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Tesis

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Spatial Modeling with Repopulation Potential for Three Flora Species of Huaytapallana Regional Conservation Area, Peru

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Abstract. In the high mountain ecosystems of the Huaytapallana Regional Conservation Area (ACR-H) there are three species of flora (*Krapfia macropetala, Gentianella scarlatinostriata* and Senecio *canescens*) of social, economic, cultural and medicinal importance, however their population status and undefined local distribution make these species area more vulnerable to extinction. Therefore, the objective of this work is to determine the population distribution for repopulation purpose in the ACR-H from the potential distribution in Peru using Maxent algorithm and a local model developed with the Saaty pairwise hierarchy matrix, adding a soil sample for a better application of the final model. The results show that the Species Distribution Models (SDMs) have a high confidence because the Area Under the Curve (AUC) surpass 0.90. Otherwise, the local model is consistent by showing a Consistency Ratio (CR) of less than 0.10. As a final result, all species obtained optimal spaces for repopulation near the Huaytapallana Cordillera, where *Krapfia macropetala* obtained the largest extension (715.334 ha) and *Gentianella scarlatinostriata* is the smallest (650.096 ha). Further there were no differences in the parameters evaluated in the three soil samples, which facilitates the application of the models for the repopulation of these three species.

1. Introduction

There are countless problems and uses promoted by human that threaten all of the world´s biodiversity, and endanger its permanence on our planet. It is clear that extinction is a natural process of species, nevertheless anthropic activities such as deforestation increase the speed of this event in a short period [1]. However, the current model of sustainable development published in the Brutland Report suggests the sustainable use of our natural resources. That is why the use of Geographic Information Systems (GIS) has become an important tool for management and decision-making within a territory. In the area of biology and ecology, having information on richness and distribution allows us to consolidate this objective [2] in the same way they are useful for predicting the distribution of species through distribution models for decision-making regarding to its conservation [3].

The SDMs based on the ecological niche prove to be the most suitable method to estimate the distribution of terrestrial species in a geographic space [4]. These SDMs are cartographic representations that show the suitability of the presence of a species [5] developed through preventive information on their location together with environmental characteristics or descriptors [6].

There are multiple modelling techniques and algorithms however Maxent is the most widely used within macroecology [7] which is based on a maximum entropy algorithm and does not require data on the absence of the species since it generates a "background" that reflects its own absences [8].

The Huaytapallana Regional Conservation Area (ACR-H), that conserves biological diversity [9] is located in the Junin region and in its area we find three flora species of great importance for tourism, the economy, culture and traditional medicine of this region. However according to syncretism these species (flowers) are used for ritual and offerings to the "Apu" Huaytapallana [10], for this reason,

predation has promoted the decrease of these species due to their commercialization in the markets during the months of July and August in the traditional festivals called "Tayta Shanti".
We refer to the following species: *Sencio canescens* (Wila wila), *Krapfia macopetala* (Lima lima) which according to peruvian regulations are in Vulnerable (VU) and Critically Endangered (CR) status, respectively, while according to the Red List of the International Union for Conservation of Nature (IUCN) these especies are in Least concern (Lc) and Endangered (En) status, respectively. However the specie *Gentianella scarlatinostriata* (Sumay suncho) is in the Endangered (EN) status [11].
Due to the situational status of each specie, the available information and their local importance, the objective of this research is to determine a spatial distribution with repopulation potential for each flora specie in the ACR-H based on an ecological niche modelling in Peru developed with the Maxent algorithm and a local model through the Saaty pairwise hierarchy matrix, and in the same way describe the soil in which they are developed for the application of this model for repopulation purposes.

