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ECOLOGÍA

PRESENCE OF AN ENDANGERED ENDEMIC PRIMATE IN AN EVER-CHANGING LANDSCAPE IN THE EASTERN PLAINS OF COLOMBIA

Presencia de un primate endémico y amenazado en un paisaje cambiante en los Llanos Orientales de Colombia

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ABSTRACT

Plecturocebus ornatus is an endemic vulnerable species due to its population decline and its restricted range within the Eastern Plains of Colombia. This region is affected by deforestation as a result of legal and illegal economic activities. The aim of this work was to analyze the presence and abundance of *P. ornatus* during a period of urban and livestock production expansion (1986-2019) in Villavicencio, Colombia. This municipality is the most affected by land-use changes associated with regional economic development and represents 3.4 % of *P. ornatus* distribution's area. The analysis was performed using satellite images Landsat 4 and 8, with V-Late in ArcGIS 10.5 to describe landscape structure, and *P. ornatus* occurrence records, obtained through field observations and the Global Biological Information Facility. Densities were calculated for each fragment based on total individuals observed by transect. A generalized lineal model was used to evaluate the effects of patch-scale, landscape-scale and other variables on *P. ornatus* abundance. By 1986 the rural and peri-urban areas of Villavicencio were already a transformed landscape. During the analyzed period, landscape was predominantly made up of disconnected linear fragments with a secondary humid forest cover. Around 82.1 % of the fragments with *P. ornatus* records are threatened by urbanization and only 50 % are in protected areas. Densities varied from 0.00 to 7.26 ind/ha (0.00–726.82 ind/km2). Abundance of *P. ornatus* was highly influenced by landscape-scale variables related with landscape connectivity, as well as fragment area and number of other primate species. Therefore, the implementation of restoration measures that increase landscape connectivity and habitat availability is proposed, as well as more control over environmental land-use planning, to contribute to the conservation of *P. ornatus* in urban areas.

Keywords: Environmental management, Landscape ecology, Orinoquia, *Plecturocebus ornatus,* Primates.

RESUMEN

Plecturocebus ornatus es una especie endémica vulnerable debido a la disminución de su población y distribución restringida al piedemonte de los Llanos Orientales Colombianos. Esta región es afectada por la deforestación resultante de actividades económicas legales e ilegales. El objetivo de este trabajo fue analizar la presencia y abundancia de *P. ornatus* durante un período de expansión urbana y ganadera (1986-2019) en Villavicencio, Colombia. Este municipio es el más afectado por cambios de uso del suelo asociados al desarrollo económico regional y representa el 3,4 % del área de distribución de *P. ornatus*. El análisis se realizó a partir de imágenes satelitales Landsat 4 y 8, con V-Late de ArcGIS 10.5, para describir la estructura del paisaje, y registros de *P. ornatus* obtenidos en observaciones de campo y del *Global Biological Information Facility*. Se calcularon densidades de cada fragmento basadas en el número total de individuos observados. Un modelo lineal generalizado fue usado para evaluar el efecto de variables a la escala del parche, paisaje y otros sobre la abundancia de *P. ornatus*. Para 1986 los sectores rurales y periurbanos de Villavicencio ya eran un paisaje transformado. Durante el período analizado, el paisaje estuvo predominantemente conformado por fragmentos lineales desconectados con cobertura de bosque húmedo secundario. Alrededor del 82,1 % de los fragmentos con registros de *P. ornatus* están amenazados por la urbanización y solo el 50 % se encuentran en áreas protegidas. Las densidades variaron de 0,00 to 7,26 ind/ha (0,00–726,82 ind/km2). La abundancia de *P. ornatus* fue altamente influenciada por variables a la escala de paisaje relacionadas con la conectividad del paisaje, así como el área del fragmento y la presencia de otras especies de primates. Por lo tanto, la implementación de medidas de restauración que incrementen la conectividad del paisaje y disponibilidad de hábitat, así como un mayor control sobre el ordenamiento territorial ambiental, pueden contribuir a la conservación de *P. ornatus* en áreas urbanas.

Palabras Clave: Ecología del paisaje, Manejo ambiental, Orinoquia, *Plecturocebus ornatus*, Primates.

INTRODUCTION

Land-use changes affect the distribution of tropical forest cover (Borrelli et al., 2017). These changes are the result of anthropic activities such as infrastructure and urban development, agriculture, livestock production and mining (Singh et al., 2017), as well as illegal activities, mostly illicit crops, and land grabbing (Landholm et al., 2019). Forest cover losses affect the supply of ecosystem services (ES) from terrestrial ecosystems (Brockerhoff et al., 2017), such as ES providing for numerous species (Kangas et al., 2018), especially in biodiversity hotspots (Brockerhoff et al., 2017). Furthermore, primates are one of the most affected groups by habitat loss since they are highly dependent on forest resources (da Silva et al., 2015). Currently, 75 % of primate species are under threat of extinction in the tropics (Cotton et al., 2016; Estrada et al., 2017).

