ROLE OF A CAMPESINE RESERVE ZONE IN THE MAGDALENA VALLEY (COLOMBIA) IN THE CONSERVATION OF ENDANGERED TROPICAL RAINFORESTS

Natalia Trujillo-Arias[1,2,*], Víctor H. Serrano-Cardozo[1], Martha P. Ramírez-Pinilla[1]

[1]*Universidad Industrial de Santander, Colombia*
[2]*Instituto de Investigación en Recursos Biológicos Alexander von Humboldt, Colombia*
**e-mail: natitrujillo@gmail.com*

Received: 15.02.2022. Revised: 14.09.2022. Accepted: 17.09.2022.

Tropical forests of Colombia have one of the highest deforestation rates in the world. The humid forest of the Magdalena valley region is one of the ecosystems with the highest risk of landscape transformation, despite being home to many endemic and threatened species. The aim of this study was to evaluate the role of a Peasant Reserve Zone in the conservation of tropical humid forests and endangered species in the Magdalena valley region. To reach this aim, we performed a multi-temporal analysis of the forest dynamics in the Peasant Reserve Zone-Cimitarra River Valley (PRZ-CRV) and assessed the extinction risk of eight species endemic to Colombia. Our outcomes indicated that the most extended land cover in the PRZ-CRV is the forest (56.30%), followed by open areas (38.75%). The forest dynamics analysis indicated that the forest cover has decreased by 3.82% between 2017 and 2019, being the area with redoubts from the Serranía de San Lucas Forest the most conserved. Finally, our results indicated that less than 50% of the climatically suitable areas for each species are covered by forests and that less than 10% of those areas are covered by Protected Areas, while for such species as *Agalychnis terranova* and *Ateles hybridus* the PRZ-CRV covered a higher percentage of their distribution than all Protected Areas together in this ecosystem. In conclusion, our results have indicated that the PRZ-CRV could be an important area for the maintenance and conservation of humid forests and their associated fauna, playing an important role as an ally to the Protected Area system in the Magdalena valley region.

Key words: Andes, forest loss, land cover, Peasant Reserve Zone, threatened species

Introduction

Deforestation is increasing in the tropics with severe implications for biodiversity conservation, climate regulation, and maintenance of ecosystem services (Etter et al., 2006; Da Ponte et al., 2017; Negret et al., 2019). Deforestation of tropical forests is responsible for the massive extinction of species (Myers, 1988; Pimm et al., 1995) and the decrease in biological diversity (Tucker & Townshend, 2000; Marsh et al., 2016), more than half of the species of plants and animals being housed in this biome type (Gallery, 2014), being of great interest for knowing the current extent of tropical forests and their deforestation rates (Tucker & Townshend, 2000).

The highland and lowland tropical forests of Colombia have one of the highest deforestation rates, with clearing accelerating to 1.4% annually during the second half of XX century (Etter et al., 2006, 2008; Armenteras et al., 2011). Specifically, the tropical humid forest of the Magdalena Valley Region (MVR) is one of the ecosystems with the highest risk of landscape transformation (Etter et al., 2006) and is one of the areas where clearing of highland and lowland forests has been documented (Etter & van Wyngaarden, 2000; Negret et al., 2019). These forests are home to a large number of endemic species, many of them being threatened (e.g. *Sachatamia punctulata* (Ruiz-Carranza & Lynch, 1995), *Crax alberti* Fraser, 1852, *Ateles hybridus* I. Geoffroy, 1829) (Cuervo Maya et al., 1999; Rojas-Morales et al., 2014; Marsh et al., 2016) and also are important as a potential bridge between populations of fauna and flora from biodiverse hotspots such as the Choco, Central America and Guyana Amazon regions (Chapman, 1917; Echeverry & Morrone, 2013).

The MVR is a critical priority area to conserve according to various national and international organisations, such as the Instituto Alexander von Humboldt and World Wildlife Fund (Sanchez-Cuervo & Aide, 2013; Quintero-Vallejo et al., 2017). Despite this, the region is underrepresented in the national system of Protected Areas (PAs) (Forero-Medina & Joppa, 2010; Sanchez-Cuervo & Aide, 2013) and its threats (such as illicit crops, glyphosate fumigation, un-controlled deforestation for timber and hunting, mining activities and armed conflict) have intensified in the last decades (Álvarez, 2002; Armenteras et al., 2011; Dávalos et al., 2011; Sanchez-Cuervo & Aide, 2013; Chadid et al., 2015; Murillo-Sandoval et al., 2020). In order to diminish these threats, the Colombian government has declared some important natural areas as Peasant Reserve Zones (PRZs) where, according to law the expansion of the agricultural frontier must be controlled to improve the human well-being and assure ecosystem and biodiversity conservation (Quintero-Vallejo et al., 2017; Tocancipá Falla & Ramírez Castrillón, 2018).

The PRZs are found throughout Colombia, and depending on their size and location, many constitute areas of great importance for the conservation of tropical forests and endangered species. The PRZ of the Cimitarra River Valley (PRZ-CRV) (Asociación campesina del valle del rio Cimitarra, 2008) located in the Middle Magdalena valley (Fig. 1a), comprises a total area of ~ 5800 km^2 that contains a peasant area (~ 2670 km^2) and a forest reserve (~ 3130 km^2) (Quijano-Mejía & Linares-García, 2017) (Fig. 1b). This PRZ is one of the largest in the country, and because it contains humid forests, among them forests of the San Lucas Mountain Range (Serranía de San Lucas), which is one of the most diverse and unprotected areas of the country, the PRZ-CRV could be a key component for the maintenance and conservation of biodiversity in the region. The aim of this study was to evaluate the role of the PRZ-CRV in the conservation of tropical humid forests and endangered species in the MVR. For reaching this goal, we have performed a multi-temporal analysis of the forest dynamics in the PRZ-CRV using Sentinel images. Additionally, we have assessed the potential extinction risk of eight species endemic to Colombia and distributed in the MVR employing species distribution models.

Material and Methods

Study area

The Middle Magdalena Valley (MMV) is located between the central and western cordilleras (Central and Eastern Cordillera) of Colombia, and it is part of the Magdalena-Urabá ecoregion (Olson et al., 2001). The MMV includes various types of habitats. Among them are premontane wet forests and tropical moist forests that span an altitudinal gradient of 0–2500 m a.s.l. These forests link the northern ecoregions of Mesoamerica and the Chocó with the Andean and Amazonian ecoregions (Echeverry & Morrone, 2013). There are no national parks in the region (Forero-Medina & Joppa, 2010), but several areas of intact habitat remain, e.g. San Lucas Mountain Range. These areas are under pressure from high populations of humans and are threatened by timber operations, cattle ranching, and illicit drug cultivation (Etter et al., 2006). The PRZ-CRV is located in the Middle Magdalena Valley by covering a part of the Antioquia and Bolivar departments (provinces) (Fig. 1a). This PRZ comprises a total area of ~ 5800 km^2. It is distributed in i) peasant area (~ 2670 km^2), where the peasants mainly carry out their productive activities (e.g. agricultural and cattle raising activities) and ii) forest reserve (~ 3130 km^2), where the peasants themselves demarcated an area around the redoubts of forests of the San Lucas Mountain Range, known as «yellow line», to restrict the colonisation advance; i.e. it is prohibited any type of intervention on the fauna and flora (Fig. 1b).

Multi-temporal analysis of forest dynamics in the PRZ-CRV

Land cover classification for the 2019

In this study, Sentinel 2 image data were acquired between the reference years of 2017 to 2019. Four tiles were needed to cover the entire extent of the PRZ-CRV. A total of 116 images with less than 40% cloud cover were obtained from the Copernicus Open Access Hub (https://scihub.copernicus.eu/) (Table A1). Atmospheric correction was performed to Level-1C images using Sen2Cor (v. 2.5.5), which converts the top-of-atmosphere reflectance Level-1C data to a bottom-of-atmosphere (BOA) reflectance Level-2A product (Müller-Wilm, 2016). Individual satellite images were merged using Sen2Mosaic (v. 0.2) to create a continuous and cloud-free coverage across the study area. A mosaicking process consisted of systematically selecting the most similar and cloud-free pixels across each time period. Only for the year 2019, it was possible to obtain a cloud-free image. For other years, the images had about 2% cloud cover. After atmospheric correction, the bands 5, 6, 7, 11 and 12 were re-sampled at a 20-m spatial resolution and georeferenced to the Transverse Mercator projection, Bogota Observatory Datum. Finally, the images were cut to the study area (PRZ-CRV). All processing of multispectral images was carried out using ESRI ArcGIS and Python scripts.

