Proceedings

Biogeographic Distribution of *Cedrela* spp. Genus in Peru Using MaxEnt Modeling: A Conservation Approach [†]

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† Presented at the 1st International Electronic Conference on Biological Diversity, Ecology and Evolution, 15–31 March 2021; Available online: https://bdee2021.sciforum.net/.

Abstract: Expansion of croplands and livestock activities over the time have been considered as major driver for deforestation in Peru. Such severe deforestation activities significantly reduced the number of timber species particularly the genus *Cedrela* spp. that have high economic and ecological value in current time. Recently *Cedrela* spp. has been incorporated (28 August 2020) into appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), a group of species that could be in danger in near-future. Considering this value, we modelled the biogeographic distribution of 10 species of the genus *Cedrela* (i.e., *C. odorata, C. montana, C. fissilis, C. longipetiolulata, C. angustifolia, C. nebulosa, C. kuelapensis, C. Saltensis, C. weberbaueri and C. molinensis)* with the objective to identify if the area legally protected by Protected Natural Areas (PNA), and prioritizing research and conservation/restoration areas of this particular genus. In this regard, 33 different environmental variables were used (19 bioclimatic variables, 3 topographic, 9 edaphic, solar radiation and relative humidity) throughout Peruvian Amazon using a maximum entropy model (MaxEnt). It was observed that 6.67% (86,235.24 km²) of the Peruvian territory presents a high probability of distribution of the evaluated species and whereas the PNA protects only 4.42% (8363.09 km²) of the territory that covers genus *Cedrela*. Furthermore, we have identified that 11.65% (21,345.16 km²) of the area have highly prone to degradation for genus *Cedrela* that needs urgent attention for protection and restoration. We believe that this study will contribute as a tool for the processes of conservation of threatened species, conservation of biodiversity, management and sustainable use of forest resources.

Keywords: *Cedrela*; MaxEnt; conservation; Peru; amazon

1. Introduction

Forest covers have been reduced drastically as a result of agricultural expansion and livestock activities, deforestation, mining, urban expansion, in the Peruvian amazon over last decades [1,2]. In Peru 2 433 314 ha of Amazonian forests have been lost during 2001–2019 [3]. Although the Amazon cover covers 60% of Peru [4], it has been fragmented by forest harvesting activities, a direct cause of deforestation, and indirectly promotes migratory agriculture [5], by eliminating the forest cover of approximately 0.5 ha for crop production [6,7]. Additionally, the selective falling of trees, mainly of species of high economic value, has caused the near extinction of species such as mahogany (*Swietenia macrophylla*) and cedar (*Cedrela odorata*) [8].

Cedrela spp. is a genus of tropical trees that includes species such as *C. odorata* L. and *C. fissilis* Vell., and that have been collected for wood for more than 500 years in Central

and South America, with *C. odorata* being the second most demanded tropical wood [9–12]. Due to the high value of the species of the genus *Cedrela* spp., their use has increased since the end of the 1980s, mainly in Mexico, Brazil, Peru and Bolivia [13,14]. This trend has led to the collapse of the populations of *Cedrela* spp. due to overexploitation, but it has also led the international conservation community to call for greater protection under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). In Peru, the National Forest and Wildlife Service (SERFOR), incorporated as of August 28, 2020, the populations of the genus *Cedrela* spp. (*C. odorata, C. montana, C. fissilis, C. longipetiolulata, C. angustifolia, C. nebulosa, C. kuelapensis, C. Saltensis, C. weberbaueri* and *C. molinensis*) of Appendix II of CITES. The main objective of this study is to identify the spatio-temporal distribution of *Cedrela* spp. in the perspective ofconservation and sustainable use of this particular species [15].

This reality suggests the need to develop studies that contribute to decision-making in relation to the sustainability and conservation of the biodiversity of *Cedrela* spp. and its habitat. Species distribution models (SDM) are tools that combine species presence data with bioclimatic, edaphic, topographic factors, etc. and allow a more effective and generous support for conservation, biogeography, evolution and climate change actions [16–20]. The SDMs have made it possible to identify the distribution of timber forest species on a regional scale [21,22], conservation of endemic species [23], wildlife [24,25], in order to intervene in areas to protect and identify the distribution of tree species in danger of extinction [26,27]. Among the SDMs, the maximum entropy algorithm (MaxEnt) [28], has been used to carry out the distribution of species under current and future conditions [29,30]. In this way, MaxEnt allows habitat mapping and produce credible, defensible and repeatable information, which contributes to a structured and transparent process of sustainable management of natural resources by predicting the possible fragmentation or reduction of the potential area of forests or species in risk under future climate change scenarios [31].