Primate species are threatened by multiple drivers, including habitat loss and fragmentation, landcover changes, infection diseases, hunting as well as climate change (Cavada et al., 2018). Benchimol and Venticinque (2014) found that the presence of primates is reduced in *Pithecia*, and even absent in *Saimiri*, at small areas (<100 ha), because of fragmented landscapes in lowland Amazonia in Brazil. The negative effects of forest fragmentation were also seen on *Ateles* species in a Guatemalan tropical forest, given their home range (again, >100 ha) and food (fruits) requirements (Thornton et al., 2011). Moreover, in the mountains of Tanzania, a study showed the direct relation between anthropogenic disturbances and low densities among metapopulations of the primate species *Colobus angolensis palliates*, *Procolobus gordonorum* and *Cercopithecus mitis monoides* (Cavada et al., 2018). Primate density, abundance and distribution is affected by land cover use product of habitat loss and fragmentation processes at the landscape scale, with positive and negative effects been reported (Chetcuti et al., 2021). Occupancy and abundance of primate species have shown weak responses to increase landscape forest cover (Anzures-Dadda and Manson, 2007; Urquiza-Haas et al., 2011; Benchimol and Venticinque, 2014), whereas other studies assessing primate density have shown a positive effect of this landscape predictor (Blanco and Waltert, 2013; Piel et al., 2015). In addition, a trend of higher densities had been found on small fragments highlighting the importance of long-term studies of primate species in fragmented landscapes (Carretero-Pinzón et al., 2015). Moreover, in rural landscapes in San Martin area, *P. ornatus* abundance and occupancy is influenced by forest cover around the forest where the species found at a 1000 m scale as well as variables at the site-scale such as number of trees with fruits (Carretero-Pinzon et al., 2017).

Plecturocebus (=*Callicebus*) *ornatus* (Gray 1866) is a primate species that typically inhabits tropical forests (Carretero-Pinzon and Defler, 2016), and is categorized as Vulnerable according to the IUCN Red List of Species, because of the continuous decline of its habitat due to deforestation (Cotton et al., 2016). This species is endemic of the Easter Plains of Colombia, mainly the Meta department (Defler, 2010). Moreover, the occurrence area of this species is severely fragmented, and has a rapid space and habitat quality decline (Carretero et al., 2020). Within its distribution area, the municipality of Villavicencio represents 3.4 % (Cotton et al., 2016), where the endemic species has not been studied yet. Besides, the real distribution of *P. ornatus* may be less than the occurrence estimated area by primatologists, particularly considering its territorial behavior (Carretero-Pinzon and Defler, 2016) and the changes in forest cover (Echeverría-Londoño et al., 2016).

Additionally, the population size of *P. ornatus* is decreasing due to anthropogenic pressures (Cotton et al., 2016). Its population density is variable, with higher densities in secondary and fragmented forest than in continuous forest in the San Martín area, Meta department (Defler and Carretero-Pinzón, 2018). Also, populations are isolated because of habitat loss and their status is unknown due to restrictions in field access in most of their distribution area (Carretero-Pinzón, 2013; Cotton et al., 2016). Only the subpopulations in the *Serranía de la Macarena* and *Tinigua* National Natural Parks, and some small, protected areas, benefit from *in situ* conservation measures (Carretero-Pinzon and Defler, 2016; Carretero-Pinzón et al., 2017). Furthermore, lack of institutional control over factors that represent a threat to the species, inside and outside of protected areas, contributes to the extinction risk of *P. ornatus* (Carretero-Pinzon and Defler, 2016; Cotton et al., 2016). In this context, the aim of this study was to analyze the landscape dynamics and its relationship with the presence and abundance of *P. ornatus* in Villavicencio municipality (Eastern Plains of Colombia, department of Meta), due to this city having the highest rate of forest cover transformation associated with anthropogenic pressures in the region, making necessary to contribute to the formulation of conservation measures for this endemic species.

MATERIALS AND METHODS

Study area

Villavicencio is in the influence area of the *Cordillera Oriental* at the center of Colombia (4°08′ N, and 73°37′ W) (Fig. 1). The city has 131 020 ha (IGAC, 2012), an altitude gradient of 200-3660 m. a. s. l. (IGAC, 2004a), and a landscape with mountains, foothills, and plains (IGAC, 2004b). Villavicencio has an average annual temperature of 27 °C and a monomodal precipitation regime (IDEAM, 2005). The population is approximately 500 000 inhabitants, with an annual increase rate of 27 % and an undetermined floating population because of forced internal displacement. Intermittent inhabitants are mainly related to the mining-energy and services sectors, and tourism, which generate a high urban demand (Ortiz-Moreno and Rodrigues-Pires, 2014). Urbanization, agriculture, livestock production and mining driving forces stimulate changes in the land-use and land-cover of the city, becoming a serious threat to the fragments of native forests and their ecosystem services (Hurtado, 2016).

