IECD 2022

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Proceedings

The Challenge of Wildlife Conservation from Its Biogeographical Distribution Perspectives, with Implications for Integrated Management in Peru †

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† Presented at the 2nd International Electronic Conference on Diversity (IECD 2022)—New Insights into the Biodiversity of Plants, Animals and Microbes, 1–15 March 2022; Available online: https://iecd2022.sciforum.net/.

Academic Editor: Matthieu Chauvat

Published: 17 March 2022

Abstract: Biodiversity is an indispensable resource and contributes to the balance of ecosystems, being of great importance for the development of a society and its culture through good management and management of natural spaces. However, the reduction and fragmentation of habitats, trafficking, and illegal trade in wild animals affect the great diversity of wild flora and fauna that characterizes Peru. Considering this problem, we modeled the biogeographic distribution of 5 species of wildlife categorized as threatened by Peruvian legislation and included in the Red List of Threatened Species of the International Union for the Conservation of Nature (IUCN), critically endangered (CR) *Lagothrix flavicauda*, endangered (EN) *Aotus miconax*, in vulnerable status (VU) *Tremarctos ornatus*, *Lagothrix cana* and in near threatened category (NT) *Panthera onca*. Our study aimed to identify its current potential distribution in the Peruvian territory is legally protected by the conservation areas of national, regional, or private administration. In this regard, we used a maximum entropy approach (MaxEnt), integrating 14 variables (7 bioclimatic variables, 3 topographic, 3 variables of vegetation cover, and relative humidity). It was observed that 3.6% (46,225.50 km^2) of the Peruvian territory presents a high probability (>0.6) of distribution of the evaluated species and 10.7% (13,6918.28 km$^{2)}$ of moderate distribution (0.4–0.6). Based on this, our study allowed us to identify geographical spaces for threatened species in which conservation actions should focus, through the formulation of strategies, plans, policies, and participatory management in the Peruvian territory.

Keywords: biodiversity; CITES; habitat; MaxEnt; protected natural areas

1. Introduction

Peru is one of the 17 megadiverse countries in the world [1–3], and to preserve this biodiversity in recent decades, national, regional and private conservation areas have been created, with the aim of conserving species of high diversity and endemism, marine biodiversity or particular groups of organisms. [4–6]. However, over time, anthropic pressures such as deforestation, installation of agricultural crops, extensive livestock, illegal mining, forest fires, among others, have reduced the habitat of native and endemic species, which has led to the reduction of their populations [7]. Based on this, Peruvian legislation [8] and the International Union for Conservation of Nature (IUCN) Red List of Threatened Species of Wildlife have categorized the species in our study as described: Critically Endangered (CR) *Lagothrix flavicauda*, Endangered (EN) *Aotus miconax*, Vulnerable Status (VU) *Tremarctos ornatus* and *Lagothrix cana* and Near Threatened Category (NT) *Panthera once* [9]. This situation describes the importance of knowing the territorial spaces in which to manage and implement plans for the survival of local populations, mitigating poaching and illegal trade [7,10].

The species considered in this study have been identified as those requiring urgent conservation measures by the International Union for Conservation of Nature, the Convention on International Trade in Endangered Species and the International Primatological Society, in addition to being protected by the Peruvian legislation [11]. However, the National Service of Natural Areas Protected by the State, reports only 22 645 810.51 hectares of protected natural areas for conservation equivalent to only 17.62% of the Peruvian territory [6]. In addition, the nature protection offices in the country work with extremely small budgets. [11], therefore, it is crucial to develop international strategic alliances for habitat conservation.

Therefore, species distribution models (SDM) are important tools in conservation approaches [12], allowing to identify geographical spaces with similar topographic characteristics, bioclimatic to the records of presence [13]. SDMs have been widely applied in the identification of potential wildlife distribution in large mammals [14], flora species, prediction of deforestation and forest fires [15–18], as well as the assessment of the impact of anthropogenic land-use change in protected areas [19]. Being the maximum entropy algorithm (MaxEnt) the one that presents reliable, optimal and defensible results and surpassing other SDM algorithms [13,20–22]. In this study, using MaxEnt we identified the biographical distribution under current conditions for an integrated management of the wild fauna of the species *L. flavicauda, A. miconax, T. ornatus, L. cana* and *P. onca* in the Peruvian territory.

