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ANALYSIS OF CLIMATE CHANGE IMPACTS ON ANDEAN FORESTS USING POTENTIAL DISTRIBUTION MODELS (2010-2069)

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ABSTRACT. In the 21st century, climate change has become the greatest global threat that affects different countries in different ways, affecting different areas, from the increased risk of desertification due to rising temperatures to areas at risk of flooding caused by increased rainfall. Combating climate change has therefore become a priority for many forests in the Andes. In this research, a study was carried out on the possible changes in the forests, as this is one of the regions with the greatest variety of ecosystems and forest formations in the world, analysing the current and future distribution of eight forest formations throughout the study area, by means of potential distribution models, using Maxent software, under three emission scenarios RCP 4.5, RCP 6.0 and RCP 8.5; with projections for the current period 2010-2039 and the future 2040-2069. The results show significant changes in the potential area of distribution of several forests across the different scenarios. Most of the analysed forests will suffer modifications in their current distribution, as is the case of the Lowland Forests and Highland Shrublands of the Humid Puna, which will decrease by more than 60% of their current extent in Bolivia. In the future distribution all the forests analysed will reduce their potential range, such as the Submontane and Dry Montane Forest of the Northern Yungas by 81.6% and the Low Andean Forest of the Western Xerophytic Puna (Peru) by 89.5% in the most restrictive scenario RCP 8.5, which may cause shifts to higher latitudes, with the loss of habitats.

Análisis de los impactos del cambio climático en los bosques andinos mediante modelos de distribución potencial (2010-2069)

RESUMEN. El cambio climático se ha convertido en el siglo XXI en la mayor amenaza global que afecta a distintos países de una forma diferente, afectando a distintas zonas desde el aumento del riesgo de desertificación debido al aumento de las temperaturas hasta las zonas con riesgo de inundaciones provocadas por el aumento de las precipitaciones. Por ello la lucha contra el cambio climático se ha convertido en una prioridad para numerosos bosques de la Cordillera de los Andes. En esta investigación se realizó un estudio sobre los posibles cambios en los bosques, ya que se trata de una de las regiones con mayor variedad de ecosistemas y formaciones forestales del mundo, analizando su distribución actual y futura de ocho formaciones forestales a lo largo de la zona de estudio, mediante modelos de distribución potencial, utilizando el software Maxent, bajo tres escenarios de emisión RCP 4.5, RCP 6.0 y RCP 8.5; con proyecciones para el periodo actual 2010-2039 y el futuro 2040-2069. Los resultados nos indican que la mayor parte de los bosques analizados sufrirá modificaciones en su distribución actual, como es el caso de los Bosques Bajos y Arbustales Altimontanos de la Puna Húmeda que disminuye más del 60% su extensión actual en Bolivia. En la distribución futura todos los bosques analizados reducirán su área de distribución potencial, como el Bosque Submontano y Montano seco de Yungas del Norte el 81,6% y el Bosque Bajo Altoandino de Puna Xerofítica Occidental (Perú) el 89,5% en el escenario más restrictivo RCP 8.5, lo que puede provocar desplazamientos hacia latitudes más elevadas, con la pérdida de hábitats.

Keywords: Andes Mountain, climate change, forest, potential distribution models (PDM).

Palabras clave: Cordillera de los Andes, cambio climático, bosques, modelos de distribución potencial (MDP).

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1. Introduction

The Andes Mountain region is the most biodiverse area in the world, where we can find the greatest variety of landscapes, ecosystems and climates, with more than 29,600 species of plants, 1990 species of birds, 700 species of mammals, 1140 species of amphibians, 70% of which are endemic, spread over 33 million hectares of forest (Navarro, 2014). These ecosystems have undergone changes and strong reductions caused by the pressure of human activity up to the present day (Báez *et al.,* 2016).

With regard to climate, various climate scenarios can be observed (Cuesta *et al.,* 2011). On the one hand, an increase of 2°C is possible, while in the Bolivian Altiplano there will be a decrease in precipitation of around 10%, and in areas such as Ecuador and Peru a decrease of 59%.

The impact of climate change on natural resources is very diverse, resulting in the disappearance of ecosystems, loss of resources and depletion of natural resources (Buytaert and Bievre, 2012). Biodiversity is characteristic of a variety of life forms (Báez *et al.,* 2016). Climate affects many aspects of ecosystems from nutrient circulation to productivity, and it is in forests that climate regulates their growth and determines their distribution limits in combination with climatic variables (Araújo and Peterson, 2012). It is estimated that the inhabitants of this area use around 25% of the species (De la Torre *et al.,* 2008). These mountain ecosystems are very vulnerable to climate change as they are topographically isolated where environmental conditions change considerably, the capacity to react to these perturbations has been studied by different methodologies. There are some studies that show an enormous loss of endemic species due to climate change in the northern Andes, a critical area of biodiversity loss (Malcolm, 2006). It is therefore important to know what will happen under the new climate scenarios. Another obvious example is the decline of trees in the Andes (Duque *et al.,* 2015), with enormous consequences for forest species (Gonzalez *et al.,* 2010), such as changes in distribution, changes in reproduction times, increased extinction rates, and changes in plant growth and development (Djoghlaf, 2007).

This situation is unprecedented, and to understand these processes it is necessary to take into account the orography that conditions and limits the use of large-scale climate models (Herzog *et al.,* 2012). It should also be taken into account that there is still some way to go in terms of species interactions and the evolution of ecosystems, and among the factors that determine their vulnerability could be related to (Pitman *et al.,* 2011) with the increase in temperatures and ecological and biological requirements. In this sense, there is an increasing need to confirm how such alterations may affect the spatial distribution of forests (Herzog *et al.,* 2012).

Among the studies related to the impacts that these alterations would have on the ecosystems of the Andes (Báez *et al.,* 2016; Terán-Valdez, 2019), in addition to those in which alterations in their habitats are verified (Ávila-Núñez and Otero 2019) and the possibility of new presences of plant species (Barrera *et al.,* 2020).