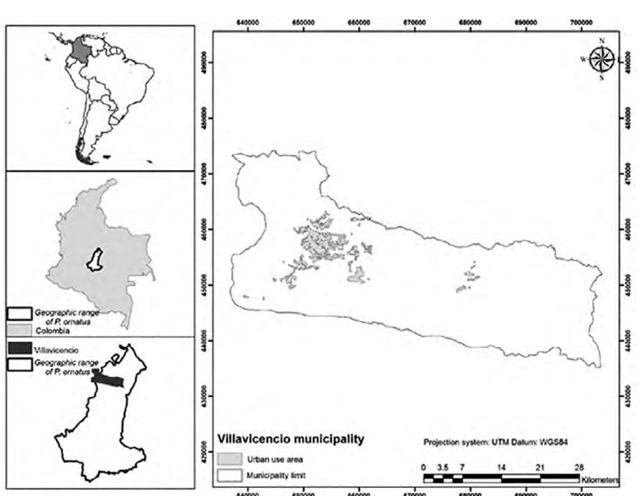

Figure 1. Colombia in South America; range of *Plecturocebus ornatus* in Colombia; Villavicencio municipality within the geographic range of *P. ornatus* distribution (left). Detail: City of Villavicencio, with the urban area in light gray (right).

The landscape of Villavicencio has undergone a historical process of transformation that dates to the 17th century, replacing tropical humid forest ecosystems with anthropized savannas and crops (Rausch, 2007; Etter et al., 2008). This transformation left a matrix of native and introduced pastures, a series of secondary forest patches around water streams, and isolated patches called *matas de monte* in low areas and mountains. During the coffee boom (20th century), large farms combining crops (mostly coffee, sugar cane, corn, tobacco, cacao and several fruit trees) and livestock were established, thus, expanding the agrarian frontier and occupying the foothills of the eastern cordillera of Colombia (Rausch, 2007). Later, with the coffee price crisis and the precariousness of the agricultural sector, the large estates were divided into smaller production units, which ended up being sold for urban development and livestock production.

Landscape structure

To analyze the dynamics of forest cover in Villavicencio, satellite images from the years 1986 (TM sensor, 7 orbit; point 57; resolution 30 m) and 2019 (OLI_TIRS sensor, orbit 7; point 57; resolution 30 m) were obtained from the United States Geological Survey (USGS, Earth explorer). The 1986 image was collected from the Landsat 5 satellite (USGS, 1986), and the 2019 image from the Landsat 8 satellite (USGS, 2019). These years were used because they represent the land-use changes within the maximum time interval recorded by satellite. For analysis, the images were georeferenced and with false color.

The images were processed in ArcGIS 10.5, using the UTM projection system zone 18N and WGS1984 Datum. From the images, the on-screen vectorization with a 1:10000 scale of the forest areas was carried out manually according to the recommendations of the *Instituto Brasileiro de Geografia e Estatística* (IBGE, 2006). The classification was validated by comparison with Google Earth based on patterns of color and texture, and with georeferenced field confirmations using a GPS (Garmin 60CSx), mostly in the peri-urban area. Forests above 1500 m. a. s. l. were not considered in the analyzes since *P. ornatus* has not been recorded at this altitude (GBIF, 2020). The municipality limits were obtained from the *Instituto Geográfico Agustín Codazzi* (scale 1: 100000) (IGAC, 2012).

To analyze the landscape structure and dynamics of forest cover between 1986 and 2019 the V-LATE (Vector-based Landscape Analysis Tools) 2.0 beta extension for ArcGIS 10.5 was used, with parameters: 30 m of edge effect (Sousa et al., 2017) and 500 m for disconnection between fragments, as reported for other primates (da Silva et al., 2015). Landscape metrics medians were used based on area categories (Table 1).

Table 1. Landscape metrics calculated for the Villavicencio municipality, Colombia.