2. Materials and methods

2.1. Study area and species

The Huaytapallana Regional Conservation Area belongs to the National System of Natural Areas Protected by the State (SINANPE). It is located in the Junin region with an area of 22406.52 ha and is part of the Eastern Cordillera of the Peruvian Andes. It is made up of five (5) peasant communities (PC). PC Acopalca, PC Marancocha Aychana, PC San Francisco de Llacsapirca, PC Quilcas y PC Racracalla [9]. The present study is carried out in the scope of ACR-H.
The species studied in this research are: *Krapfia macropetala* (Lima lima) that grows at altitudes of 4100 to 4500 meters above sea level, they have large red and bright petals being the reverse greenish white, a huge button that opens like a typical flower "butercup" bearing in the center an immense head full of anthers and green stigmas with their serrated leaves. In popular language they are called "habla habla" y "rima rima", as it is used in folk medicine to help children to speak. [12]. Second, *Senecio canescens* (Wila wila) is a perennial herb 60-80 cm tall; with inflorescence in capitula (heads) 8-10 cm wide, flattened, ray-shaped flowers with white tube and pale green petals; Simple leaves 20 to 30 cm long, white, woolly-pubescent and ridged at the base of the stem [13]. Finally, we have the *Gentianella scarlatinostriata* (Sumay suncho), it is a rosette herb, 60 cm high, with a thickened dark brown stem, elongated sub-scaly green leaves at the base and solitary yellowish-red flowers [14].

2.2. Presence data and environmental descriptors

Presence data of each species were obtained in two ways. First from the GBIF (https://www.gbif.org/) and iNaturalist (https://www.inaturalist.org/) platforms, and on the other hand, data was collected in the field in the peasant communities of Acopalca, Marancocha Aychana and San Francisco de Llacsapirca during the months of June and July.
In the same way, a soil sample was taken for each species from the areas where a large number of individuals were found in good condition, so these samples were sent to the laboratory of the National Agricultural Innovation Institute (INIA).
For the present study, 27 variables distributed in two groups were selected. In the first place, there are the variables used for the SDM in Peru, which correspond to the 19 bioclimatic variables of the Chelsa with a spatial resolution of 0.93 km [15], the aridity index, evapotranspiration and elevation. On the other hand, there are the variables of slope, physiography, geology, vegetation cover and soil texture that were obtained from the Ecological and Economic Zoning (ZEE) of Junín for the development of the local model in the ACR-H.

2.3. Methodology

Two phases were established for the development of the model with repopulation potential. The first phase consisted of determining the potential ecological niche model in Peru for each specie with the 22 variables previously determined. The Maxent program was running with 10 replicates, and according to the AUC, the similarity between the predicted omission curve and the omission on training samples curve, the best model was selected and their variables that presented a higher percentage of contribution at 0.75. Then the program was run again with the previously selected variables however was necessary worked with 100 replicas to choose the most suitable model according to the considerations taken in the first selection. Finally, based on a multiple correlation analysis carried out initially with all the variables, those highly correlated with others were excluded, running the model with 5 replications and choosing the best model, the variables and the percentage of contribution for each of them.

On the other hand, through an analysis with the Saaty pairwise hierarchy matrix at the ACR-H scale, the slope, geology (rock type), physiography (sub-landscape), plant cover and soils (soil texture) were evaluated by means of descriptors each one according to the presence data of each of the species in these spaces to obtain a local model classified in 4 probabilities of presence (very high, high, medium and low). For this case units such as snow-capped mountains, lagoons and wetlands were excluded.

Finally, with the SDM obtained for each specie, its cut-off threshold was determined from the lowest value of the Fractional Area that is related to the Corresponding Cloglog value. This cut allows locating suitable potential areas in Peru however at the scale of the ACR-H, the SDM was intersected with the local model with a "very high" probability of presence to determine the spaces with potential for repopulation of each species.

3. Results

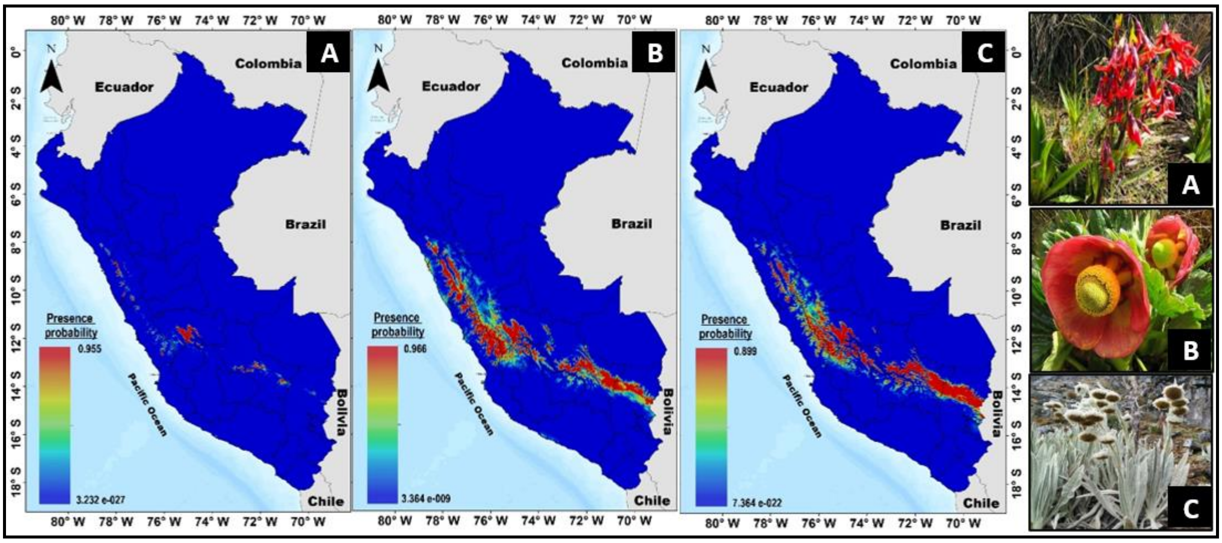
Table 1. Contribution percent of variables in the Species Distribution Models for each specie