There is still a long way to go regarding the future of forest species in the Andes, for which there is not much work compared to other areas such as Central America and the Amazon (Pitman *et al.,* 2011). There are some studies with resolutions as low as 50km that have not been able to capture the enormous heterogeneity of the area (Gonzalez and Neilson 2010; Beaumont *et al.,* 2011), other works that focus on specific areas such as the Peruvian Andes (Cuentas, 2022) and the Ecuadorian Andes (Vistín *et al.,* 2022), but very few works as extensive as that of Villarreal-Veloz 2023.

At present, potential distribution models (PDM) are widely used tools to generate useful information to analyse and study forest species. Studies showing predictive modelling techniques use the association of environmental values, in this case climatic variables and known presence in the area of interest, i.e. a statistical relationship between the occurrence and non-occurrence of species (Araujo and Peterson, 2012; Saupe *et al.,* 2012). It is proposed to target conservation action in areas with higher percentages of occurrence, as well as areas where species are expected to remain in the future. There are numerous methods to determine the distribution of species, including different techniques to generate each model and different biological data necessary for each model (Gutiérrez and Trejo 2023), of the most widely used are Generalised Linear Models (GLM) such as Maxent, which is a maximum entropy algorithm and works with both continuous and categorical variables, with a clear advantage over the rest (Felicísimo and Muñoz, 2011).

Therefore, the general objective of this research is to find out how climate change will influence the future distribution of forests in the Andes. To this end, an analysis of the current potential distribution and possible future projections was carried out using predictive models based on GLM such as MaxEnt (Maximum Entropy Modelling), for different emission scenarios RCP 4.5, RCP 6.0 and RCP 8.5, using the CCCma. The conclusions obtained showed the result of probable impacts on the future disposition of a series of forests in the Andes Mountains.

2. Methodology

2.1 Study area

The Andes occupy the coast of the Pacific Ocean from north to south with a length of 8,500 km (Fig. 1), and an average altitude of 4,000 m, covering an area of 2,870,596 km^2 (FAO, 2014) it is a mountain system located between 13°N and 48°S and crossing different countries, Colombia, Ecuador, Perú and Bolivia.

The Andes mountain range occupies a large territory and is characterised by its great environmental, geological and physiological variety. These characteristics are determined by several factors, among which are the relief and climatic variability, this great and diverse relief with river valleys, Andean plateaus, foothills, highlands and great altitudinal variation in which the Huascaran Peak (Peru) is located at 6,768 m. In addition to a great diversity of plant communities such as savannahs, scrublands, rainforests and coastal swamps (Alaggia *et al.,* 2022), the most geomorphologically diverse mountain range on the planet.

Temperature variability in the Andes depends mainly on two aspects: the altitudinal gradient and the time of year, so that the average temperature rate with respect to altitude is between 0.6°C and 0.7°C per 100 metres.

Precipitation in the Andes does not have a linear pattern but is determined by orography and wind influence, which characterises it by its high temporal and spatial variability (Mujica and Holle, 2002), with precipitation values ranging from areas of less than 200 mm per year to 3,000 mm.

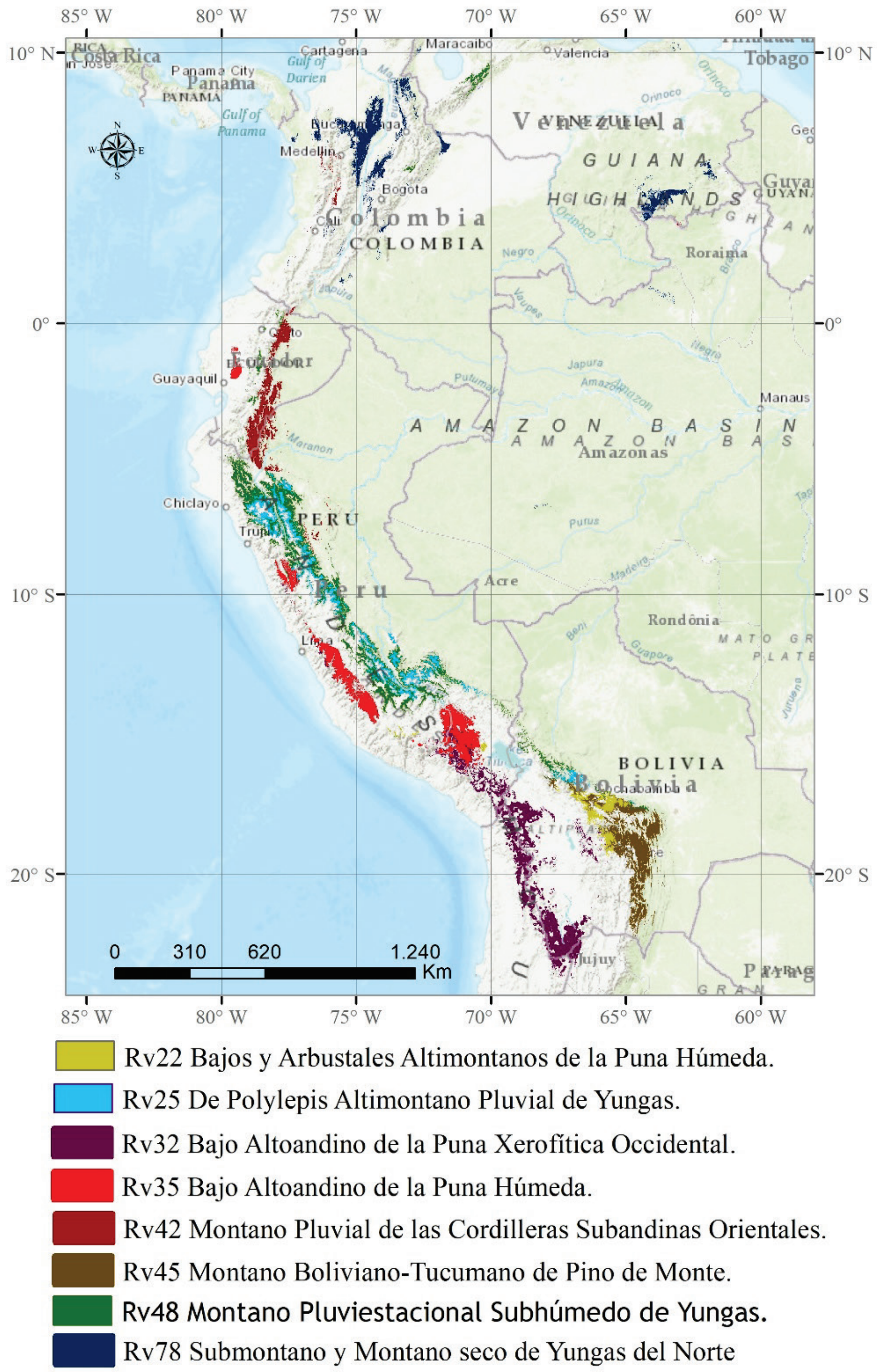

Figure 1. The forest of the Andes Mountain on this study.