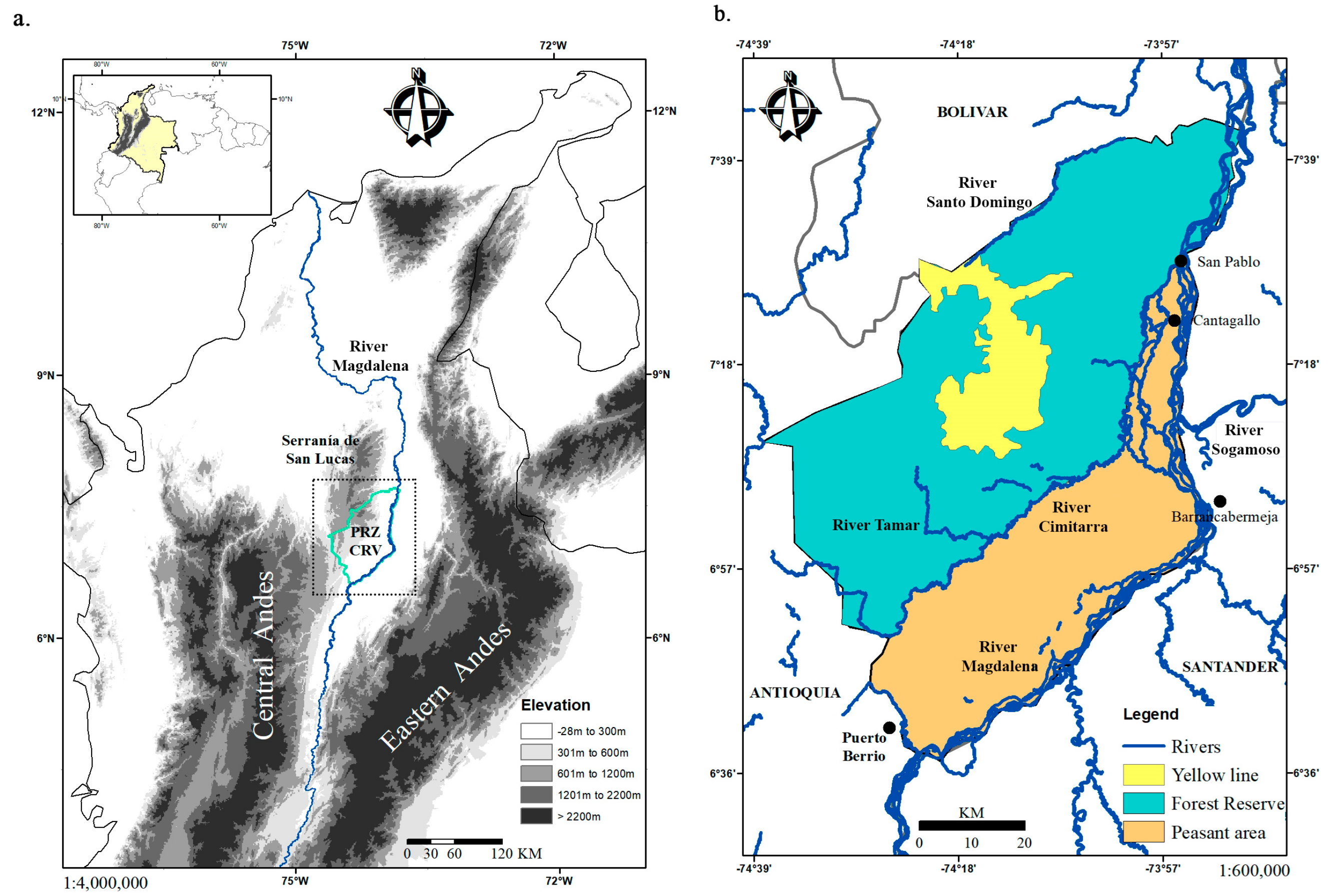

Fig. 1. The location of the Magdalena region in the northern Andes, showing the Magdalena River, the San Lucas Mountain Range and the Peasant Reserve Zone of the Cimitarra river Valley (PRZ-CRV) (a.). Map of the Peasant Reserve Zone of the Cimitarra river Valley, showing the forest reserve area, the peasant area and the area delimited as «Yellow line» (b.).

We classified the study area into five land cover categories, namely forest (a), open areas (b), rivers (c), wetlands (d), other covers (e). «Forest» areas correspond to primary and secondary vegetation grouped as a single natural land use. The «open areas» designation was used to identify pastures, crops and grasslands for cattle ranching and farming. «Other cover» was represented by urban areas, sands, and small dense clouds. For each land cover, a minimum of 15 training polygons were targeted between 45-pixels and 100-pixels using ground truth data collected during a field trip in 2019, as well as on the basis of very high-resolution (VHR) imagery in GoogleEarth®. Finally, to determine and quantify the land cover of each category, we first tested the performance of three non-parametric classifier algorithms Support Vector Machines (Cortes & Vapnik, 1995), Neural Network (Yoshida & Omatu, 1994) and Random Forest (Breiman, 2001) using «svm» (Becker et al., 2009), «nnet» (Venables & Ripley, 2002), «randomForest» (Liaw & Wiener, 2002) and «caret» (Kuhn, 2008) packages in R version 4.0.2 (R Core Team, 2020). For this purpose, a dataset from the previously targeted polygons was employed to train the model and another independent dataset was used to test the model. After this, we assessed the three algorithms based on the confusion matrices, accuracy statistics, such as accuracy, Kappa, Sensibility and Specificity (Olofsson et al., 2013; Foody, 2020). In addition, based on the Bonferroni test, we assessed whether there were significant differences between the performance of the algorithms (p-value < 0.05). After those analyses, we selected «random forest» as the best method to perform the final land cover classification due to its bigger accuracy with smaller intervals (Fig. A1), greater values of Sensibility and Specificity for almost all categories (values > 0.98) (only the wetland category was 0.83, but much higher than for the other two algorithms (0.55 or 0.76)), and because the differences between this algorithm with the other two were significant.

Forest dynamic analysis (2017–2019)

To analyse the forest dynamics between 2017 and 2019, we compared the estimated cover area of each category between years. For this purpose, we used «random forest» and the same training polygons for all land cover types employed for the

2019 classification (those polygons were designed on constant areas through the three years). The exception was for «wetlands» and «other covers», because these land covers were highly dynamic through space and time. Specifically, to quantify the area of the forest cover that has been lost from 2017 to 2019, we followed Chadid et al. (2015). We did not consider for the land cover quantification areas where there was presence of clouds in any of the analysed years to avoid under- or overestimations of the forest loss. The total area covered by clouds was 2%. Finally, we quantified in square kilometres (km^2) the lost forest area and generated a forest dynamic map by identifying areas, where the forest had been conserved through years, as well as the areas where have occurred deforestation or forest recover events using the classification images and ESRI ArcGIS.

Extinction risk: Species distribution models and gap analysis

For the extinction risk analysis, we selected eight species endemics (or near endemics) to Colombia distributed in the MVR. They are under threat (or near threat) according to the IUCN: three amphibians (*Sachatamia punctulata* (Ruíz-Carranza & Lynch, 1995) (Vulnerable, VU), *Diasporus anthrax* (Lynch, 2001) (VU), and *Agalychnis terranova* Rivera-Correa, Duarte-Cubides, Rueda-Almonacid & Daza-R., 2013 (Near Threatened, NT)), three birds (*Crax alberti* (Critically Endangered, CR), *Capito hypoleucus* Salvin, 1897 (VU) and *Habia gutturalis* (Sclater, 1854) (Least Concern, LC, but this species was assessed as NT in 2017)), and two primate species (*Saguinus leucopus* (Günther, 1877) (VU), and *Ateles hybridus* (CR)). These species were selected based on their ecological characteristics, such as low vagility, dependence on forest, and sensitivity to changes in vegetation cover, which makes them excellent models to evaluate the dynamics of the forests and its consequences on the fauna of the region.

We modelled the climatic distribution of the eight species using MaxEnt (Phillips et al., 2006). We used MaxEnt because it performs well, compared to other modelling approaches (Elith et al., 2006). We compiled occurrence records from: i) national biological collections (e.g. Universidad Industrial de Santander (UIS), SiB Colombia), ii) Global Biodiversity Information Facility (GBIF) (www.gbif.org), and iii) scientific articles (e.g. Cuervo Maya et al., 1999; Salaman et al., 2002; Laverde-R et al., 2005; Ochoa-Quintero et al., 2005; Rojas-Morales et al., 2014). To reduce the spatial autocorrelation, for each species we randomly removed duplicate occurrence records that were less than 1 km apart from each other. The database has been resulted in a final dataset of 13–98 presence records (see number of occurrences by species in Table A2).

For MaxEnt analyses, we used 19 climate variables available at WordClim 1.4 (Hijmans et al., 2005) with a resolution of 30 arc sec. For the final analysis, we selected the climatic variables by first rejecting highly correlated variables ($r > 0.85$) (Peterson et al., 2011), and then by selecting relevant variables by a rationale of permutation importance > 5% (Trujillo-Arias et al., 2017). The general conditions for analyses were random test points = 20; replicates = 10; replicate type: subsample; maximum iterations = 5000; background points = default (max: 10 000). For species with less than 50 occurrences, we used the bootstrap replicate type. We did not use bias file because the background manipulation usually results in higher commission errors (Kramer-Schadt et al., 2013). We validated models by evaluating AUC values (Pearson et al., 2007) and the True Skill Statistic (TSS) (Allouche et al., 2006) (see examples of receiver operating characteristic curves in Fig. A2). Then, we projected the species distribution models to the future (year 2050) using three emission models of Representative Concentration Paths 4.5 (RCP 4.5). They represent a conservative scenario of greenhouse emissions (van Vuuren et al., 2011), namely 1) HadGEM2-ES predicting a high temperature increase and a reduction in precipitation (i.e. hotter / drier scenario) (Jones et al., 2011); 2) GISS-E2-R predicting a moderate increase in temperature and rates of relatively constant precipitation (i.e. moderate scenario) (Schmidt et al., 2014); 3) IPSL-CM5a-LR predicting warm temperatures and reduced precipitation (i.e. warmer / drier scenario) (Dufresne et al., 2013). Models were generated in ASCII format and exported directly to the GIS to obtain binary maps using the threshold of equally training sensitivity and specificity. For this purpose, all pixels with a value under that threshold were assigned a value of zero (0), which would represent the absence of the species.

