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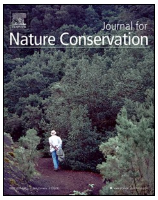

Predicting potential distribution and identifying priority areas for conservation of the Yellow-tailed Woolly Monkey (*Lagothrix flavicauda*) in Peru

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ABSTRACT

Species distribution models (SDMs) provide conservationist with spatial distributions estimations of priority species. *Lagothrix flavicauda* (Humboldt, 1812), commonly known as the Yellow-tailed Woolly Monkey, is one of the largest primates in the New World. This species is endemic to the montane forests of northern Peru, in the departments of Amazonas, San Martín, Huánuco, Junín, La Libertad, and Loreto at elevation from1,000 to 2,800 m. It is classified as "Critically Endangered" (CR) by the International Union for Conservation of Nature (IUCN) as well as by Peruvian legislation. Furthermore, it is listed in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Research on precise estimates of its potential distribution are scare. Therefore, in this study we modeled the potential distribution area of this species in Peru, the model was generated using the MaxEnt algorithm, along with 80 georeferenced occurrence records and 28 environmental variables. The total distribution (high, moderate, and low) for *L. flavicauda* is 29,383.3 km^2, having 3,480.7 km^2 as high potential distribution. In effect, 22.64 % (6,648.49 km^2) of the total distribution area of *L. flavicauda* is found within Natural Protected Areas (NPAs), with the following categories representing the largest areas of distribution: Protected Forests (1,620.41 km^2), Regional Conservation Areas (1,976.79 km^2), and Private Conservation Areas (1,166.55 km^2). After comparing the predicted distribution with the current NPAs system, we identified new priority areas for the conservation of the species. We, therefore, believe that this study will contribute significantly to the conservation of *L. flavicauda* in Peru.

1. Introduction

The Yellow-tailed Woolly Monkey, *Lagothrix flavicauda* (Humboldt, 1812), was first described over 200 years ago and believed extinct before being rediscovered in 1974. It is amongts the rarest and largest monkeys in the new world, but also one of the least studied (Leo, 1980; Mittermeier et al., 1977; Shanee, 2011). The fur of *L. flavicauda* is a deep mahogany color in both males and females. It has a dark grey pelage with a white patch, supraorbital hairs around its snout, and a gold-yellow patch on the genital region which is a principal distinctive feature (Serrano-Villavicencio et al., 2021). *L. flavicauda* is endemic to northern and central Peru along the eastern side of the Andean Cordillera (Serrano-Villavicencio et al., 2021). This area is considered a biodiversity hotspot of the Tropical Andes (Shanee, 2011). *L. flavicauda* has been recorded mainly between 1,400 and 2,800 m above sea level (m.a.s.l) in the departments of Amazonas, San Martín (Shanee, 2011), Loreto (Patterson & López, 2014), La Libertad (Parker & Barkley, 1981), Huánuco (Aquino et al., 2016; Shanee, 2011), and recently in the department of Junín (McHugh et al., 2019).

The Yellow-tailed Woolly Monkey's population is drastically

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declining mainly due to habitat loss and hunting pressure (Shanee & Shanee, 2014; Shanee & Shanee, 2015). It is currently estimated that its total available habitat has reduced by 82 % and its population size by as much as 93 % (Serrano-Villavicencio et al., 2021). The threats the species faces include habitat loss and fragmentation, hunting, logging (Aquino et al., 2017; Leo, 1980; Shanee & Shanee, 2014; Shanee, 2011), conversion of forest cover for cattle and crops (Aquino et al., 2015), and mining (Shanee & Shanee, 2014). In addition to this, *L. flavicauda* has a low reproductive rate, restricted range, and a potential large reduction of niche availability caused by climate change in Amazonas, San Martín, and Huánuco (Serrano-Villavicencio et al., 2021). For these reasons, the IUCN/SSC Primate Specialist Group (PSG) and the International Primatological Society (IPS), between 2008 and 2010, considered *L. flavicauda* to be one of the most endangered primate species in the world (Mittermeier et al., 2009). With a declining population trend, it is currently classified as "Critically Endangered" (CR) according to the A4cd criteria of the International Union for Conservation of Nature and Natural Resources (IUCN) Red List of Threatened Species (Shanee et al., 2021). It is also included in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES; UNEP-WCMC, 2021), categorized as a "Critically Endangered" species in Peruvian legislation (D.S. N° 004–2014-MINAGRI; MINAGRI, 2014), and included in the Red Book of Threatened Wild Fauna of Peru (SERFOR, 2018).

In the last 15 years, several efforts, using information available at the time, have been made to establish natural protected areas for the conservation of *L. flavicauda*, focusing on specific departments such as Amazonas and San Martín (Buckingham & Shanee, 2009; Shanee et al., 2007). Nevertheless, one of the challenges in complementing these conservation efforts is the identification and analysis of new areas of potential distribution. Species Distribution Models (SDMs) can help to determine the ecological requirements of specific species and predict their potential range based on ecology and biogeography (Zhang et al., 2019). SDMs are tools for mapping, monitoring, and predicting the potential distribution of wild flora and fauna (Miller, 2010), based on the presence data of a given species in combination with predictive environmental variables through statistical and cartographic procedures (Guisan & Zimmermann, 2000).

SDMs have been increasingly applied in different studies on wildlife distribution, for example, in large mammals such as *Helarctos malayanus* (Nazeri et al., 2012), *Cervus nippon*, *Capricornis crispus*, *Sus scrofa*, *Macaca fuscata*, *Ursus thibetanus* (Saito et al., 2014), *Tremarctos ornatus* (Meza et al., 2020), *Ailurus fulgens* (Su et al., 2021). Examples for primates include such as *L. flavicauda*, *Aotus miconax* and *Lagothrix cana* (Cotrina et al., 2022; Shanee, 2016). Although no algorithm is considered to be the "best" (Qiao et al., 2015), the most frequently used are bioclimatic modeling (BIOCLIM), domain environmental envelope (DOMAIN), ecological niche factor analysis (ENFA), Generalized Additive Model (GAM), genetic algorithm for rule-set production (GARP), and Maximum Entropy Model (MaxEnt). Nevertheless, MaxEnt modeling has been widely used because it performs well with either incomplete data or presence-only data (Zhang et al., 2019), demonstrating higher predictive accuracy, which together with its easy use and combination with geographic information systems, yields optimal and defensible results (Elith, et al., 2006; Meza et al., 2020; Nazeri et al., 2012; Pearson et al., 2007; Wisz et al., 2008).