Metric (Abbreviation)	Definition	Author
Fragment Area		
(Frag. Area)	The fragment area in hectares. It represents the percentage of the landscape occupied by forest. Categorized (Cat_area): <1ha; 1-50 ha; 51-100 ha; 101-1000 ha; 1001-10000 ha.	(Carretero-Pinzón et al., 2017)
Nuclear area		
(Core Area)	The measure of patch area without the edge area. It represents habitat quality as indicates how much effective fragment area exists, disregarding its edge area.	(Seganfredo et al., 2019)
Shape index	The fragments closest to the circular format with a perimeter/area ratio close to 1, the center is equidistant from the edges. In the more asymmetrical shape with less area, the value of the shape index is greater (> 2) and the fragments are more exposed to edge effects. Average shape index for the landscape was calculated.	(Csorba and Szabó, 2012; da Silva et al., 2015; Farah et al., 2017; Frazier and Kedron, 2017)
Distance from the closest neighbor		
(NNDist)	The connection between the fragments determined by the distances between them (structural connectivity). The distance from the closest neighbor quantifies the distance between fragments with the same class vegetation.	(Frazier and Kedron, 2017; Volk et al., 2018)
Proximity between fragments within a 500 m buffer		
(Prox 500 m)	The sum of patch size divided by the square of distance to focal patch type. It quantifies the spatial context of a patch (habitat) relative to its neighbors of the same class, distinguishing groups of small patches of dispersed habitat from groups of more large patches. Average proximity was determined for the landscape.	(Volk et al., 2018)
Total forest area	The sum of the area occupied by forest in the landscape.	(Frazier and Kedron, 2017)
Total nuclear area	The sum of the core area occupied by forest in the landscape.	(Frazier and Kedron, 2017)
Number of fragments		
(N. frag)	The total number of forest fragments in the landscape.	(Csorba and Szabó, 2012)
Total edge distance	The sum of the area occupied by the edges of the forest fragments in the landscape.	(Csorba and Szabó, 2012)
Average edge density	The average of the forest fragment edges area divided by the landscape area (edge density).	(Csorba and Szabó, 2012)
Average edge per patch	The average of the edge area for each fragment in the landscape.	(Csorba and Szabó, 2012)
Relative fragments richness	Richness based on Shannon's Diversity Index.	(Frazier and Kedron, 2017)
Fragmentation index		
(Split)	Number of equal-sized patches of a particular class required to produce a degree of landscape division. Calculated to identify trends in the transformation of forest cover.	(Etter et al., 2008; Frazier and Kedron, 2017; Arce-Peña et al., 2019)

Species

Plecturocebus ornatus is a primate of the Pitheciidae family, included within the cupreus group (Gusmão et al., 2019). This primate has a frugivorous diet, consuming fruits from 31 species in nine plant families, mainly Burseraceae, Annonaceae, Fabaceae and Melastomataceae (Defler, 2010; Carretero-Pinzon and Defler, 2016). The species supplements its diet with arthropods by approximately 25.5 % (Carretero-Pinzon and Defler, 2016) and obtains insects from the soil (Souza-Alves et al., 2019). The species can adapt to different tree covers, being able to use secondary forests, riparian forests, forests dominated by *Mauritia flexuosa* called *morichales*, isolated fragments and live fences (Polanco-Ochoa and Cadena, 1993; Carretero-Pinzon and Defler, 2016). The home range of *P. ornatus* fluctuates according to food resources availability approximately 1-15 ha, being most frequently recorded at forest edges and forest fragments of 1-50 ha (Carretero-Pinzon and Defler, 2016). The dispersal capacity of this primate is 200-3000 m (Carretero-Pinzón et al., 2017).

Distribution of the records of *Plecturocebus ornatus*

Primate surveys were done between 2011 to 2020, inside of fragments or through roads crossing or close to forest fragment in areas with different vegetation types in Villavicencio municipality. Primate surveys were obtained using local people transect (Allan and Hill, 2018) and incidental encounters, from the Global Biodiversity Information Facility (GBIF, 2020), Buitrago-Valenzuela and Ceballos-Ladino (2018), Ortiz-Moreno (2019, data not published), and from Rojas and Aguilar, members of the *Fundación William Barrios* (2020, data not published). Each fragment (30 fragments) with sizes ranging from 1.26 to 8318.68 ha, was visited at least once. Fragment visits were limited by logistic constrains such as permits, with fragments located in public and private lands (range of visit frequency to each fragment: 1-12, Table S1). Sampling effort was calculated for each fragment, dividing the time spend searching for monkeys by distance sampled. Transect were of 1187.7 m (range: 1.5 – 64.77 km). Transects were walked on an average of 0.0017 m/hour (range 0.001 – 0.003 m/hour). Sampling effort was not symmetrical in the entire area and was concentrated near the urban area due to resource availability and permits to access fragments in private properties for field sampling. Details regarding the sampling effort are presented in Table S1.

All records were imported into ArcGIS 10.5. Records also included the number of *P. ornatus* individuals observed, vegetation cover, presence of other primate species, which could be competitors, number of individuals of potential competitors and the main cause of habitat loss, which was corroborated by importing the data into ArcGIS on the 2019 satellite image and the basemap with labels.

Statistical analysis

P. ornatus densities

P. ornatus records using primate surveys on local people transect were not enough to calculate density estimates using Distance 7.3 software, as the software requires a minimum of 40 observations for area sampled (Buckland et al., 2010). Population density was calculated by dividing the number of all *P. ornatus* individuals counted in each fragment-by-fragment area in hectares and square kilometers (Mandujano, 2011). Details regarding the fragment density are presented in Table S1.