Finally, we estimated habitats for the present and the habitat loss between the future and present for each species employing two measures. First is the currently available habitat based on climate and forest cover. This estimation was based on determining how much (in km^2) of the climatically suitable area according to MaxEnt models is covered with forest. For this purpose, we employed the binary maps for the present period and the layer of forest cover for 2019 produced by the Instituto de Hidrología, Meteorología y Estudios Ambientales de Colombia (IDEAM). Basically, using GIS tools, we overlapped the forest layer over the climatically suitable area for each species, and we quantified how much of that climatic area is actually covered by forests. This measure allows us to have a quantification of the available area in the present, not only based on climate, but also on forest cover in the region. The second measure is the potential future habitat change (in km^2). This estimate was based on comparing the climatically suitable areas indicated by the MaxEnt models for the present and the future. Specifically, from the binary maps, we quantified the climatically suitable area for each species in each period and made a description of whether its area, based on climate, increases or decreases. This measure allows us to know how much and what type of change (expansion or contraction) the species might face according to various future climate scenarios. In addition, we also evaluated how much of the range of each species is covered by PAs employing gap analysis, as a methodological tool frequently used in conservation to identify «gaps» in the network of PAs. For this purpose, we considered the National Protected Areas (PNN), Forest Reserves (comprised of public and private areas), and the Natural Reserves of Civil Society. We also calculated how much of the current distribution of each species is found within the current distribution covered by the PRZ-CRV.

Results

Land cover and forest dynamics

In general, classification accuracies obtained from Sentinel images in 2017–2019 fluctuated from 96% to 99%, with kappa coefficients ranging from 0.96 to 0.98. The 2019 classification indicated that the land covers with the highest percentage of area were forest with 56.30% (3307.18 km^2), followed by open areas with 38.75% (2276.25 km^2), while the other land covers received percentages lower than 3% (rivers: 2.83% (166 km^2), wetlands: 1.77% (103.96 km^2), and other covers: 0.31% (18.21 km^2) (Fig. 2a).

The forest dynamics map for 2017–2019 indicated that the forest cover in the PRZ-CRV decreased by 3.82%, while the open areas increased by 3.5% (Table 1). This estimation was compared with values of the forest cover loss obtained on the global forest watch platform (https://www.globalforestwatch.org/), by finding a slightly higher loss (4.1%). This difference may be related to areas, which were not quantified in our analysis due to the presence of clouds. Finally, the forest dynamics map (Fig. 2b) has identified that the conserved forest areas (without change) were located west of the PRZ-CRV, mainly in the area defined as «yellow line» characterised by presenting redoubts of forests of the San Lucas Mountain Range. Areas with the greatest loss of the forest were distributed around the «yellow line», both to the north and to the south, with some spotlights of deforestation within this area or very close to its limits. This analysis also allowed us to observe some areas of forest restoration, which are mainly concentrated east of the study area, a region characterised by wetlands.

Species distribution models and gap analysis

The species distribution models for the eight species have been performed better than a random model with AUC and TSS values greater than 0.83 (Fig. A3). Specifically, the species distribution models for the present period were consistent with the distribution range of each species. However, for some species such as *Diasporus anthrax* and *Capito hypoleucus*, the models also indicated other areas outside the distribution range as climatically viable areas for their distribution (e.g. the Pacific or the southeast of the Colombian Amazon) (see Fig. A3). However, although for some species the climatic niche for the present period (i.e. fundamental niche) was a little larger than the known (i.e. realised) niche, the estimations of the currently available habitat indicated for most of the species, that less than 50% of their climatic suitable areas are covered by forests suggesting that in fact its optimal distribution area is smaller (Table 2a). For instance, for *D. anthrax* and *Crax alberti* only 33% and 36% of their distributions were covered by forests, respectively. Other species, such as *Agalychnis terranova*, showed a higher forest cover along their distributions (59%). For the potential future habitat change measure, the ecological niche models suggested variable responses among the species and the climatic scenarios (Table 2b). However, in most species (except for *C. hypoleucus* and *Habia gutturalis*) a contraction of their distribution range is observed for the hotter / drier scenario (HadGEM2-ES). For other scenarios (GISS-E2-R and IPSL-CM5a-LR), the response was highly variable, with some species showing the range expansion, while others showed contraction. It should be noted that these results should be taken with caution considering the small number of records used to model the distribution of some species (e.g. amphibians).

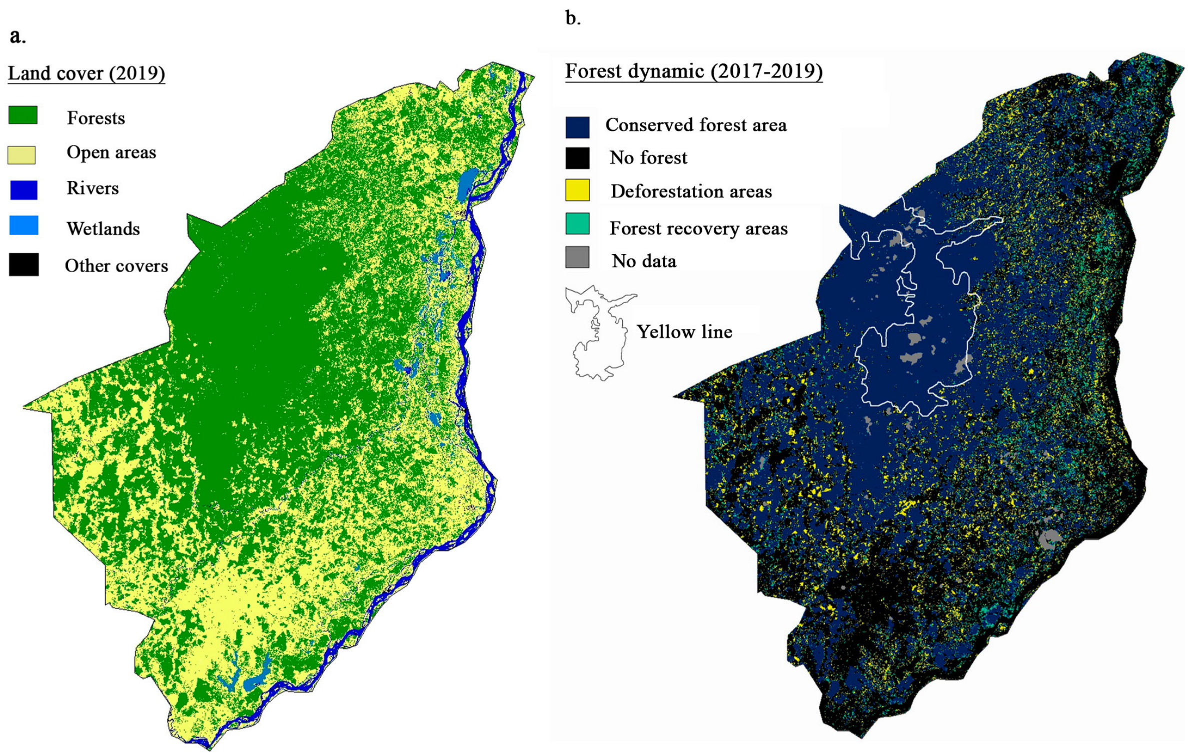

Fig. 2. Land cover classification for the year 2019 using the Random Forest algorithm (a.); designations: «Forest» corresponds to primary and secondary vegetation grouped as single natural land use. «Open areas» represents pastures, crops and grasslands for cattle ranching and farming. «Other covers» represents urban areas, sand, and small clouds. Forest dynamics in the PRZ-CRV in 2017–2019 (b.); designations: the blue and black colours represent forest areas and open areas respectively, which have not changed during the study time; the yellow and light blue colours identify areas where the land cover has changed because of the loss of forest (deforestation areas) or because of restoration of the vegetation cover (forest recovery areas).

