Predicting the Potential Distribution of *Olea ferruginea* in Pakistan incorporating Climate Change by Using Maxent Model

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**Abstract:** The potential distribution of *Olea ferruginea* was predicted by Maxent model for present and the upcoming hypothetical (2050) climatic scenario. *O. ferruginea* is an economically beneficial plant species. For predicting the potential distribution of *O. ferruginea* in Pakistan, Worldclim variables for current and future climatic change scenarios, digital elevation model (DEM) slope, and aspects with the occurrence point were used. Pearson correlation was used to reject highly correlated variables. A total of 219 sighting points were used in the Maxent modeling. The area under curve (AUC) value was higher than 0.98. The approach used in this study is considered useful in predicting the potential distribution of *O. ferruginea* species, and can be an effective tool in the conservation and restoration planning for human welfare. The results show that there is a significant impact under future bioclimatic scenarios on the potential distribution of *O. ferruginea* in Pakistan. There is a significant decrease in the overall distribution of *O. ferruginea* due to loss of habitats under current distribution range, but this will be compensated by gain of habitat at higher altitudes in the future climate change scenario (habitat shift). It is recommended that the areas predicted suitable for the *O. ferruginea* may be used for plantation of this species while the deforested land should be restored for human welfare.

**Keywords:** bioclimatic; climate change; habitat shift; Jackknife test; Maxent model; *Olea ferruginea*

1. **Introduction**

*O. ferruginea* is a species of the family Oleaceae. *Olea ferruginea* is a synonym of *Olea europaea subsp cuspidate*. It is known as Indian olive and *Kahoo* in native language. From this species a number of different products can be obtained including fodder, firewood, edible fruits, and olive oil. Thus, olive is an important tree species from an economic point of view [1–4].

Past ecological studies highlighted the relation between the climatic indicators, occurrence, and abundance of different species [5–12]. The drastic change in species distributions or population status in an area is considered to be the result of land cover changes, human influence, and climate change [13,14].
Species distribution and habitat evaluation can be determined by different modelling techniques. [7, 15–23]. The main purpose of this research is to predict the spatial shift of *O. ferruginea* in response to hypothetical projected climatic values for 2050. In ecological niche modelling (ENM) environmental parameters are compared within the geographical space. ENM techniques are based on statistical methods (e.g., generalized additive models (GAMs) and generalized linear models (GLMs)) and scientist-developed machine learning methods (e.g., artificial neural networks (ANNs) and maximum entropy (Maxent)) that are based on different statistical techniques [24–30].

If we relate ENM results of the habitat evolution of the species, there are fewer restrictions in terms of ecological variables, e.g., layers of environment and occurrence data where choice is available. Thus, unnecessary restriction should be avoided for unbiased results [7].

In a geographical space, ENM (ecological niche modelling) predictive high output values (high threshold) at grid cells shows relatively high probability of finding a species under suitable environment [14, 31, 32].

To evaluate the habitat and distribution of the *Olea ferruginea* in Pakistan, Maxent was used in this study. The study area includes the provinces of Pakistan (Punjab, Baluchistan, Khyber Pakhtunkhwa, and Sindh) and the area of Azad Jammu and Kasmir (AJK) except Kasmir territory under Indian control. The main objectives of the research are; (1) to understand the relation of *O. ferruginea* with reference to bioclimatic layers, digital elevation model (DEM), slope, and aspect; (2) to predict the current potential distribution of *O. ferruginea* in Pakistan by incorporating recent bioclimatic and topographic data; and (3) to project the distribution of *O. ferruginea* in Pakistan by incorporating Intergovernmental Panel on Climate Change (IPCC) climate change hypothetical projections (future bioclimatics).

2. Materials and Methods

Figure 1 shows the flow of methods which were adopted to predict the distribution of the *O. ferruginea*.

