Revista de Estudios Andaluces (REA) | Núm. 48, julio (2024) | e-ISSN: 2340-2776
https://dx.doi.org/10.12795/rea.2024.i48 | © Editorial Universidad de Sevilla 2024
https://editorial.us.es/es/revistas/revista-de-estudios-andaluces
https://revistascientificas.us.es/index.php/REA

SUMMARY OF ARTICLE: HTTPS://DX.DOI.ORG/10.12795/REA.2024.I48.01

Potential distribution of ecosystems in the Southern Zone of Ecuador: modeling from a correlative approach

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KEYWORDS

Climate Change
Modeling
Ecosystems
Biomod2
Southern region of Ecuador

INTRODUCTION

Climate is the outcome of complex interactions among atmospheric, geographical, and meteorological factors that impact ecological, economic, and socio-productive processes globally. Throughout the history of the planet, the climate has been in constant variation, initially following natural dynamic cycles. However, in the last century, humans have taken center stage and are considered partially or entirely responsible for their contribution to the increase in greenhouse gases. Anthropogenic climate change is becoming increasingly prevalent and affects the energy balance of the climate sytems of the planet, leading to an increase in the average surface temperature by ~1°C compared to the average temperature of the years 1850-1900. Therefore, it is considered a global threat, whose effects can be increasingly severe, affecting the physical and mental health of people and endangering the current biodiversity of the planet. The anomalies in global precipitation and temperature patterns, the main effects evidenced as a result of climate change, negatively impact terrestrial ecosystems on a global scale, forcing species to modify their geographic boundaries and driving the redistribution of life on the planet. In the Southern Zone of Ecuador, changes in land use, driven by urban growth, deforestation, mining, and agricultural expansion, historically contribute to ecosystem fragmentation, with dry forests being the most threatened ecosystems due to recent agricultural conversion processes. The climatic and anthropogenic stressors have negatively influenced the ecosystems of the Southern Zone of Ecuador, making it a region vulnerable to the effects of climate change. In this context, correlational models are used to predict possible distribution zones of ecosystems and determine

DOI: https://dx.doi.org/10.12795/rea.2024.i48.01
Formato de cita / Citation: Poma-Sarango, M.A., Poma-Sarango, D., Guaman, L., Chuncho, C.G., Juela, O., & Benavides-Silva, C. (2024). Potential distribution of ecosystems in the Southern Zone of Ecuador: modeling from a correlative approach. *Revista de Estudios Andaluces,*(48), 8-32. https://dx.doi.org/10.12795/rea.2024.i48.01
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the spatial and temporal variations that ecosystems would undergo in different climate scenarios to predict their proper management. Understanding how the climate has evolved in recent decades is crucial to anticipate future changes in the biodiversity structure.

METHODOLOGY

This research was conducted in the Southern Zone of Ecuador, encompassing the provinces of Loja, Zamora Chinchipe, and El Oro. This region, with an approximate area of 27,500 km^2, represents around 11% of the national territory. Characterized by its climatic, ethnic, and biological diversity, the Southern Zone hosts a wide variety of ecosystems, including dry valleys, paramos, cloud forests, and Amazonian forests, reaching altitudes of up to 3,880 meters above sea level. Biodiversity in this region is influenced by factors such as geographical location, the presence of hydrographic basins, and the diversity of altitudinal zones. Additionally, it is located within biodiversity hotspots such as the Tumbes-Chocó-Magdalena and the Tropical Andes. The flora of this area is one of the richest and most diverse in the world, adapting to dry megathermic climates, semihumid mesothermic equatorial climates, and very humid megathermic tropical climates.

The research focused on modeling the potential distribution of 40 ecosystems present in these provinces. Presence and pseudo-absence data, randomly generated, georeferenced in geographic coordinates, were used. The environmental variables included bioclimatic and topographic data, evaluated for current periods (1970-2020) and future periods (2061-2080) under the RCP 6.0 scenario.

The modeling process was conducted using the Biomod2 library implemented in R Studio, employing a set of 10 modeling techniques. Model calibration involved addressing multicollinearity between variables and assessing the quality of predictors through cross-validation. The evaluation of the models was carried out using metrics such as TSS and AUC-ROC, considering a threshold of 0.8 for model selection. Simulation and projection were carried out for each ecosystem, using models with the best predictive performance. An ensemble method was implemented to reduce uncertainty, projecting the results to the current and future (2080) geographic and climatic space under a specific climate scenario (RCP 6.0).