Table 1. Changes in land cover at the Peasant Reserve Zone of the River Cimitarra Valley in 2017–2019

	Years			Percent change	
Land covers	2017 (%)	2018 (%)	2019 (%)	Lost	Gain
Forest	59.64	57.92	55.82	3.82%	–
Open areas	35.58	36.88	38.81	–	3.50%
Rivers	2.97	2.71	2.97	–	–
Wetlands	1.56	2.06	1.71	–	–
Other covers	0.25	0.34	0.43	–	0.18%

Table 2. Available habitats for each species during the present (2019) (based on the potential distribution polygons obtained from MaxEnt and the forest layer from the IDEAM) and the future (2050) (based on the future potential distribution polygons obtained from MaxEnt) scenarios. The area is indicated in km^2 and in percent (in brackets). See potential distribution of species in Fig. A3

Scenarios	Amphibians			Birds			Primates	
	Sachatamia punctulata	*Diasporus anthrax*	*Agalychnis terranova*	*Crax alberti*	*Capito hypoleucus*	*Habia gutturalis*	*Saguinus leucopus*	*Ateles hybridus*
a. Present								
Total area	127 118 (100.0)	64 458 (100.0)	60 962 (100.0)	87 902 (100.0)	131 256 (100.0)	121 495 (100.0)	97 893 (100.0)	113 667 (100.0)
Forest	53 238 (41.8)	21 783 (33.80)	36 256 (59.47)	31 968 (36.4)	56 913 (43.3)	49 190 (40.5)	38 807 (30.5)	28 893 (22.7)
No forest	73 182 (57.6)	42 219 (65.50)	24 646 (40.43)	55 853 (63.5)	73 896 (56.3)	71 686 (59)	58 750 (46.2)	84 699 (6.6)
No data	697 (0.55)	455 (0.70)	59 (0.10)	79 (0.09)	447 (0.34)	618 (0.51)	335 (0.26)	74 (0.06)
PAs (%)	6.95	8.31	1.67	6.20	9.43	8.89	8.26	3.74
PRZ-CRV (%)	4	4	4	6	3	4	4.85	5.12
b. Future								
HadGEM2-ES	51 267 (↓)	29 454 (↓)	33 233 (↓)	84 940 (↓)	149 778 (↑)	129 379 (↑)	96 947 (↓)	–
GISS-E2-R	60 267 (↓)	41 913 (↓)	104 409 (↑)	69 019 (↓)	141 572 (↑)	145 043 (↑)	97 370 (↓)	200 153 (↑)
IPSL-CM5a-LR	171 872 (↑)	38 279 (↓)	120 287 (↑)	148 628 (↑)	148 628 (↑)	124 276 (↑)	95 747 (↓)	298 501 (↑)

Note: PAs – Protected Areas, PRZ-CRV – Peasant Reserve Zone of the Cimitarra River Valley. Arrows indicate expansion (↑) or contraction (↓) of the distribution range in the future in relation to the range distribution in the present (i.e. total area).

Finally, the gap analyses indicated that for all species less than 10% of their current distributions are covered by PAs (Table 2a). The species with the lowest percentages were *Agalychnis terranova* with only 1.67% of its distribution covered by PAs, followed by *Ateles hybridus* (3.74%) and *Crax alberti* (6.20%). For *A. terranova* and *A. hybridus*, the PRZ-CRV covered a higher percentage than the cover of PAs.

Discussion

We evaluated the role of the PRZ-CRV in the conservation of tropical humid forests and endangered species in the MVR. Our findings suggest that the PRZ-CRV is an important area for the maintenance and conservation of humid forests and its associated fauna, playing an important role as a complement to the system of PAs to preserve biodiversity.

Role of the PRZ-CRV in conservation of tropical humid forests

The main land cover in the PRZ-CRV through the years has been represented by forests followed by open areas. This dynamics between these land covers reveals a deforestation rate of approximately 1.3% annually, which is very similar to deforestation rates estimated by other authors for the MVR, suggesting that this region is one of the ecosystems with the highest risk of landscape transformation in Colombia (Etter & van Wyngaarden, 2000; Etter et al., 2006, 2008; Negret et al., 2019). The areas with cleared lands are mainly found in the peasant area and to a lesser extent in the forest reserve zone (Fig. 1, Fig. 2), which is expected since the main tasks of PRZs is not only to ensure the conservation of ecosystems and biodiversity but also to improve human well-being through the strengthening of the local economy with agricultural and cattle raising activities, among others (Quijano-Mejía & Linares-García, 2017; Ortiz, 2018).

Despite the rate of deforestation in the area, the PRZ-CRV is an important area for the maintenance and conservation of humid forests, especially those that belong to the San Lucas Mountain Range. The conserved forest areas (without change) are mainly located within the «yellow line» (Fig. 2b), an area located in the forest reserve zone (Fig. 1b). The «yellow line» is a demarcation made by the peasants themselves around the redoubts of forests of the San Lucas Mountain Range, which restricts the advance of colonisation. The peasants have reached an agreement that any type of intervention on the fauna and flora is prohibited in this area (Quijano-Mejía & Linares-García, 2017). Even though our results support this initiative as successful and as a case of community management of the territory with specific effects on the conservation of ecosystems, some spotlights of deforestation have appeared within this area or very close to its limits (Fig. 2b). This could be related to high levels of armed conflict in the region, which contributed to a lack of governance and to an increase in the level of deforestation (Dávalos, 2001; Dávalos et al., 2011; Castro-Nunez et al., 2017; Liévano-Latorre et al., 2021). For instance, Chadid et al. (2015) evaluated the dynamics in deforestation in the San Lucas Mountain Range, reporting a high increase in the transition from forests to coca crops or pastures in 2002–2010. These results were also corroborated by Negret et al. (2019), where they generated spatial predictions of deforestation in Colombia from 2000–2015, by finding a high deforestation pressure induced by armed conflict and coca cultivation in the San Lucas Mountain Range. Even though we did not evaluate illicit crops as a land cover, we identified cleared areas in remote sites (e.g. into the «yellow line» area) that could be associated with the increase of illegal practices, which has intensified since the signing of the peace accords, where persistent illegal groups fight to gain control (Yagoub, 2018; Murillo-Sandoval et al., 2020; Liévano-Latorre et al., 2021).

The PRZ-CRV hosts a great diversity of plant species, and it is important for conservation of humid forests in the region. Both forest remnants in the peasant area and in the forest reserve area harbour endemic species of ecological importance. For instance, a recent study carried out in forest remnants has been located in the south of the Bolívar department (i.e. in the peasant area) indicated that despite being in an intermediate successional stage, these forests harbour a high richness of species and are important for the conservation of threatened and endemic species, such as *Wettinia hirsuta* Burret, *Astrocaryum malybo* H.Karst., *Chamaedorea ricardoi* R.Bernal, Galeano & Hodel, and *Unonopsis aviceps* Maas. Additionally, this study also demonstrated that forest remnants still retain their similarity in species composition with the Amazon and Choco forests (Ortiz-Lozada, 2020), which suggests that despite their alteration, these forest remnants might continue to play an important role as a potential bridge between populations of fauna and flora from other regions (Chapman, 1917; Echeverry & Morrone, 2013).

Role of the PRZ-CRV in conservation of threatened and endemic species

Our results, taken together with other studies (e.g. Marsh et al., 2016; Negret et al., 2019), suggest that threatened and endemic Colombia's species with distributions in the MVR are facing a dramatic loss of their habitats. Our results indicated that less than 50% of the climatically suitable areas for each species are covered by forests, indicating that in fact their optimal distribution area is smaller. This pattern could get worse in the future under climatic scenarios with a higher temperature and lower precipitation (Table 2b). Additionally, our results showed that less than 10% of the species distribution in the present period is covered by PAs, which aggravates the situation of maintenance and conservation of these species.

The forest loss is one of the main threats to the species conservation. During the last decades, more than 2 000 000 km^2 of tropical forest have been lost, threatening the survival of forest specialist species (Hansen et al., 2010; Symes et al., 2018; Agudelo-Hz et al., 2019; Donald et al., 2019; Negret et al., 2019). In Colombia, humid forests are one of the most diverse and fragmented habitats. A recent study indicated that more than half of Colombia's regionally endemic bird species are projected to lose at least half of their habitats by 2040 (Negret et al., 2021), including *Crax alberti*, a Cracidae species threatened by habitat loss and also assessed in our study. According to our analysis, this species has only 36% of its climatically suitable area covered by forests (i.e. less than 60% of its distribution) and it is expected that in future scenarios with higher temperature and lower precipitation, its climatically suitable area decreases (Table 2b). For forest-dependent amphibian species, a dramatic impact is also observed in their distribution range, with a reduction of 50% (e.g. *Sachatamia punctulata*) and 70% (e.g. *Diasporus anthrax*) by 2050. Additionally, ecological characteristics of species could worsen the situation, since some of them have a reduced vagility (e.g. amphibians) or little tolerance to open habitats (e.g. primates), which limit their ability to respond to changes in their habitat and climatic conditions.

An additional problem is the lack of PAs in the MVR to ensure the conservation of habitats suitable for species. Our results indicated that for the eight analysed species less than 10% of their distribution is covered by PAs. This evidences the need to create PAs in this region of the country, where a high number of endangered and endemic species live. It should be noted that this problem has not been ignored by researchers and national institutions (e.g. Fundación Proyecto Primates, Panthera, and Wildlife Conservation Society of Colombia), which since 2016 have requested the Colombian government to incorporate the San Lucas Mountain Range into the National Park system (Parques Nacionales Naturales de Colombia, 2021). Unfortunately, the San Lucas Mountain Range has still remained unprotected and its forests and fauna are subject to armed conflict and illegal activities in the region (Negret et al., 2019).

