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Variation in population density of the Andean night monkey (*Aotus lemurinus*) in areas with different landscape characteristics

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In the Colombian Andes, most of the populations of Andean night monkeys (*Aotus lemurinus*) are found in fragmented landscapes due to the predominant changes in land use in the region. Thus, forest fragments differ in shape, size, degree of isolation, and availability of resources. These factors have had a differential effect on the ecology and permanence of their populations. In order to determine the effect of fragmentation on *A. lemurinus*, we estimated its population density in a protected area of 489 ha of sub-Andean forest - at Otún Quimbaya Wildlife Sanctuary- which is structurally connected with other protected areas; then, we compared it with another study carried out in the unprotected Sub-andean forest fragments (900 ha) of Dapa, at the Valle del Cauca department. To estimate its density, the distance sampling method was used with 31 linear transects, and the data were analyzed with the software Distance. Landscape metrics was estimate with patch analyses tools with a Corine Land Cover information 1:100,000 scale. The plant structure and diversity were measurement with transects to 50 x 4 m and taking account the trees with diameter at breast height over 10 cm. We use average comparison to evaluate the similarities between patrons of the population density and explanatory variables. A population density of 39 ind/km^2 was found in our study, which is lower than the 113 ind/km^2 found in the Dapa. This relation was similar to relations of mean shape index, mean patch size and mean diameter at breast height, and inverse with the relations of proportion of the forest in the area, weighted cover index, plant diversity and density of trees. It is likely that the protected area, by being connected and having a greater diversity of primates and trees, allows this population not to suffer from a crowding phenomenon, and that the population does not increase it carrying capacity due to the low presence of competing species, conversely to what could be occurring in the unprotected fragments. Conversely, high density in Dapa could be reflect a system depletion in diversity and ecological processes.

En los Andes colombianos, la mayoría de las poblaciones de monos nocturnos andinos (*Aotus lemurinus*) se encuentran en paisajes fragmentados debido a los cambios en el uso de suelo predominantes en la región. Los fragmentos de bosque difieren en forma, tamaño, grado de aislamiento y disponibilidad de recursos. Estos factores han tenido un efecto diferencial en la ecología y permanencia de sus poblaciones. Para determinar el efecto de la fragmentación sobre *A. lemurinus*, se estimó su densidad poblacional en un área protegida de 489 ha de bosque subandino - Santuario de Fauna y Flora Silvestre Otún Quimbaya- que está estructuralmente conectado con otras áreas protegidas; luego, lo comparamos con otro estudio realizado en fragmentos de bosque Subandino no protegidos (900 ha) de Dapa, en el departamento del Valle del Cauca. Para estimar su densidad se utilizó el método de muestreo a distancia con 31 transectos lineales, y los datos se analizaron con el programa Distance. Las métricas del paisaje se estimaron con herramientas de análisis de parche con información Corine Land Cover a escala 1:100,000. La estructura y diversidad de las plantas se midió con transectos de 50 x 4 m y teniendo en cuenta los arboles con un diámetro a la altura del pecho de más 10 cm. Usamos la comparación de medias para evaluar las similitudes entre los patrones de la densidad de población y las variables explicativas. Se encontró una densidad poblacional de 39 ind/km^2, menor a los 113 ind/km^2 encontrados en Dapa. Esta relación fue similar a las relaciones de índice medio de forma, tamaño medio de parche y diámetro medio a la altura del pecho de los árboles, e inversa a las relaciones de proporción de bosque en el área, índice de cobertura ponderado, diversidad vegetal y densidad de árboles. Es probable que el área protegida al estar conectada y tener una mayor diversidad de primates y árboles, permita que esta población no presente un fenómeno de hacinamiento, y que la población no aumente su capacidad de carga por la baja presencia de especies competidoras, al contrario de lo que podría estar ocurriendo en los fragmentos no protegidos. Por el contrario, la alta densidad en Dapa podría reflejar un agotamiento del sistema en diversidad y procesos ecológicos.

Keywords: Abundance; Landscape metrics; lemurine owl monkey; plant diversity and structure; Sub-andean Forest.