Variables explaining abundance

Landscape-scale variables (near neighbor distance and fragment connectivity), patch-scale variables (fragment area, perimeter, paratio, core area) used to analyze the landcover change in Villavicencio municipality in 2019, as well as human pressure (urbanization, deforestation and cattle raising), number of other primate species present in each fragment and type of vegetation (secondary or pioneer vegetation) were used to determine the effect of those variables on *P. ornatus* abundance. A correlation matrix was made, and correlated variables were excluded from the analysis. A set of models including all, some, and none (null) was set to evaluate the influence of each variable on *P. ornatus* abundance. We used a generalized linear model with a Poisson distribution. The response variable was the number of individuals observed per transect each time a fragment was visited. The modeled counts were indices of abundance rather than true abundances as we did not account explicitly for detection error. Ignoring detectability essentially assumes it is constant in the study area, as all observations were made inside forest. Since forest structural characteristics do not vary strongly in the study area, except for some variation in canopy height and closure, we do not expect this to be a major issue. Variables grouped by categories of patch-scale variables (area, shape index and paratio), landscape connectivity variables (near neighbor distance and fragment proximity) and other (pressure, number of other primate species (potential competitors) and vegetation type to calculate the relative importance of each variable category). We controlled for the number of variables by taking the importance of the set rather than each variable separately (Rhodes et al., 2009).

All statistical analyses were performed using R software (www.r-project.org; version 4.0.5). We ranked all models according to their AIC values and calculated their Akaike weights (Burnham and Anderson, 2002). A 95 % confidence was constructed using the cumulative Akaike weight for each model, starting with the highest and adding the next model until the cumulative sum of weights exceeded 0.95 (Burnham and Anderson, 2002).

Table 2. Landscape metrics of forest fragments in 1986 and 2019, Villavicencio, Colombia. Number and proportion of fragments in each fragment size category. Medians of fragment area, core area, shape index, nearest neighbor distance (NNDist) and proximity index at 500 m (Prox 500 m; see Table 1).

Year	Frag. size category	N. frag. (N)	Prop. frag. (%)	Frag. area(ha) median	Core area (ha) median	Shape index median	NNDist mediam	Prox 500m median
1986	<1	67	9.8	0.5	0.0	1.22	141.9	30.5
	1-50	556	81.4	5.7	1.2	1.83	118.3	24.3
	51-100	27	4.0	65.1	38.7	2.82	85.5	126.2
	101-1000	32	4.7	166.3	122.2	3.74	67.5	312.3
	1001-10000	1	0.1	8787.4	6910	19.89	24.7	3068.2
2019	<1	28	6.0	0.7	0.0	1.28	107.5	48.8
	1-50	361	77.0	5.9	1.5	1.97	117.0	33.6
	51-100	33	7.0	66.9	36.6	3.25	100.0	92.7
	101-1000	45	9.6	154.6	102.0	5.56	79.7	251.3
	1001-10000	2	0.4	4759.1	3808.3	14.94	63.1	2327.9

RESULTS

Landscape dynamic analysis: comparison 1986 vs 2019

Between 1986 and 2019 the total forest area increased by 2768.5 ha (10.5 %) and its core area by 1469.3 ha (8.62 %), and a reduction in the number of fragments by 214 was observed (31.3 %). The relative richness of fragments also increased by 0.06 %. This apparently positive scenario (Fig. 2) is determined by an increase in fragments of 51-100 ha (3.0 %), 101-1000 ha (4.9 %), and 1001-10 000 ha (0.3 %), as well as their median nuclear area (Table 2). However, the landscape nuclear area index decreased from 66.4 % to 64.9 % (1.5 %) and the landscape fragmentation index increased by 2.3, due to local patterns of forest cover transformation (Fig. 2).

Fragments in the landscape tend to irregularity; however, they are in transition to become more circular in some areas of the municipality (Fig. 2), which is reflected in the total distance of the edge that increased from 2 963 169.2 m to 3 434 098.6 m (13.7 %), the average edge density that augmented from 126.1 m/ha to 130.7 m/ha (3.5 %), and the average shape index that increased from 2.2 to 2.7 (18.3 %). In turn, the mean value of the shape index by category of the fragments underwent changes: positive for the fragments of 1001-10 000 ha, and negative for the other categories (Table 2, Fig. 2).

During the analyzed period, connectivity showed an increase in median distance to the nearest neighbor in the 51-100 ha, 101-10 00 ha, and 1001-10000 ha fragment categories (Table 2). A reduction in the fragment proximity was observed in the categories 51-100 ha, 101-1000 ha, and 1001-10 000 ha (Table 2); and average proximity of the landscape increased from 1198.1 m to 682.7 m (56.98 %), which shows the importance of a local analysis (Fig. 2).

