature of Coldest Month (Bio6) that contributed 74.9% and 17.5% to the MaxEnt model respectively. The remaining six bioclimatic variables collectively contributed 7.6% only. As to the permutation importance, Bio1 and Bio6 had permutated 93% for the given species distribution model. Annual Mean Temperature (bio1) is the environmental variable with highest gain when used in isolation. Bio3 is the environmental variable that decreases the gain the most when it is omitted, which therefore appears to have the most information that isn't present in the other variables.

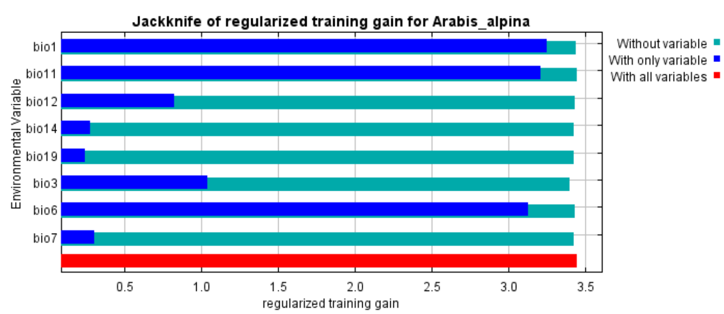

Figure 3. Jackknife of regularized training gain for *Arabis alpina* under current climatic condition

Species response curve also portrays the correlation among bioclimatic variables and the likelihood of species occurrence. Those curves indicate how each bioclimatic variable affects the Maxent prediction (Young *et al*., 2011 and Fourcade *et al*.,2014).

The species response curves developed under current climatic condition portrayed Arabis *alpina* prefers the annual precipitation sorted from 250 to 2000 mm, precipitation of the coldest quarter ranged from 100 to 1200mm, Annual Mean Temperature ranged from 5 to 35 °C, temperature Annual Range (P5-P6) sorted from 12 to 26°C, Mean Temperature of coldest Quarter ranged from 5 to 30°C and Min Temperature of Coldest Month range from -4 to 25°C. The curves can be hard to interpret if there are strongly correlated variables, as the model may depend on the correlations in ways that are not evident in the curves. This was not the case in this investigation since the selected bio-climatic variables were the least correlated (bio1, bio3, bio6, bio7, bio11, bio12, bio14 and bio19). The curves also showed the mean response of the 10 replicate Maxent runs (red) and the mean +/- one standard deviation (blue).

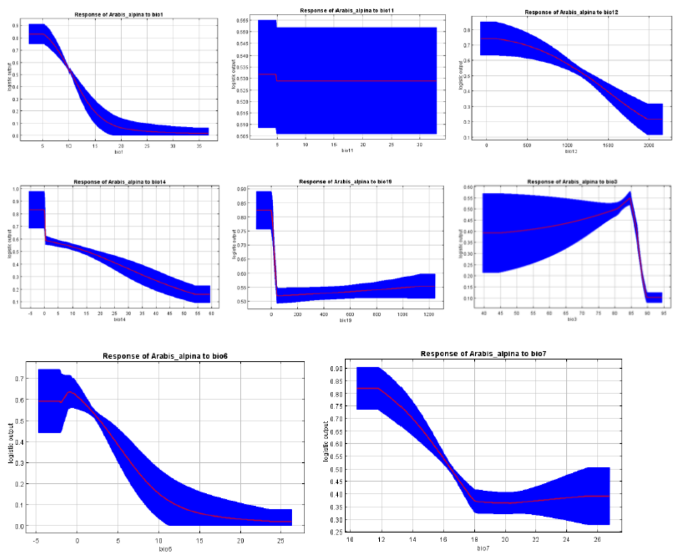

Figure 4. *Arabis alpine* response curves in relation to Annual Mean Temperature (Bio1), Annual Precipitation_Bio12, Mean Temperature of Coldest Quarter _Bio11, a precipitation of coldest quarter_Bio19, Precipitation of Driest Month (Bio14), Precipitation of Coldest Quarter(Bio19), temperature Annual Range (Bio7) and Min Temperature of Coldest Month (Bio6) under current climatic conditions.

Habitat suitability investigation of *Arabis alpina* under Current Climatic condition

The developed current potential distribution map uses different colors to show the projected likelihood that the sites were classified as highly suitable(4), indicating high probability of suitable conditions for the species *Arabis alpina*, suitable(3), indicating conditions were suitable for the selected species, moderately suitable(2) indicating moderate predicted possibility of appropriate conditions and the least suitable(1) indicating the least or almost nil predicted probability of suitable conditions(Figure 5). The total number of pixels contributing to the suitability classes (the least suitable, moderately suitable, suitable and highly suitable) are 1268082, 55443, 11097 and 4640 respectively. The area in hectare of the least suitable, moderately suitable, suitable and highly suitable habitat were 107287579.3, 4690820.673, 938874.8266 and 392572.6949 respectively (Table 3).