Finally, our study suggests that the PRZ-CRV is a significant territory for conservation and maintenance of endemic and threatened species in the MVR. It plays an important role as an ally to the PAs system. Our results indicated that the PRZ-CRV covers a part of distribution range of studied species. Even for some of them, this PRZ covers a higher percentage than PAs (Table 2a). Additionally, if we consider the change in the species distribution under future climatic scenarios, this region might present suitable climatic areas for the maintenance of these species (Fig. A3). Although in the PRZ-CRV there are processes of changes in the natural cover, forests of the region conserve a structure and floristic composition typical for tropical humid forests (Ortiz-Lozada, 2020). This is also supported by some recent studies that report the presence of bioindicator species of high-quality habitats in relict forests in southern Bolivar (Arbeláez-Cortés et al., 2021). Therefore, the higher forest coverage in the PRZ-CRV, the greater species diversity, and the peasant commitment to the conservation of their natural resources make this area a potential ally for the biodiversity conservation of the region. Even more, if we consider that until now there are no formal PAs in the San Lucas Mountain Range (one of the most diverse regions of Colombia) and that a few PAs around the MVR have a low-moderate impact in avoiding deforestation by their small size (Liévano-Latorre et al., 2021), this PRZ is a valuable community tool for biodiversity management that can support the mission of PAs.

Conclusions

Our findings suggest that the PRZ-CRV is an important area aiming to maintain and protect humid forests (especially those belonging to the San Lucas Mountain Range) and its fauna, acting as an ally to the PA system in the MVR. Additionally, we showed that the capacity of this peasant organisation to recognise, define, and generate conservation agreements (e.g. the establishment of the «yellow line») is a successful case of community management in the area with concrete effects on the conservation of ecosystems. It should be noted that among the aims of PRZs are controlling the inadequate expansion of the country's agricultural frontier, creating and building a comprehensive proposal for sustainable human development, and assuring ecosystem and biodiversity conservation. Thus, these peasant agreements could serve as allies in the biodiversity conservation of such areas as MVR where there is a poor representation of PAs and buffer zones around PAs with controlled activities.

Acknowledgements

The authors thank funding from the Ministerio de Ciencia, Tecnología e Innovación, Ministerio de Educación Nacional, Ministerio de Industria, Comercio y Turismo, and ICETEX, Programme Ecosistema Científico-Colombia Científica from Fondo Francisco José de Caldas (Grant RC-FP44842-212-2018). We are also grateful for the postdoctoral stay programme of the Universidad Industrial de Santanter (Colombia) for the support received. Finally, we thank Sergio Cordoba and Björn Reu (Industrial University of Santander) for their advice on the pre-processing of satellite images.

References

Agudelo-Hz W.J., Urbina-Cardona N., Armenteras-Pascual D. 2019. Critical shifts on spatial traits and the risk of extinction of Andean anurans: an assessment of the combined effects of climate and land-use change in Colombia. *Perspectives in Ecology and Conservation* 17(4): 206–219. DOI: 10.1016/j.pecon.2019.11.002

Allouche O., Tsoar A., Kadmon R. 2006. Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). *Journal of Applied Ecology* 43(6): 1223–1232. DOI: 10.1111/j.1365-2664.2006.01214.x

Álvarez M.D. 2002. Illicit Crops and Bird Conservation Priorities in Colombia. *Conservation Biology* 16(4): 1086–1096. DOI: 10.1046/j.1523-1739.2002.00537.x

Arbeláez-Cortés E., Villamizar-Escalante D., Trujillo-Arias N. 2021. New voucher specimens and tissue samples from an avifaunal survey of the Middle Magdalena Valley of Bolívar, Colombia, bridge geographical and temporal gaps. *Wilson Journal of Ornithology* 132(3): 773–779. DOI: 10.1676/20-56

Armenteras D., Rodríguez N., Retana J., Morales M. 2011. Understanding deforestation in montane and lowland forests of the Colombian Andes. *Regional Environmental Change* 11(3): 693–705. DOI: 10.1007/s10113-010-0200-y

Asociación campesina del valle del rio Cimitarra. 2008. *La zona de reserva campesina del valle del río Cimitarra: una iniciativa agraria de paz*. Available from https://www.prensarural.org/spip/spip.php?article1098

Becker N., Werft W., Toedt G., Lichter P., Benner A. 2009. penalizedSVM: a R-package for feature selection SVM classification. *Bioinformatics* 25(13): 1711–1712. DOI: 10.1093/bioinformatics/btp286

Breiman L. 2001. Random Forests. *Machine Learning* 451(45): 5–32. DOI: 10.1023/A:1010933404324

Castro-Nunez A., Mertz O., Buritica A., Sosa C.C., Lee S.T. 2017. Land related grievances shape tropical forest-cover in areas affected by armed-conflict. *Applied Geography* 85: 39–50. DOI: 10.1016/j.apgeog.2017.05.007

Chadid M.A., Dávalos L.M., Molina J., Armenteras D. 2015. A Bayesian Spatial Model highlights distinct dynamics in deforestation from coca and pastures in an Andean biodiversity hotspot. *Forests* 6(11): 3828–3846. DOI: 10.3390/f6113828

Chapman F. 1917. The distribution of bird-life in Colombia: a contribution to a biological survey of South America. *Bulletin of the American Museum of Natural History* 36: 1–728.

Cortes C., Vapnik V. 1995. Support-vector networks. *Machine Learning* 20: 273–297. DOI: 10.1007/bf00994018

Cuervo Maya A.M., Manuel Ochoa J., Salaman P. 1999. Últimas evidencias del Paujil de Pico Azul (*Crax alberti*) con anotaciones sobre su historia natural, distribución actual y amenazas específicas. *Boletín de la Sociedad Antioqueña de Ornitología* 10: 18–19.

Da Ponte E., Mack B., Wohlfart C., Rodas O., Fleckenstein M., Oppelt N., Dech S., Kuenzer C. 2017. Assessing forest cover dynamics and forest perception in the Atlantic Forest of Paraguay, combining remote sensing and household level data. *Forests* 8(10): 389. DOI: 10.3390/f8100389

Dávalos L.M. 2001. The San Lucas mountain range in Colombia: How much conservation is owed to the violence?. *Biodiversity and Conservation* 10(1): 69–78. DOI: 10.1023/A:1016651011294

Dávalos L.M., Bejarano A.C., Hall M.A., Correa H.L., Corthals A., Espejo O.J. 2011. Forests and drugs: Coca-driven deforestation in tropical biodiversity hotspots. *Environmental Science and Technology* 45(4): 1219–1227. DOI: 10.1021/es102373d

Donald P.F., Arendarczyk B., Spooner F., Buchanan G.M. 2019. Loss of forest intactness elevates global extinction risk in birds. *Animal Conservation* 22(4): 341–347. DOI: 10.1111/acv.12469

Dufresne J.L., Foujols M.A., Denvil S., Caubel A., Marti O., Aumont O., Balkanski Y., Bekki S., Bellenger H., Benshila R., Bony S., Bopp L., Braconnot P., Brockmann P., Cadule P., Cheruy F., Codron F., Cozic A., Cugnet D., de Noblet N., Duvel J.P., Ethé C., Fairhead L., Fichefet T., Flavoni S., Friedlingstein P., Grandpeix J.Y., Guez L., Guilyardi E., Hauglustaine D. et al. 2013. Climate change projections using the IPSL-CM5 Earth System Model: From CMIP3 to CMIP5. *Climate Dynamics* 40(9–10): 2123–2165. DOI: 10.1007/s00382-012-1636-1

Echeverry A., Morrone J.J. 2013. Generalized tracks, area cladograms and tectonics in the Caribbean. *Journal of Biogeography* 40(9): 1619–1637. DOI: 10.1111/jbi.12117

Elith J., Graham C.H., Anderson R.P., Dudík M., Ferrier S., Guisan A., Hijmans R.J., Huettmann F., Leathwick J.R., Lehmann A., Li J., Lohmann L.G., Loiselle B.A., Manion G., Moritz C., Nakamura M., Nakazawa Y., Overton J., Peterson A.T., Phillips S.J., Richardson K.S., Scachetti-Pereira R., Schapire R.E., Soberón J., Williams S., Wisz M.S., Zimmermann N. 2006. Novel methods improve prediction of species' distributions from occurrence data. *Ecography* 29(2): 129–151. DOI: 10.1111/j.2006.0906-7590.04596.x

Etter A., van Wyngaarden W. 2000. Patterns of landscape transformation in Colombia, with emphasis in the Andean region. *Ambio* 29(7): 432–439. DOI: 10.1579/0044-7447-29.7.432

Etter A., McAlpine C., Wilson K., Phinn S., Possingham H. 2006. Regional patterns of agricultural land use and deforestation in Colombia. *Agriculture, Ecosystems and Environment* 114(2–4): 369–386. DOI: 10.1016/j.agee.2005.11.013

Etter A., McAlpine C., Possingham H. 2008. Historical patterns and drivers of landscape change in Colombia since 1500: A regionalized spatial approach. *Annals of the Association of American Geographers* 98(1): 2–23. DOI: 10.1080/00045600701733911

Foody G.M. 2020. Explaining the unsuitability of the kappa coefficient in the assessment and comparison of the accuracy of thematic maps obtained by image classification. *Remote Sensing of Environment* 239: 111–630. DOI: 10.1016/J.RSE.2019.111630

Forero-Medina G., Joppa L. 2010. Representation of global and national conservation priorities by Colombia's protected area network. *PLoS ONE* 5(10): e13210. DOI: 10.1371/journal.pone.0013210

Gallery R.E. 2014. Ecology of Tropical Rain Forests. In: R. Monson (Eds.): *Ecology and the Environment. The Plant Sciences*. Vol. 8. New York: Springer. P. 247–272. DOI: 10.1007/978-1-4614-7501-9_4