Introduction

The reduction, loss, and fragmentation of natural or semi-natural habitats are considered the main causes of the biodiversity crisis (Santos and Telleria 2006). Fragmentation increasingly modifies the environmental space accessible for species, reducing the available territory as well as the access to resources, precipitating population decline until reaching local extinctions; it also increases the amount of edge relative to the amount of interior habitat (Bender *et al.* 1998). Historical, geographical, and ecological processes have caused the largest proportion of the Colombian population is located in the Andean region and the Caribbean; therefore, these regions are the most affected in terms of transformation and fragmentation of their natural ecosystems (including mountain ranges of the Andes and its valleys; Kattan 1998; Etter and van Wyngaarden 2000).

This situation affects the Andean night monkey, *Aotus lemurinus* (Aotidae), which is categorized as Vulnerable (VU), on the IUCN red list, by a reduction in population size ≥ 30% over the last 10 years that is inferred by a decline in area of extent of occurrence and it not have ceased (Link *et al.* 2021a) and in the list of threatened species of the Colombian fauna (MADS 2018). These monkeys inhabit mature and advanced successional montane forests between 1,000 to 3,200 m of elevation, in Colombia, Ecuador, and Venezuela. They can also occupy fragments within agricultural areas, such as coffee plantations (Defler 2010). The potential distribution range of *A. lemurinus* in Colombia was 172,382 Km^2 and the remnant is 63,508 Km^2 with a loss of 63 % from 1990 to 2016 (Defler 2020).

Population density is a parameter that relates to the population and the area occupied by its individuals. This parameter is spatially and temporally dynamic, therefore, its monitoring is essential to detect trends and implement effective management strategies, as well as to compare their effectiveness (Anzures and Manson 2007; Arroyo *et al.* 2007). Thus, in this work, the population density of *A. lemurinus* in the Wildlife Sanctuary Otún Quimbaya was estimated to evaluate the differences with the results obtained in a previous study carried out in a non-protected area known as the Dapa region, Valle del Cauca (Hirche *et al.* 2017).

Materials and methods

Study area. The Wildlife Sanctuary Otún Quimbaya is located on the western slope of the Central Cordillera, Pereira municipality, Risaralda Department of Colombia (Figure 1). It comprises 489 ha and is located between 1,750 and 2,276 m of elevation. The average annual temperature is 16.8 °C, and the average rainfall is 2,638 mm/year. The Sub-Andean forest that it protects is part of a biological corridor of the Eje Cafetero Regional System of Protected Areas, which includes Los Nevados National Natural Park (58300 ha), Ucumarí Regional Natural Park (3986 ha), Barbas Bremen soil conservation district (9,651.90 ha), among others (Parques Nacionales Naturales de Colombia-PNN 2018).

Population Density. The distance sampling method with linear transects was used; this method involves measuring the perpendicular distance from the transect to the point where the animal was observed, or the geographic center of the observed group. The distribution of detection distances is then used to build a detection function that determines detection probabilities as a function of distance from the transect, assuming that there is a 100 % probability of detecting an animal on the transect and the probability decreases with perpendicular distance. The detection function allows an estimation of densities within a band extending on both sides of the transect, based on encounter rates and correcting for undetected individuals. With this method, transects can be resampled to increase the sampling effort for calculating encounter rates, and no individual recognition is necessary (Buckland *et al.* 2015). The fieldwork was carried out between July and December 2018; 31 transects were systematically located and separated in such a way that they covered as much area as possible whereas assuring the independence of the observations (Figure 1). The total length of the transects, it is mean, the sum of the distance of all transects was 11,770 m (mean length of 380 m; SD ± 34). The samplings were carried out between 18:30 and 0:30 with the appropriate conditions for data collection, mainly in the absence of rain. Each transect was traveled between 8 and 11 times, accumulating total sampling efforts of 106 km. Generally, the nocturnal monkeys were located by their vocalizations, the reflection of red light in their eyes, and the noise made by tree branches with their movements (Castaño *et al.* 2010). Once the individuals of *A. lemurinus* were visualized, the perpendicular distance, the number of individuals, time, and coordinates were taken.