The objectives of this study are to: (1) to use a Maximum Entropy (MaxEnt) approach to determine the current potential distribution of *L. flavicauda* and (2) to compare the predicted distribution with the current system of Natural Protected Areas (NPAs) to identify priority areas for the conservation of *L. flavicauda* in Peru.

2. Materials and methods

2.1. Study area

This study encompasses the entire territory of Peru (approximately 1,300,000 km^2) located between parallels 0°03′00′' and 18°30′0′' south, and meridians 68°30′00′' and 81°30′00′' west, sharing borders with Ecuador and Colombia to the north, Brazil to the east, Bolivia to the southeast, Chile to the south, and the Pacific Ocean to the west. The altitudinal gradient of this region starts from 0 m.a.s.l. in the north and reaches up to 6,800 m.a.s.l (Mataraju Mountain; Cotrina et al., 2021). The NPAs belong to the National System of Natural Areas Protected by the Peruvian State (SINANPE; SERNANP, 2022) and the categories present in the study area are National Reserve (NR), National Park (NP), Protected Forest (PF), Hunting Reserve (HR), Communal Reserve (CR), Landscape Reserve (LR), Historic Sanctuary (HS), National Sanctuary (NS), Wildlife Refuge (WR), Reserved Zone (RZ), Regional Conservation Areas (RCA), and Private Conservation Areas (PCA, Fig. 1).

2.2. Occurrence records of L. flavicauda

Georeferenced records (latitude/longitude) of sightings were obtained from six sources of information: (i) Population Distribution of Priority CITES Species of the Ministry of Environment (MINAM), available at: https://geoservidor.minam.gob.pe/recursos/intercambio-de-datos/; (ii) Global Biodiversity Information Facility (GBIF) platform, available at: https://www.gbif.org/, through QGIS Occurrences Plugin of QGIS version 3.16; (iii) surveillance reports from park rangers of the National Service of Natural Areas Protected by the Peruvian State (SERNANP); (iv) scientific publications, specifically McHugh et al. (2019); (v) reports from private researchers, obtained through personal communications; and finally, (vi) georeferenced sightings of the species obtained (observational method) during field expeditions in Berlin Forest PCA and Hierba Buena Allpayaku PCA.

Subsequently and having in mind that MaxEnt performs well compared to other commonly used techniques (Elith, Graham, et al., 2006; Wisz et al., 2008). However, it is sensitive to sampling biases (Anderson & Gonzalez, 2011; Phillips et al., 2009). Therefore, considering as a basis the reduction of inherent geographic biases associated with the collection data (Boria et al., 2014), and added to that considered in previous studies in mountainous areas with high geographic heterogeneity (Anderson & Raza, 2010; Pearson et al., 2007). Through filtering, we reduced from 136 to 80 occurrence records, following the following criteria that may affect model overfitting and correlations between variables, (i) records with insufficient identification, i.e., not identified to species level; (ii) elimination of records with species names not related to the species under study, and (iii) elimination of records with missing or duplicate coordinates (Gueta & Carmel, 2016). The final 80 occurrence records (Fig. 1), are located between the years 1974 to 2012. It is known that sample size influences the results of SDMs, and it is considered that no algorithm predicts consistently well with a small sample size: $n < 30$ (Wisz et al., 2008), and that once the sample size reaches a value of around 70, the reliability of the model becomes independent of sample size (Jiménez-Valverde et al., 2009). Given this, we consider 80 occurrence records for our sample size is acceptable.

2.3. Cartographic variables

In the present study, 28 mapping variables were used (Table 1), including 19 bioclimatic variables; three topographic variables (altitude, slope, and aspect); species requirements (tree cover, tree height, water source availability, and ecosystems), considering that the species is found in the premontane and montane forests of the eastern slopes of the Peruvian Andes, on steep slopes up to 60 %, trees with heights of 18–40 m, canopy and subcanopy, at heights of 8–15 m, and soil strata between 15 and 25 m above ground level 53 % of the time, > 25 m above ground level 32 % of the time, between 10 and 15 m above ground 12 % of the time, and only 3 % of their time below 10 m (Serrano-Villavicencio et al., 2021); and other environmental conditions (air humidity and solar radiation). Bioclimatic variables and solar radiation were obtained from the high spatial resolution global weather and climate