2.2. Data

The selection of forests was carried out following distribution and seat representativeness judgements in different information sources (Josse *et al.,* 2009). The study modelled eight very characteristic forest formations of the Andes Cordillera (Fig. 1), selected because these eight formations are highly representative in the study area (Table 1).

Table 1. Type of forest formation selected with the distribution data and forest occurrence data.

Cod	Type of forest	Model	km²
CES409.074	Bajos y Arbustales Altimontanos de la Puna Húmeda	Rv22	4.368
CES409.045	De Polylepis Altimontano Pluvial de Yungas	Rv25	8.425
CES505.007	Bajo Altoandino de la Puna Xerofítica Occidental	Rv32	570
CES409.068	Bajo Altoandino de la Puna Húmeda	Rv35	173
CES409.913	Montano Pluvial de las Cordilleras Subandinas Orientales	Rv42	5.029
CES409.197	Montano Boliviano-Tucumano de Pino de Monte	Rv45	3.641
CES409.921	Montano Pluviestacional Subhúmedo de Yungas	Rv48	13.480
CES411.434	Submontano y Montano seco de Yungas del norte	Rv78	10.196

Source: information source Condesan Project (Cuesta, 2009).

The Bioclimatic Variables (Vb) used for the study were obtained from World Climate Monitor. This server allows the download of data from 19 Vb, as well as the insertion of data from climate stations from 1949 to 2069 excluding Antarctica (Hijmans *et al.,* 2005) with information on these variables in the past and future. For this purpose, the ANUCLIM software was used with the CCma.

The 19 bioclimatic variables (Vb) of Worldclim are organised into 11 temperature vb, from Vb1 to Vb11, annual mean temperature, maximum, minimum, monthly, four-monthly, four-monthly and seasonal, and into 8 precipitation vb from Vb12 to Vb 19 (Fick and Hijmans, 2017) (Table 2).

Table 2. Description of the nineteen Bioclimatic Variables.

Bioclimatic Variable (Bv)	Description	Unit
Bv 1	Annual Mean Temperature	ºC
Bv 2	Mean Diurnal Range (Mean of monthly (max temp - min temp))	ºC
Bv 3	Isothermality (Vb2/Vb7*100)	Variation
Bv 4	Temperature Seasonality (standard deviation *100)	%
Bv 5	Max Temperature of Warmest Month	ºC
Bv 6	Min Temperature of Coldest Month	ºC
Bv 7	Temperature Annual Range (Vb5-Vb6)	ºC
Bv 8	Mean Temperature of Wettest Quarter	ºC
Bv 9	Mean Temperature of Driest Quarter	ºC
Bv 10	Mean Temperature of Warmest Quarter	ºC
Bv 11	Mean Temperature of Coldest Quarter	ºC
Bv 12	Annual Precipitation	mm
Bv 13	Precipitation of Wettest Month	mm
Bv 14	Precipitation of Driest Month	mm
Bv 15	Precipitation of Seasonality (Coefficient of Variation)	%
Bv 16	Precipitation of Wettest Quarter	mm
Bv 17	Precipitation of Driest Quarter	mm
Bv 18	Precipitation of Warmest Quarter	mm
Bv 19	Precipitation of Coldest Quarter	mm

Data: °C: degrees Celsius; Cv: coefficient of variation; mm: millimetres. Obtained from wordlclim and Hijmans (Hijmans *et al*. 2005).

2.3. Methodology

In the development of the PDMs, data on the presence and absence of the species studied were used to create Generalised Linear Models, in which the MaxEnt v.3.3.3 software was used with 100% of the presence data. It provides a continuous range of probability across the geographical area with values ranging from 0 to 1, and the closer they are to 1 the greater the probability of finding presence of the forest formations used, and the further away from 1 the lower the probability (Phillips and Dudík, 2008).

The area of potential distribution is the area where there are suitable environmental conditions for that species or plant formation to thrive. Its extent may be due to both abiotic (topography, geology, climate) and biotic factors (interspecific competition, barriers, dispersal capacity...) (Recalde-Coronel *et al.,* 2020). MDP are indicators of habitat suitability for the development of populations of a particular species or community estimated from observations of field occurrences and their relationships with a series of environmental variables that act as predictors (Elith *et al.,* 2006).

This software is based on a set of methodological (Fig. 2) principles in which the distribution of forests is subject to a binary logistic regression of probability (ρ) of occurrence and non-occurrence (γ^') on a set of potential distribution sites (Gutiérrez and Trejo, 2023). The likelihood function for γ environmental variables is expressed as follows:

Absence $\gamma' = \text{In}(\gamma/(1-\gamma)$

Presence $\rho = e^{y}/(1+e^{y'})$

The MDP (ρ) is constructed through probability values thus obtained, by means of relative suitability values for the presence of forest formations, where (γ) represents the vector of environmental variables, (e^y) refers to Napier's constant, and is used to ensure that (ρ) results in the disposition of the species (Saraiva, 2023).

The derived parameters of sensitivity (true/disposition) and specificity (true absences/inexistences) of the models are Area Under Curve and Receiver Operating Characteristic indicating the validity of the model. The Maximum Entropy distribution estimates the probability of presence-disposition of forests depending on environmental conditions (Phillips and Anderson, 2006). And for validation it indicates the Receiver Operating Characteristic behaviour which has an AUC value greater than 0.7, indicating that the models are acceptable and in this case the AUC values define the degree of fit of the data.