From the identification of the potential distribution areas of a species, the areas with the best aptitude to carry out reforestation or recovery of degraded areas with the evaluated species need to be quantified and monitored. Restoration is of great interest since 13.78% (177 592. 82 km^2) of the Peruvian territory has been identified as degraded, as a consequence of deforestation, livestock, agriculture, mining, forest fires, among others [32]. The strategies to be implemented must be oriented to the restoration and/or conservation of threatened species that are widely distributed in geographic spaces integrated into the territorial order, through the use of environmental services, ecotourism, management of renewable resources and productive practices promoting through the Protected Natural Areas (PNA) [33].

This study modeled the potential distribution of 10 species of the genus Cedrela (i.e., *C. odorata, C. montana, C. fissilis, C. longipetiolulata, C. angustifolia, C. nebulosa, C. kuelapensis, C. Saltensis, C. weberbaueri* and *C. molinensis*) through MaxEnt model, using the data on the presence of the species and 33 different variables (19 bioclimatic variables, 3 topographic, 9 edaphic, solar radiation and relative humidity), identifying the distribution within PNA and areas degraded for forest recovery and conservation of natural resources in the Peruvian territory.

2. Study Area

This study covers the entire territory of Peru (1.300.000 km² Aprox.), considering the Natural Protected Areas (PNAs) (Figure 1) belonging to the National System of Natural Areas Protected by the State (SINPNAE) (SINANPE) [33] and the degraded areas areas identified by the Ministry of the Environment of Peru [32].
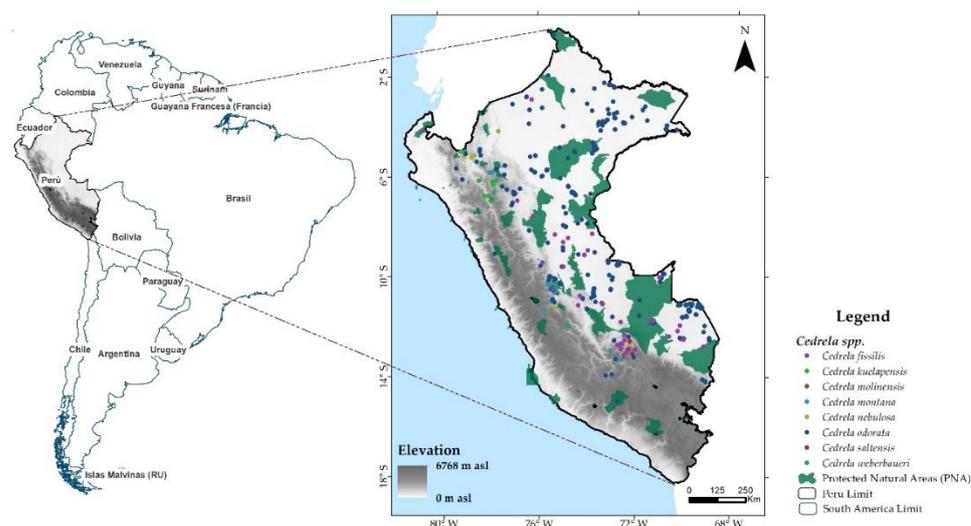
Figure 1. Study area and presence of *Cedrela* spp. species.

3. Materials and Methods

3.1. Datase

The presence data (geographic coordinates) of the 10 species of the genus *Cedrela* spp. were obtained from the GBIF Global Biodiversity Information Service (https://www.gbif.org/), through the Species Explorer plugin in QGIS. The data were filtered at a spatial resolution of 250 m [34] exported in CSV format to be used in the MaxEnt program.

33 variables were selected (Table 1) to carry out the modeling. These variables include 19 bioclimatic and solar radiation obtained from WorldClim 2.1 (https://www.worldclim.org/) [35]; 3 topographic derived from digital elevation model (DEM), obtained from the United States Geological Survey (USGS) web portal (http://srtm.usgs.gov); the relative humidity obtained from the Climate Research Unit (CRU) [36] (www.cru.uea.ac.uk) and 9 soil properties from SoilGrids 0.5.3 (http://soilgrids.org) [37]. All variables were rescaled to a spatial resolution of 250 m. to overcome the issues like collinearity between variables causes overfitting problems, increases uncertainty and decreases the statistical power of the model [38]. Therefore, using the function 'removeCollinearity' from the package 'virtualspecies' [39] in R 3.6, the variables were grouped (clustering) according to a Pearson correlation coefficient and considered those have the Pearson's r ≥ 0.7. This threshold is an acceptable measure to minimize multicollinearity of fitted models [38]. To select an important variable for each cluster, a preliminary MaxEnt model was run (the configuration is explained in Section 3.2.) Using all the variables and the variable with the best performance in the Jackknife test [25] was selected (that is, the smallest difference in regularized training gains obtained from a model generated with all criteria except that of interest and a model generated only with the criterion of interest [21], Table 1).