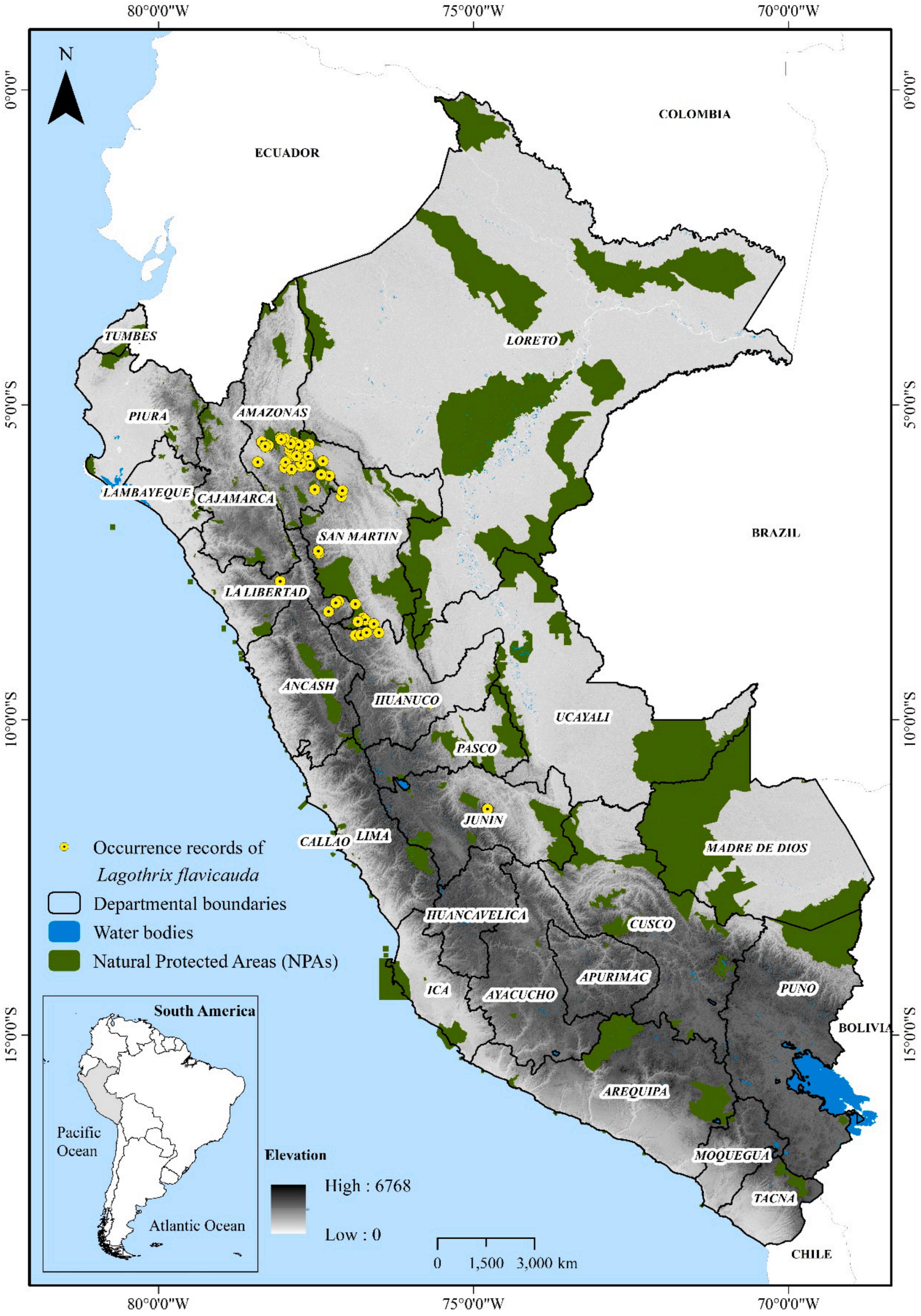

Fig. 1. Study area and occurrence records of *L. flavicauda.*

Table 1
Variables for MaxEnt modeling of *L. flavicauda* in Peru.

Variable	Units	Symbol
Bioclimatic		
Annual Mean Temperature	°C	bio_01
Mean Diurnal Range	°C	bio_02
Isothermality		bio_03
Temperature Seasonality	oC	bio_04
Max Temperature of Warmest Month	oC	bio_05
Min Temperature of Coldest Month	oC	bio_06
Annual Temperature Range	oC	bio_07
Mean Temperature of Wettest Quarter	oC	bio_08
Mean Temperature of Driest Quarter	oC	bio_09
Mean Temperature of Warmest Quarter	oC	bio_10
Mean Temperature of Coldest Quarter	oC	bio_11
Annual Precipitation	mm	bio_12
Precipitation of Wettest Month	mm	bio_13
Precipitation of Driest Month	mm	bio_14
Precipitation Seasonality	mm	bio_15
Precipitation of Wettest Quarter	mm	bio_16
Precipitation of Driest Quarter	mm	bio_17
Precipitation of Warmest Quarter	mm	bio_18
Precipitation of Coldest Quarter	mm	bio_19
Topographic		
Elevation above mean sea level	msnm	elevation
Slope of the terrain	%	slope
Cardinal orientation of the slope	–	aspect
Species requirements		
Tree cover	%	tree_cover
Tree height	m	dosel
Distance to water sources	m	water_d
Ecosystems	type	ecosystems
Other environmental variables		
Solar radiation	kJ m^{-2} day^{-1}	radiation
Relative humidity	%	humidity_r

database, WorldClim ver 2.1 (https://www.worldclim.org/; Fick & Hijmans, 2017), with a spatial resolution of 30 arcseconds (∼1 km), and bioclimatic information was used under current conditions (average 1970–2000). Topographic variables were derived from the 90-meter spatial resolution Digital Elevation Model (DEM) dataset downloaded from the EarthEnv-DEM90 portal (http://www.earthenv.org/DEM) sourced from CGIAR-CSI SRTM v4.1 and ASTER GDEM v2 data products (Robinson et al., 2014). Proximity to water was generated using the Euclidean distance algorithm (at 250 m of spatial resolution) from the water network described in the national charts of the National Geographic Institute (IGN) of Peru, available through the Ministry of Education (MINEDU, 2002). The tree cover variable PROBAV-LC100-v3.0.1, was downloaded from Copernicus Global Land Service: Land Cover 100 m: collection 3: epoch 2015: Globe (Buchhorn et al., 2020). Tree height was downloaded from Mapping global forest canopy height (Potapov et al., 2021) and the ecosystem layer was obtained from the geoserver of the Ministry of Environment of Peru (https://geoservidor.minam.gob.pe/recursos/intercambio-de-datos/). Finally, relative humidity was obtained from the surface climate dataset (New et al., 2002), and to standardize spatial data formats, we interpolated them using the ordinary Kriging method in ArcGis version 10.5, with semi-variogram models: gaussian, spherical and exponential (Varouchakis, 2019).

Together, all 28 variables had a spatial resolution of 30 arcseconds (approximately 1 km^2), which were converted to ASCII format to be used in the model.

2.4. Selection of environmental variables

In species distribution models, variables to be used are crucial, as some are biologically significant and others are of little importance if they are all incorporated into the model (Tanner et al., 2017). In that sense, to avoid overfitting the model, we used only the most informative variables (>1% contribution) selected using the permutation method implemented in the MaxEnt program (Martínez-Meyer et al., 2021; Phillips et al., 2006). Considering, that collinearity can lead within variables to problems of overfitting or ambiguous interpretation (Zhong et al., 2021), consequently, collinearity represents a minor problem than over-fitting or data uncertainty (De Marco & Nóbrega, 2018). Our final set included 14 variables (Table 2).