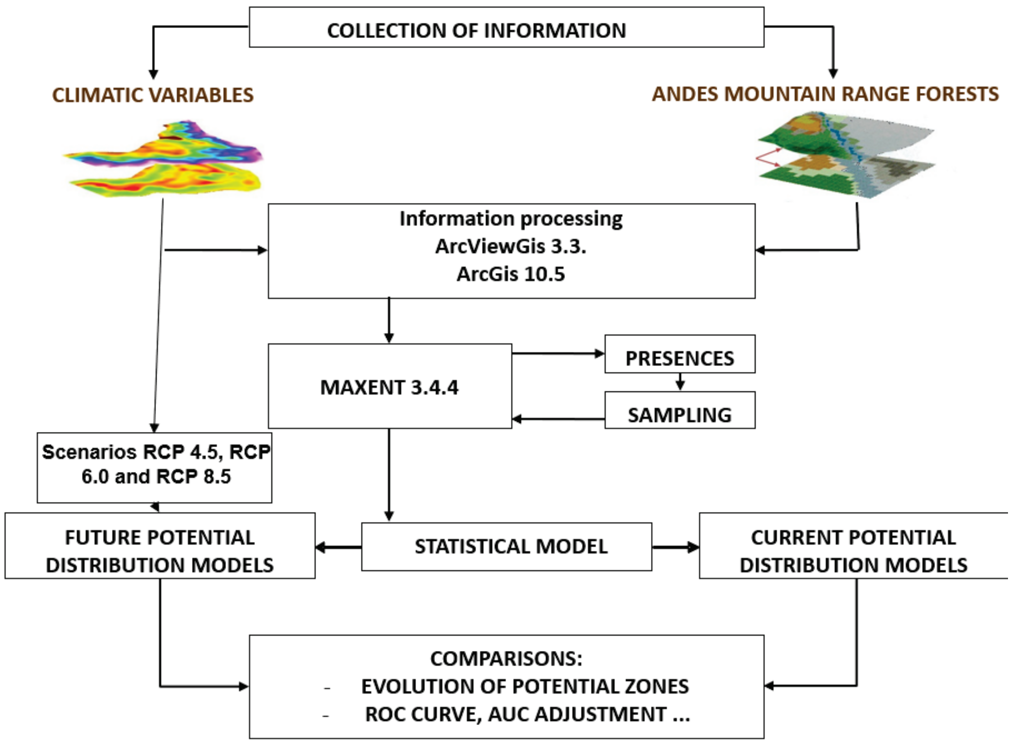

Figure 2. The overall methodological framework of this study.

For each model, 20% of the entries were used for cross-validation and estimation of the error of these parameters derived from the sensitivity and specificity of the models (Jain and Jana, 2023), so only those whose final test values were greater than 0.7 were included. An AUC of less than 0.6 indicates that the MDP is inaccurate, but a value greater than 0.7 indicates a highly accurate MDP (Alaggia *et al.,* 2022).

3. Results

The first results that were analysed were those used to evaluate the degree of adjustment of the models created. This is done through the ROC (Receiver Operating Characteristic) curve, for which Area Under the Curve AUC is used, a value that indicates the discrimination capacity of the model and defines its fit. The construction of the ROC curve is a process applied to each fitness threshold of the model; Maxent uses the presence records, and the area under the ROC curve indicates that for a presence point a random one is selected. The probability that the fitness value predicted by the model for the point of presence is greater than that predicted for the random point is determined by AUC. Therefore, the AUC statistic can take values between 0 and 1. A value of AUC between 0.5 and 0.7 corresponds to a low-precision model, while a value greater than 0.7 corresponds to a high-precision or high-discrimination model. In this case, all models were found to have a degree of fit to the data greater than 0.97, indicating that they are highly accurate (Table 3).

In the results obtained we can analyse the climatic variables that have had a greater influence on each forest typology in the model.

Table 3. Percentage contribution of the variables used for each forest type after analysis and validation of the models. Source: Calculations base on bioclimatic variables used on the models. CPD: Current potencial distribution; FPD: Future potencial distribution.

Forest	Bioclimatic Variable (Bv)	(%) CPD	Bioclimatic Variable (Bv)	(%) FPD	AUC (TD)
Rv22	Bv 2	25.8	Bv 2	26.7	0.991
	Bv 15	13.4	Bv 15	13.4	
	Bv 11	11.3	Bv 11	12	
Rv25	Bv 10	22.4	Bv 10	23	0.989
	Bv 6	15	Bv 6	11	
	Bv 2	12.2	Bv 2	12.2	
Rv32	Bv 11	37.8	Bv 11	38	0.988
	Bv 19	26.4	Bv 19	27.3	
	Bv 6	14.6	Bv 6	14	
Rv35	Bv 1	36.6	Bv 1	28	0.987
	Bv 19	14.6	Bv 19	17.3	
	Bv 18	11.2	Bv 18	13.6	
Rv42	Bv 8	35.1	Bv 8	37.3	0.990
	Bv 15	34.7	Bv 15	34.7	
	Bv 14	10.6	Bv 14	11.6	
Rv45	Bv 9	28.3	Bv 9	26	0.988
	Bv 4	22.1	Bv 4	22	
	Bv 1	11.9	Bv 1	14	
Rv48	Bv 8	43.7	Bv 8	37.7	0.972
	Bv 14	12.1	Bv 14	12.1	
	Bv 11	11.1	Bv 11	13	
Rv78	Bv 15	24.1	Bv 15	28.2	0.994
	Bv 3	22.6	Bv 3	22	
	Bv 13	15	Bv 13	14	

In the analysis of the results obtained for each type of forest formation, the three most representative Vb that influence each forest were selected. For all the forests studied, the same bioclimatic variables have influenced their current potential distribution (CPD) and future potential distribution (FPD), but with different influences. For the forest Rv22 Bajos y Arbustales Altimontanos de la Puna Húmeda (Table 3), the same Vb 2, Vb 15 and Vb 11, related to mean temperatures 25.8% and 13.4% and seasonal precipitation 11.3%, increasing significantly in the FPD, it is a forest characteristic of a supratropical pluvial-pluvial bioclimatic floor with sub-humid and humid ombrotypes.

