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Research Article

A scenario-driven strategy for future habitat management of the Andean bear

Ahmet Acarer

Department of Wildlife Ecology and Management, Faculty of Forestry, Isparta Applied Sciences University, Isparta, Türkiye

*Email: aacarer32@gmail.com

*https://orcid.org/0000-0003-0864-7880

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Abstract

Today, climate adaptation strategies are at the forefront in wildlife management and protection studies. This study aimed to model and map the effects of global climate change on the Andean bear, which is in the vulnerable category and distributed in South America. For this purpose, 20 environmental variables and 19 high-resolution Chelsa climate maps that could be effective on Andean bear modeling were created. Moreover, the Maximum Entropy method, which is frequently preferred in species distribution modeling, was preferred. The current habitat suitability model of the Andean bear was in the "very good" model category with the training data set ROC value of 0.973 and the test data set ROC value of 0.972. The variables contributing to the current model are roughness index (41.1%), isothermality (38%), elevation (14%), and annual mean temperature (6.9%), respectively. Variables contributing to the current Andean bear model have been simulated in different scenarios (SSP126/SSP370/SSP585) for the year 2100. However, it has been determined that Andean bear habitats will shrink according to the SSP126 Chelsa climate scenario of the year 2100, these habitats will fragment according to the SSP370 scenario, and brown bear habitats will disappear in some regions in the SSP585 scenario. In conclusion, this study raises alarms that the possible decrease in Andean bear habitats will be approximately 67.3% by the year 2100 due to global climate change.

Keywords: Andean bear, Chelsa climate, modeling and mapping, planning, wildlife

Introduction

The interaction between wild animals distributed in natural ecosystems affects habitat preferences. In other words, different food sources in their habitats affect wild animal habitat preference (Uzal et al., 2013; Reher et al., 2016). Because continuity in nutritional needs is one of wild animals' most important physiological needs. Therefore, the food density, type, and amount found in different habitats are essential in terms of body size, activities, and habitat preferences of wild animals and directly or indirectly affect species distribution (Mert &Acarer, 2018; Ballari & Barrios-Garcia, 2014). Body size is an essential factor for wild animal species. Since large-sized mammalian species tend to have large home ranges (McNab, 1963), it takes a long time to maintain viable populations of these species and to protect their habitats. Therefore, large body-sized wild animal species distributed in broad geographical areas are generally considered flags, indicators, or key species regarding biodiversity resources (Özçelik, 2006). When this situation is evaluated on the Ursidae family distributed worldwide, bear species are generally accepted as indicators or key species of biodiversity in the habitats in which they are found (Acarer & Mert, 2024; Ertuğrul et al., 2017; Mert & Kıraç, 2017; Oruç et al., 2017).

Today, it is known that there are eight subspecies of the *Ursidae* family, namely Ursus arctos, *Ursus thibetanus, Helarctos malayanus, Ursus americanus, Ursus maritimus, Melursus ursinus, Ailuropoda melanoleuca* and *Tremarctos ornatus* (Servheen, 1999). The spectacled or Andean bear (*Tremarctos ornatus*) in the Ursidae family, which has a wide distribution area, is only distributed in South America (Peyton, 1980). In other words, it represents South America (Meza Mori et al., 2020). The Andean bear is distributed in areas where the elevation difference between 200 meters and 4750 meters has a wide range in this geography (Peyton, 1999). In addition to having a significant elevation difference, different areas, such as tropical forests and mountain ecosystems, play a role in habitat preference (Garcia-Rangel, 2012). Therefore, considering its widespread distribution in different ecosystems and elevations, it is important to include the Andean bear in the protection and planning studies in South America (Yerena, 1998; Jorgenson & Sandoval-A, 2005; Velez-Liendo et al., 2013; Osterman et al., 2021).

Much information has been obtained for the 1970 year for the conservation and management plans of the Andean bear (Andrade, 2004), which is considered a critical species in terms of biodiversity (Cuesta et al., 2003). Despite this information, it is stated that information on the Andean bear population status and habitat preference is less than that of other bear species (Castellanos, 2011).

In addition, considering the population size and density of the Andean bear, it is a matter of concern that it is listed as "vulnerable" (VU) and in CITES Appendix I according to the IUCN (International Union for Conservation of Nature) and continues to be one of the least known bears (Peyton, 1999; IUCN, 2024) In addition to the danger of extinction of the Andean bear in the South American where it is distributed, human density and illegal hunting activities have been associated with the decrease in the habitats of the species. Therefore, it has been stated that excessive deforestation and agricultural activities are responsible for the decrease in the Andean bear population (Goldstein et al., 2006; Velez-Liendo et al., 2013; Osterman et al., 2021; Aurich-Rodriguez et al., 2022; Castrillon-Hoyos et al., 2023). As a result, the main threats to the Andean bear are habitat shrinkage, fragmentation and extinction, poaching, bear-human conflict, and climate change.

Climate change affects living species and their habitats in different ecosystems. The shrinkage, fragmentation, or loss of habitats for wild animal species is attributed to climate change (Acarer, 2024b; Özdemir et al., 2020). This situation causes the ecological balance to be disrupted and biodiversity to be endangered (Özkan et al., 2024). Different climate models have been developed to determine the affected areas in advance and initiate the rehabilitation process to eliminate these ecosystem disruptions. One of these models, the Chelsa V2.1 climate scenarios, has a very high resolution (30 arc seconds, ~1 km*1km) (Karger & Zimmermann, 2021). The reliability of the Chelsa V2.1 global climate models is quite high compared to other climate scenarios in wildlife studies of these scenarios (Morales-Barbero & Vega-Alvarez, 2019).