2.5. Building the model

We used MaxEnt 3.4.4 (Philips et al., 2021) to model the habitat suitability of *L. flavicauda* in the study area. Randomly selected, 75 % and 25 % of the georeferenced records were used for training and model validation, respectively. The algorithm was run using 10 replicates in 5,000 iterations with different random partitions, Bootstrap method, where the training data is selected by sampling with replacement from the occurrence points, with the number of samples equaling the total number of occurrence points (Phillips, 2017), a convergence threshold of 0.000001, and 10,000 maximum background points. Furthermore, we used the Jackknife method to measure the importance of variables in habitat mapping (Cotrina et al., 2021; Meza et al., 2020). The area under the curve (AUC) obtained from a ROC curve was used to evaluate our model (Phillips et al., 2006). The AUC is an effective autonomous threshold index capable of assessing the ability of a model to discriminate occurrence from absence (Gebrewahid et al., 2020). It is a model performance measure (Mohammad-Reza et al., 2018) that has been widely used in species distribution modeling (Elith et al., 2006; Saha et al., 2021). In general, the AUC should be between 0.5 and 1: when the AUC equals 0.5, model performance is equivalent to the pure guess; therefore, model performance is rated as failed (0.5–0.6), poor (0.6–0.7), fair (0.7–0.8), good (0.8–0.9) and excellent (0.9–1) (Manel et al., 2001; Phillips et al., 2006). The logistic output format was chosen to obtain the species model by generating a raster of continuous values in a range from 0 to 1. The obtained raster was reclassified into four ranges: (1) “high potential habitat” (>0.6), (2) ”moderate potential habitat” (0.4–0.6), (3) “low potential habitat” (0.2–0.4), and (4) ”no potential“ habitat (<0.2), considering previous studies (Cotrina et al., 2021; Cotrina et al., 2020; Gebrewahid et al., 2020; Mohammad-Reza et al., 2018; Saha et al., 2021; Yang et al., 2013; Zhang et al., 2019).

2.6. Identification of potential conservation areas

The identification of potential conservation areas is based on the intersection between the high potential distribution of *L. flavicuda* and the NPAs created in the Peruvian territory of national, regional, and private administration, obtained from the Geoserver (https://geo.sernanp.gob.pe/visorsernanp/) managed by SERNANP.

Table 2
Relative contributions (%) of environmental variables to the MaxEnt model of *L. flavicauda* in Peru.

Variable	Percent contribution	Permutation importance
ecosystems	31.7	1.3
elevation	25.5	22.6
bio_15	13	14.1
bio_6	6.8	38.2
bio_14	6	1.4
humidity_r	4.4	2.2
bio_10	4.4	1.5
dosel	2.5	0.2
water_d	1.6	1.4
tree_cover	1.4	0.5
bio_13	1.1	1.3
bio_3	0.6	1.3
bio_4	0.5	10.8
bio_18	0.4	3.2

3. Results

3.1. Model performance and importance of environmental variables

The model performance showed an area under the curve (AUC) value of 0.990 (Fig. 2a), considered excellent ($0.8 < \text{AUC} < 0.9$). The response curves (Fig. 2c-q) reflect the dependence of the predicted suitability on both the selected variable and the dependencies induced by the correlations between the selected variables and other variables.

3.2. Potential distribution of *L. flavicauda*

The distribution of *L. flavicauda* under current climatic and environmental conditions was identified predominantly in the northern and central lands of Peru along the eastern side of the Andean Cordillera, covering 29,383.28 km^2 (2.3 %) of the study area. This potential habitat distribution covers around eight departments of the Peruvian territory, distributed as follows: "high potential" habitat, 3,480.7 km^2 (0.3 %), "moderate potential" 8,007.3 km^2 (0.6 %), and "low potential", 17,895.2 km^2 (1.4 %). The IUCN map, however, shows that the resident distribution of *L. flavicauda* is 24,240.32 km^2 (Fig. 3) distributed in six departments of Peru (Amazonas, San Martín, Loreto, Cajamarca, La Libertad and Huánuco).

3.3. Priority areas for the conservation of *L. flavicauda*

The intersection between the potential distribution (Fig. 3) and the NPAs (Fig. 1) are considered priority areas for the conservation of the species under study within the scope of the NPAs (Fig. 4). It was identified that the total distribution of *L. flavicauda* covers 22.64 % (6,648.49 km^2) of the territory of the NPAs, with a high potential distribution of 1,258.59 km^2, a moderate potential distribution of 1,799.25 km^2, and finally a low potential distribution of 3,590.66 km^2. The potential distribution of *L. flavicauda* was located in PF: 1,620.41 km^2 (5.51 %), HR: 4.65 km^2 (0.02 %), NP: 839.85 km^2 (2.86 %), CR: 237.88 km^2 (0.81 %), NS: 443.67 km^2 (1.51 %), RZ: 363.34 km^2 (1.24 %), RCA: 1,976.79 km^2 (6.73 %) and in PCA: 1,166.55 km^2 (3.97 %) (Fig. 4; Table 3).

4. Discussion

4.1. Model performance and importance of environmental variables

Our model obtained an excellent predictive performance ($\text{AUC} > 0.9$). By evaluating model performance, we assess the accuracy of predictive models based on machine learning and ensure confidence in the results obtained (Cotrina et al., 2021). We selected 14 out of 28 environmental variables to model the potential distribution of *L. flavicauda*. In our model, 87.4 % of the potential distribution was driven by the variables of ecosystems (Yunga montane forests), elevation, precipitation seasonality (bio_15), min temperature of the coldest month (bio_06), precipitation of the driest month (bio_14), and the percentage of relative humidity. In terms of contribution and permutation, altitude (elevation above mean sea level) emerges as the most significant variable (percent contribution: 25.5 and permutation importance: 22.6), proving to be a determining factor in the distribution range, as you are only evaluating one species. This confirms elevation as one of the main characteristics of the species' habitat, with values recorded between 1,918 – 2,529 m.a.s.l. and steep slopes between 0 % and 60 % (Almeyda et al., 2019; Serrano-Villavicencio et al., 2021). On the other hand, although forest composition and especially the dominance of mature foraging trees for *L. flavicauda* seem to be major factors in determining habitat use; there is no clear influence of forest structure on habitat use by this species (Almeyda et al., 2019), which could explain the low values of contribution and permutation of canopy and tree height variables in our model.