The mean temperature of the coldest quarter Bv11 influences about 40% in the CPD of the forest (Rv32) of the Bajo Altoandino de Puna Xerofítica Occidental, the precipitation of the coldest quarter Bv11 influences 26.4 and the minimum temperature Bv6 14.6%, of the three variables only the minimum temperature of the coldest month (Bv6) decreases in its FPD (Fig. 3). It is located at an altitude of 3600 m to 4000 m on the Altiplano, the characteristic and dominant species is Polylepis. It develops on substrates of predominantly volcanic lithology (rhyodacites and andesites), and still maintains remarkably extensive forest patches, especially in western Bolivia. The forest Rv22 Bajos y Arbustales Altimontanos de la Puna Húmeda (Fig. 4), it is a forest characteristic of a supratropical pluvial-pluvial bioclimatic floor with sub-humid and humid ombrotypes.

The mapping of potential suitable areas may shed some more light on the expected variations in the area of distribution in some of the cases mentioned. Table 3 shows the CPD and FPD for the different forest formations. In this case the current distribution is only a fraction of the CPD, so that high percentages of suitability indicate good conservation, as in the case of the Rv35 *Bajo Altoandino de la Puna Húmeda* with 20.4% of its surface and the Rv48 *Montano Pluviestacional Subhúmedo de Yungas* with 36.8% of its Surface.

There is an increase in WTP in the different forests as shown in Table 3, values that indicate the suitability conditions of each forest formation.

In the three scenarios there are notable differences in the potential area of distribution, there is a predominance of generalised loss in all forest types in the CPD and in the FPD, the Rv32 *Bajo Altoandino de Puna Xerofítica Occidental,* suffers a FPD of more than 80% in the RCP 8.5 scenario (Fig. 5), and the Rv78 *Submontano y Montano Seco de Yungas del Norte* ha 81.6% (Fig. 6), and the Rv48 Montano Pluviestacional Subhúmedo de Yungas with 36.8% of its Surface (Fig. 7).

The pattern of potential site decline was most pronounced in climate scenario RCP 4.5 (2040-2069) for forest Rv35 Bajo Altoandino de la Puna Húmeda, reducing its potential area by 78.5%. The layout of each forest and its potential site is shown in Table 4.

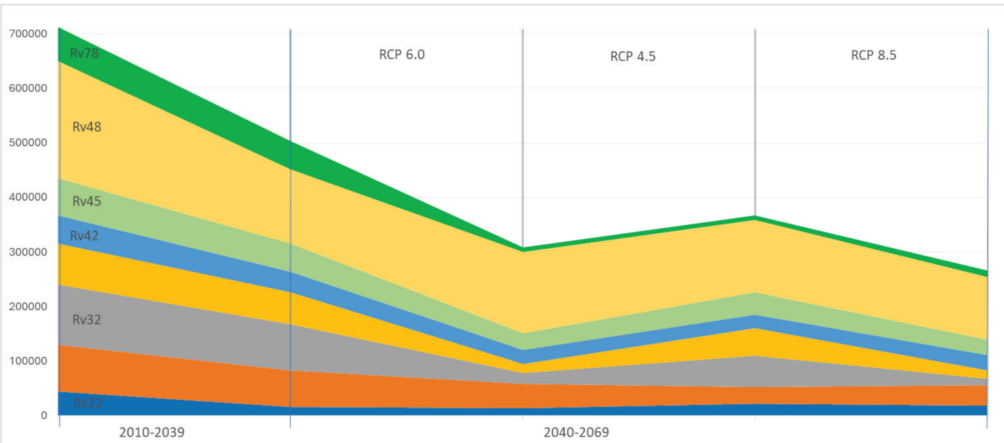

Figure 3. Potential current and future distribution of forests under three emission scenarios RCP.6.0, RCP4.5 and RCP. 8.5.