Table 3. Suitability Classes under current climate condition

Values	Suitability class	Number of Pixel	Area of one Pixel	Area of total Pixel in hectares	Percentage
1.	The least suitable	1268082	84.60618425	107287579.3	94.68513256
2.	Moderately suitable	55443	84.60618425	4690820.673	4.139817302
3.	Suitable	11097	84.60618425	938874.8266	0.828590672
4.	Highly suitable	4640	84.60618425	392572.6949	0.346459468

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From picture of the model, it is realized that the suitable conditions for *Arabis alpina* are forecasted to be greatly possible through most of highland of the country such as south west Ethiopia; Bale, Arsi , some part of Eastern Ethiopia; Hararge, central Ethiopia ;Shewa upland, Northern Ethiopia;Gondar, Tigray and Welo high land areas etc.. The modeled current place covers most of the area published on Flora of Ethiopia and Eritrea(Sebsebe Demissew, and Hedberg, 2000) but the current modeled place even covers large areas than the documented areas on Flora of Ethiopia and Eritrea. This might be due to the change in temperature and precipitation. Hence, precipitation and temperature play the key role in defining the possible habitats distribution of *Arabis alpina*.

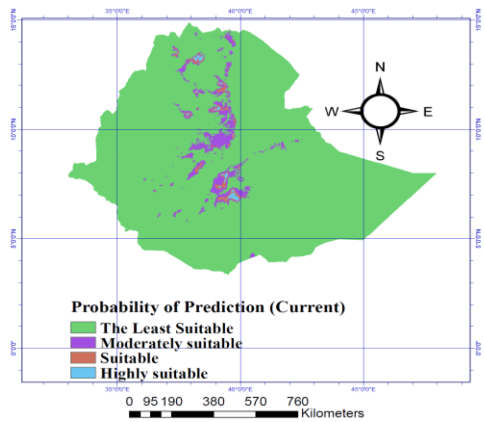

Figure 5. Potentially suitable climatic distribution of *Arabis alpina* under current climate condition

Evaluations of the model under future climatic condition

Analysis of omission/commission

In this study, the omission level and forecasted area as a function of the cumulative threshold, averaged over the 10 replicate runs. The result of this analysis indicated that the Omission on training samples (blue line) is close to Predicted omission (black line)(figure 6).The closer the Omission on training samples line is to the Predicted omission, the more accurate the generated model (Yikunoamlak Gebrewahid *et al*., 2020). From figure of average omission and predicted areas; the model generated under future climatic condition for *Arabis alpina* could be more accurate.

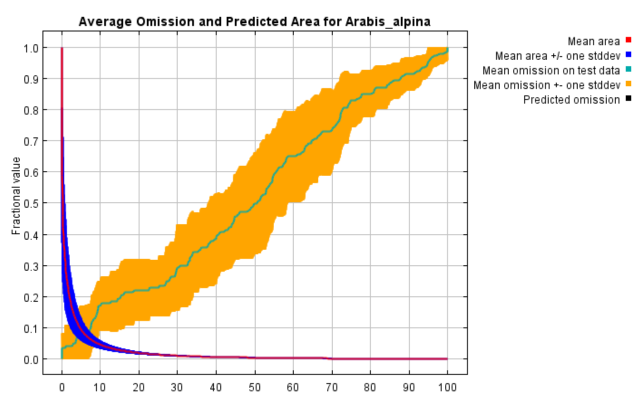

Figure 6. Average omission and predicted areas under future climatic condition for *Arabis alpina* (10 replicas).

The ROC curve of the model under future climatic condition

The result of this investigation indicated that the average value of AUC for the replicate runs is 0.959 with a random prediction of AUC 0.5 and the standard deviation of 0.032. This is an excellent model since the AUC value is more than 0.90 as described in the model of current climatic condition (Figure 7).

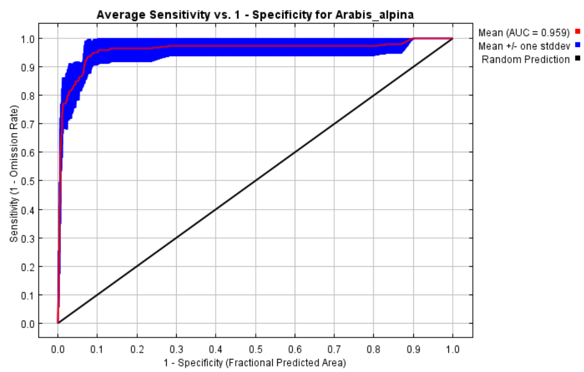

Figure 7.The ROC curve of the model under future climatic condition (10 replicates).