Global climate models are essential in making statistical assessments based on current climate conditions and simulating future scenarios (Flato et al., 2014). Global climate models, based on some parameters in the landform, atmosphere, and oceans, are advanced systems used to determine how and in what way greenhouse gas emissions react to the climate (Pelletier et al., 2015). However, analyzing global climate models and presenting their results is long and complex (Randall et al., 2007). Although it is a long and complex process, it is an effective method for future species distribution modeling and mapping studies of wild animal species that are endangered or facing extinction (Acarer, 2024a). Numerical and model-based species distribution models are increasingly used in wildlife ecology and management studies. Species Distribution Modelling (SDM) methods are divided into two groups as working with presence-absent data (connection) and working with only presence data (profile) techniques (Engler et al., 2004; Özkan, 2012). Due to the high cost and time required to obtain absence data for wild animal and plant species, only presence data is generally preferred in modeling studies. In wild animal habitat suitability modeling studies, Enfa, Garp, Domain, and BioClim are some methods that work only with presence data. Maximum Entropy is another method that works only with data (Tekin, 2019; Acarer, 2024c; Özdemir, 2024). Maximum Entropy (MaxEnt) software, which provides accurate and reliable data with the least amount of existing data, is essential (Phillips et al., 2006; Elith et al., 2011). MaxEnt is considered to perform better than other SDMs in terms of prediction accuracy with minimal sample size tolerance. Additionally, the MaxEnt software is straightforward and widely used to study the habitats of different bear species, which wildlife authorities can use. For the reasons stated above, this study aims to map the current and future (2100 years) habitat suitability of the Andean bear distributed in South America and the "vulnerable" category using the MaxEnt method. For this purpose, the current and future climate envelope models of the Chelsa V2.1 technical specification (IPSL-CM6A-LR SSP126, SSP370, SSP585) were used.

Material and methods

Study area and Andean bear data collection

This study was carried out within the borders of South America, where the Andean bear is distributed worldwide. The geographical location of South America, which has an area of approximately 17.824.370 km^2, is between 15° north and 60° south latitudes and 30° - 90° west longitudes. South America has various climate types as it covers a wide geographical area. Climates generally vary depending on factors such as location and elevation in the region but generally host the following main climate types: equatorial climate, monsoon climate, subtropical climate, desert climate, and high mountain climate (Eidt, 1969; Garreaud et al., 2009; Labraga &Villalba, 2009). South America is home to the richest wildlife species in the world due to different ecosystems and climate conditions. In addition, according to the archive reports of the IUCN, many wild animal species that are endangered, facing extinction or at a sensitive level are distributed in South America (IUCN, 2024). To fill the gap and improve the existing knowledge on the impact of the climate conditions that are likely to change soon on the Andean bear distributed in South America, the target species presence data were obtained from the Global Biodiversity Information Facility (GBIF) data infrastructure. The Andean bear presence data downloaded from the GBIF database, which provides open access to species living on Earth, were resized globally according to the study area border, and the "WGS 1984 Mercator" coordinate system was introduced (GBIF 2024). Data on the spatial distribution of 387 Andean bear individuals recorded within the study borders are shown in red (Fig. 1).

Figure 1. Distribution of 387 presence data of Andean bears in South America

Production of environmental base maps

This study aims to reveal the effects of globally changing climate conditions on the distribution of Andean bears. Despite other regional or area-based literature studies conducted for this purpose, larger-scale (South America) current and future habitat suitability modeling and mapping will be presented because it has been stated that digital and model-based mappings provide more accurate and reliable results in large-scale studies. In this perspective, the digital elevation model (DEM: 30 arc seconds) downloaded at the world scale was obtained from https://www.usgs.gov/ internet address. The digital elevation model obtained at the world scale was resized based on South America, and the "WGS 1984 Mercator" coordinate system was introduced. The digital elevation model with appropriate coordinates belonging to the study area was divided into 1x1 km pixels, which is generally preferred in studies on the current and potential distribution modeling of wild animals and the determination of climate change on the potential distribution of plant species (Wright et al., 2020). Finally, based on this grid system belonging to the study area, 20 base maps were produced thanks to different formula indexes or toolboxes in the ArcMap software (Table 1).

Table 1. Environmental variables

Code	Name	Code		Name
ykslti	Elevation	**Solar illumination index**	**6 am**	06:00
Slope	Slope		**8 am**	08:00
Slope_class	Slope class		**10 am**	10:00
Aspect	Aspect		**noon**	12:00
Aspect_class	Aspect_class		**2 pm**	14:00
bui	Aspect suitability index		**4 pm**	16:00
ri	Radiation index		**6 pm**	18:00
Si	Heat index		**8 pm**	20:00
Si_mc	Heat index (mccune)		**Solarillum**	total
rough	Roughness index	**Landform classification (Lpi)**	**A**	Canyons
rugg	Ruggedness index		**B**	Shallow valleys
Elev_class	Elevation class		**C**	Upland drainages
cti	Compound topographic index		**D**	U-Shape valleys
hillshade	Shading index		**E**	Plains
tpi	Topographic position index		**F**	Open slopes
bdrock	Bedrock map		**G**	Upper slopes
sri	Solar radiation index		**H**	Hills in valleys
Rugg_5	Ruggedness 5 pixel		**I**	Mid slope ridged
Rough_5	Roughness5 pixel		**J**	High ridges

Chelsa climate V2.1 data

Globally changing climate conditions are causing the shrinkage, fragmentation, and extinction of wildlife habitats distributed in natural ecosystems. Therefore, the high resolution of climate scenarios affects species distribution modeling results. In addition, while more correct results are obtained with other scenarios in small-scale areas, it has been stated that Chelsa climate scenarios are better suited to larger-scale areas. In this study, Chelsa climate scenarios V2.1 (future and current) were obtained from www.chelsa-climate.org to reveal the effect of climate change. (Karger et al., 2017; Karger et al. 2023). Current and future (2100-year/SSP126-SSP370-SSP585) Chelsa climate data (30 arc seconds) were downloaded in ESRI Grid format in version 2.1 and scaled according to the study area boundary (Table 2).