SDMs are considered a set of numerical tools that combine observations of species occurrence with environmental variables to answer the relationship between a species and its environment (More et al., 2022); however, in theory, species SDMs are based on the realized niche concept, and some studies suggest that they do not fully inform on biotic interactions (Wisz et al., 2013). Large-scale species patterns are influenced by both abiotic predictors and biotic interaction variables (Zimmermann et al., 2010). Therefore, considering the potentially important implications of biotic interactions in shaping species distribution patterns, the application of spatially explicit modeling tools is considered challenging (Wisz et al., 2013). Considering the modeling of our study over a large geographic extent and with available data of coarse-grained, this limits the measurement of biotic interactions in detail (Araújo & Luoto, 2007; Schweiger et al., 2012). Therefore, the use of highly accurate observational data (GPS coordinates), and variables with a high spatial resolution (e.g., temperature, precipitation), which in turn will make our predictions of current and future distribution more accurate, will be required in the future for better accuracy in determining habitat categories (Graham et al., 2008; McPherson et al., 2006; Wisz et al., 2013).

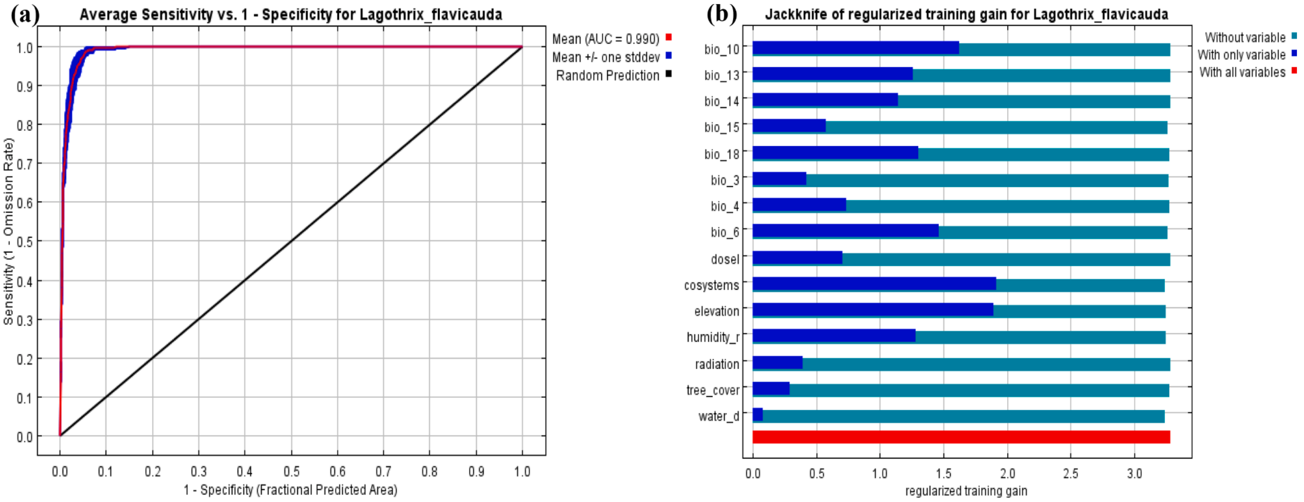

Fig. 2. Model performance based on the area under the curve (AUC) (a), Jackknife test of the significance of environmental variables for the MaxEnt model (b), and mean response curves of the 100 replicate MaxEnt runs (red) and standard deviation (blue) (c-p).