Jackknife and Species response curve of the model under future climatic condition

The jackknife test is used to evaluate the governing bioclimatic variables that determine the species potential distribution (Phillips, 2009). The bioclimatic variable with maximum achievement while used in isolation is Precipitation of Wettest Quarter (bio16fut), which consequently seemed to have the most useful information by itself. The environmental variable that decreased the gain the most when it was omitted is bio16fut, which therefore appeared to have the most information that wasn't present in the other variables. Values shown were averages over replicate runs (figure 8).

Average Percent Contribution and Permutation importance of bioclimatic variables indicated that, under future climatic condition the distribution of *Arabis alpina* was largely influenced by Precipitation of Wettest Quarter (bio16fut) that contributed 95.1% to the MaxEnt model. The remaining seven bioclimatic variables contributed only 4.9% of the total Percent contribution. Concerning to the permutation importance, Precipitation of Wettest Quarter (Bio16fut) had permutated 94.6% of the total, while the remaining seven bioclimatic variables contributed collectively only 5.4% of the total permutation.

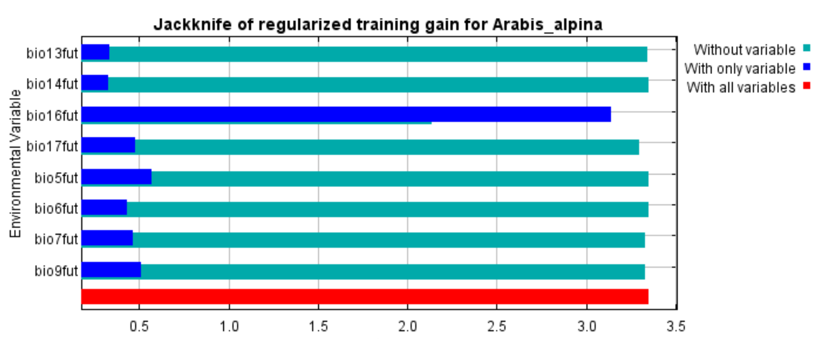

Figure 8.Jackknife of regularized training gain for *Arabis alpina* under future climatic condition

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Species response curves is used to study the correlation between the given species habitat suitability and bioclimatic factors (Scheldeman, and Zonneveld,2010). The species response curves developed under future climatic condition portrayed *Arabis alpina* prefers Precipitation of Wettest Quarter (Bio16) ranged from 50 to 110 mm, and with Annual temperature ranges from 20 to35°C. In addition, the curves display in what way the forecasted likelihood of presence changes as each bioclimatic variable is varied, keeping all other variables at their average sample value.

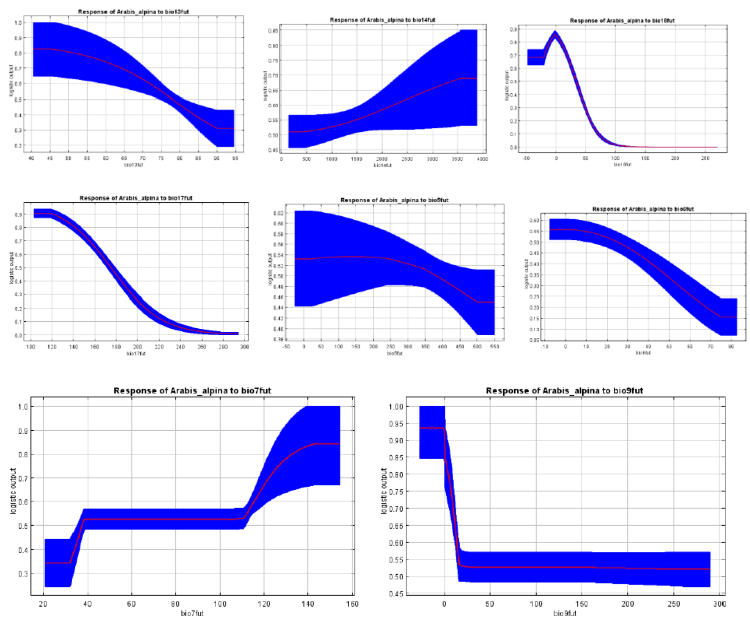

Figure 9. *Arabis alpina* response curves in relation Precipitation of Wettest Quarter (Bio16), Precipitation of Driest Quarter(Bio17), Precipitation of Wettest Month(Bio13), Precipitation of Driest Month(Bio14), Mean Temperature of Driest Quarter(Bio9), temperature Annual Range (P5-P6)(Bio7), Min Temperature of Coldest Month(Bio6) and Max Temperature of Warmest Month(Bio5) under future climatic condition

Variations in distribution of *Arabis alpina* under the future Climatic conditions

This future potential distribution map also uses colors(figure 10) to designate anticipated likelihood that environments are classified as highly suitable(4), suitable(3), moderately suitable(2) and the least suitable(1). The totals number of pixels contributing to the suitability classes (the least suitable, moderately suitable, suitable and highly suitable) were 1272761, 46933, 13751 and 5817 respectively. The area in hectares of the least suitable, moderately suitable, suitable and highly suitable habitat were 107683451.7, 3970822.045, 1163419.64 and 492154.1738 respectively (Table 4).The Pictures of the model indicated that the future distribution /suitable areas/ of *Arabis alpina* will be restricted to some areas of Ethiopia or exist in few areas of the country when compare to current distribution.