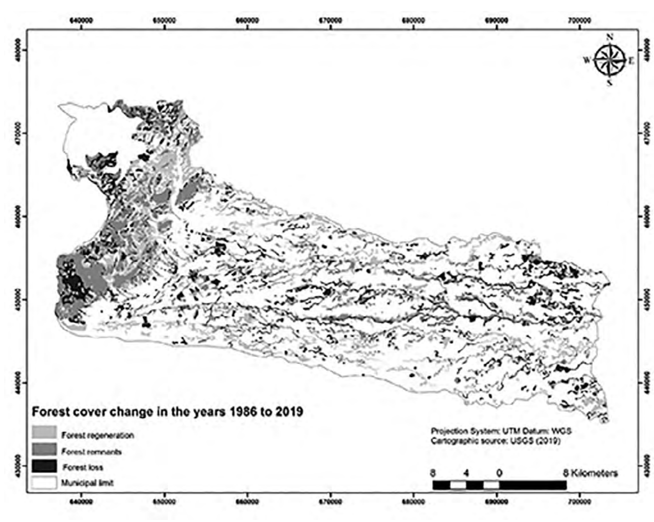

Figure 2. Changes in forest cover in Villavicencio municipality (Meta, Colombia) between 1986 and 2019. In light gray the forests regenerated by succession; in gray the remaining forest fragments, and in dark gray the forest losses during the analyzed period.

Records distribution

The majority of *P. ornatus* records were located nearby the urban and peri-urban areas (89.2 %) and only 10.8 % were in the rural area (Fig. 3). The records of *P. ornatus* were from 9769.3 ha of forest (37.2 % of the total forest area in 2019), with a total fragment core area of 7665.6 ha. This metric fluctuated individually between 0.00845-6936.9 ha, where 82.1 % of the fragments have a core area greater than 1 ha (Fig. 3). All records were in fragments with an altitude of 215-791 m. a. s. l. In addition, 75 % of the fragments have a shape index greater than 2, range from 1.074 to 14.65. The species was found on fragments of different sizes (range: 1.26 – 8318 ha).

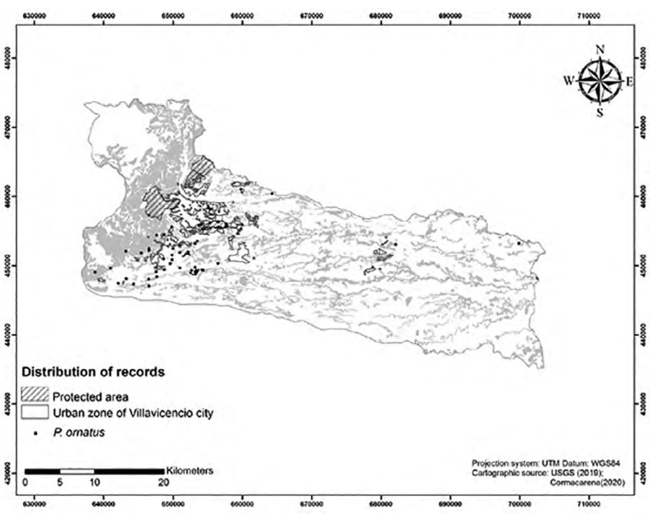

Figure 3. Distribution of *Plecturocebus ornatus* records (black dots) in the Villavicencio municipality (Meta, Colombia). The urban area is outlined in black, and the protected areas are in gray with stripes, while the forest cover is in light gray.

Distance to the closest neighbor fluctuated between 47.3-463.2 m for fragments where *P. ornatus* was present, 28.6 % of the fragments had greater distance than 200 m. Fragment proximity fluctuated between 0.5807-2825.1, with 25 % of the fragments being best connected (values greater than 50), and only 7.1 % of them were associated or included within a protected area, the other fragments are found around water courses. Most of the records (78.6 %) were made in secondary humid forest and only 21.4 % were in vegetation of early stages of succession. Half of the total of records (50 %) were obtained in protected areas, mostly located in the *Kirpas-Pinilla-La Cuerera* Soil Conservation District (nine records) (Fig. 3). On the other hand, deforestation associated with livestock affects 14.3 % of the fragments, 3.6 % of the fragments are affected by non-specific deforestation, and the remaining 82.1 % of the fragments are threatened by urbanization.

P. ornatus densities

The total number of *P. ornatus* individuals registered was 211. Densities ranged from 0.00 to 7.26 ind/ha (0.00–726.82 ind/km2) (Table S1). In 39.2 % of the fragments, the presence of primates that could be competitors of *P. ornatus* was not recorded. Of the remaining 60.8 % fragments (Fig. 3), 28.6 % presented *Saimiri cassiquiarensis albigena*, 3.6 % *Sapajus apella*, 10.7 % *Aotus brumbacki*, and 17.9 % had two potentially competing primate species, of which 10.7 % correspond to the combination of *S.c. albigena* and *S. apella*, while 7.2 % to *S.c. albigena* and *A. brumbacki*.