Hansen M.C., Stehman S.V., Potapov P.V. 2010. Quantification of global gross forest cover loss. *Proceedings of the National Academy of Sciences of the United States of America* 107(19): 8650–8655. DOI: 10.1073/pnas.0912668107

Hijmans R.J., Cameron S.E., Parra J.L., Jones P.G., Jarvis A. 2005. Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* 25(15): 1965–1978. DOI: 10.1002/joc.1276

Jones C.D., Hughes J.K., Bellouin N., Hardiman S.C., Jones G.S., Knight J., Liddicoat S., O'Connor F.M., Andres R.J., Bell C., Boo K.O., Bozzo A., Butchart N., Cadule P., Corbin K.D., Doutriaux-Boucher M., Friedlingstein P., Gornall J., Gray L., Halloran P.R., Hurtt G., Ingram W.J., Lamarque J.F., Law R.M., Meinshausen M., Osprey S., Palin E.J., Parsons Chini L., Raddatz T., Sanderson M.G. et al. 2011. The HadGEM2-ES implementation of CMIP5 centennial simulations. *Geoscientific Model Development* 4(3): 543–570. DOI: 10.5194/gmd-4-543-2011

Kramer-Schadt S., Niedballa J., Pilgrim J.D., Schröder B., Lindenborn J., Reinfelder V., Stillfried M., Heckmann I., Scharf A.K., Augeri D.M., Cheyne S.M., Hearn A.J., Ross J., Macdonald D.W., Mathai J., Eaton J., Marshall A.J., Semiadi G., Rustam R., Bernard H., Alfred R., Samejima H., Duckworth J.W., Breitenmoser-Wuersten C., Belant J.L., Hofer H., Wilting A. 2013. The importance of correcting for sampling bias in MaxEnt species distribution models. *Diversity and Distributions* 19(11):1366–1379. DOI: 10.1111/ddi.12096

Kuhn M. 2008. Building predictive models in R using the caret package. *Journal of Statistical Software* 28(5): 1–26. DOI: 10.18637/jss.v028.i05

Laverde-R O., Múnera-R C., Renjifo L.M. 2005. Preferencia de hábitat por *Capito hypoleucus*, ave colombiana endémica y amenazada. *Ornitología Colombiana* 3: 62–73.

Liaw A., Wiener M. 2002. Classification and Regression by randomForest. *R News* 2(3): 18–22.

Liévano-Latorre L.F., Brum F.T., Loyola R. 2021. How effective have been guerrilla occupation and protected areas in avoiding deforestation in Colombia?. *Biological Conservation* 253: 108916. DOI: 10.1016/j.biocon.2020.108916

Marsh C., Link A., King-Bailey G., Donati G. 2016. Effects of fragment and vegetation structure on the population abundance of *Ateles hybridus*, *Alouatta seniculus* and *Cebus albifrons* in Magdalena Valley, Colombia. *Folia Primatolgica* 87(1): 17–30. DOI: 10.1159/000443929

Müller-Wilm U. 2016. *Sen2Cor configuration and user manual, Ref. S2-PDGS-MPC-L2A- SUM-V2.3. European Space Agency*. Available from http://step.esa.int/thirdparties/sen2cor/2.3.0/[L2A-SUM]%20S2-PDGS-MPC-L2A-SUM%20[2.3.0].pdf

Murillo-Sandoval P.J., Van Dexter K., Van Den Hoek J., Wrathall D., Kennedy R. 2020. The end of gunpoint conservation: forest disturbance after the Colombian peace agreement. *Environmental Research Letters* 15(3): 034033. DOI: 10.1088/1748-9326/AB6AE3

Myers N. 1988. Threatened biotas: «Hotspots» in tropical forests. *Environmentalist* 8: 187–208.

Negret P.J., Sonter L., Watson J., Possingham H.P., Jones K.R., Suarez C., Ochoa-Quintero J.M., Maron M. 2019. Emerging evidence that armed conflict and coca cultivation influence deforestation patterns. *Biological Conservation* 239: 108176. DOI: 10.1016/j.biocon.2019.07.021

Negret P.J., Maron M., Fuller R.A., Possingham H.P., Watson J.E.M., Simmonds J.S. 2021. Deforestation and bird habitat loss in Colombia. *Biological Conservation* 257: 109044. DOI: 10.1016/j.biocon.2021.109044

Ochoa-Quintero J.M., Melo-Vásquez I., Palacio-Vieira J.A., Patiño Á.M. 2005. Nuevos registros y notas sobre la historia natural del paujil colombiano *Crax alberti* al nororiente de la cordillera central colombiana. *Ornitología Colombiana* 3: 42–50.

Olofsson P., Foody G.M., Stehman S.V., Woodcock C.E. 2013. Making better use of accuracy data in land change studies: Estimating accuracy and area and quantifying uncertainty using stratified estimation. *Remote Sensing of Environment* 129: 122–131. DOI: 10.1016/j.rse.2012.10.031

Olson D.M., Dinerstein E., Wikramanayake E.D., Burgess N.D., Powell G.V., Underwood E.C., D'Amico J.A., Itoua I., Strand H.E., Morrison J.C., Loucks C.J., Allnutt T.F., Ricketts T.H., Kura Y., Lamoreux J.F., Wettengel W.W., Hedao P., Kassem K.R. 2001. Terrestrial Ecoregions of the World: A New Map of Life on Earth: A new global map of terrestrial ecoregions provides an innovative tool for conserving biodiversity. *BioScience* 51(11): 933–938. DOI: 10.1641/0006-3568(2001)051[0933:TEOTWA]2.0.CO;2

Ortiz S. 2018. *Las Zonas de Reserva Campesina: retos y experiencias significativas en su implementación*. Bogotá: FAO/ANT. 545 p.

Ortiz-Lozada J.D. 2020. *Estructura y composición florística de un bosque húmedo tropical, en el sur del departamento de Bolívar, Colombia*. B.Sc. Thesis. Bucaramanga, Santander, Colombia: Universidad Industrial de Santander. 48 p.

Parques Nacionales Naturales de Colombia. 2021. *Serranía de San Lucas: busca una estrategia de conservación. Parques Nacionales*. Available from https://www.parquesnacionales.gov.co/portal/es/serrania-de-san-lucas-busca-una-estrategia-de-conservacion

Pearson R., Raxworthy C., Nakamura M., Peterson A.T. 2007. Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. *Journal of Biogeography* 34(1): 102–117. DOI: 10.1111/j.1365-2699.2006.01594.x

Peterson A.T., Soberón J., Pearson R.G., Anderson R.P., Martínez-Meyer E., Nakamura M., Araújo M. 2011. *Ecological Niches and Geographic Distributions (MPB-49)*. Princeton: Princeton University Press. 328 p. DOI: 10.23943/princeton/9780691136868.001.0001

Phillips S.J., Anderson R.P., Schapire R.E. 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modelling* 190(3–4): 231–259. DOI: 10.1016/j.ecolmodel.2005.03.026

Pimm S.L., Russell G.J., Gittleman J.L., Brooks T.M. 1995. The future of biodiversity. *Science* 269(5222): 347–350. DOI: 10.1126/science.269.5222.347

Quijano-Mejía C., Linares-García J. 2017. Zonas de Reserva Campesina: territorialidades en disputa. El caso del Valle del río Cimitarra, Colombia. *Revista De Trabajo Social e Intervención Social* 24: 225–251. DOI: 10.25100/prts.v0i24.4478

Quintero-Vallejo E., Benavides A., Moreno N., Gonzalez-Caro S. 2017. *Bosques Andinos, estado actual y retos para su conservación en Antioquia*. Medellín, Colombia: Fundación Jardín Botánico de Medellín Joaquín Antonio Uribe-Programa Bosques Andinos. 542 p.

R Core Team. 2020. *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. Available from https://www.R-project.org/

Rojas-Morales J., Castro-Gómez A., Ramírez-Castaño V. 2014. *Sachatamia punctulata* (Ruiz-Carranza y Lynch 1995). *Catálogo de Anfibios y Reptiles de Colombia* 2: 30–36.

Salaman P., Donegan T., Cuervo A. 2002. New distributional bird records from Serranía de San Lucas and adjacent Central Cordillera of Colombia. *Bulletin of the British Ornithologists' Club* 122: 285–303.