2. Study Area

This study is located between the parallels 0°03′00′′ and 18°30′00″ south and the meridians 68°30′00″ and 81°30′00′′ to the west, covering the Peruvian territory, in an area of 1,300,000 km^2 approx., with a rugged area consisting of geographical regions of coast, mountains and jungle, with altitudinal gradients from 0 m to 6800 m above sea level (m.a.s.l).

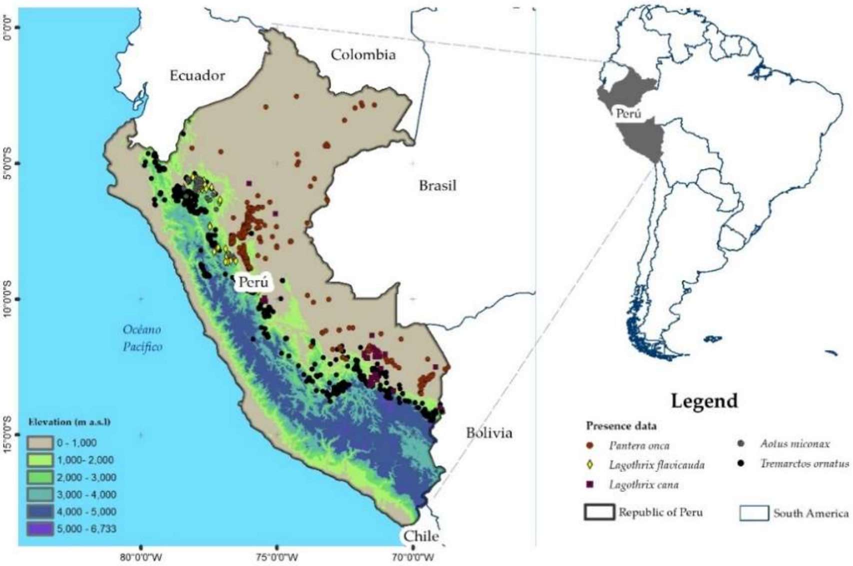

Figure 1. Study area and species presence data.

3. Material and Methods

3.1. Datase

The presence data of the species was obtained from the register of CITES species by the Ministry of the Environment of Peru—MINAM [23], in combination with spatial information from the Global Biodiversity Information Service—GBIF [24] and "Species Explorer", collected through the non-commercial software QGIS. The data was exported in comma-delimited format (.csv) for integration into the maximum entropy (MaxEnt) software ver. 3.4.1 [25]. To perform the spatial modeling of the species, initially 28 variables were included (Table S1) and rescaled to a spatial resolution of 250 m Likewise, in order to minimize the multiple multicollinearity of these variables, they were filtered using the Pearson correlation coefficient through the R 3.6 software and r = ±0.8 was established as the cut-off value for the highly correlated variables [26–28]. Finally, the 14 variables (Table 1) were chosen for the final modeling: 7 bioclimatic variables were included in addition to relative humidity from WorlClim [29], 3 topographic variables derived from the Digital Elevation Model (DEM), available on the United States Geological Survey (USGS) portal [30]. The variables of vegetation cover of ecosystems from the MINAM study [23,31], tree altitude [32] and Land use/land cover (LULC)[33].

Table 1. Bioclimatic, topographic and vegetation cover variables used in modelling.

	Variable	Units	Symbol
Bioclimatic	Annual Mean Temperature	°C	bio01
	Min Temperature of Coldest Month	°C	bio06
	Mean Temperature of Warmest Quarter	°C	bio10
	Precipitation of Driest Month	mm	bio14
	Precipitation Seasonality	mm	bio15
	Precipitation of Wettest Quarter	mm	bio16
	Precipitation of Coldest Quarter	mm	bio19
	Relative humidity	%	rhm
Topographic	Elevation above mean sea level	m a.l.s	dem
	Slope of the terrain	°	slope
	Distance to hydrography	m	d_water
Vegetation cover	Ecosystem	Type	Ecosystem
	Tree height	m	Tree_h