Variable	Contribution percent for specie		
	Gentianella scarlatinostriata	*Krapfia macropetala*	*Senecio canescens*
BIO 1	14.90	-	9.60
BIO 2	20.10	25.40	14.80
BIO 5	20.70	46.70	14.00
BIO 7	12.70	-	-
BIO 9	13.50	-	-
BIO 11	1.10	-	10.00
BIO 12	-	-	0.90
BIO 14	2.10	2.00	-
BIO 19	-	-	15.40
ALT	5.70	25.80	34.20
ETO	9.30	0.10	1.30

The AUC values for each SDMs developed for *Gentianella scarlatinostriata* (0.999), *Krapfia macropetala* (0.988) and *Senecio canescens* (0.987) demonstrate high confidence because they surpassed the recommended value of 0.90. For the *Gentianella scarlatinostriata* 9 variables were selected for the SDM, in the *Krapfia macropetala* 5 variables were selected and for the *Senecio canescens* 8 variables were necessary for its distribution, where the percentage of contribution of each one in the SDM is also shown (Table 1).

The *Gentianella scarlatinostriata* species have a small distribution in the country with a higher probability of presence in the regions of Junín, Cusco, Lima and Ancash with a maximum value of 0.955. In second place, *Krapfia macropetala* presents a maximum probability of 0.987, distributed in the regions of Junín, Cusco, Puno, Huancavelica, Ayacucho, Lima, Ancash and La Libertad. Finally, the highest probability of the presence of *Senecio canescens* reaches a value of 0.899, being distributed along the Andes Mountains range with greater probability in the regions of Junín, Cusco, Puno, Huancavelica, Lima, Ancash, Ayacucho and Apurímac (Figure 1).

Figure 1. Model Specie Distribution for each specie with presence probability in Peru: A) *Gentianella scarlatinostriata* SDM, B) *Krapfia macropetala* SDM and C) *Senecio canescens* SDM.



The local distribution model developed through the 5 variables of the Junin ZEE turned out to be adequate since the Consistency Ratio value obtained was less than 0.10 in the final matrix as well as in the analysis for each variable. Vegetation cover was the most influential in the development of this model with a contribution percentage close to 45%, the soil texture with 25.188%, the type of rock with a contribution of 15.405%, the physiography with 6.206% while slope obtained the lowest contribution percentage with a value of 3.947% (Table 2).