Sanchez-Cuervo A.M., Aide T.M. 2013. Identifying hotspots of deforestation and reforestation in Colombia (2001–2010): implications for protected areas. *Ecosphere* 4(11): 1–21. DOI: 10.1890/ES13-00207.1

Schmidt G.A., Kelley M., Nazarenko L., Ruedy R., Russell G.L., Aleinov I., Bauer M., Bauer S.E., Bhat M.K., Bleck R., Canuto V., Chen Y.H., Cheng Y., Clune T.L., Del Genio A., De Fainchtein R., Faluvegi G., Hansen J.E., Healy R.J., Kiang N.Y., Koch D., Lacis A.A., Legrande A.N., Lerner J., Lo K.K., Matthews E.E., Menon S., Miller R.L., Oinas V., Oloso A.O. et al. 2014. Configuration and assessment of the GISS ModelE2 contributions to the CMIP5 archive. *Journal of Advances in Modeling Earth Systems* 6(1): 141–184. DOI: 10.1002/2013MS000265

Symes W.S., Edwards D.P., Miettinen J., Rheindt F.E., Carrasco L.R. 2018. Combined impacts of deforestation and wildlife trade on tropical biodiversity are severely underestimated. *Nature Communications* 9(1): 4052. DOI: 10.1038/s41467-018-06579-2

Tocancipá Falla J., Ramírez Castrillón C.A. 2018. The new rural dynamics in peasants reserve zones in Colombia. *Perspectiva Geográfica* 23(1): 31–52. DOI: 10.19053/01233769.5796

Trujillo-Arias N., Dantas G.P.M., Arbeláez-Cortés E., Naoki K., Gómez M.I., Santos F.R., Miyaki C.Y., Aleixo A., Tubaro P.L., Cabanne G.S. 2017. The niche and phylogeography of a passerine reveal the history of biological diversification between the Andean and the Atlantic forests. *Molecular Phylogenetics and Evolution* 112: 107–121. DOI: 10.1016/j.ympev.2017.03.025

Tucker C., Townshend J. 2000. Strategies for monitoring tropical deforestation using satellite data. *International Journal of Remote Sensing* 21(6–7): 1461–1471. DOI: 10.1080/014311600210263

van Vuuren D.P., Edmonds J., Kainuma M., Riahi K., Thomson A., Hibbard K., Hurtt G.C., Kram T., Krey V., Lamarque J.F., Masui T., Meinshausen M., Nakicenovic N., Smith S.J., Rose S.K. 2011. The representative concentration pathways: An overview. *Climatic Change* 109(1): 5. DOI: 10.1007/s10584-011-0148-z

Venables W.N., Ripley B.D. 2002. *Modern Applied Statistics with S. 4th ed*. New York: Springer. 498 p.

Yagoub M. 2018. With Armed Strike in Colombia, ELN's Warmongers Seek Upper Hand. In: *InSight Crime*. Available from https://www.insightcrime.org/news/ analysis/armed-strike-colombia-eln-warmongers-seek-upper-hand/

Yoshida T., Omatu S. 1994. Neural Network Approach to Land Cover Mapping. *IEEE Transactions on Geoscience and Remote Sensing* 32(5): 1103–1109. DOI: 10.1109/36.312899

Appendix. Sentinel images employed for forest classification analyses and performance of three non-parametric classifier algorithms in the classification of coverage, and number of species occurrences, performance and validation of ecological niche models obtained from MaxEnt.

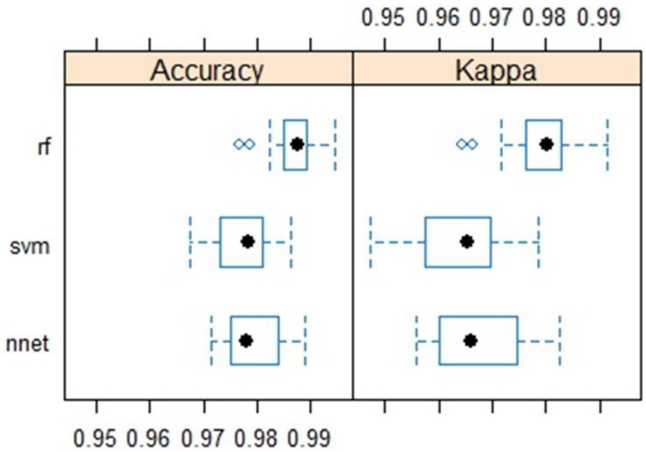

Fig. A1. Performance of the random forest (rf), support vector machines (svm) and neural network (nnet) algorithms in the classification of coverage based on the accuracy and kappa statistics.

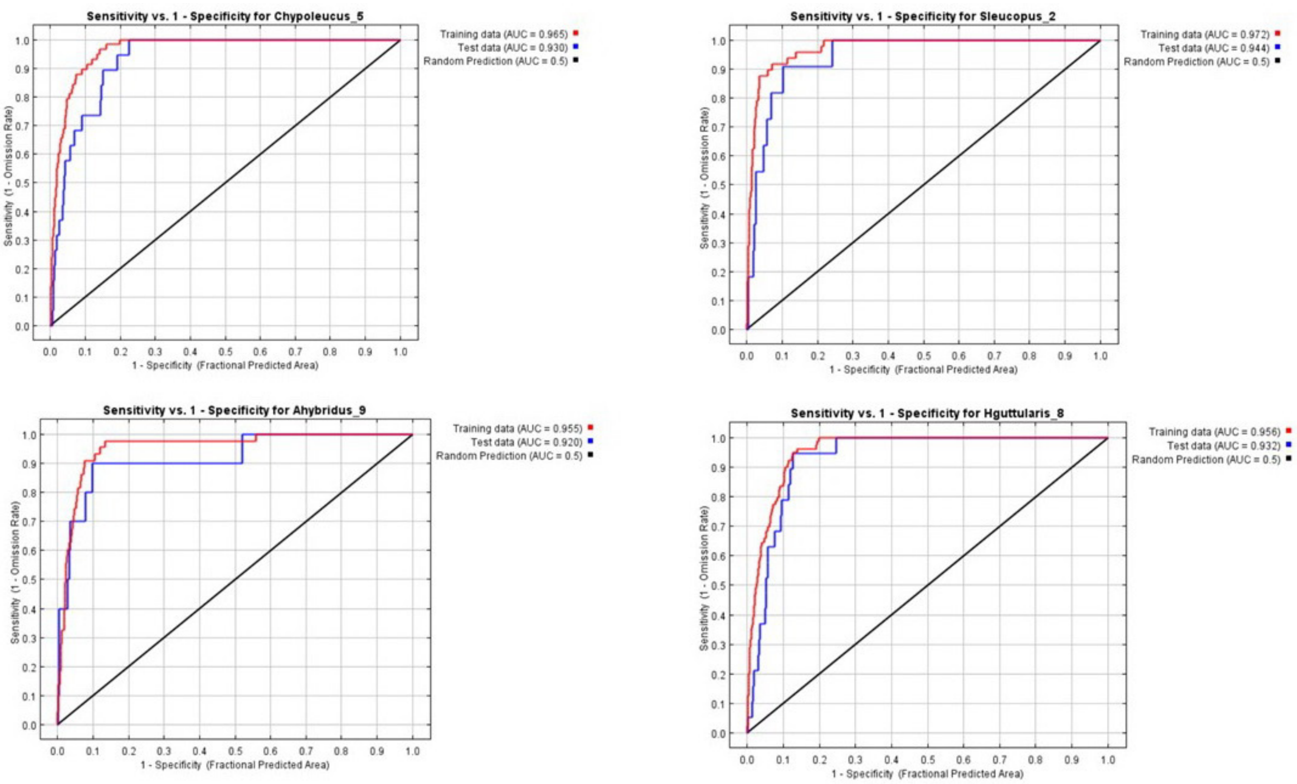

Fig. A2. Some examples of receiver operating characteristic (ROC) curves obtained from MaxEnt models for the present period. The AUC (area under ROC curve) values vary from 0 to 1. Values < 0.5 indicate that the model performance is worse than random; the value 0.5 indicates the performance that is not better than random; values 0.5–0.7 indicate the poor performance; values 0.7–0.9 indicate the reasonable or moderate performance; values > 0.9 indicates the high performance.