RESULTS

By the year 2080, ecosystems in the Southern Zone of Ecuador face significant changes due to climate change, particularly under the RCP6.0 emission scenario. Divergent environmental variables were identified among ecosystems, with topographic variables being the most frequently used in modeling, followed by climatic variables Bio 2, Bio 7, Bio 18, Bio 4, and Bio 12. Maps of replacement areas were projected, indicating the possibility of several ecosystems sharing geographic space in the future, generating overlapping climatic and topographic conditions. The areas with the highest replacement suggest the potential coexistence of up to 12 ecosystems simultaneously, while the areas with the lowest replacement show lower climatic suitability and limit the establishment of ecosystems. It is observed that areas with lower convergence are located at provincial boundaries, the coasts of El Oro, Loja canton, and a significant portion of Zamora Chinchipe. Some coastal and specific areas of El Oro could harbor ecosystems from the Lowlands bioclimatic zone. In Zamora Chinchipe and parts of Loja canton, conditions for the presence of 1 to 8 ecosystems could develop, including montane evergreen forests and shrublands (figure 1).

The areas of higher convergence are located in provinces such as Loja and El Oro, as well as in the western part of the Yacuambi canton of Zamora Chinchipe. Cantons such as Espíndola, Quilanga, Loja, Catamayo, Saraguro, Macará, Sozoranga, Portovelo, Zaruma, Chila, and Atahualpa could potentially host conditions for between 5 and 12 ecosystems. Some ecosystems include deciduous forests, shrublands, and grasslands across various bioclimatic zones. Out of the 40 ecosystems analyzed, it is anticipated that two, namely the Floodable Paramo Herbaceous Ecosystem and the Montane Evergreen Forest on Sandstone Plateaus, may disappear in the Southern Zone of Ecuador due to climate change. These ecosystems could potentially migrate northward, primarily within Ecuador and Colombian territory, and to a lesser extent southward into Peru.