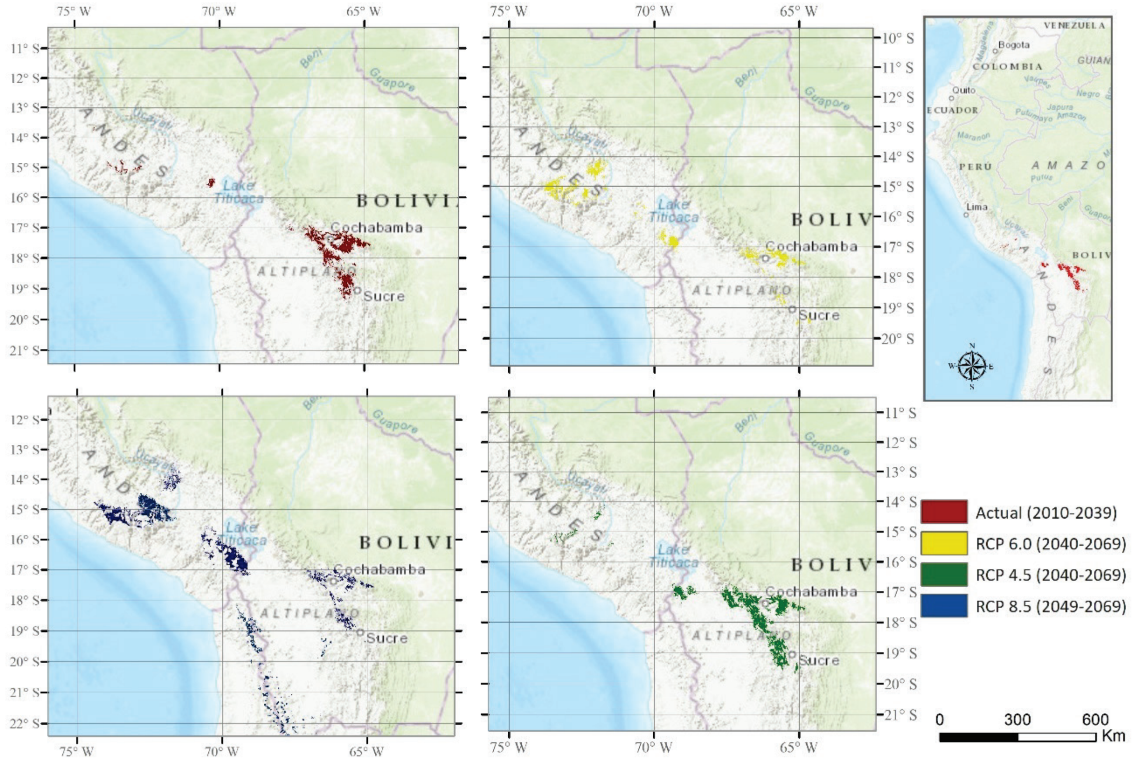

Figure 4. The potential site of forest Rv22 Bajos y Arbustales Altimontanos de la Puna Húmeda in different scenarios. Source: ArcGis 10.3 implementation. WGS84 datum system. Universal Transverse Mercator Datum.

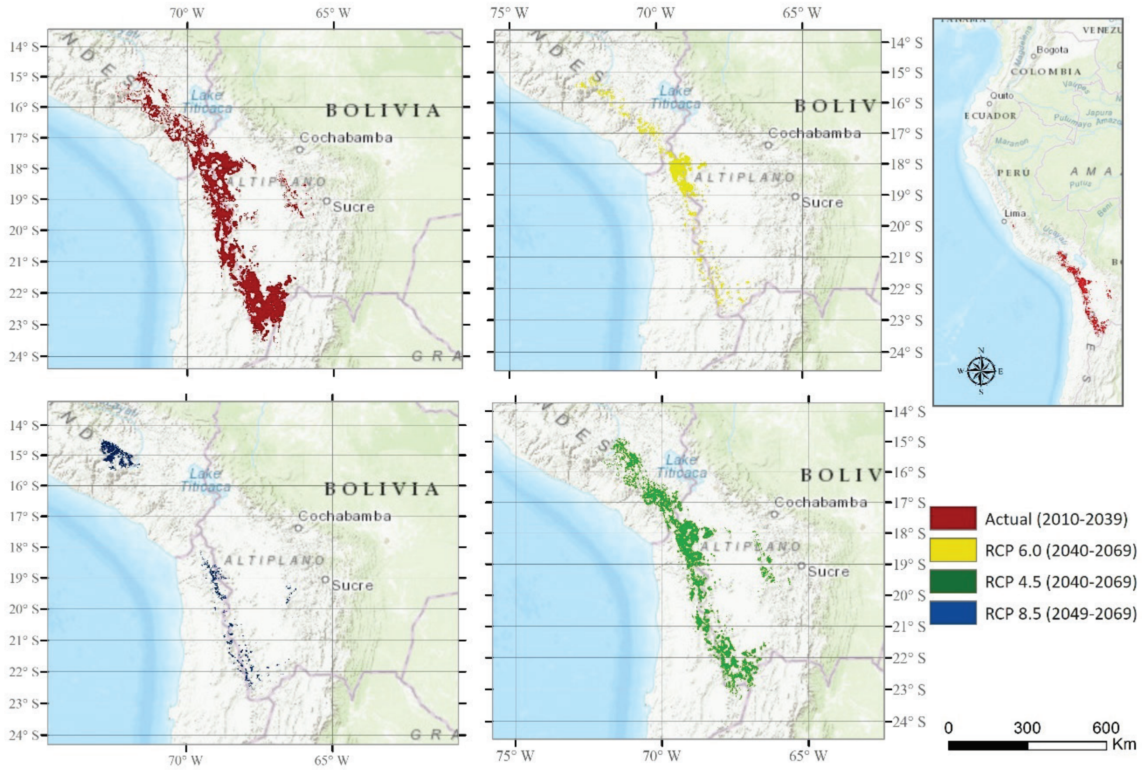

Figure 5. Potential site forest Rv32 Bajo Altoandino de Puna Xerofítica Occidental. Source: ArcGis 10.3 implementation. WGS84 datum system. Universal Transverse Mercator Datum.