Table 2. Chelsa V2.1 Climate variables

short name	long name	scale	offset
Bio1	Annual mean temperature	0.1	-273.15
Bio2	Mean diurnal range	0.1	0
Bio3	Isothermality (BIO2/BIO7)	0.1	0
Bio4	Temperature seasonality (standard deviation)	0.1	0
Bio5	Max temperature of the warmest month	0.1	-273.15
Bio6	Min temperature of the coldest month	0.1	-273.15
Bio7	Temperature annual range (BIO5-BIO6)	0.1	0
Bio8	Mean temperature of wettest quarter	0.1	-273.15
Bio9	Mean temperature of driest quarter	0.1	-273.15
Bio10	Mean temperature of warmest quarter	0.1	-273.15
Bio11	Mean temperature of coldest quarter	0.1	-273.15
Bio12	Annual precipitation	0.1	0
Bio13	Precipitation of the wettest month	0.1	0
Bio14	Precipitation of the driest month	0.1	0
Bio15	Precipitation seasonality (coefficient of variation)	0.1	0
Bio16	Precipitation of the wettest quarter	0.1	0
Bio17	Precipitation of the driest quarter	0.1	0
Bio18	Precipitation of the warmest quarter	0.1	0
Bio19	Precipitation of the coldest quarter	0.1	0

***The data presented in the CHELSA database includes values transformed using scale and offset values. This transformation is done by multiplying the value with the scale value and adding it to the offset value. For example, the value 8000 for bio4 corresponds to (8000 / 100) x 0.1 +(0) = 8 °C.

Habitat suitability mapping of Andean bear (Maximum Entropy)

Globally changing climate conditions, Maximum Entropy (MaxEnt) version 3.4.4 was used for Andean bear habitat suitability modeling and mapping. The purpose of the MaxEnt method is to explain the arbitrarily bounded variable and the measure of the uncertainty of this variable. Entropy is a probability calculation method. Entropy measures how many alternatives can be classified to obtain information about a situation. Therefore, a situation with high entropy contains more options (Phillips et al. 2004). The entropy formula:

$$H(\pi) = -\Sigma(\hat{\pi}) ln \hat{\pi}(x) x \in X \quad (1)$$

According to the formula, entropy is "H", unknown situation probability is "$\hat{\pi}$" and the distribution range of this probability is "X" axis. "π" in the formula is used for the probability of the species being found and "X" is used for environmental variable values that may affect the distribution of the species. The value of the number "π" expresses the positive "x" function and the sum of the probability corresponds to the value 1. "$\hat{\pi}$" here expresses the probability of a distribution and "$\hat{\pi}$" is defined in the equation (Phillips et al. 2006). MaxEnt probability calculation method is obtained by dividing the total rating coefficient of the variables affecting the species distribution by "Zλ". The probability distribution takes a value between 1 and 0 and the sum of all values reveals the value 1. (Phillips et al. 2006). Thus, the MaxEnt probability method distribution formula takes the form below

$$q\lambda(x) = e\lambda \text{ x} f(x) / Z\lambda \quad (2)$$

The "λ" specified in the formula represents the number, "n" represents the coefficient indicating the weight of the environmental factors, and "f" represents the vector indicated by all factors. The "qλ" value is equal to the value shown in the equation formula 2 according to the convex duality theorem (Phillips et al. 2006).

The similarity software MaxEnt is the probability of finding each pixel in the study area for the target species and simulating this probability for the entire study area (Yost et al. 2008). This software works with a regular distribution and calculates the degree to which the variable distribution changes with the specified degree and repetition. This analysis result, called gain, is called covariance calculation. The model is repeated until the gain value reaches the maximum value or until it is lower than the previous gain value. In light of this information, modelling was conducted until two variables remained for the Andean bear distribution in South America. To check the accuracy of the obtained models, the average deficiency graph, ROC (Receiver Operating Characteristic) values and Jackknife training graphs were examined. There are two different methods for examining the ROC values. The first of these is the highest training value of the repetitions of the obtained model. The other is that the difference between the training and test data values between the repetitions is the lowest and the test data ROC value is not higher than the training data ROC value. Classifying the model explanation share according to the training and test data set values for Baldwin's (2009) wildlife studies, if 0.9<ROC is "very good," if 0.7<ROC<0.89 is "good," and if ROC<0.69 is "not informative."

After determining the variables contributing to the accurate and reliable current habitat suitability model of the Andean bear, the current model was simulated to future (2100-year) Chelsa climate scenarios (SSP1 2.6-SSP3 7.0-SSP5 8.5 / IPSL-CM6A-LR). The maps presented were classified and calculated as unsuitable habitats preferred by wildlife <0.5, 0.51-0.8 suitable, and 0.81-1 most suitable habitats. Thus, it will be determined how much the areas where the Andean bear is distributed will increase or decrease in the future.