Land Use and Land Cover	Type	LULC

3.2. Methods

Figure 2 summarizes the methodological design of our research, based on the spatial standardization of cartographic variables and their trimming at the level of the Peruvian territory, the biogeographic modeling of the 05 species was carried out using the MaxEnt software [25,34]. We used 75% of the presence data for training and 25% for validation [34], using 5000 iterations and 10 replicas with random partitions (cross-validation method), other settings were maintained by default. The validation of the models was carried out according to the area under the curve (AUC), differentiated performance in five levels: invalid (<0.6), bad (0.6–0.7), accepted (0.7–0.8), good (0.8–0.9), excellent (> 0.9) [34–36], in the same way, the contribution of each of the variables in the model was obtained. Finally the resulting raster of distribution was reclassified into four potential habitat ranges ("high" > 0.6, "moderate" 0.4–0.6, "low" 0.2–0.4 and "non-potential" <0.2) [15–17,37] and its conversion to vector cartographic data to perform the surface calculation.

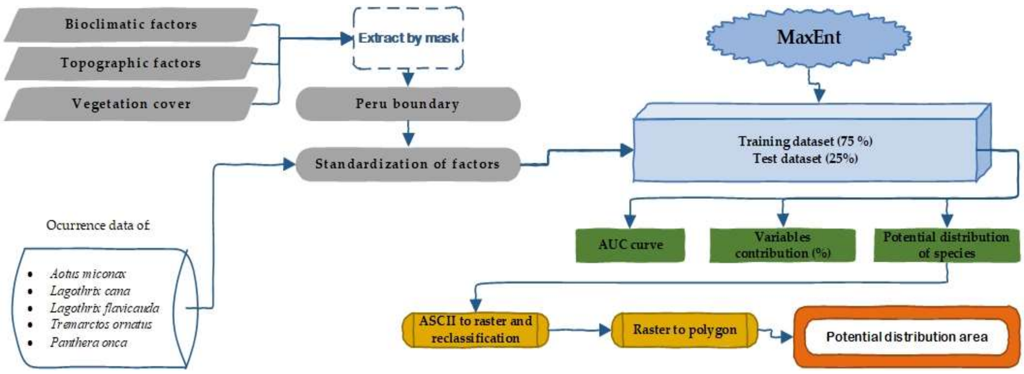

Figure 2. Methodological design.

4. Result and Discussion

4.1. Results

It was observed that, from integrating the high potential individual distribution of the 05 species (L. *flavicauda*, A. *miconax*, T. *ornatus*, L. *cana* and P. *onca*), 3.6% (46,225.50 km^2) of the Peruvian territory presents a high probability of distribution (>0.6) and 10.7% (13,6918.28 km^2) a moderate distribution (0.4–0.6) (Figure 3f). Corresponding a high potential distribution of L. *flavicauda* in 3 354.74 km^2 (Figure 3a), 2 324.96 km^2 of high distribution for A. *miconax* (Figure 3b), T. *ornatus* presents the largest area of high potential distribution in 23 179.96 km^2 (Figure 3c), finally the high potential distribution of L. *cana* covers 5 833.33 km^2 (Figure 3d) and 11 532.50 km^2 for P. *onca* respectively (Figure 3e).