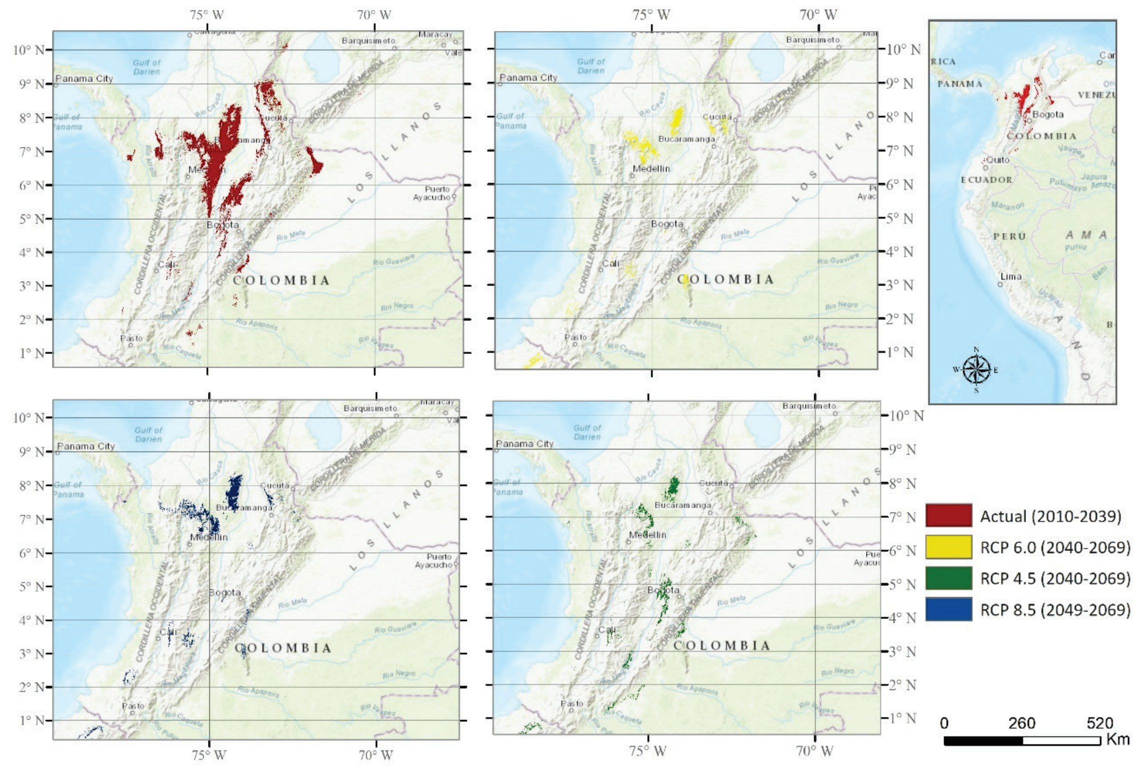

Figure 6. Potential site forest Rv78 Submontano y Montano seco de Yungas del Norte in differents scenarios. Source: ArcGis 10.3 implementation. WGS84 datum system. Universal Transverse Mercator Datum.

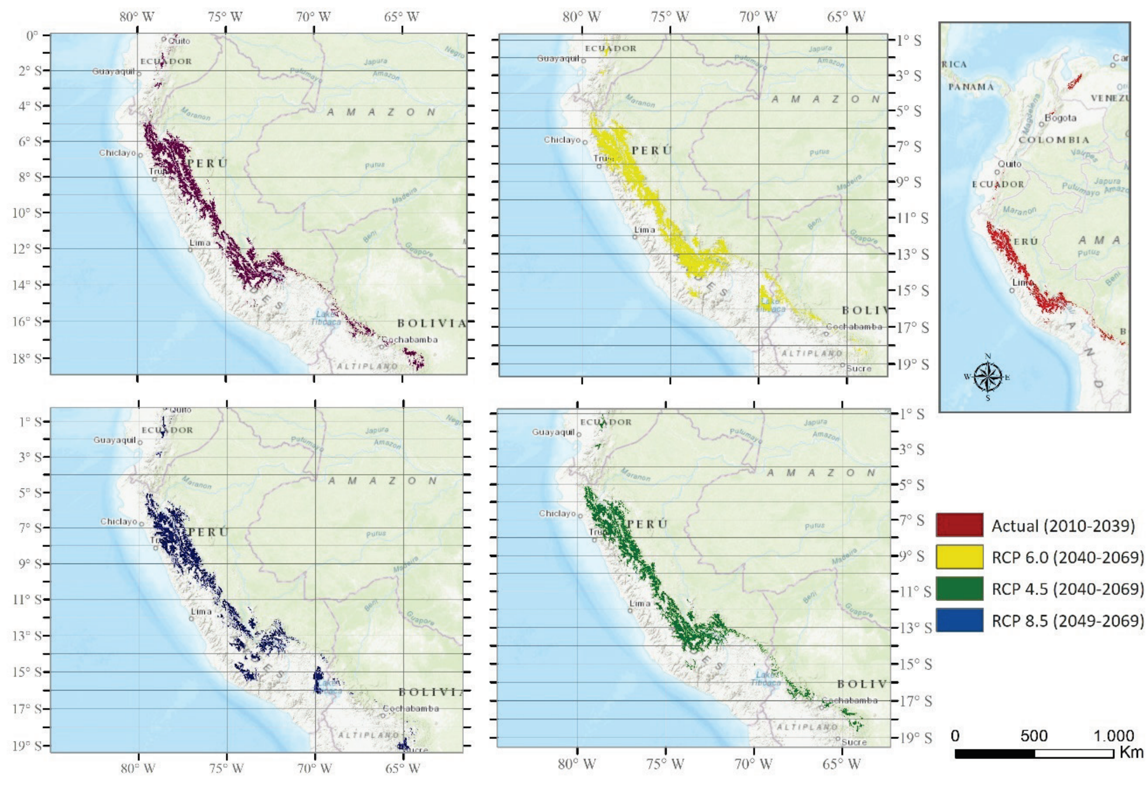

Figure 7. Potential site forest Rv48 Montano Pluviestacional Subhúmedo de Yungas in differents scenarios. Source: ArcGis 10.3 implementation. WGS84 datum system. Universal Transverse Mercator Datum.

Table 4. Evolution of the current and future potential distribution of forests in the Andes Mountain under three emissions scenarios RCP.6.0, RCP4.5 and RCP 8.5.

		2010-2039				***2040-2069***			
	Forest	***Current***		***RCP 6.0***	***Future %***	***RCP 4.5***	***Future %***	***RCP 8.5***	***Future %***
Rv22	Bajos y Arbustales Altimontanos de la Puna Húmeda	15.693	64.6	14.179	68.3	21.710	51.5	18.467	58.4
Rv25	De Polylepis Altimontano Pluvial de Yungas	67.029	21.8	44.723	47.8	30.728	64.2	37.616	56.1
Rv32	Bajo Altoandino de Puna Xerofítica Occidental	84.948	23.3	19.541	82.3	57.147	48.4	11.551	89.5
Rv35	Bajo Altoandino de la Puna Húmeda	58.947	20.4	16.061	78.3	50.518	31.7	15.890	78.5
Rv42	Montano Pluvial de las Cordilleras Subandinas Orientales	36.650	29.2	26.545	48.7	25.136	51.4	27.191	47.4
Rv45	Montano Boliviano-Tucumano de Pino de Monte	52.517	23.2	30.161	55.8	40.460	40.8	29.158	57.3
Rv48	Montano Pluviestacional Subhúmedo de Yungas	135.884	36.8	148.773	30.8	133.213	38.0	11.4801	46.6
Rv78	Submontano y Montano Seco de Yungas del Norte	51.519	15.9	8.445	86.2	8.281	86.5	11.248	81.6

Source: Percentage results of potential distribution models for each forest through the Maxent Software.