In reaction to the expected climate changes, the inclusive locations of the un-suitable habitat will be significantly increases for future climatic condition (more than 395872.3 hectares than current prediction). Conversely, the moderately suitable habitats will efficiently reduce via 719998.63 hectares as compare to current climatic condition. Beside, in reaction to climate change highly suitable and suitable habitats will be expanded by 99581.5 and 224544.8 hectare respectively under future climatic condition. This might me due to climate change, deforestation, Invasive Alien Species, increasing use of chemical fertilizer and herbicide etc. In addition from the picture of the model there might be shifting of habitat from the lower altitude to the higher altitude .This might be due to an increase in temperature and decrease in precipitation.

Table 4. Suitability classes under current climate condition

Value	Suitability classes	Number of Pixel	Area of one Pixel	Area of total Pixel in hectares	Percentage
1.	The least suitable	1272761	84.60618425	107683451.7	95.03450408
2.	Moderately suitable	46933	84.60618425	3970822.045	3.504392718
3.	Suitable	13751	84.60618425	1163419.64	1.026759514
4.	Highly suitable	5817	84.60618425	492154.1738	0.434343691

List of Figures

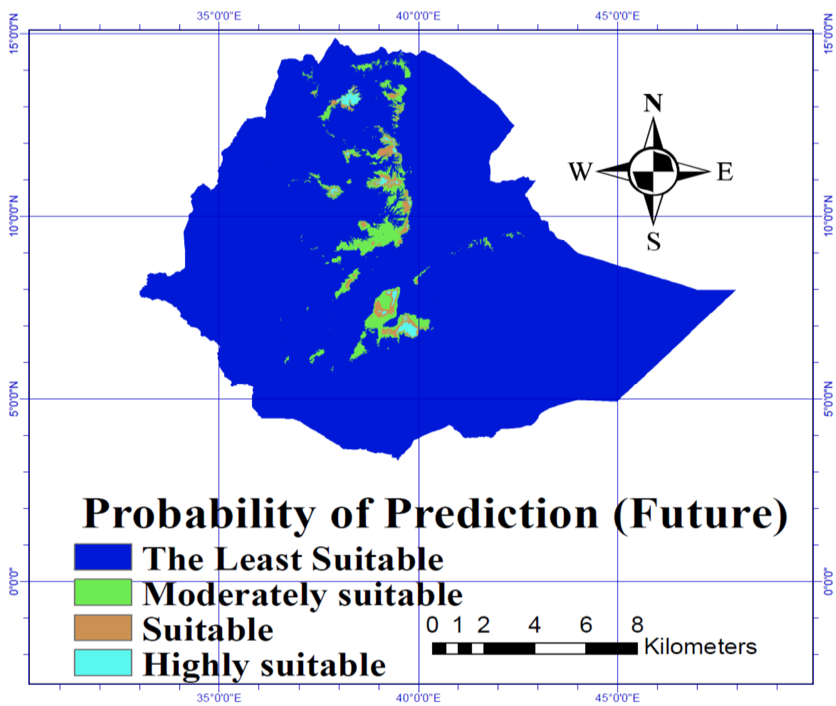

Figure 10. Potentially suitable climatic distributions of *Arabis alpina* under future climate condition

CONCLUSION AND RECOMMENDATION

The outcomes of this investigation might provide an understanding of the bioclimatic factors affecting current and future distributions *Arabis alpina*'s. The picture of the model of current climatic conditions and from Flora of Ethiopia and Eretria indicated that *Arabis alpina* occurs in most Ethiopian regions but the picture of the model for future climatic condition indicated that this plant will be restricted to very few area of the country. This might me due to climate change/global warming, anthropogenic degradation or human impact (deforestation), overgrazing, invasive alien species, increasing use of chemical fertilizer and herbicide, etc. In addition from the picture of the model there might be shifting of habitat from the lower altitude to the higher altitude. This might be due to an increase in temperature and decrease in precipitation for future climatic condition. Therefore, this study recommends integrating future climate situation into recent rehabilitation, conservation and sustainable utilization strategies to safeguard naturally sensitive species like *Arabis alpina*. However, the justification of this model needs additional field study on the distribution of *Arabis alpina*.

CONFLICTS OF INTEREST

The authors declare no conflict of interest

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