The reference study, to compare the local density of this primate and infer the potential effect of some explanatory variables, was carried out in the Dapa region, between May and July 2015 with the same methodology of the current study, *i. e.*, Distance sampling (Hirche *et al.* 2017). This method estimates unbiased population density given that it estimates detectability by site and species incorporating the effect of the observer, weather, vegetation features, etc. So, the estimations between any two or more places are comparable; of course, the sampling design (location, number and sampling effort or repetitions) and number of transects (sampling units) varies in each site by area, topography, and relative abundance of the target species (Buckland *et al.* 2015). The population density is variable in space and time; however, we assume that the population density was stable given that the reproductive cycle of the *Aotus* is around three years and there were not notable changes in the any features of the site, that let us to think that the population density could be down, so, in spite of the differences of sampling period, the results of both sites are comparable. The Dapa region is located on the eastern slope of the western mountain range near the city of Cali, department of Valle del Cauca. The elevation in this region varies

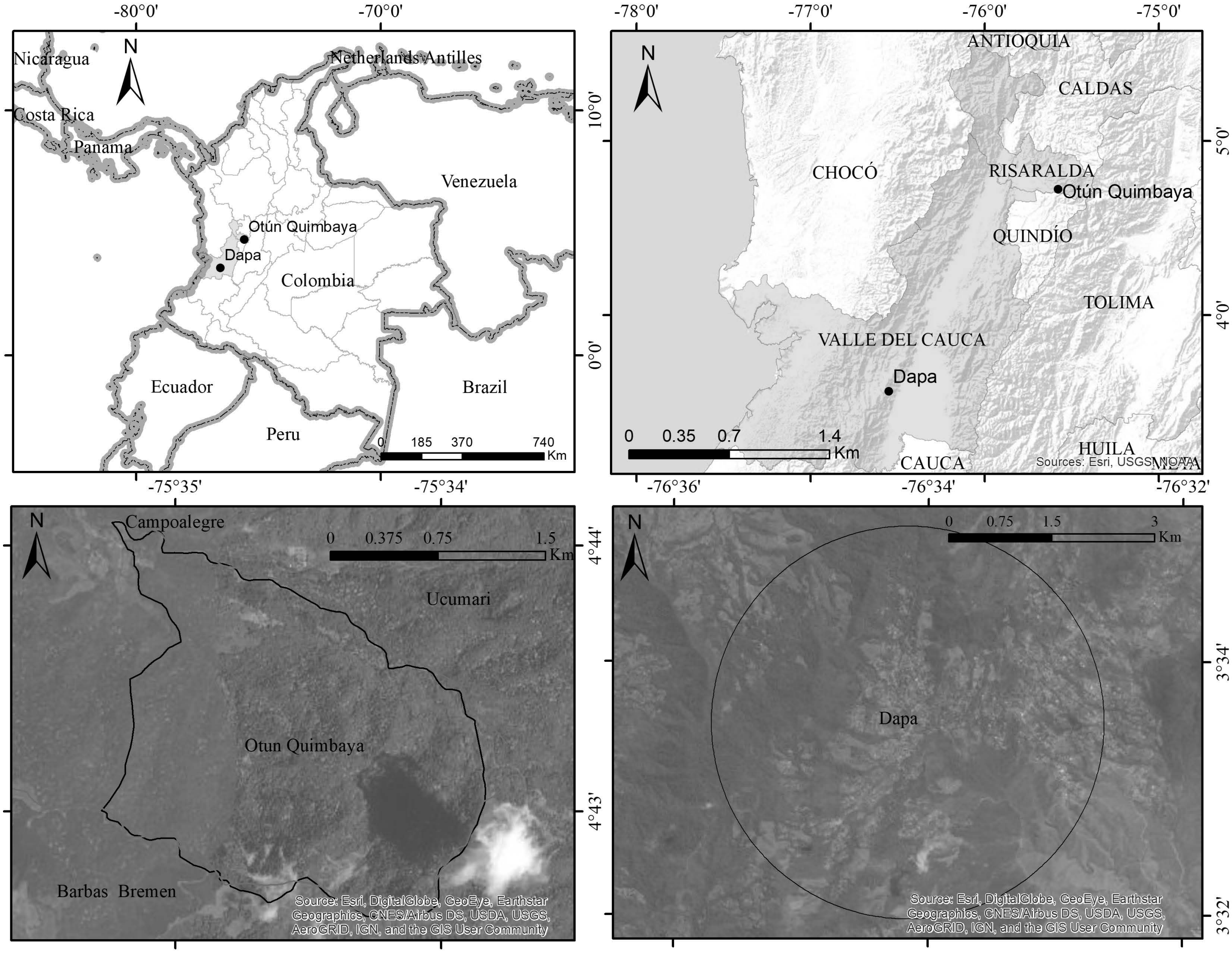

Figure 1. The map shows the location of the Otún Quimbaya SFF (4° 43' 25" N, -75° 34' 455" W) and the Dapa Reserve (comparison site; 3° 33' 46" N, -76° 33' 04"W). Dapa has not a delimited area, so, we delimited the study site with the polygon used to clip the plant cover information to estimate the cover and landscape metrics.

from 1,000 to 2,200 meters above the sea level covering the Andean and Sub-Andean humid forest (IDEAM 2021).

The population density of *A. lemurinus* was estimated with the DISTANCE 7.3 release 2 software (Thomas *et al.* 2010). The objective of the distance sampling analysis is to fit a detection function of the obtained perpendicular distances and use this function to estimate the proportion of individuals that were not detected in the sampling. In this way, the unbased value of the density and abundance of the sampled species in the total area can be obtained (Thomas *et al.* 2002; Roncancio *et al.* 2011). To find the detection function that best fits the data, the frequency distribution of the perpendicular distances was compared with six models (Key function + expansion series): 1. Half normal - Cosine, 2. Half normal - Hermite polynomial, 3. Uniform - Cosine, 4. Uniform - Simple polynomial, 5. Hazard-rate – Cosine, and 6. Hazard-rate - Simple polynomial. From the previous models, the one that presented the lowest value in the Akaike information criterion (AIC) was chosen. AIC is a quantitative method for selecting the model that best fits the data and uses the least number of parameters (Buckland *et al.* 2010, 2015).