Result

Variables selection

In this study, a total of 39 different digital base maps were produced, including 19 climate and 20 environmental variables that may affect the distribution of the Andean bear. It has been stated in the studies conducted that there is a high (r<0.8) correlation between the Chesa climate variables produced according to the study area borders. 19 Chelsea climates with high correlations among each other cause a multi-connection problem. Therefore, a correlation analysis was conducted between 19 Chelsea climate variables in the R studio program before proceeding to the Andean bear modeling study. As a result, it was determined that there was a high correlation between the 19 Chelsea climate variables produced for the area.

Factor analysis determined the variable that best represents the climate variables with high correlation. Among the 19 Chelsea climate variables, four variables explained the model best with a cumulative value of 93.223% and a variance value of 10.409% (Table 3). In the component matrix results (R^2>0.8), it was determined that the components that contributed the most to the model were bio7 (-0.967), bio12 (-0.808), bio1 (0.806) and bio14 (-0.824), respectively (Table 4).

Table 3. Results of Factor Analysis applied to Chelsa Bioclimate variables

Component	Subtractive Sums of Square Loadings		
	Cumulative %	% of Variance	Total
1	51,435	51,435	9,773
2	78,295	26,860	5,103
3	90,667	12,372	2,351
4	**93,223**	**10,409**	**1,836**

Table 4. Results of the Component Matrix applied to Chelsa Bioclimate variables (R^2)

climatic variable	Component			
	1	2	3	4
Bio1	,764	,610	**,806**	,172
Bio2	-,734	,289	,573	-,189
Bio3	-,669	,287	,566	-,215
Bio4	-,804	,231	,471	-,046
Bio5	,326	,794	,497	,087
Bio6	,895	,392	-,105	,174
Bio7	**-,967**	,246	,568	-,128
Bio8	,935	,304	,048	,112
Bio9	,653	,697	,238	,165
Bio10	,636	,713	,242	,157
Bio11	,866	,473	-,014	,145
Bio12	,532	**-,808**	,429	,145
Bio13	,694	-,639	,324	-,025
Bio14	-,597	-,289	,128	**,824**
Bio15	,870	-,209	,100	-,382
Bio16	,681	-,630	,370	-,026
Bio17	-,596	-,355	,175	,692
Bio18	,681	-,630	,370	-,026
Bio19	,668	-,632	,386	-,026

With the help of statistical analysis applied to 39 different environmental and climatic base maps created for the South American region, habitat suitability modeling was started with 24 environmental and climatic variables that could affect the distribution of the Andean bear. For habitat suitability modeling, 24 base maps were converted to ASCII format to be processed in the Maxent software. The habitat suitability modeling phase was started by converting 387 presence data and 24 different variables belonging to the Andean bear to ASCII format.

Results of climatic habitat suitability modeling for the Andean bear

Current modeling and mapping

A total of 30 models were developed using the presence data to assess the current habitat suitability of the Andean bear. Among these models, 26 were identified as the most effective, with an AUC of 0.971 (Fig. 2A). Six replications, both in the training data (ROC: 0.973) and in the test data (ROC: 0.972), provided the optimal separation for these 26 models (Fig. 2B).

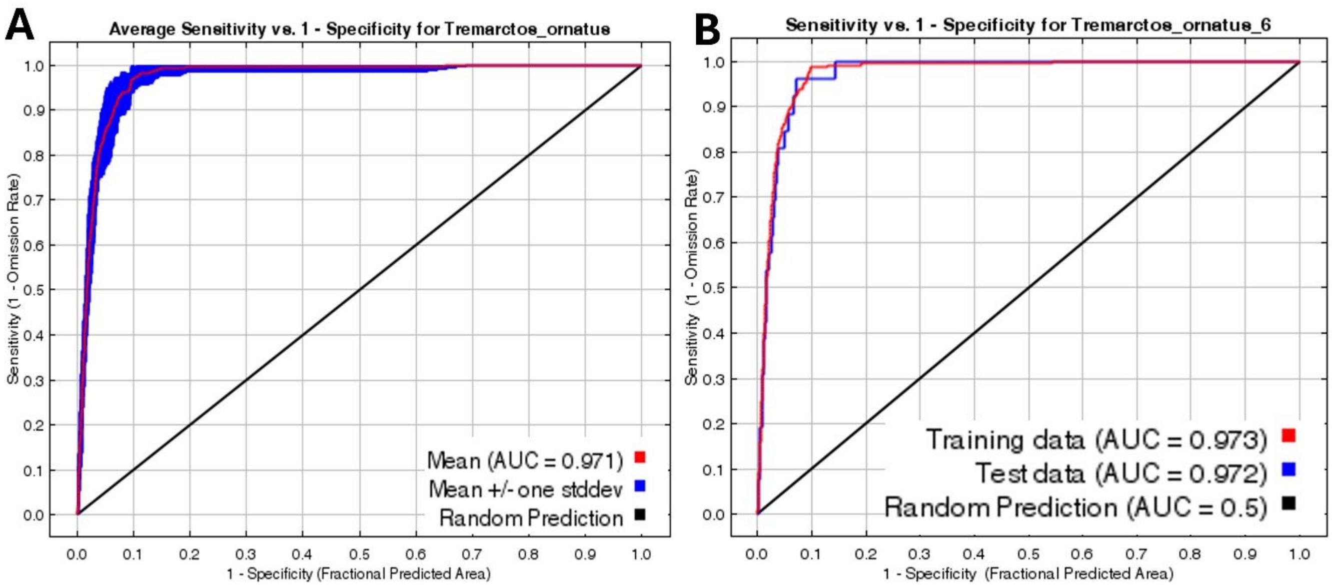

Figure 2. A) AUC values for the current habitat suitability model of the Andean bear B) Receiver operating characteristic (ROC) curves for the current model.