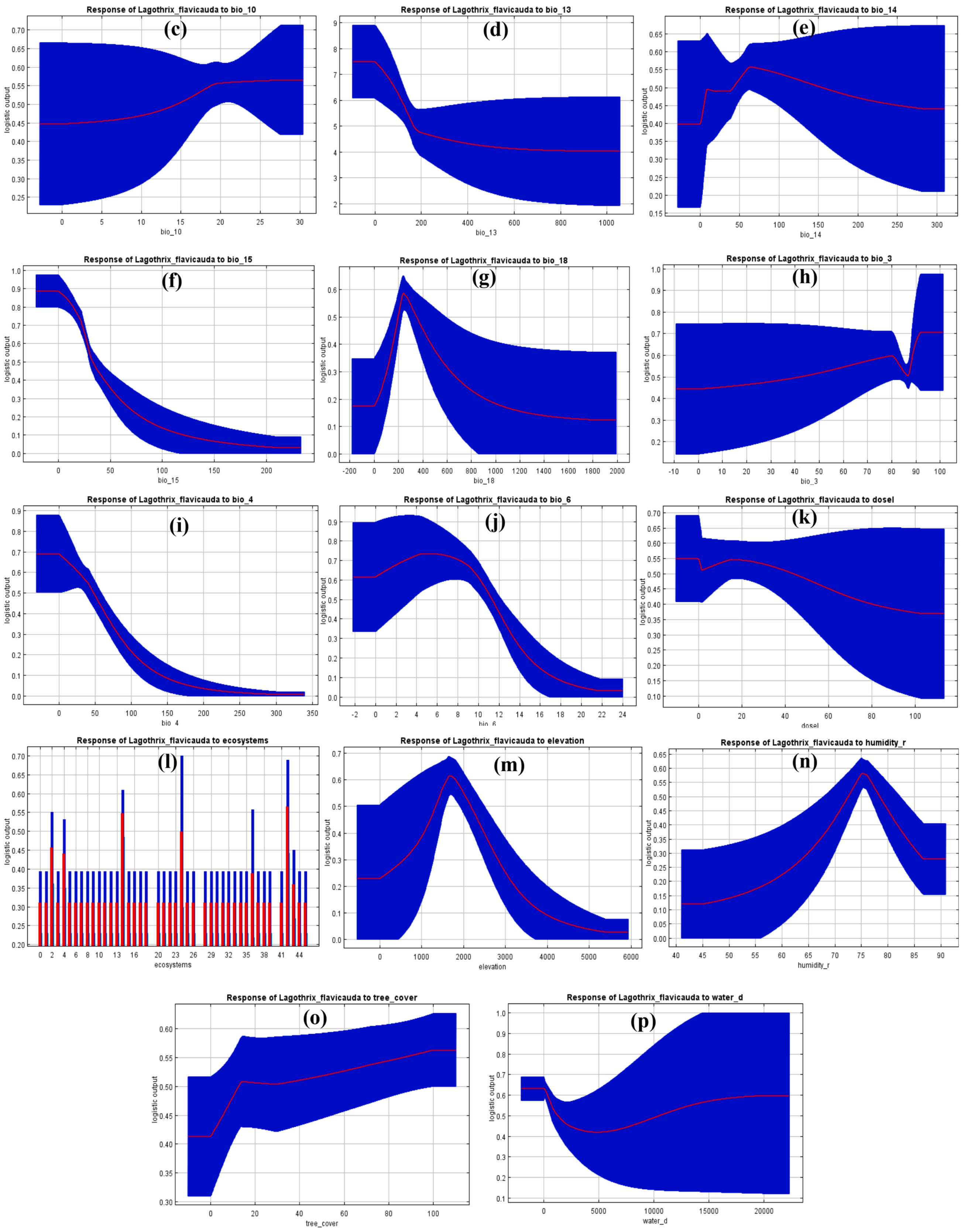

Fig. 2. (*continued*).

4.2. *Potential distribution of L. flavicauda*

Our study presents new information on the distribution of Yellow-tailed Woolly Monkey. Our distribution considers a “high potential” habitat of 3,480.7 km^2 for *L. flavicauda* under current climatic and environmental conditions, largely lower than the species’ original

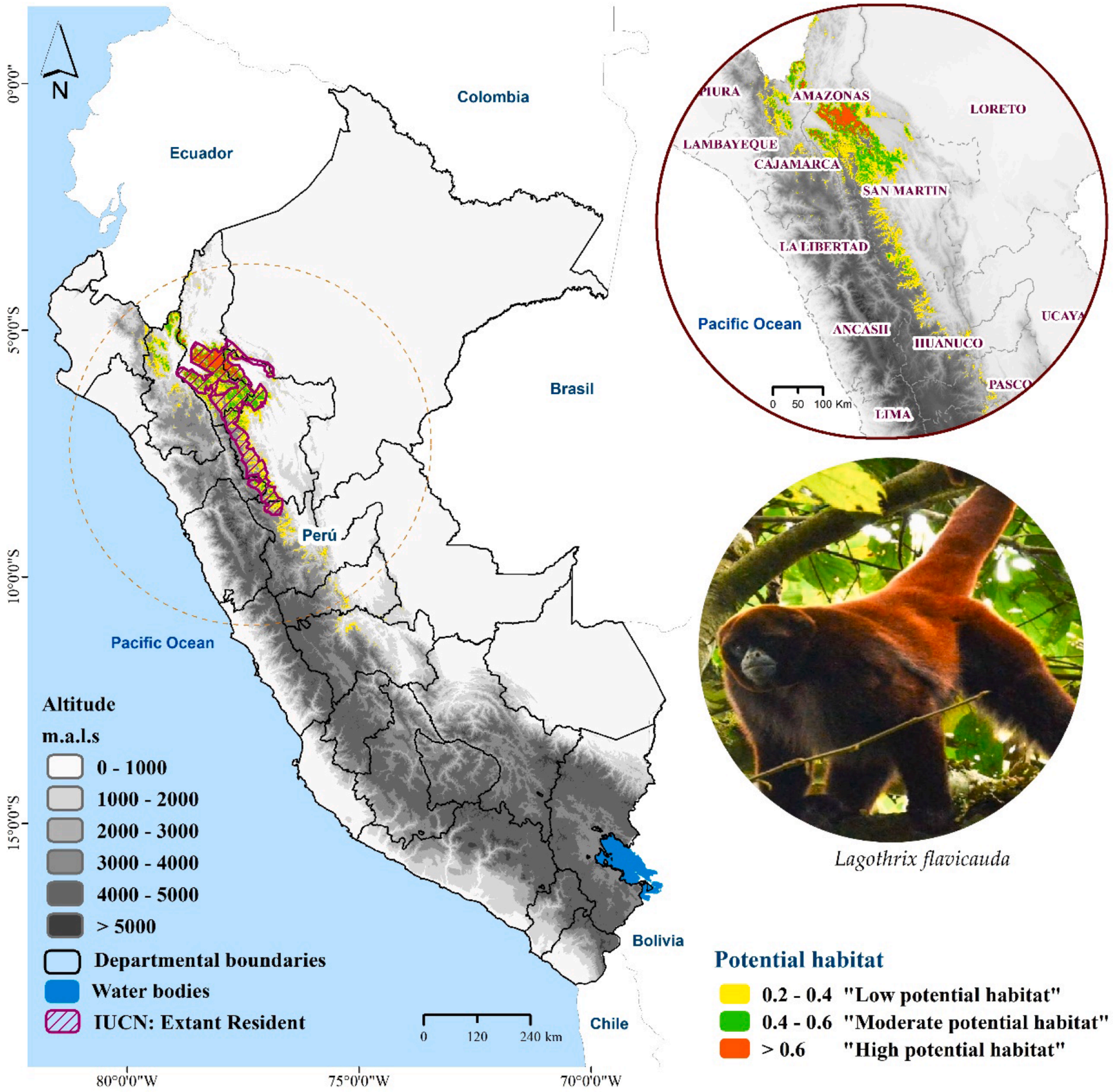

Fig. 3. Potential distribution of *L. flavicauda* in Peru.

national range previously estimated at 11,240 and 12,863 km^2 (Leo, 1980). It is even smaller than the area considered by Shanee, (2016), who estimated the current maximum extent of occurrence of the species at ~ 39,060 km^2, of which 22,460 km^2 were classified as good and 16,600 km^2 as very good. However, our distribution is close to the distribution reported by Cotrina et al., (2022), who considered a high potential distribution of 3,354.74 km^2 in the Peruvian territory.