2.1. Data Collection

Species sighting data with longitude, latitude, and elevation were gathered by field surveys using quadrates of 10 × 10 m of Murree, Islamabad, Mansehra, Kohistan, Swat, Lower Dir, Bajur Agency, Malakand PA, Sibi, and D.I Khan (major districts where *O. ferruginea* can grow) as well as extracted from the literature [3, 10]. Field survey was conducted while recording GPS points of *O. ferruginea* sightings. Before conducting the survey, literature was studied regarding *Olea* growing regions in Pakistan [4, 10, 33–35]. These geographical coordinates were helpful in locating the areas of *O. ferruginea* distribution. With the help of ArcGIS 10.2 (Esri, Redlands, CA, USA), the sighting point map was developed. A total of 219 sighting points were used for Maxent modelling, and are shown in Figure 2.

Three types of variables were used in this study, including topographical variables (DEM, slope, and aspect) and current and future bioclimatic variables. Literature review showed that a broad range of ecological inputs (environmental layers) can be used in predicting the potential distribution of *Olea ferruginea* by using habitat modelling, which in this case was Maxent [24, 36]. DEM layer was downloaded from the SRTM web site [37]. Slope and aspect from the DEM data were derived by using “spatial analysis” tools of ArcGIS desktop and projected to WGS 1984 UTM zone 42 North [38, 39]. Current and future (2050) bioclimatic variables for the study area were downloaded from the Worldclim website for the current conditions with a resolution of 1 km. Climate change can be predicted with fair degree of confidence in Pakistan up to the year of 2050 [40–43]. Bioclimatic layers were prepared by incorporating the past trends of temperature and precipitation. These are important to estimate the difference of current and the future patterns of climate and hence the species distribution. Future climatic projections were calculated using statistics by the Intergovernmental Panel on Climate Change (IPCC) 4th assessment data.
Figure 1. Processing methodology in flow diagram.
2.2. Data Processing

DEM, slope, and aspect were aggregated to a 1 × 1 km pixel size to harmonize the dataset with bioclim datasets [39]. In Figure 1 the data processing method can be clearly seen. DEM and derived variables (slope and aspect) were used in the model because altitude is not going to change in the near future. After aggregating, all layers were converted to ASCII format by using model builder function of ArcGIS (extract by mask and raster to ASCII conversion tools were used). By using the SDM tool for ArcGIS the Pearson correlation was calculated. The Maxent model was also run using all variables to find out the most contributing variables for current predictions with an option of 10 replicates. The variables that have no impact on O. ferruginea prediction—based on current variables in the Maxent model—were ignored and the remaining variables were used for Maxent modelling [40]. Discriminant analysis was performed in Excel. Out of highly correlated (R > ±0.8) variables, one variable each was eliminated (Figure 3 and Table A1). Bio12 (annual precipitation), bio19 (precipitation of coldest quarter), bio17 (precipitation of driest quarter), bio11 (mean temperature of coldest quarter), bio18 (precipitation of warmest quarter), bio2 (mean diurnal range), bio14 (precipitation of driest month), DEM, bio7 (temperature annual range), bio4 (temperature seasonality), and aspect were used for further processing with the Maxent model, while other variables were ignored.

Maxent is a machine learning method. It works on the principle of maximum entropy defined as “how much choice is involved in the selection of an event” [40,42]. Maxent works efficiently with a low level of presence background data for animal or plant species, for prediction, as well as for projection of suitable habitat [24,44]. Maxent estimates the distribution of the species based on presence background data and imposes the restriction that the value of each expected variable should match its empirical average under this estimated algorithm [7,30]. For the current study, Maxent 3.3.3k version was used [45]. In settings, the random seed option was selected with a 10% of test sample size and 5000 iterations. Jacknife tests and the area under curve (AUC) with training and test data were also calculated in Maxent for evaluating the accuracy of the models. After running the model for predicting the current suitable habitat with selected input variables, prediction was projected for the future (2050)
as well. For future predictions, ‘fade-by-clamping’ option was kept on so that over-prediction would be reduced [7,46]. For development of the species distribution map, ASCII outputs were converted to the raster and reclassified for area calculation.