The forest Rv42 Montano Pluvial de las Cordilleras Subandinas Orientales decreases its potential site by 48.7% and 51.4% in scenarios RCP 6.0 and RCP 4.5. In contrast, Rv25 De Polylepis Altimontano Pluvial de Yungas decreases its potential site by 51% for the period 2040-2069, characterised by conserved forests with tree ferns and woody vines in northern Peru.

Forests Rv 45 Montano Boliviano-Tucumano de Pino de Monte and Rv48 Submontano y Montano Seco de Yungas del Norte, decrease 57.3% and 46.6% of their future distribution in the FPD in the RCP 8.5 scenario, where mean temperatures influence (Bv9) 28.3% and (Bv8) 43.7%; and precipitation Bv 14 12.1%.

4. Discussion

The analysis of the forest formations used in the study shows the complexity and heterogeneity of the natural forest (Mateo *et al.,* 2011). The use of models is based on the ecological interpretation they receive from different authors. Some consider that we are working with 'suitability models' that represent the potential distribution of the species, understanding as such the space where the species under study could be present according to its environmental characteristics (Felicísimo and Muñoz, 2011), others define it as 'potential habitat models', where the concept of habitat can be applied to the description of the association between organisms and environmental factors, understood as descriptive habitat modelling exercises for a given species (Kessler, 2006), but most of these models, regardless of their ecological interpretation, reflect the distribution of species in a defined temporal space.

From the analysis of the effects of climate change on forest formations we have obtained information on the potential distribution models for each forest formation. In general, very different results are observed for each scenario, taking into account that the RCP 4.5 and RCP 8.5 scenarios on average may be more unfavourable than the RCP 6.0 scenario (Alberdi, 2021).

In order to analyse the effects of climate change on forest formations, information on bioclimatic variables can be considered. The temperature variations in the future could mark the seasonality and precipitation in these forest habitats, it can be considered that the bioclimatic variables related to temperature have influenced 80% of the expected changes in the medium term in the near future are the reduction of the potential site of the forest formations studied, the Bv 8 which refers to the average temperature of the wettest month influences the forest Rv 48 *Montano Pluviestacional Subhúmedo de Yungas* 43.7%, decreasing in the future to 37%, on the other hand the variable Vb 15 which is characterized by the seasonality of precipitation has an influence of 28.2% in the Rv78 *Submontano y Montano seco de Yungas del Norte* forest for its future distribution, so it is observed that the probability of presence increases in a higher humidity regime (Hernández-Silva and Juárez-García, 2019; Acosta *et al.,* 2022). This increase in average temperature could shift these forests to higher latitudes, as also indicated by Anderson *et al.* (2003) in their work, where an increase in temperature of 3ºC could cause a displacement of 600 m upwards with the consequent loss of habitat area. There are several studies linking displacements of forest formations caused by temperature increases (Duque *et al.*, 2015; Fadrique *et al.*, 2018).

The Rv35 Bajo Altoandino de la Puna Húmeda forest, are structurally low shrubs forests with, semi-open to open, with a canopy of 3-10 m and a variable understory depending on the degree of conservation, where grasses and other herbaceous plants are frequent, as well as some shrubs and ferns (Navarro and Maldonado, 2002). In most of its potential area, these climax forests have been replaced by a complex of seral plant communities, mainly grasslands and scrublands. It develops between 3200 m altitude and 4,100 m.

Temperature variations show that seasonality may increase in forest formations where Bv15, related to rainfall variability, has an important influence of 34%, as in the case of Rv42 Montano Pluvial de las Cordilleras Subandinas Orientales where a 47.4% decrease in its DPF is observed. In the Rv32 Lower High Andean forest of the Western Xerophytic Puna, Bv19 influences precipitation of the coldest quarter, with 26.4% and Bv11 with 37.8% of average temperature where a strong decrease in forest formation of 89. 7% in its DPF and in all scenarios because the area meets the climatic suitability but does not take into account other factors related to land uses (Hernández-Silva and Juárez-García, 2019), deforestation or human intervention (Alberdi, 2021).

The problem of potential areas disconnected from the current range is the difficulty for seeds to get from the current area to the new, potentially suitable area (Poblete and Albeiro 2021). The actual management of these areas must take into account this circumstance, which can nullify the real potential of emerging areas and which conditions the expansion processes of forest stands which (García-Romero *et al.,* 2010), in turn, are governed by a series of ecological elements, mechanisms and processes such as competition, fragmentation, stability, disturbance, fragment shape and connectivity (Storch *et al.*, 2012).

On the other hand, we can conclude that there is a reduction of the potential future range by more than 50% compared to the current potential range of the seven forest types.

In all three climate scenarios there is a pattern of decrease in potential area, most marked in the RCP 8.5 scenario where there is a clear pattern for the period 2040-2069, with three forests decreasing by half and one by almost 80%.

5. Conclusion

Most projections of future scenarios foresee a reduction in the potential area of the most representative forests in the Andes. Of the scenarios considered, the most benign is RCP 6.0 and the most restrictive RCP 8.5. These projections should be taken only as a guideline or warning and there are several considerations to be made in their interpretation.

The first is that the actual scenario that will occur in the coming decades is unknown. The range is wide and the available models predict values of change consistent in their general trends but with significant differences. The possibility of harsher scenarios than those shown here cannot be ruled out in view of the scant success in complying with the Kyoto agreements in their first and second periods of validity.

Even so, there are factors that may profoundly modify the response of vegetation to climate change compared to what is predicted in these models.

One such factor is the plasticity of forest formations to change. It is possible that some species or forests as a whole may respond more flexibly to environmental change than models estimate. For example, a rise in temperature could be supported if it occurs simultaneously with a rise in precipitation in the warmer season. Unfortunately, we do not have the information to assess these responses, so it is more prudent to assume the situation that the models predict. The vulnerability of species to climate change has sometimes been discussed, but the scarcity of data is always a limiting factor in the effectiveness of models (Arribas and Abellán, 2012).

It should also be considered that this type of model does not consider biotic interactions or other factors that can influence such a complex spatio-temporal process as species distribution (Cuesta and Becerra, 2012). Nature is complex and models are simplifications that allow us to manage it, but the uncertainties are great.

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