Table 1. Variables for MaxEnt modeling of *Cedrela* spp. in Peru.

Variable	Units	Symbol	Δ Earnings in Jackknife [1]	Clúster
Bioclimatic				
Annual Mean Temperature	°C	bio01	0.7379	1
Mean Diurnal Range	°C	bio02	0.7627	7
Isothermality		bio03	0.9150	4
Temperature Seasonality	**°C**	**bio04**	**0.7097**	**9**
Max Temperature of Warmest Month	°C	bio05	0.6811	1
Min Temperature of Coldest Month	°C	bio06	0.7068	1

Annual Temperature Range	°C	bio07	0.7655	9
Mean Temperature of Wettest Quarter	°C	bio08	0.7608	1
Mean Temperature of Driest Quarter	°C	bio09	0.7107	1
Mean Temperature of Warmest Quarter	°C	bio10	0.7606	1
Mean Temperature of Coldest Quarter	°C	bio11	0.7067	1
Annual Precipitation	**mm**	**bio12**	**0.6231**	**3**
Precipitation of Wettest Month	mm	bio13	0.7674	2
Precipitation of Driest Month	mm	bio14	0.5525	3
Precipitation Seasonality	mm	bio15	0.6692	9
Precipitation of Wettest Quarter	mm	bio16	0.7524	2
Precipitation of Driest Quarter	mm	bio17	0.5481	3
Precipitation of Warmest Quarter	mm	bio18	0.7915	2
Precipitation of Coldest Quarter	**mm**	**bio19**	**0.5147**	**3**
Topographic				
Elevation above mean sea level	**msnm**	**dem**	**0.6709**	**7**
Slope of the terrain	**°**	**slope**	**0.9104**	**7**
Cardinal orientation of the slope	**°**	**aspect**	**1.0117**	**5**
Edáficas				
pH in H$_2$O a 0.30 m	**pHx10**	**ph**	**0.6543**	**7**
Cation exchange capacity at 0.30 m	**cmol kg^{-1}**	**cec**	**0.7898**	**6**
Organic carbon at 0.30 m	**g kg^{-1}**	**soc**	**0.8094**	**4**
Apparent density of the fine earth fraction	**cg/cm³**	**bdod**	**0.8881**	**8**
Volumetric fraction of coarse fragments	cm³/dm³ (vol ‰)	cfvo	0.7051	7
Total nitrogen	**cg/kg**	**nitrogen**	**0.8375**	**6**
Clay content	%	clay	0.8743	4
Sand content	**%**	**sand**	**0.8155**	**7**
Slime content	**%**	**silt**	**0.7970**	**2**
Solar radiation	MJ m^{-2} day^{-1}	srad	0.6801	9
Relative humidity	%	rhm	0.7777	3

[1] In bold, the variables with less variation between the regularized training win without the variable and with only the variable for each cluster, and that therefore was used in the final MaxEnt model.

3.2. Methods

The biogeographic distribution model for the 10 species of the genus *Cedrela* spp. was performed using a maximum entropy algorithm [28], which estimates the probability of potential distribution of each species from the presence data, using the open source software MaxEnt ver. 3.4.1 (https://biodiversityinformatics.amnh.org/open_source/maxent/). For the validation of the model, randomly selected presence data were used, 75% for training and 25% for validation respectively [28]. The algorithm was run using 100 repetitions in 5000 iterations with different random partitions (Bootstrap method), other configurations (i.e., extrapolation, graph drawing, etc.) were kept by default [40].

The resulting model was validated based on the area under the curve (AUC), calculated from the operating characteristic of the receptor (ROC) [28,41,42]. According to the AUC values, five performance levels are differentiated: excellent (>0.9), good (0.8–0.9), accepted (0.7–0.8), poor (0.6–0.7) and invalid (<0.6) [41,43]. We have used the logistic output format to obtain the model of the 10 species evaluated, by generating a raster of continuous values in a range from 0 to 1. The raster obtained was reclassified into four ranges: (1) "High potential" habitat (> 0.6), (2) "moderate" habitat (0.4–0.6), (3) "low" habitat (0.2–0.4) and (4) "no potential" habitat (<0.2) [21,22,25,44].