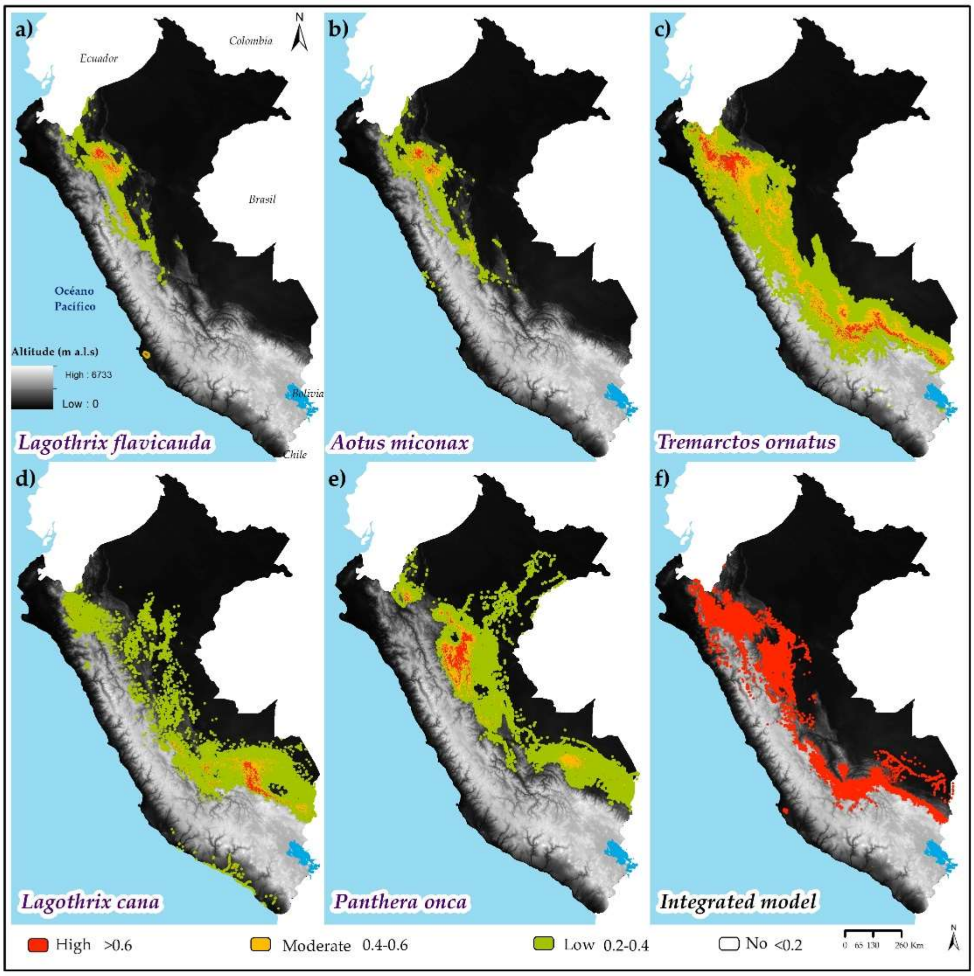

Figure 3. Biogeographic distribution of Red List of Threatened Species.

Modeling showed an average performance of AUC = 0.97, considered excellent (AUC > 0. 9). Likewise, the bioclimatic variables with the greatest contribution to modeling were the precipitation of driest month (Bio14) and relative humidity (rhm), in the same way the variables such as altitude (DEM), type of ecosystem (Ecosystem) and slope (Slope) have a high contribution in the modeling of each species (Figure 4).

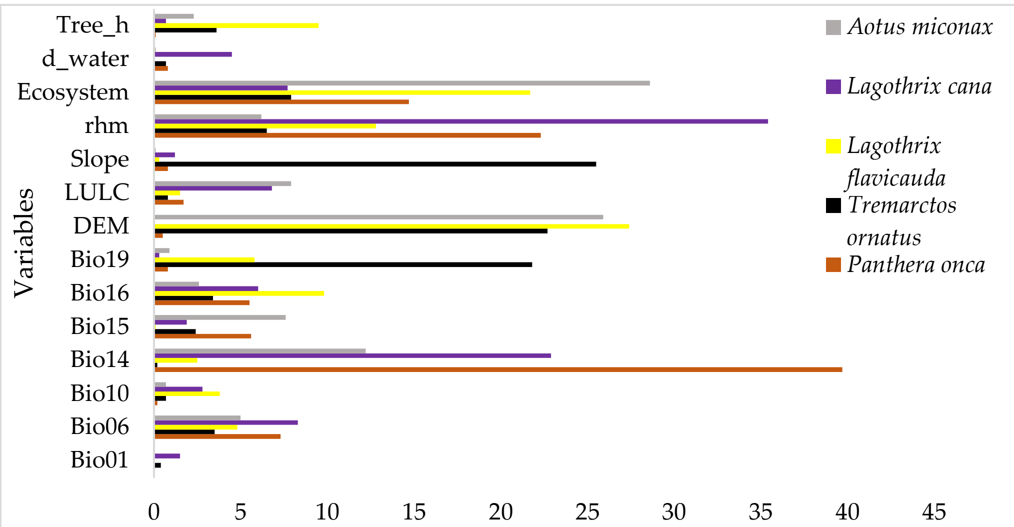

Figure 4. Percentage of contribution of variables in MaxEnt modeling.