Our study, along with research by Cotrina et al., (2022) and Shanee, (2016), constitute the first efforts to consider the use of SDMs as a probabilistic decision-making tool for this species, which allows the prediction and identification of geographical areas of potential habitat by using the Maximum Entropy modeling technique (Elith, et al., 2006; Soberón & Townsend Peterson, 2005).

L. flavicauda has been recorded from several localities since its rediscovery in 1970 (Mittermeier et al., 1977). In 2019, an *L. flavicauda* population was discovered in the department of Junín (Fig. 1), in the Inchatoshi Kametsha Conservation Concession, near Pampa Hermosa River, far south of the rest of the species' distribution (Serrano-Villavicencio et al., 2021). This may explain why our potential distribution model differs from the IUCN Extant (resident) range of the species by 5,143 km^2 south of the Peruvian territory. It could also be due to a difference in scales, considering that the IUCN classification is complicated by issues of spatial scale, i.e., the finer the scale at which the distributions or habitats of taxa are represented, the smaller the area occupied. Thus, the choice of scale at which range is estimated may influence the outcome of Red List assessments and could be a source of inconsistency and bias, and result in estimates that are more likely to exceed thresholds for the species' threat categories (UICN, 2012). However, our results agree with the IUCN in the distribution of *L. flavicauda* in the territories of San Martín, Amazonas, La Libertad, Huánuco, Pasco, and Loreto.

4.3. Priority areas for the conservation of L. flavicauda

Modeling the distribution of a species provides insight into its ecology, which has many applications in conservation, through the identification of areas with a higher probability of occurrence to guide future survey expeditions (Nazeri et al., 2012).

Peru's National System of State Protected Areas (SINANPE) considers a number and categories of protected areas, each with a different

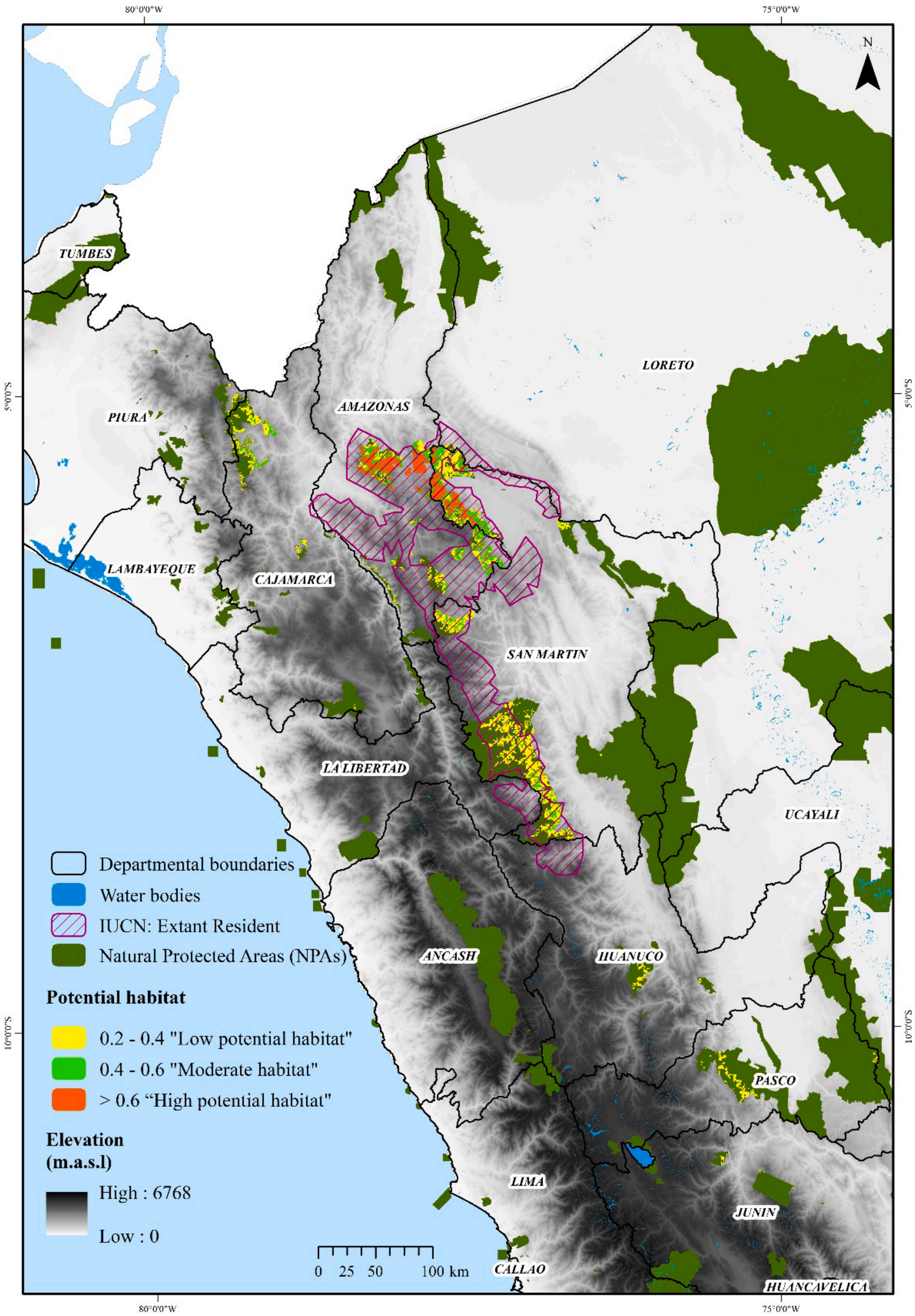

Fig. 4. Priority areas for conservation of *L. flavicauda*.

Table 3
Total potential area of distribution protected by the Natural Protected Area modalities in Peru.