Subsequently, the areas of "high" distribution potential were overlapped with the Protected Natural Areas (PNA) [33], obtained from the geoserver (https://geo.sernPNA.gob.pe/visorsernPNA/) of the National Service of Natural Areas

protected by the State (SERNPNA) and in the same way with the degraded areas identified by the Ministry of the Environment of Peru (MINAM) and available on its geoserver (https://geoservidor.minam.gob.pe/) [32]. Finally, the distribution surface of the 10 species within the PNA and degraded areas were quantified.

4. Result and Discussion

4.1. Result

The performance of the model obtained an AUC = 0.866 (Figure 2b), considered good (0.8 < AUC < 0.9). Likewise, the Jackknife test (Figure 2a) Obtained identified that the variables Bio 19 (coldest quarter precipitation), Bio 12 (annual precipitation), pH and soil elevation (DEM) contributed highly in the biogeographic distribution model of the species.
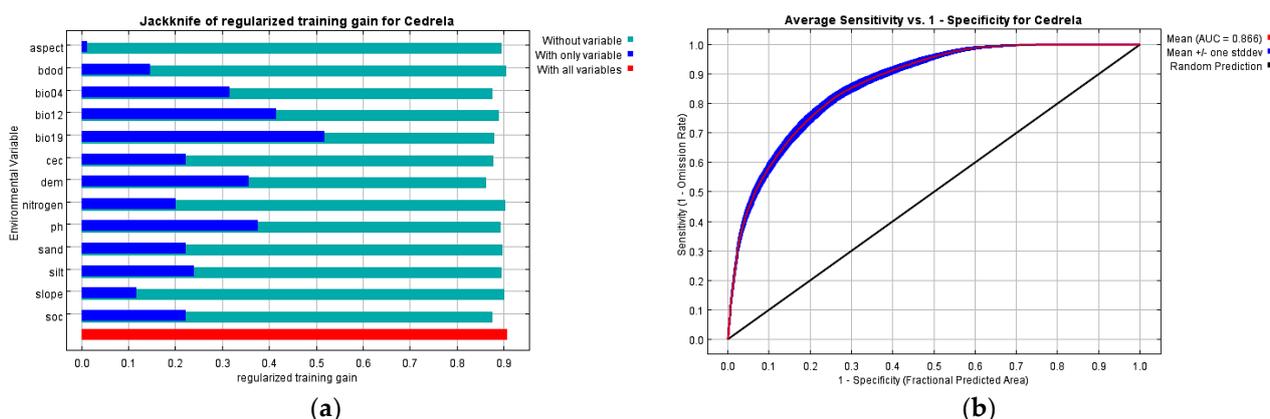

Figure 2. Jackknife performance of variables and Area Under the Curve (AUC).

The high biogeographic distribution of the 10 species of the genus *Cedrela* spp. cover 6.67% (86,235.24 km²) of the Peruvian territory (Figure 3a), of which the PNA cover 4.42% (8363.09 km²) of said distribution (Figure 3b). Likewise, there was a potential for recovery of degraded areas in an area of 11.65% (21,345.16 km²) with the species evaluated (Figure 3c).
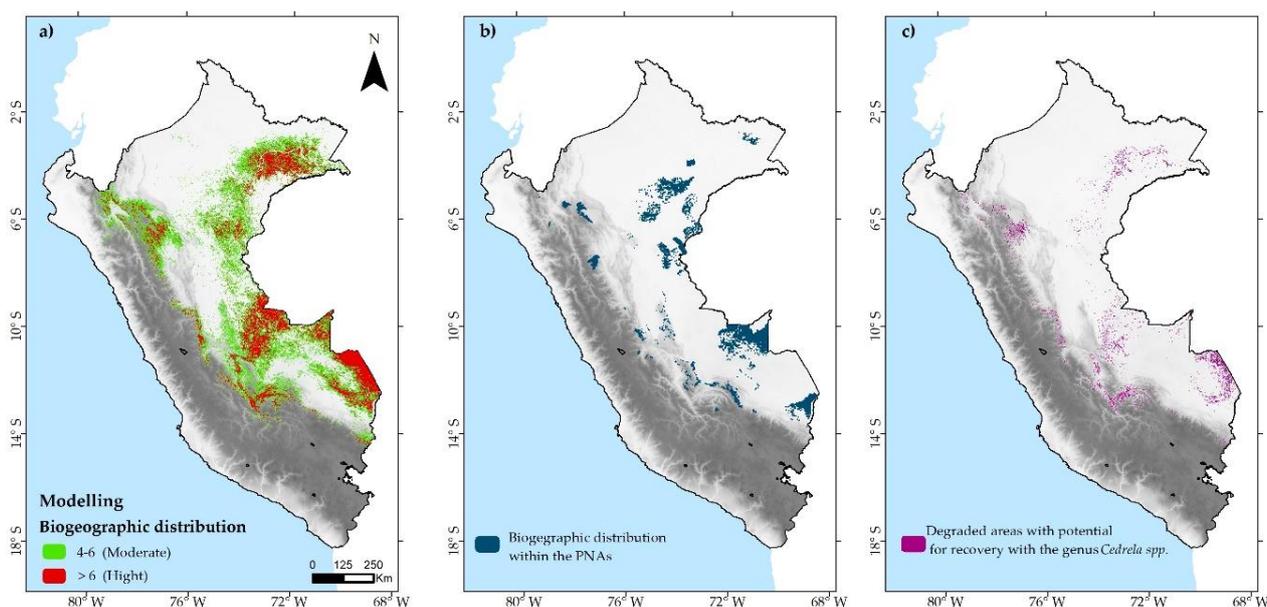