4.2. Discussion

The SDMs are a statistical tool [38] widely used in studies of rare and endangered groups, as well as the environmental variables that affect them [39]. The SDMs have contributed significantly to the challenge of wildlife conservation from a biogeographical approach [40–45]. Our study is the first to integrate the high potential individual distribution of 05 species of threatened wildlife, in critically endangered condition (*L. flavicauda),*" endangered (*A. miconax),* vulnerable (*T. ornatus* and *L. cana)* and near threatened (*P. onca)* within Peruvian territory. The model required strong performance values of AUC = 0.97 [45,46]. Of the 14 integrated variables, the precipitation of driest month (Bio14) and relative humidity (rhm) are the most representative to predict integrated areas for the 5 species, according to the potential habitat ranges, however, the topographic variables (altitude), the type of ecosystem (Ecosystem) and the slope (Slope) that also contributed significantly during the modeling are not dismissed. Our study validates the restricted range of endemic species (*L. miconax* and *L. Favicauda*) [7], it is necessary to indicate that it is possible to find *P. onca* in other territories of native communities in the Peruvian Amazon, in which recent studies are documenting and reporting it [47]. Thus, it is necessary to carry out subsequent studies to improve the performance of the model with a greater amount of presence data and other variables, this will allow to identify territories for their conservation, avoiding the reduction of their population by hunting and habitat loss, as is happening with *L. cana* [7]. The different methods used to select the variables and, therefore, the different variables introduced in the models, contributed to differentiate their contribution [45,48].

Thus, from the identification of potential areas, it is possible to establish measures to mitigate the reduction and fragmentation of the habitats of these 5 species, in the Peruvian territory. [45]. So, 46,225.50 km^2 of the territory are within the 33 geographical spaces suggested in this study, for the threatened species on which conservation actions should be focused [49], through the formulation of strategies, plans, policies and participatory management in the Peruvian territory. New studies will allow to evaluate the distribution in future conditions of climate change, in an integrated way for these 5 species; as long as this is carried out considering the qualities of the species to adapt to new conditions of persistence, survival [44]. Finally, modeling allows to have a support for the management and adequate management of the territory to ensure the survival of the species.

5. Conclusions

Modeling through Maximum Entropy (MaxEnt) obtained a performance considered excellent, with an area under the curve (AUC = 0.97). From this, under current conditions, the biogeographic distribution of the 05 species (*L. flavicauda*, *A. miconax*, *T. ornatus, L. cana* and *P. onca*) covers 3.6% (46,225.50 km^2) of the Peruvian territory, this area presents a high probability of distribution, added to this, 13,6918.28 km^2 (10.7%) was identified with moderate probability of distribution. Finally, the bioclimatic variables with the greatest contribution to modeling are the precipitation of driest month (Bio14) and relative humidity (rhm), as well as the topographic variables (altitude), the type of ecosystem (Ecosystem) and the slope (Slope) contributed significantly during the modeling.

Supplementary Materials: The following supporting information can be downloaded at: www.mdpi.com/xxx/s1, Table S1: Initial variables for MaxEnt modeling of Red List of Threatened Species in Peru.

Author Contributions: Conceptualization, A.C.S., N.B.R.B., G.M.M. and L.G.; methodology, A.C.S., N.B.R.B., S.B., C.O., C.T.G., L.G. and G.M.M.; formal analysis, S.B. and L.G.; funding acquisition, C.T.G. and M.O.; investigation, A.C.S., G.M.M., S.B., N.B.R.B., M.O.,L.G. and C.O; project administration, C.T.G. and M.O.; resources, C.T.G., M.O.; software, A.C.S. and G.M.M.; supervision, A.C.S., S.B. and L.G.; validation, A.C.S., N.B.R.B., G.M.M., M.O., C.O. and L.G writing—original draft preparation, A.C.S., G.M.M., L.G. and S.B.; writing—review and editing, A.C.S.,S.B., L.G and N.B.R.B. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the SNIP project Nº 316114 “Service Creation Project of the Biodiversity and Conservation of Wild Species Genetic Resources Laboratory at the Toribio Rodríguez de Mendoza National University—Amazonas Region”.

Acknowledgments: The authors appreciate and acknowledge the support of the Research Institute for the Sustainable Development of the Eyebrow of the Jungle (INDES-CES) of the National University Toribio Rodriguez de Amazonas (UNTRM). A.C.S was supported by Highlander Project.

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

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