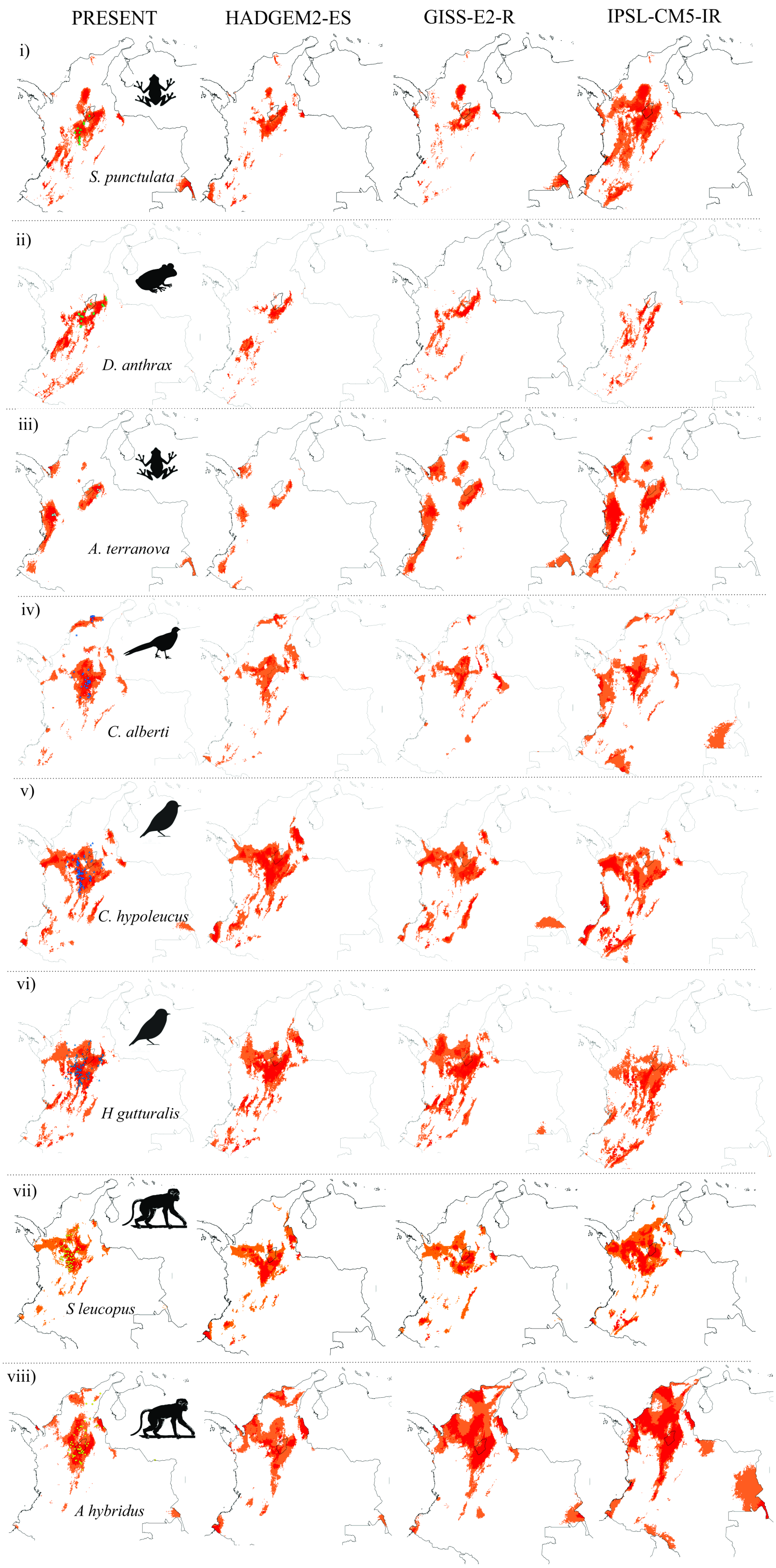

Fig. A3. Ecological niche models for the present and the future (2050) of eight endemic species in Colombia. Designations: i) *Sachatamia punctulata*, AUC: 0.96 / TSS: 0.90; ii) *Diasporus anthrax*, AUC: 0.97 / TSS: 0.95; iii) *Agalychnis terranova*, AUC: 0.98 / TSS: 0.94; iv) *Crax alberti*, AUC: 0.96 / TSS: 0.92; v) *Capito hypolucus*, AUC: 0.94 / TSS; 0.84; vi) *Habia gutturalis*, AUC: 0.94 / TSS; 0.87; vii) *Saguinus leucopus*, AUC: 0.96 / TSS: 0.88; viii) *Ateles hybridus*, AUC: 0.95 / TSS: 0.80). Points on the maps in the present models represent the species occurrence.

Table A1. Sentinel images with less than 40% cloud cover employed for the forest classification analyses of the Peasant Reserve Zone-Cimitarra River Valley, Colombia

Satellite	Image level	Date	Tile	18NWN	18NWP	18NXN	18NXP
S2A	MSIL1C	04.01.2017	18NWN	X	X	X	X
S2A	MSIL1C	03.02.2017	18NWN	X	X	X	X
S2A	MSIL1C	13.02.2017	18NWN	X	X	X	X
S2A	MSIL1C	04.05.2017	18NWN	X	X	X	X
S2A	MSIL1C	24.05.2017	18NWN	X	X	X	–
S2A	MSIL1C	01.09.2017	18NWN	X	X	X	X
S2A	MSIL1C	31.10.2017	18NWN	X	X	X	X
S2B	MSIL1C	15.11.2017	18NWN	X	X	X	X
S2B	MSIL1C	05.12.2017	18NWN	X	X	X	X
S2A	MSIL1C	10.12.2017	18NWP	–	X	–	–
S2B	MSIL1C	15.12.2017	18NWN	X	X	X	X
S2B	MSIL1C	25.12.2017	18NWN	X	X	X	X
S2A	MSIL1C	08.02.2018	18NWP	–	X	–	X
S2B	MSIL1C	13.02.2018	18NWP	–	X	–	X
S2A	MSIL1C	18.02.2018	18NWP	–	X	–	X
S2B	MSIL1C	23.06.2018	18NWN	X	X	–	X
S2A	MSIL1C	18.07.2018	18NXN	–	–	X	X
S2B	MSIL1C	02.08.2018	18NXN	–	–	X	–
S2A	MSIL1C	07.08.2018	18NWN	X	–	–	X
S2A	MSIL1C	27.08.2018	18NXN	–	–	X	–
S2A	MSIL1C	05.12.2018	18NXP	–	–	–	X
S2B	MSIL1C	10.12.2018	18NWN	X	X	X	–
S2A	MSIL2A	15.12.2018	18NXP	–	–	–	X
S2A	MSIL2A	25.12.2018	18NWN	X	X	X	X
S2B	MSIL2A	30.12.2018	18NWP	–	X	–	–
S2A	MSIL2A	04.01.2019	18NWP	–	X	–	–
S2A	MSIL2A	24.01.2019	18NWP	–	X	–	–
S2A	MSIL2A	04.04.2019	18NWP	–	X	–	–
S2A	MSIL2A	24.05.2019	18NWP	–	X	–	X
S2A	MSIL2A	03.06.2019	18NXP	–	–	–	X
S2B	MSIL2A	08.06.2019	18NWN	X	X	X	X
S2B	MSIL2A	18.06.2019	18NXP	–	–	–	X
S2A	MSIL2A	03.07.2019	18NWN	X	–	–	–
S2B	MSIL2A	18.07.2019	18NWN	X	X	X	X
S2B	MSIL2A	28.07.2019	18NWN	X	X	X	X
S2A	MSIL2A	02.08.2019	18NXN	–	–	X	X
S2B	MSIL2A	07.08.2019	18NWN	X	X	X	X
S2A	MSIL2A	13.08.2019	18NXP	–	–	–	X
S2A	MSIL2A	22.08.2019	18NWN	X	–	X	X
S2B	MSIL2A	27.08.2019	18NWN	X	X	X	X
S2A	MSIL2A	09.09.2019	18NWN	X	–	–	–

Table A2. The number of occurrences used to create MaxEnt models of eight species endemic (or near endemic) to Colombia distributed in the Magdalena Valley Region, Colombia

Class	Species	Occurrences
Birds	*Habia gutturalis*	98
	Capito hypoleucus	77
	Crax alberti	38
Amphibians	*Sachatamia punctulata*	13
	Diasporus anthrax	21
	Agalychnis terranova	15
Primates	*Saguinus leucopus*	60
	Ateles hybridus	72

РОЛЬ ЗАПОВЕДНОЙ ЗОНЫ КАМПЕСИНО В ДОЛИНЕ РЕКИ МАГДАЛЕНА (КОЛУМБИЯ) В СОХРАНЕНИИ НАХОДЯЩИХСЯ ПОД УГРОЗОЙ ИСЧЕЗНОВЕНИЯ ВЛАЖНЫХ ТРОПИЧЕСКИХ ЛЕСОВ

Н. Трухильо-Ариас[1,2,*], В. Х. Серрано-Кардозо[1], М. П. Рамирез-Пинилла[1]

[1]*Индустриальный университет Сантандера, Колумбия*
[2]*Институт исследования биологических ресурсов Александра фон Гумбольдта, Колумбия*
**e-mail: natitrujillo@gmail.com*

Тропические леса Колумбии имеют один из самых высоких показателей сокращения площади лесов в мире. Влажный тропический лес в долине реки Магдалена является одной из экосистем с самым высоким риском трансформации ландшафта, несмотря на то, что он является местом обитания для многих эндемичных и находящихся под угрозой исчезновения видов. Целью данного исследования было оценить роль крестьянской заповедной зоны в сохранении влажных тропических лесов и видов, находящихся под угрозой исчезновения, в районе долины реки Магдалена. Для достижения этой цели мы провели многовременной анализ динамики лесов в крестьянской заповедной зоне – долине реки Чимитарра (КЗЗ-ДРЧ) и оценили риск исчезновения восьми видов, эндемичных для Колумбии. Полученные результаты показали, что наиболее обширным типом ландшафта в КЗЗ-ДРЧ является лес (56.30%), за которым следуют открытые территории (38.75%). Анализ динамики лесов показал, что лесной покров сократился на 3.82% с 2017 по 2019 гг. При этом наиболее сохранившейся является территория с редутами леса Серрания-де-Сан-Лукас. Наконец, результаты показали, что менее 50% климатически подходящих территорий для каждого вида покрыты лесами и менее 10% этих площадей занимают особо охраняемые природные территории (ООПТ). В то же время для таких видов, как *Agalychnis terranova* и *Ateles hybridus*, КЗЗ-ДРЧ охватил более высокую долю их ареала, чем все вместе взятые ООПТ в этой экосистеме. Таким образом, полученные результаты показали, что КЗЗ-ДРЧ может быть ключевой территорией для поддержания и сохранения влажных тропических лесов и связанной с ними фауны, играя важную роль «союзника» системы ООПТ в регионе долины реки Магдалена.

Ключевые слова: Анды, крестьянская заповедная зона, ландшафт, сокращение лесов, угрожаемый вид