Variables explaining abundance

The best-fit model included two patch-scale variables and at least one variable of landscape-scale and other categories at 95 % confidence (Table 3). The difference between the best model and the null model was 32.94 indicating very little support for the null model. The relative importance of the variables showed that landscape-scale variables were higher than patch-scale and other variables (Fig. 4). Coefficient estimate of the best model showed a positive effect on area (0.0013) and shape (0.2375) index, both patch-scale variables, while a negative effect was observed for fragment connectivity (-0.0047) and number of other primate species present (-0.3829) in the same forest fragment than *P. ornatus*.

Table 3. Model rank and Akaike's information criteria (AIC) at 95 % confidence for *Plecturocebus ornatus* abundance in Villavicencio municipality, Meta, Colombia

Type Model	AIC	Δi	exp(-1/2Δi)	wi
Area + Shape + No. Other Spp + PXfg_500	369.14	0	1	0.504430269
Area + Shape + No. Other Spp + NNDist + PXfg_500	369.66	0.52	0.771052	0.388941759
All variables	372.64	3.5	0.173774	0.087656837

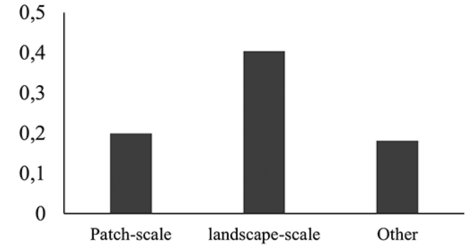

Figure 4. Relative importance of variables for *Plecturocebus ornatus* abundance in Villavicencio municipality, Meta, Colombia.

DISCUSSION

Continuous deforestation in the tropics represents a major threat to biodiversity, especially to primates (Estrada et al., 2017; Arce-Peña et al., 2019). Moreover, habitat availability is essential for long-term *in situ* conservation of primate populations (da Silva et al., 2015; Gouveia et al., 2016). The present study focused on the endemic species *P. ornatus* in an ever-changing landscape (urban and peri-urban) of Villavicencio, in the Eastern Plains of Colombia (Fernandez et al., 2020). Villavicencio has a high ecological value as it is the meeting spot between trans-Andean and cis-Andean fauna (Avendaño et al., 2018). This study highlights the importance of evaluating the landscape dynamic for primate populations inside urban areas, as it showed the high impact of urbanization as a threat for the endemic species *P. ornatus* in the Villavicencio municipality, as well as the effect that landscape-scale variables related with connectivity had in the abundance of this endemic primate.

Landscape structure dynamics

With the uprising of mining and illegal economic activities, many properties were underused and even abandoned in the Villavicencio municipality, allowing succession in some areas (Rausch, 2009). This is reflected in the positive trend identified in the period 1986-2019. This type of pattern has been identified in Colombia before associated with socioeconomic changes and armed conflict (Echeverría-Londoño et al., 2016). However, it is not all positive, the livestock production, mining activity, and accelerated urban development have led to a progressive increase in the linearization and asymmetry of forest fragments (Ortiz-Moreno, 2015; Fernandez et al., 2020). This transformation generally occurs due to a gradual deforestation pattern in which the trees of greater size and potential timber use are removed, rather than total devastation, which is not seen in remote sensors and satellite images analysis (Cord and Rödder, 2011). This type of gradual deforestation has negative effects on the supply of nutritional and shelter resources, as Arce-Peña et al. (2019) has found in a rainforest in Mexico with the black howler monkey (*Alouatta pigra*).

An important aspect of landscape structure is connectivity (Volk *et al*., 2018). During the analyzed period a decrease in connectivity was exhibited. This indicates that the gradual deforestation has led to isolation of fragments, however, in some places the fragmented areas had increased due to plant succession. The influence of economic activities on the landscape is evident and worrisome considering that with the urban centers' development in the foothills of the *Cordillera Oriental*, the landscape would be permanently modified, reducing the availability and quality of forest habitat for biodiversity, especially for *P. ornatus*, endemic of the area. This event will deteriorate the gene flow (Crouzeilles et al., 2015), and increase the negative incidents between humans and fauna such as roadkills, zoonosis, attacks by domestic fauna and/or people (Buitrago-Valenzuela and Ceballos-Ladino, 2018).

Records distribution

One of the main threats for *P. ornatus* in Villavicencio is urbanization. This has not been identified in previous studies (Carretero-Pinzon and Defler, 2016; Carretero-Pinzón et al., 2017), and it is particularly important to evaluate for primate species using urban areas as part of their distribution (Estrada et al., 2017). This study found the presence of *P. ornatus* mainly on fragments with a core area greater than one ha as reported by other authors and field observations (Carretero-Pinzon and Defler, 2016; Carretero-Pinzón et al., 2017). Additionally, most of the records were collected in fragments in the plains and foothills, which are the most susceptible to anthropic land-use changes (Carretero-Pinzón et al., 2017).