According to the Jackknife of AUC graph (Fig. 3), roughness, isothermality (bio3), elevation, and annual mean temperature (bio1) are the variables contributing to the current habitat suitability model for the Andean bear, an endangered species in South America.

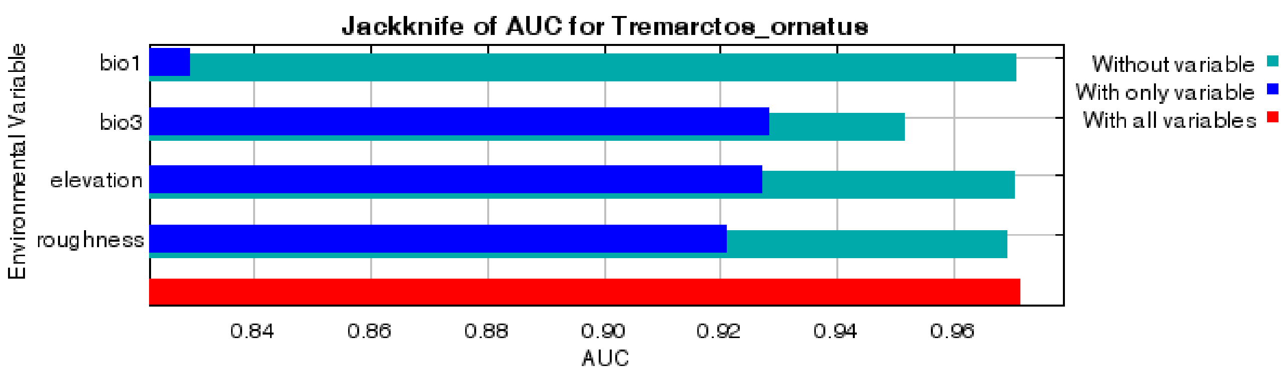

Figure 3. Jackknife graph of variables contributing to the current habitat suitability model of the Andean bear

Marginal response graphs were examined for the accuracy and reliability of the current habitat suitability modeling for the Andean bear. Upon examining the marginal response graphs, it was observed that the probability of the target species' presence increased with higher roughness index values within the study area. (Fig. 4A). Areas with an isothermality (bio3) value between 8 °C and 10 °C affect species distribution positively (Fig. 4B). According to the elevation digital base map within the study area, it was determined that the Andean bear distribution was suitable in the regions between approximately 1500 m and 4200 m (Fig. 4C). Finally, it has been determined that areas in South America where the Annual Mean Temperature (bio1) is between 4.35 °C and 19.35 °C have the highest habitat suitability for the Andean bear (Fig. 4D).

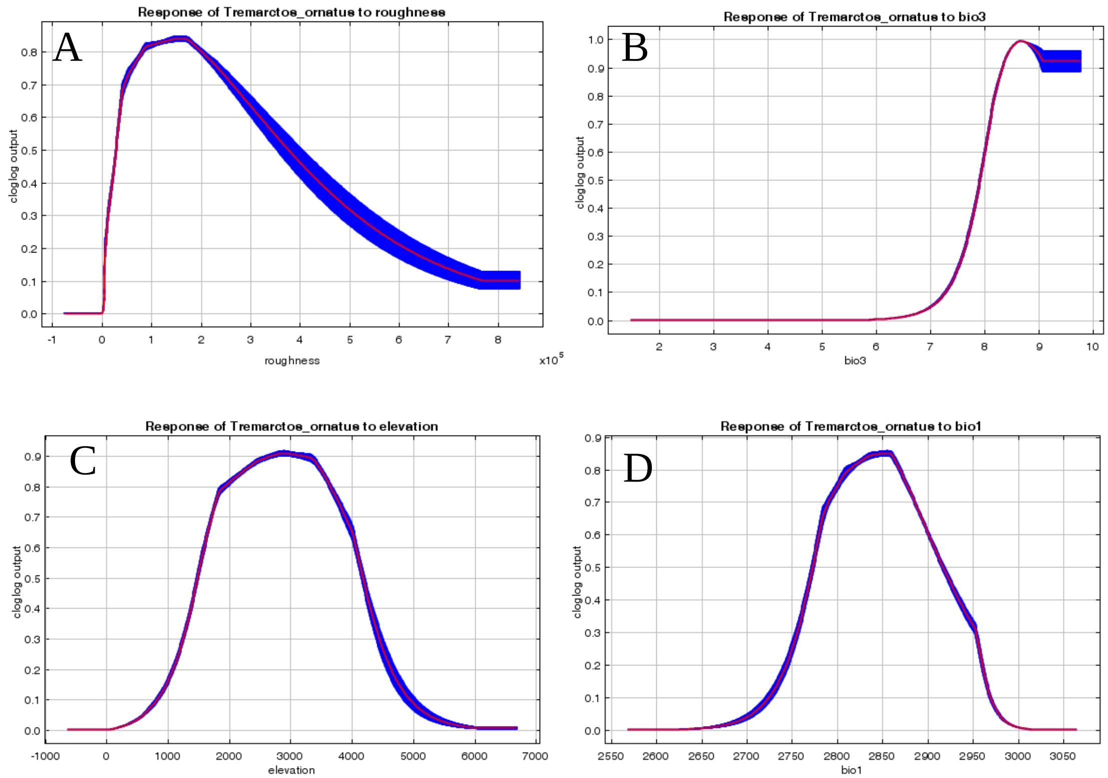

Figure 4. A) Roughness index graph; B) Isothermality (bio3) graph; C) Elevation graph; D) Annual mean temperature (bio1)

The marginal response graph analysis indicates the current habitat suitability mapping for the Andean bear (Figure 6). In this mapping, areas with high habitat suitability are depicted in red, while regions with low habitat suitability are shown in blue. Examination of the habitat suitability mapping reveals that optimal habitats for the species are predominantly located in the rugged terrains of the northwestern portion of the study area. Furthermore, these suitable habitats are also characterized by high elevation. Consequently, the large-scale, model-based habitat suitability mapping for the Andean bear is demonstrated to be both accurate and reliable.