The sample variance of population density was calculated empirically as the sum of the sample variance of the encounter rate, the sample variance of the estimated detection probability, and the sample variance of group size (Buckland *et al.* 2015). For the comparison between the population density estimated in the Wildlife Sanctuary Otún Quimbaya with the study carried out in the Dapa region, a graph of confidence intervals (CI) was made. When the confidence intervals of the sites overlapped more than 25 %, it was considered that there was no positive evidence that the population densities were different, with a 95 % confidence (Cumming *et al.* 2007).

Fragmentation statistics. A local landscape was defined for each of the study sites (Dapa and Otún Quimbaya) with the smallest perimeter circle that included all the transects used for the density sampling. This circle was overlapped on a vector file of land cover polygons (IDEAM 2021). One landscape metrics, weighted coverage index (WCI), and four class metrics were considered: mean shape index (MSI), mean patch size (MPS), class area (CA), and the number of patches (NumP) for each land cover (class) found in each site. The WCI integrates a value that allows measuring the land cover composition and structure (Type of cover and its relative area; Fahrig *et al.* 2011; Roncancio 2021); for this, the covers were classified as follows: Dense Forest = 7, Fragmented Forest = 6, Secondary or transitional vegetation = 5, Mosaic of pastures with natural spaces = 4, Mosaic of pastures, crops, and natural spaces = 3, Pastures = 2, Rivers and others = 1. Then, the value of each cover was multiplied by its size proportion in the local landscape and finally, the products were added to obtain the WCI. The MSI is the shape index average of the patches present in the landscape; it tends to 1 when the landscape fragments are circular or square, and increases without limit when the patches become irregular. The MPS is the total area of each class, divided by the number of fragments in that class; the CA is the total size of each class, and the NumP is the number of patches or fragments present by class, indicating how fragmented is that class. The MPS, MSI, CA, NumP values were estimated in the ArcGis 10.5 program, with the Patch Analysis tool (Mitchel 2005).

Plant structure and diversity. As there was not a characterization of structure and plant diversity for Dapa, we carried out the sampling in both sites. To get a representative sample of the structure and plant diversity in these sites, we stablished, as sampling units, six rectangular vegetation plots with a fixed area of 50 x 4 m (0.12 ha) in each one, these were randomly located in the study area. Trees with 10 cm or more in diameter at breast height (DBH) and 1.50 m in height were selected (Castaño *et al.* 2010). When necessary, samples of plants were taken for immediate taxonomic determination by expert personnel from the protected area. The mean DBH, tree density, and Simpson's inverse index (ISI) were estimated for each site as possible explanatory variables.