![Figure 3. Jackknife of regularized training gain (a) and area under curve (AUC) (b) for O. ferruginea.](image)

### 3. Results and Discussions

The results are presented in three steps. First, the relative percentage contribution of predictor variables is given, followed by model performance evaluation on the bases of AUC values, and finally current and future hypothetical habitat suitability maps are presented and compared.

The Jackknife tests from Maxent show the relative contribution of each predictor variable for *O. ferruginea* prediction (Figure 3). The main variables for predicting potential distribution of *O. ferruginea* in Pakistan are annual precipitation (bio12) and precipitation of coldest quarter (bio19) for the current scenario with respective contributions of 38.6% and 20.5% (Table A1). Therefore, bio12, bio19, bio17 (precipitation of driest quarter), and bio11 (mean temperature of coldest quarter) have a greater contribution compared to other variables for the potential distribution of *O. ferruginea*. Bio18 (precipitation of warmest quarter) and bio11 (mean temperature of coldest quarter) are more important for permutation (Figure 3a). Figure 3b also shows that variables with high contribution factor have...
a higher AUC value. Aspect has low AUC value with less contribution, thus this is not important parameter for *Olea* distribution.

By applying the maximum entropy principle of Maxent, the maximum possible areas under receiver operating characteristic curves (AUC) test is 0.988 for current prediction and future projection [46,47]. The calculated AUC value shows that the results are significant (above 0.9) (Figure A1).

The model provides the species’ future distribution under hypothetical projected climatic values for 2050, compared to the climatic values under which the species currently occurs. The results calculated from present bioclimatics for the current prediction show that the total suitable area for *O. ferruginea* is approximately 41,449 km$^2$, which is 4.83% of the total study area. In the future bioclimatic projection scenario (hypothetical), total distributional area of *O. ferruginea* is 19,192 km$^2$, which is 2.23% of the total study area, as shown in Figure 4 (and Table 1). Species distribution maps were developed by using Maxent results. The map is categorized into four classes which are highly suitable (greater than 0.6 threshold value), moderately suitable (0.4 to 0.6), less suitable (0.2–0.4), and not suitable (<0.2) (Figure 4). For current and future classified maps, the threshold values are kept constant.

**Table 1.** Comparison showing current and future distributional area of *O. ferruginea*.

<table>
<thead>
<tr>
<th>Suitability</th>
<th>Threshold</th>
<th>Current Prediction (Km$^2$)</th>
<th>Current Prediction (%)</th>
<th>Future Projection (Km$^2$)</th>
<th>Future Projection (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unsuitable area</td>
<td>&lt;0.2</td>
<td>816169</td>
<td>95.16</td>
<td>838426</td>
<td>97.76</td>
</tr>
<tr>
<td>Less suitable area</td>
<td>0.2–0.4</td>
<td>35185</td>
<td>4.10</td>
<td>11098</td>
<td>2.29</td>
</tr>
<tr>
<td>Moderately Suitable area</td>
<td>0.4–0.6</td>
<td>4972</td>
<td>0.57</td>
<td>4361</td>
<td>0.50</td>
</tr>
<tr>
<td>Highly Suitable area</td>
<td>&gt;0.6</td>
<td>1292</td>
<td>0.15</td>
<td>3733</td>
<td>0.43</td>
</tr>
<tr>
<td>Total Suitable area</td>
<td>0.2–1.0</td>
<td>41449</td>
<td>4.83</td>
<td>19192</td>
<td>2.23</td>
</tr>
</tbody>
</table>

Figure 4c–f shows the zoom parts of the study area where major changes in the distribution were observed during current prediction and future projection.