Based on the results from the marginal response graphs, the current habitat suitability mapping for the Andean bear is illustrated (Figure 5). High suitability areas are depicted in red, while low suitability areas are shown in blue. Analysis of the habitat suitability mapping indicates that optimal habitats for the species are predominantly located in the rugged, northwestern region of the study area. Additionally, these areas are characterized by high elevation. Thus, the large-scale, model-based habitat suitability mapping for the Andean bear is demonstrated to be both accurate and reliable.

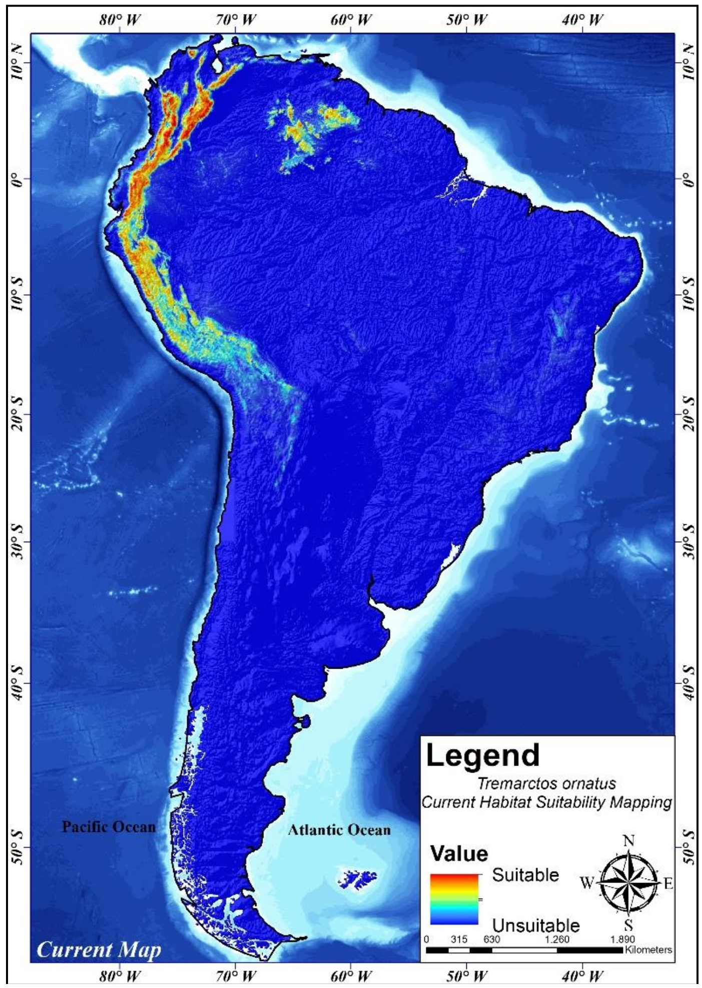

Figure 5. Current habitat suitability mapping of the Andean bear

Future modeling and mapping

Utilizing the variables contributing to the current habitat suitability model for the Andean bear, simulations for the year 2100 were conducted under the Chelsa climate using the IPSL-CM6A-LR models for the SSP126, SSP370, and SSP585 scenarios (Figures 6a 6b, and 6c). It was observed that the distribution of suitable habitats for the Andean bear varies across these scenarios for 2100. The variation is minimal under the SSP126 scenario (Figure 6a) and more pronounced under the SSP585 scenario (Figure 6c). Consequently, the study aimed to identify and quantify these changes through field-based and numerical analyses.