 e-ISSN: 2340-2776 | doi: https://dx.doi.org/10.12795/rea.2024.i48.01

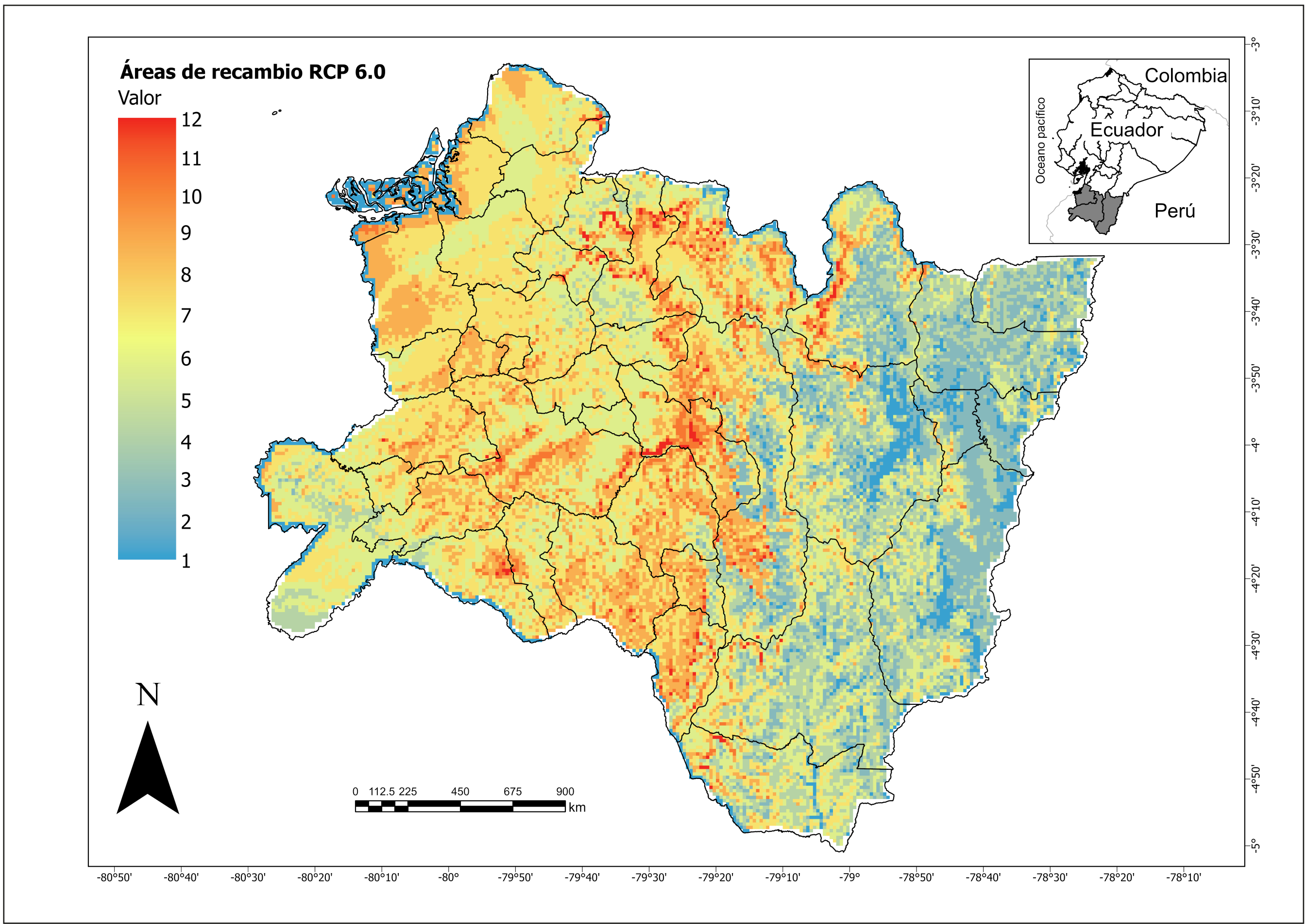

Figure 1. Replacement areas in the Southern Zone of Ecuador under the influence of climate change (RCP 6.0 scenario). Source: modeling process results. Own elaboration.

The projections indicate an average increase in precipitation of 14.9 mm and a temperature increase of 3.56 °C in the Southern Zone. However, these changes would not be uniform, with some areas experiencing significant increases in precipitation and others, especially in higher bioclimatic zones, experiencing reductions. The new climatic conditions are likely to favor the development of certain vegetation formations and the expansion of ecosystems, although these results should be interpreted in terms of climatic suitability rather than precise distribution models. Some ecosystems may remain unchanged in their distribution over time and space.

DISCUSSION

The modeling of ecosystem distribution in the Southern Zone of Ecuador in 2080 is based on specific variables dependent on the characteristics of each ecosystem and the scale of work. Topographic variables are frequently used, supported by the central thesis of plant ecology that emphasizes the influence of climatic conditions and secondary factors such as soil and topography. In a mountainous and irregular province, these variables are crucial due to their impact on temperature, solar radiation, and hydrology. Although replacement areas indicate climatic suitability for ecosystems, uncertainty persists regarding which ecosystems might occupy them. The diffuse relationship between geographic and climatic space creates the possibility that different ecosystems could share similar climatic and geographic conditions in the future, complicating precise prediction.

Although turnover areas indicate climatic suitability for ecosystems, uncertainty persists about which ecosystems could occupy them. The fuzzy relationship between geographic space and climate generates the possibility that different ecosystems may share similar climatic and geographic conditions in the future, complicating precise prediction. The changes in climatic space are due to variations in precipitation and temperature, leading to adjustments in the latitudinal and longitudinal distribution ranges of vegetation. The projected increases in temperature and precipitation align with the IPCC estimates and local studies for the Southern Zone. The projections for 2080 suggest changes in climatic suitability, especially for high montane forest, montane forest, high Andean Forest, and Páramo ecosystems. The decrease in precipitation during the driest months could make these ecosystems more sensitive to climate variability, increasing their vulnerability to drought.

CONCLUSION

In conclusion, the research highlights the complexity of modeling ecosystem distribution in the context of climate change, with topographic and climatic variables being fundamental. Uncertainty persists due to the diversity of species and structural components in ecosystems. The projected changes in climatic space point to challenges for vegetation adaptation, and the results emphasize the need to address this complexity in future research and conservation policies.