**Figure 4.** Cont.
Maxent results for current suitable habitats for *O. ferruginea* are predicted to be in northern Punjab (some parts of Khushab, Chakwal, Attock, and Rawalpindi) with low threshold value, in eastern to central and northwestern part of Khyber Pakhtunkhwa (KP) (Lower Dir, Swat, Kohistan, Karak, and D.I. Khan) with low to high threshold value, in northeastern parts of Baluchistan (Ziarat, Harnai, Mastung, and Kalat) and FATA (northwestern parts of Kurram Agency and western parts of Waziristan agency), AJK (Muzaffraabad, Hattian, Haveli, Bagh, Poonch, Kotli, and Sudhnoti) and in Islamabad (Figure 4c, e). The future projected species distribution map reveals that there is a significant decrease
in the overall distribution of *O. ferruginea*, as can be seen from the calculated area (Table 1). Averaged future predictions from bioclimatic Maxent model of 2050 has shown a decrease in suitable habitat of *Olea* in Kurram Agency, central Khyber Pakhtunkhwa, northern Punjab, AJK, and Islamabad, and an increase in suitable habitat in northern Khyber Pakhtunkhwa (Figure 4d,f). So with future bioclimatics there will be a total decrease with a shift in *Olea* habitat toward higher latitude and altitude (Figure 4) [46–48].

Distributional maps are important sources for planning conservation strategy. Ground realities also indicate the area which is predicted by Maxent to be suitable for growth of *O. ferruginea*. The cutting of this species should be minimized because habitat fragmentation is the first step in degradation of any species.

4. Conclusions

This study presents occurrence data for the present and a model projection to a hypothetical future climatic scenario. Furthermore, future hypothetical projections of species response to environmental changes are difficult to ascertain. Therefore, there is a need to adopt proactive conservation planning measures using forecasts of species responses with respect to change in future environment.

Maxent software was used to predict the current and future potential distribution and habitat of *Olea ferruginea* in different climatic scenarios. The results reveal that under upcoming bioclimatic scenarios, there will be a moderate to high impact on the *O. ferruginea* distribution in Pakistan. There is a significant decrease in the overall distribution of *O. ferruginea*. It was also observed that in some areas *O. ferruginea* lost habitat in its present distribution range but shifted towards higher altitude and latitude in the future climate change scenario. It is recommended that the areas predicted suitable for the *O. ferruginea* with both current and hypothetical future scenarios be used for plantation of this species and the deforested land can be restored.

**Author Contributions:** Hassan Ali and Irfan Ashraf conceived and designed the experiments; Zafeer Saqib and Irfan Ashraf conducted the survey; Uzma Ashraf, Adila Batool, performed the experiments; Muhammad Nawaz Chaudry, Hassan Ali and Uzma Ashraf analyzed the data; Uzma Ashraf wrote the paper.

**Conflicts of Interest:** The authors declare no conflict of interest.

**Appendix**

![Figure A1](image1.png)

**Figure A1.** (a) Average omissions and prediction Area; (b) Receiver Operating Characteristic (ROC) curve by using Current bioclimatics for *O. ferruginea* prediction.
Table A1. Percentage contribution comparison of used variable.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Percent Contribution</th>
<th>Permutation Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>bio12</td>
<td>38.6</td>
<td>4</td>
</tr>
<tr>
<td>bio19</td>
<td>20.5</td>
<td>21.2</td>
</tr>
<tr>
<td>bio17</td>
<td>12.3</td>
<td>0.1</td>
</tr>
<tr>
<td>bio11</td>
<td>8</td>
<td>19.3</td>
</tr>
<tr>
<td>bio18</td>
<td>6.1</td>
<td>39.1</td>
</tr>
<tr>
<td>bio2</td>
<td>4.1</td>
<td>0.2</td>
</tr>
<tr>
<td>bio14</td>
<td>3.2</td>
<td>6.6</td>
</tr>
<tr>
<td>dem22</td>
<td>2.8</td>
<td>2.5</td>
</tr>
<tr>
<td>bio7</td>
<td>2.5</td>
<td>4.4</td>
</tr>
<tr>
<td>bio4</td>
<td>1.3</td>
<td>2.2</td>
</tr>
<tr>
<td>asp23</td>
<td>0.5</td>
<td>0.4</td>
</tr>
</tbody>
</table>

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