Categories	Name	Low km^2	Moderate km^2	High km^2	Total	%
Protected forest	de Pui Pui	4.92	–	–		
	San Matias-San Carlos	12.94	–	–	1620.41	5.51
	Alto Mayo	531.83	562.43	508.29		
Hunting reserves	Sunchubamba	4.65	–	–	4.65	0.02
National Park	de Cutervo	33.90	3.52	–	839.85	2.86
	del Río Abiseo	604.04	18.65	–		
	Yanachaga-Chemillén	167.12	–	–		
	Cordillera Azul	4.23	–	–		
	Ichigkat Muja-Cordillera del Cóndor	2.07	–	–		
	Yanachaga-Chemillén	–	1.68	–		
Communal reserve	Yanesha	2.11	–	–	237.88	0.81
	El Sira	18.50	–	–		
	Tuntanain	3.37	–	–		
	Chayu Naín	47.78	78.28	87.83		
National Sanctuaries	Pampa Hermosa	16.91	–	–	443.67	1.51
	Tabaconas-Namballe	66.98	11.44	–		
	Cordillera de Colán	75.00	95.45	177.88		
Reserved Zones	Río Nieva	52.44	100.50	210.40	363.34	1.24
Regional Consevation Areas	Cordillera Escalera	61.04	13.23	–	1976.79	6.73
	Vista Alegre-Omia	145.46	277.61	31.26		
	Bosques Tropicales Estacionalmente Secos del Marañón	39.73	2.43	–		
	Bosques de Shunté y Mishollo	826.34	191.45	–		
	Bosque Montano de Carpish	83.04	–	–		
	Bosques El Chaupe, Cunia y Chinchiquilla	109.46	43.06	0.85		
	Paramos y Bosques Montanos de Jaén y Tabaconas	63.64	67.40	15.31		
	Codo del Pozuzo	5.48	–	–		
Private Conservation Areas	Paraje Capiro Llaylla	1.07	–	–	1166.55	3.97
	Bosques Montanos y Páramos Chicuate - Chinguelas	36.15	–	–		
	San Pedro de Chuquibamba	0.85	–	–		
	Llamapampa - La Jalca	100.98	32.23			
	Cavernas de Leo	0.12	–	–		
	La Pampa del Burro	–	0.62	27.15		
	Bosque Berlín	–	–	0.59		
	Los Chilchos	240.39	98.68	–		
	Bosque de Palmeras de la Comunidad Campesina Taulia Molinopampa	40.30	65.43	0.87		
	Huaylla Belén - Colcamar	16.18	7.63	–		
	Milpuj - La Heredad	0.13	–	–		
	Copallín	25.75	24.15	51.37		
	San Marcos	0.49	–	–		
	Hierba Buena - Allpayacu	3.26	12.72	6.84		
	Tilacancha	9.25	–	–		
	La Niebla Forest	0.47	–	–		
	Arroyo Negro	1.03	0.52	0.01		
	Comunal San Pablo - Catarata Gocta	12.26	13.37	0.41		
	Páramos y Bosques Montanos, Paraíso de la Comunidad Campesina San Felipe	5.10	–	–		
	Copal Cuilungo	0.27	5.27	20.20		
	Páramos y Bosques Montanos San Miguel de Tabaconas	62.99	28.45	5.30		
	Monte Puyo (Bosque de Nubes)	14.89	41.08	99.93		
	Páramos y Bosques Montanos de la Comunidad Campesina San Juan de Sallique	15.33	1.92	–		
	Bosques Montanos y Páramos de Huaricancha	12.41	–	–		
	Abra Patricia - Alto Nieva	–	0.06	14.09		
	San Antonio	3.57	–	–		
	Huiquilla	4.41	–	–		
Total		3590.66	1799.25	1258.59	6648.49	22.64

level of protection (Table 3). These protected areas cover a total potential distribution area of *L. flavicauda* of 6,648.49 km^2, which represents only 22.64 % of the total potential distribution area, of which the high potential represents only 4.28 % (1,258.59 km^2). These figures confirm that, the current network of protected areas is insufficient to conserve the current suitable habitat for *L. flavicauda*. Protected areas are an efficient tool for conserving forests; however, deforestation occurs on a smaller scale than outside their boundaries (Buckingham & Shanee, 2009). In this sense, we recommend increasing the size and effectiveness of the current network of NPAs, considering the connectivity between them based on this type of study as a criterion when choosing new sites for the creation of new natural protected areas, and complementary strategies, such as reforestation, environmental education and community management with the population involved in the work of conservation and protection of *L. flavicauda*.

Primate dominance, abundance, and distribution for most species are mainly associated with habitat alteration and loss due to deforestation for agriculture, livestock, and extraction of timber and other forest resources (Aquino et al., 2017). IUCN considers these activities to be the main threats to the world's primates, and they are responsible for 36 % of the species inhabiting the Neotropics being threatened and their populations declining by 63 % (Estrada et al., 2017). Estimates using predictions of future climate change suggest a further 7 % reduction in habitat availability for *L. flavicauda* over the next 50 years (Serrano-Villavicencio et al., 2021; Shanee, 2016).

However, considering the 24 Private Conservation Areas where there is a high potential distribution for *L. flavicauda* (Table 3) we agree with Shanee, (2016) and Shanee et al., (2015) that a large number of private and communal protected areas makes these mechanisms extremely important for the survival of the species, especially in areas with higher human population density. This is because *L. flavicauda* can survive in highly disturbed habitats but only temporarily (Serrano-Villavicencio et al., 2021).

To effectively conserve *L. flavicauda*, we strongly recommend intensive conservation of the high potential habitat areas identified by our model as well as the areas on the IUCN map inhabited by this species. Ultimately, our model provides knowledge of the potential distribution of the species for a better understanding of the habitat preferences of the yellow-tailed woolly monkey in Peru; it also offers a basis for the formulation of policies such as the national conservation plan for the species.

5. Conclusion

The current potential distribution of *L. flavicauda* using MaxEnt covers 29,383.28 km^2, accounting for 2.3 % of Peruvian territory, distributed in eight departments, Amazonas, San Martín, Loreto, Cajamarca, La Libertad, Huánuco, Pasco and Junín. This study provides an opening step in the identification of the core habitats for the conservation of yellow-tailed woolly monkey. The NPAs of SINANPE play a fundamental role for the conservation of 22.64 % (6,648.49 km^2) of the total potential distribution areas of the species, as a result of various conservation initiatives at both the individual and community levels. Nevertheless, these initiatives are largely insufficient to achieve effective protection of the species.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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