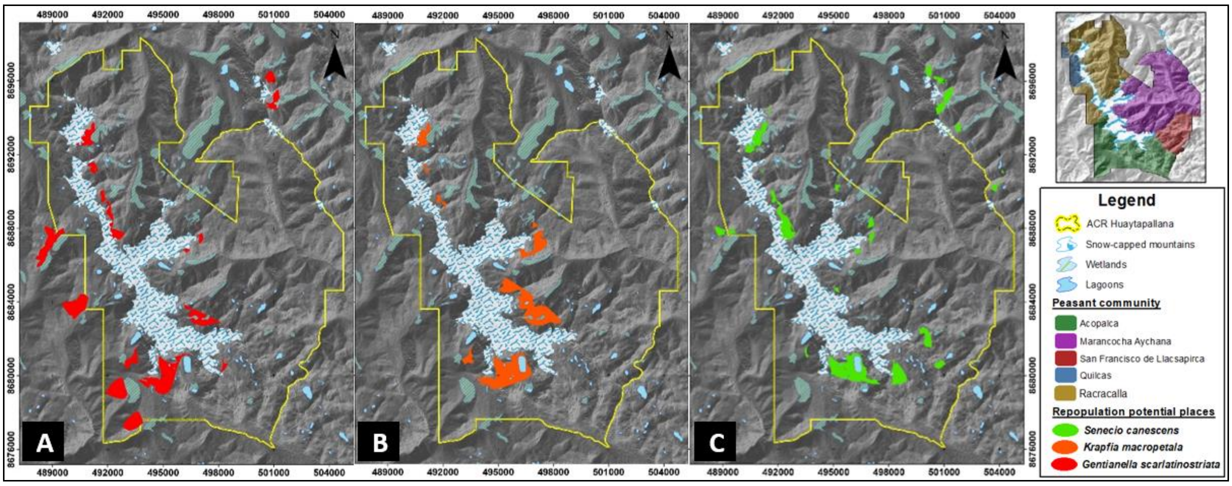
Table 2. Values of the consistency index and consistency ratio in the analysis of each variable and final matrix through the Saaty pairwise hierarchy matrix

Variable	Contribution percent	Consistency index*	Consistency ratio**
Vegetable cover	42.254	0.026	0.020
Soils	25.188	0.013	0.011
Geology	15.405	0.039	0.045
Physiography	6.206	0.061	0.054
Slope	3.947	0.039	0.045
Final matrix	100.000	0.035	0.031

* The Consistency index allows to determine the maximum lambda of each variable from the lambda for each parameter.
** The Consistency ratio is the relationship between the Consistency index and the Random index, the latter depends on the number of parameters analyzed in each matrix.

Finally, the local model with a "very high" probability was intersected with the SDM obtained at the national scale to find the optimal repopulation spaces. The cut-off threshold for the SDMs were as follows: *Gentianella scarlatinostriata* (0.7308), *Krapfia macropetala* (0.8984) and *Senecio canescens* (0.8719). With this, the optimal spaces were determined to repopulate these species in the ACR-H. Thus, the calculating of the expansion (ha) for each species: *Gentianella scarlatinostriata* (650,096 ha), *Krapfia macropetala* (715,334 ha) and *Senecio canescens* (708,735 ha) (Figure 2).

Figure 2. Repopulation potential model for each specie in the ACR-H: A) *Gentianella scarlatinostriata* model, B) *Krapfia macropetala* model and C) *Senecio canescens* model.



The soil where these species grow up has a pH value lower than 7.00, showing acid soils with a high amount of organic matter with a sandy loam texture. On the other hand, the amount of P and K nutrients are low, while nitrogen is high in these soils for all species (Table 3).

Table 3. Soil sample results

Specie	pH	MO (%)	P (ppm)	K (ppm)	Al (me/100g)	N (%)	Soil type
Gentianella scarlatinostriata	5.50	5.86	1.99	98.00	1.55	0.29	Loamy sand
Krapfia macropetala	5.20	6.33	4.48	90.00	1.45	0.32	Sandy loam
Senecio canescens	5.10	6.80	3.49	80.00	0.35	0.34	Sandy loam

4. Conclusions

The SMDs developed at the national scale turn out to be suitable with high confidence due to the AUC value obtained. Each species was influenced by at least 4 variables, BIO5 is the most influential in *Gentianella scarlatinostriata* SMD and *Krapfia macropetala* SMD, while altitude had the highest contribution in *Senecio canescens* SMD. These models reaffirm the endemism of *Gentianella scarlatinostriata* and the native status of *Krapfia macropetala* and *Senecio canescens*. On the other hand, the local model is consistent according to the analysis in Saaty pairwise hierarchy matrix, which allows selecting suitable repopulation spaces from the SMD determined by the cut-off threshold at the ACR-H scale. As a result, the species *Krapfia macropetala* was the one that obtained the greatest extension of repopulation, followed by *Senecio canescens* and finally *Gentianella scarlatinostriata*, located near the Huaytapallana mountain range. Finally, there were no differences in the parameters evaluated in the three soil samples, which facilitates the application of the models for the repopulation of these three species.

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Acknowledgments
The main contribution of this research is to recommend a methodology for the selection of spaces for the repopulation of flora species in high mountain ecosystems through the use of GIS and land use planning.