Relationship between explanatory variables and population density. To evaluate this relationship, all explanatory variables between the two sites were compared and the result was contrasted with the comparison of densities to evaluate if they had the same behavior. For the structure of the vegetation, comparisons of means were carried out. The assumptions of normality and homogeneity of variances were previously tested. The DAP frequency distribution was not normal (S-W, Otún Quimbaya: $P < 0.001 = 2.48e-13$. Dapa: $P = < 0.001$; F test: $P = < 0.001$); therefore, the nonparametric Mann-Whitney U test was used. For the tree density, we calculate the density per site by dividing the total number of trees and the area of each plot (ha) for each of the study sites (Otún Quimbaya and Dapa); then, the assumptions of normality and homogeneity of variances were tested. The density was adjusted to the normal distribution and was homoscedastic (S-W, Otún Quimbaya: $P = 0.54$, Dapa: $P = 0.80$; $F = 1.122$, $P = 0.85$), leading to a parametric T-test for two independent samples. These tests were performed in Rcmdr package of R (Fox *et al.* 2021). Additionally, Simpson's inverse index was calculated with the Vegan package of R (Oksanen *et al.* 2015). For Simpson's inverse and the fragmentation statistics, arithmetic comparisons were made between the two sites.

Results

Population density. For the Wildlife Sanctuary Otún Quimbaya, the estimated population density of *A. lemurinus* was 39 ind/km^2 (95 % CI = 24.0 to 63.2), and the estimated group density was 20 groups/km^2 (95 % CI = 12.7 to 31.6) with coefficients of variation of 24.7 % and 23.17 %, respectively. This density was estimated from 44 visual records of the species. The model that best fit according to the frequency distribution of the perpendicular distances was the Half-normal with cosine. The effective transect width (ESW) for this species in this locality was 10.39 m (95 % CI = 7.43 to 14.51, CV = 16.7) and the probability of detection was 0.45 (95 % CI = 0.32 to 0.63, CV = 16.7). The average group size was 1.9 individuals (95 % CI = 1.6 to 2.3). The coefficient of variation of the density was influenced by the detection probability 45.7 %, the encounter rate 42.3 %, and the size of the group 12 %. Significant differences were found in the estimates of the primate population densities for both sites (Figure 2), with a 95 % confidence interval.

Fragmentation, plant structure and diversity. Both local landscapes presented the same amount of vegetation covers (5), but of different types and relative area. In Dapa, 47 % of the area was a mosaic of crops, pastures, and natural spaces, while the fragmented forest and secondary or transitional vegetation represented 48 %. For Otún Quimaya, 75 % was Dense Forest and 17 % Fragmented Forest. Therefore, the WCI was higher in Otún Quimbaya. The forest cover in Otún Quimbaya presented more regular forms (Table 1). Comparatively, Dapa presented a higher DAP value and lower tree density, whereas the diversity was relatively similar among sites but bigger in Otún Quimbaya (Table 2).

Discussion

With 39 ind/km^2, the population density found for *A. lemurinus* in Otún Quimbaya was lower than in Dapa (113 ind/km^2). However, our result is similar to population density values found for the genus *Aotus* in other localities, which are mostly between 30 and 40 ind/km^2 (Maldonado-Rodriguez 2011; Roncancio *et al.* 2013; Roncancio *et al.* 2019). The population density of *A. lemurinus* was higher in Dapa, which has more elongated or irregularly shaped forests (higher MSI), with larger fragments (higher MPS; Table 1), and with bigger trees (higher DBH; Table 2). On the other hand, the population density was lower in Otún Quimbaya, which presented more mature plant cover (higher WCI), more forest (higher proportion of forest area), where trees are more abundant (Tree density) and diverse (higher ISI). In relation to altitude, it was found that the population density was lower at higher altitudes.

Table 1. Covers and landscape metrics for SFFOQ and Dapa.