Figure 3. Distribution of the biographical model of the genus *Cedrela* spp., distribution of PNA and in degraded areas for recovery.

4.2. Discussion

This study graphs the biogeographic distribution of 10 species of the genus *Cedrela* spp. (*C. odorata, C. montana, C. fissilis, C. longipetiolulata, C. angustifolia, C. nebulosa, C. kuelapensis, C. Saltensis, C. weberbaueri* and *C. molinensis*) also identified the spatio-temporal distribution, which will allow the establishment of forest management strategies [45], mainly for the species of high economic value that have been reduced by selective logging and overexploitation [8,11,14,15].

This study showed that MaxEnt based SDM tools that will allow the identification and prediction of geographic spaces with edaphoclimatic, topographic, equal or similar characteristics of the presence data [46]. Previous studies have used MaxEnt, this being the most accepted [47] and was related to the distribution of timber species at the regional [21,22], national [48–50] level and the identification of niches ecological for *C. odorata* in Peru [51].

Our model obtained a performance considered good (AUC = 0.866) [28,41,43,52], where the variables Bio 19 (precipitation of the coldest room), Bio 12 (annual precipitation), pH and soil elevation (DEM) present a greater contribution independently in the model. Therefore, as in this study, it is recommended to use climatic and edaphic variables in the species distribution modeling [53], considering that altitude was also a determining factor in the distribution ranges of a species [21,22]. Likewise, our results were in agreement with the location of the botanical collections and inventories of the evaluated species [12,49,50]. This will help the local stack holders to knowing the distribution of a indengered species and implement strategies that allow the conservation of biodiversity, in one of the most megadiverse countries in the world such as Peru [54,55].

The PNAs play a fundamental role in the conservation and protection of biodiversity [56], so that 4.42% of the PNAs in Peru contains the genus *Cedrela* which highlights the importance of protecting these vulnerable species which were usually the most threatened [55]. Likewise, there are degraded areas [32] with the potential to be recovered with the *Cedrela* species whereas 11.65% of the Peruvian territory, promoting the practice of forest restoration to maintain natural ecosystems, through the installation of enrichment plantations, regeneration natural management, agroforestry systems and silvicultural practices for the regeneration of degraded forests [4,57–59].

5. Conclusions

The biogeographic model of the 10 species of the genus *Cedrela* spp. (*C. odorata, C. montana, C. fissilis, C. longipetiolulata, C. angustifolia, C. nebulosa, C. kuelapensis, C. Saltensis, C. weberbaueri* and *C. molinensis*) using MaxEnt obtained a good performance, with an AUC of 0.866. Our model has a high distribution in the Peruvian territory, coveringc6.67% (86,235.24 km^2) of the surface. Likewise, contemplates that the potential distribution of the 10 species were distributed within these areas in an area of 8363.09 km^2 in 4.42% of its protected territory. Finally, our study identified that 11.65% (21,345.16 km^2) of the areas identified as degraded present conditions to be recovered with one or more types of species under study. This study will allow to restrore many ecosystem functions and recovering many components of biodiversity in an original form.

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