Half of the records in this study were obtained in protected areas, however, all fragments have threats related to urbanization, livestock production and non-specific deforestation. This shows the deficiencies in the activity regulation in these areas by government entities, and the importance of private initiatives to protect these fragments. In fact, most of the records were made in secondary humid forest and wooded plant communities at initial stages of succession, highlighting the use of anthropized vegetation by *P. ornatus* (Kulp and Heymann, 2015; Carretero-Pinzón et al., 2017; Defler and Carretero-Pinzón, 2018). On the other hand, linearized and irregular fragments such as those identified here, as well as protected areas, represent a challenge for the *in situ* conservation of *P. ornatus*, since the food supply is unknown. Reports of individuals of the species state that they feed on a variety of fruits and insects (Carretero-Pinzon and Defler, 2016; Souza-Alves et al., 2019). Nevertheless, it is unknown if in the study area there is a relation between the nutritional supply and the fragment characteristics, considering that tropical humid forests harbor a great diversity of plants despite the intervention processes (Farah et al., 2017). What is clear is that irregular fragments are more susceptible to the effects of global climate change (Gouveia et al., 2016), fires (Silvério et al., 2019), invasion by domestic and feral fauna (Ünal et al., 2020), pathogens (Arce-Peña et al., 2019), which can be very important for a species with cryptic habits (Kulp and Heymann, 2015; Carretero-Pinzon and Defler, 2016; Colorado Zuluaga et al., 2017).

P. ornatus densities

Densities found in this study are similar and higher than densities reported in other studies (Wagner et al., 2009: 192.2 ind./km^2; Carretero-Pinzón, 2013: 1.07–54.76 ind/

km2). This variation can be explained by multiple factors affecting the species in our study. For example, studies from Wagner et al. (2009) and Carretero-Pinzón (2013) were focused on rural areas where fragment of 51–100 ha or larger are more common and found in higher numbers than in our study area, as those big fragments are the first one to pass through a gradual deforestation (Cord and Rödder, 2011). Higher densities were found in smaller fragments similar to what has been previously reported for the species (Wagner et al., 2009; Carretero-Pinzón, 2013) and other primate species such as *Colobus angolensis palliates* and *Callicebus coimbrai* (Anderson et al., 2007; Chagas and Ferrari, 2011). Competition and extinction processes among primate species can explain this result. A crowded effect in small fragments product of a reduction in forest area and poor dispersal opportunities (Anderson et al., 2007; Wagner et al., 2009; Chagas and Ferrari, 2011; Carretero-Pinzón, 2013). Other possibility is a density compensation effect product of local extinction of other primate species in the area like changes in densities reported in areas with different degrees of hunting (Chapman et al., 2013). Connectivity loss in the landscape studied can be favored the observed pattern of higher densities in smaller fragments by reducing dispersal opportunities.

Variables explaining abundance

Abundance of *P. ornatus* is highly influenced by landscape-scale variables, as reported for rural landscapes of San Martin area (Carretero-Pinzón et al., 2017). However, in Villavicencio municipality influence of variables related to fragment area and shape are also important for the abundance of this species, contrary to what is reported by (Carretero-Pinzón et al., 2017). Although not the same variables were measure in this and previous studies, it is important to highlight that landscape-scale variables are important for *P. ornatus* abundance. In rural areas forest cover are particularly important for presence and abundance of the species (Carretero-Pinzón et al., 2017), while in urban areas connectivity, as well as fragment size and shape are important (this study). The present work represents a first approximation on the population density of *P. ornatus* in the urban and peri-urban area of Villavicencio, and further research is needed. Therefore, management action needs to consider the context, rural versus urban, while evaluating the actions to improve habitat availability at the landscape scale for this species.

The contradictory effect of fragment area on *P. ornatus* abundance in rural and urban areas can be explained by the associated pressures that primate species had in urban areas that can increase mortality, such as road killing, predation by domestic dogs, and killing and capture by humans due to conflict and for the illegal pet trade, common in the study area.

CONCLUSIONS

The presence and abundance of *P. ornatus* in the study area was negatively influenced by the presence of other primate species and the reduced connectivity among forest fragments. Our analysis highlights the importance of variable at the landscape-scale for *P. ornatus* abundance, where increasing habitat area and connectivity is important for the survivorship of this species in the urban and peri-urban area of Villavicencio. Planning strategies promoted by the productive and private sector, which generate connectivity and habitats for primates in anthropogenic areas outside of the conservation units need to be implemented. Conservation initiatives that involve private landowners and governmental entities managing protected areas in restoration projects with native species, as well as preservation of forest around water courses and connectivity through living fences, is recommended. This must be accompanied by environmental awareness in the communities that could be led by Non-Governmental Organizations and educational institutions.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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