	MSI	MPS	NumP	WCI	% Area	Area
Wildlife Sanctuary Otún Quimbaya						
Dense forest	1.38	270	2	5.24	0.75	540.75
Fragmented forest	1.58	120	1	1.00	0.17	119.63
Secondary or transitional vegetation	2.67	0	1	0.00	0	0.29
Mosaic of crops, pastures and natural spaces	1.97	16	2	0.13	0.04	32.06
Mosaic of pastures and natural spaces	1.73	28	1	0.16	0.04	28.15
Clouds	2.10	1	1	0.00	0.00	0.65
Rivers	1.44	1	1	0.00	0.00	0.63
				6.53		**722.16**
Dapa						
Fragmented forest	2	571	1	1.46	0.24	571.48
Secondary or transitional vegetation	1.9	184	3	1.18	0.24	550.7
Mosaic of pastures, crops and natural spaces	2.24	554	2	1.42	0.47	1107.5
Mosaic of pastures with natural spaces	1.56	31	1	0.05	0.01	31.12
Pastures	1.33	41	2	0.07	0.04	82.30
				4.18		**2343.1**

MSI = mean shape index, MPS = mean patch size, NumP = number of the patches to each plant covers, and WCI = weighted cover index.

These results suggest an apparent tolerance of *A. lemurinus* to various disturbances, which has allowed it to live, reproduce and maintain stable populations in a level of disturbance and forest fragmentation such as that of Dapa. In addition, the species seems able to increase its population density as a result of the local decrease or extinction of other primate species that could compete in some dimensions of the niche (Peres and Dolman 2000; González-Solís *et al.* 2001; Castaño *et al.* 2010). This trend has been found in other primate species, such as *Saguinus leucopus*, for which high population density values (> 100 ind/km^2) have been found in forest fragments where no other primate species were found. Whereas, in fragments where other primates (*Ateles hybridus, Alouatta seniculus,* and *Cebus versicolor*) were present, *S. leucopus* had lower density values (Roncancio *et al.* 2011; Roncancio 2021). For Dapa, it was suggested that the high population density of *A. lemurinus* could be the result of a "density compensation", where an increase in its population carrying capacity is due to the decrease in competition in niche dimensions resulting from the local extinction of other primates (*A. seniculus*, *A. fusciceps,* and *C. capucinus*) that occupied the same area but failed to adapt to the effects of fragmentation of their habitat (Hirche *et al.* 2017). The high densities found in these studies may be the product of situations resulting from, and dependent on, the population dynamics of the species in isolated conditions, the size and functional connectivity of the fragment, as well as the population's ability to adapt (Kattan and Álvarez-López 1996; Harcourt and Doherty 2005; Hirche *et al.* 2017). Also, the heavy hunting of large primates favors the densities of smaller primates that are not usually at risk of being hunted (Peres and Dolman 2000; González-Solís *et al.* 2001).

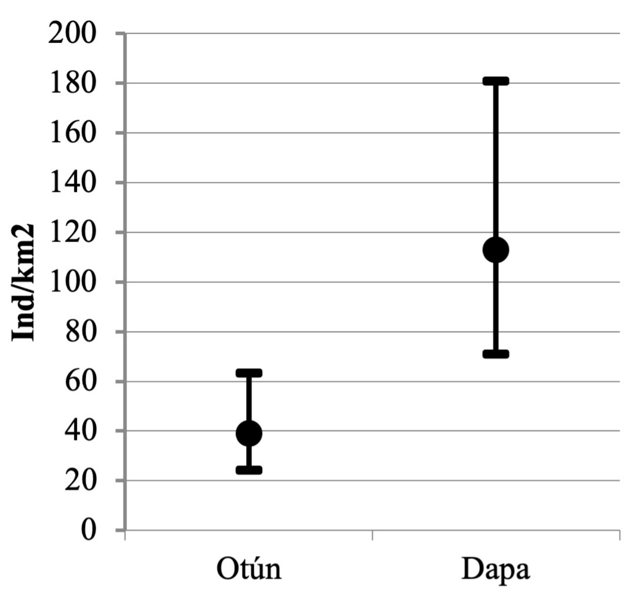

Figure 2. Comparison of confidence intervals of the estimated population density for *Aotus lemurinus* in the study sites (SFFOQ and Dapa).