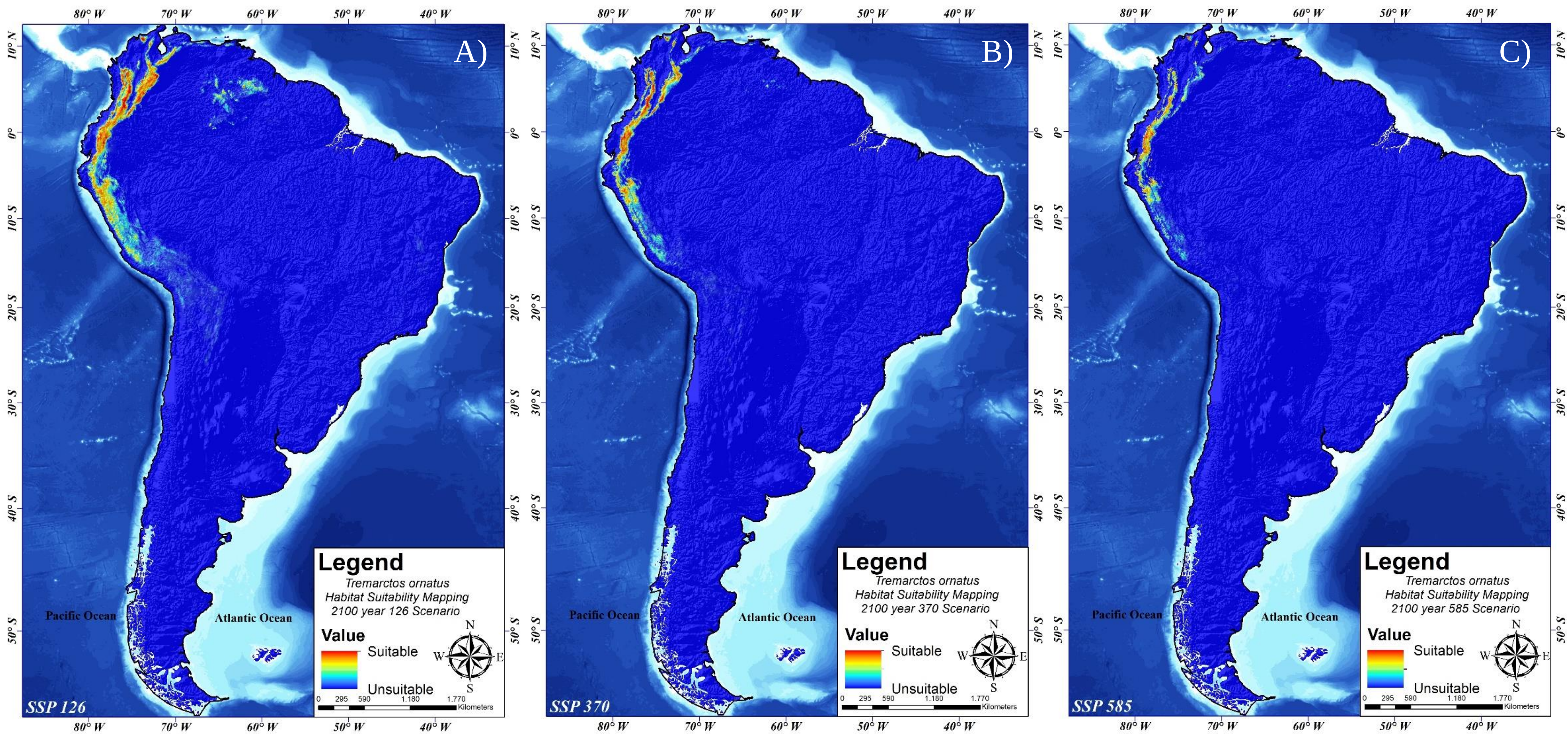

Figure 6. Andean bear habitat suitability mapping 2100-year A) future model1: 126 scenarios, B) future model2: 370 scenarios, C) future model3: 585 scenarios

The results were classified according to suitability values: 0.0–0.5 (Unsuitable Habitat), 0.51–0.80 (Suitable Habitat), and 0.81–1.00 (Most Suitable Habitat). Based on this classification, the percentage of unsuitable, suitable, and most suitable habitat areas for the species was determined and presented in Table 5.

Tab 5. Habitat suitability modeling rate

Habitat suitability (rate)	**Current**	**Future SSP (2100-year)**		
		126	**370**	**585**
0.0-0.50	90,45%	91,98%	94,33%	96,87%
0.51-0.80	5,43%	4,83%	3,99%	2,47%
0.81-1.00	4,12%	3,19%	1,68%	0,66%
Total suitable	**9,55%**	**8,02%**	**5,67%**	**3,13%**

Evaluation of the habitat suitability degree table (Table 5) reveals that, under the current model, the combined proportion of suitable and most suitable habitats for the Andean bear is 9.55%. According to the Chelsa climate scenario for 2100 under SSP126, this proportion decreases to 8.02%. In the SSP370 scenario for 2100, the value further declines to 5.67%. Additionally, under the SSP585 scenario for 2100, the combined suitable and most suitable habitat for the species is reduced to 3.13%. Compared to the current model, analysis of the SSP585 climate scenario for 2100 indicates a reduction of approximately 67.3% in the total suitable habitat for the Andean bear. Consequently, it is projected that the distribution area of the Andean bear will diminish by the year 2100 across all climate scenarios.

Discussion

This study is the first to reveal the distribution of the Andean bear, which is distributed only in South America, in 2100 years using Chelsa climate data. Because other studies on the impact of climate change soon (2040 -2070-year range) are smaller scale and regional (Meza Mori et al., 2020; Cabezas et al., 2022; Huanca et al., 2022). In addition, it is thought that the Chelsa climate model results preferred in this study are more accurate and reliable than the general use of WorldClim climate data to reveal climate change. Morales-Barbero and Vega-Alvarez (2019) reported that the model made in Chelsa had a higher explanation margin in the study on the distribution of 14 different wild animal species. Moreover, although the modeling methods used in the studies revealing the effects of climate change on the Andean bear are the same (MaxEnt), the margin of error in this study has been minimized thanks to the statistical analyses performed before proceeding with the modeling. Although the modeling study was accurate and reliable (Training / Test ROC: 973 / 972), it was determined that the Andean bear habitat suitability maps for South America decreased significantly according to Chelsa's 2100 year and different climate scenarios. With this study, alarms were raised about the possible decrease in Andean bear habitats by 2100 year due to global climate change. Based on this, a scenario-oriented modeling was developed for the protection and management of Andean bear habitats.

A total of 39 digital base maps, 19 climate and 20 environmental, were produced for the Andean bear current model. As a result of statistical analyses, the modeling process was started with 24 base maps. Based on the principle of reaching the correct result with the least number of variables in the modeling studies, 4 different variable Andean bear current habitat suitability modeling and mapping were presented. For the current habitat suitability model of the Andean bear, Meza Mori et al. (2020) preferred 12 different variables, and Figueroa et al. (2016) preferred 8 different variables. No statistical analysis was performed between the environmental and climate variables created in these studies. Therefore, no information was found about these studies' training data set ROC and test data set ROC values (Figueroa et al., 2016; Meza Mori et al., 2020). The accuracy of the model results presented in this study was checked, and the training data set ROC: 973 and the test data set ROC: 972 values were in the "very good model" category. Based on this, the variable values of roughness, isothermality, elevation, and annual mean temperature, which contribute to the formation of the current potential distribution modeling of the Andean bear, were examined.

The roughness index is the variable that contributes most to the current habitat suitability model for the Andean bear, and it plays a key role in species distribution. It has been stated that the areas in which the Andean bear, which takes its name from the region where it lives, are distributed have relatively high roughness (Meybeck et al., 2001). Peyton (1999) suggested focusing on roughness and densely covered areas to conserve the Andean bear, whose future in South America is bleak. At the same time, the fact that human pressure is less in these areas than in other areas supports the idea that they provide shelter for Andean bear (Peyton et al., 1998). As a result, the roughness variable value results, which contribute the most to the current habitat suitability model of the Andean bear, are in the same direction as the literature. However, this study has shown that the environmental variable of roughness index should not be ignored in the species distribution in modeling studies to be conducted on the Andean bear.

It was determined that the isothermality variable contributed the most to the model after the ruggedness variable. Isothermality, that is, areas where the daytime and nighttime air temperature difference is 8 °C and 10 °C, positively affects bear distribution. Figueroa et al. (2016) found that the isothermality variable influences species distribution in their study aiming to model the distribution of Andean bears in Maranon dry forests. It was also emphasized that the isothermality variable (15%) was the second variable that contributed the most to the distribution modeling. Meza Mori et al., (2020), put forward many models in the study that aimed to determine the effects of climate change on the Andean bear. However, they found that isothermality was one of the variables that contributed least to the species distribution in at least three or more current models. Therefore, in the models put forward, it is stated that it prefers areas with isothermality close to the peak of 78 ^{0}C and 92 ^{0}C. Based on this, the areas where isothermality variable values, the difference in air temperatures during the day and night, were determined as these values. However, it is thought that it is almost impossible for this area to match the day and night difference values of air temperatures during the day to these values. Because in this study, modeling work was started without making real value conversions of bioclimate data. Therefore, the isothermality variable contributing to this modeling is in the same direction as the literature in that it is effective on the species.

According to the elevation variable contributing to the model, it was determined that the Andean bear has a high probability of existence in areas between approximately 1500 and 4200 meters. Cuesta et al. (2003), reported in their study on the habitat use of the Andean bear that the study area varied between 1600 and 4500 meters. Additionally, Andean bear habitat use was found to be related to elevation variability. Therefore, it has been stated that the protection and management plans of the Andean bear should focus on the protection of areas with a wide range of elevation differences (Yerena, 1993; Bennet, 1998; Yerena, 1993), rather than small and isolated areas. Ríos-Uzeda et al., (2006) found that climate change is a critical threat to the Andean bear, which generally prefers high elevation. Meza Mori et al. (2020) divided the present-day distribution of the Andean bear into three groups: “high”, “medium,” and “low” potential habitat. They found that only areas with an elevation of approximately 470–3700 meters were considered to have potential “high” habitat. As a result, the estimated elevation value is different from this study because the Andean bear habitat suitability model was presented in a smaller area. In this context, the elevation variable value results that are effective on the Andean bear distribution are consistent with the literature.

Areas where the annual mean temperature variable is between 4.35 °C and 19.35 °C, which contributes least to the current model of the Andean bear, have been found to have a high probability of the species existing. In a study aimed at determining the home range of the Andean bear, Castellanos (2011) stated that the annual average temperature of the area was approximately between 6 °C and 20 °C. Paisley and Garshelis (2006) stated that heat stress is a disadvantage to daily activity, especially for a large mammal with black fur. It has been found that this disadvantage occurs due to a decrease in activity depending on the daily or annual average temperatures and that in these cases bears generally spend time in forest areas. The results obtained show that monthly, daily or annual temperatures influence the Andean bear. As a result, no modeling study was found with the annual mean temperature variable contributing to the model. Therefore, this variable value and its results are of a nature to contribute to the literature.

In short, the results of the variable values of roughness index, isothermality and elevation on the Andean bear distribution, which is only distributed in South America, are consistent with the literature. Since there is no study based on the annual average temperature variable value, it will provide important contributions to the literature for the Andean bear. Therefore, temperature climate variables are expected to impact the feeding, breeding, and sheltering areas of the Andean bear, leading to temporal changes in these three factors. In South America, excessive increases in annual average temperatures or the difference between day and night temperatures will increase heat stress on the species. According to the model results obtained in this context, the Andean bear, which is sensitive to temperature variables, will narrow its current distribution. If this situation continues, it has been determined that the areas suitable for the species will decrease by approximately 67.3% in 2100 year.

Conclusion

In this study, a scenario-oriented modeling was presented for the Andean Bear to be affected at the least level by the changing climate conditions on a global scale. According to the modeling results, priority should be given to the habitats or regions specified in the habitat suitability maps so that the Andean Bear will be less affected by future climate change. In addition, before starting modeling studies to be carried out according to different years and scenarios, statistical analysis should be performed between variables that may show high correlation with each other and habitat suitability maps should be presented in this way. Habitat suitability maps play a crucial role in studies focused on species or habitat conservation within the broader context of biodiversity protection. Consequently, it is anticipated that the habitat suitability maps generated in this study, based on the projections for the year 2100 and the SSP126, SSP370, and SSP585 scenarios, will significantly influence researchers investigating the Andean bear species.

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