The Wildlife Sanctuary Otún Quimbaya is a non-isolated area, which is part of a biological corridor for the conservation of sub-Andean and high Andean forests (PNN 2018). This connection explains, in part, the population density results, since it suggests a greater probability of movement of individuals through the corridor, and it has been documented that its distance traveled per night could be from 640 to 901 m (Montilla *et al.* 2021). On the other hand, other species of mammals such as the kinkajou (*Potos flavus*) and the red howler monkeys (*Alouatta seniculus*), as well as other medium-frugivorous such as four species of Cracids, also inhabit this area (PNN 2018), which may be a direct competition for *A. lemurinus*.

Table 2. Metrics of structure and plant diversity for both sites

	DBH (SE)	Tree density (SE)	Simpson Inverse
Otún Quimbaya	18.07 (8.83)	107 (29.09)	9.5
Dapa	99.45 (67.73)	65 (30.82)	10.2

DBH = diameter at breast height, SE = Standard error

The components that contributed the most to the variation in population density were the probability of detection and the encounter rate, which may vary for various reasons. Otún Quimbaya is a mountainous area with many slopes, cliffs, and high diversity in vegetation, therefore, some transects may be more frequented by primates than others, thus varying the quantity and frequency of detections (Roncancio *et al.* 2013; Buckland *et al.* 2015). The size of the group also influenced the variation in population density. Although it has been shown that nocturnal primates are generally in groups of three to five individuals (Castaño *et al.* 2010; Fernández-Duque *et al.* 2001), many detections of only one individual were recorded in this study; this data could come from the dispersion of young individuals by emancipation of the born group (Fernández-Duque and Huntington 2002; Castaño *et al.* 2010). In this sense, it is likely that the *Aotus* population in the Wildlife Sanctuary Otún Quimbaya is reproductively active.

The effects of forest fragmentation and reduction limit the animals to the available fragments, causing a crowding effect (Defler *et al.* 2003; Ramos-Fernández and Wallace 2008). This can generate behavioral changes due to a high level of stress in individuals such as continuous aggression, predation, low survival rates, and birth rates (Milner and Albon 1999; Begon *et al.* 2006); health conditions such as immune depression, the spread of diseases (Gómez-Posada et al. 2009); and cause an increase in the probability of overexploitation of the resources available in the habitat (Hirche *et al.* 2017).

Most of the species of the genus *Aotus* reported in Colombia are in a state of vulnerability (VU) due to the fragmentation suffered by their habitat (Carretero *et al.* 2020; Maldonado *et al.* 2020; Link *et al.* 2021a, b). In particular, for *A. lemurinus*, more of these studies are required to have information on population trends (Defler and Bueno 2010), integrated effective monitoring programs, inventories, and wildlife management and conservation plans. These require specific data such as the size and density of the populations to evaluate the state in which they are found and thus, to be able to carry out management actions at the species level (Lancia *et al.* 1994; Naranjo 2000). Knowing the specific effects of some habitat traits on local populations, and how these respond to them, should contribute to a better understanding of the differences found among protected and non-protected areas for the survival of the species of night monkeys in Colombia.

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Literature cited

Anzures-Dadda, A., and R. H. Manson. 2007. Patch and landscape-scale effects on howler monkey distribution and abundance in rainforest fragments. Animal Conservation 10:69-76.

Arroyo-Rodríguez, V., *et al.* 2007. The influence of large tree density on Howler Monkey (*Alouatta palliata mexicana*) presence in very small rain forest fragments. Biotropica 39:760-766.

Begon, M., C. R. Townsend, and J. L. Harper. 2006. Ecology: Individuals, Populations and Communities. 4th edition. Blackwell Publishing, Oxford, U.K.

Bender, D. J., T. A. Contreras, and L. Fahrig. 1998. Habitat loss and population decline: a meta-analysis of the patch size effect. Ecology 79:517-533.

Buckland, S. T., *et al.* 2010. Design and analysis of line transect surveys for Primates. International Journal of Primatology 31:833-847.

Buckland, S. T., *et al.* 2015. Distance Sampling: Methods and Applications. In Bird Study (Vol. 63, Issue 1). Springer International Publishing. https://doi.org/10.1007/978-3-319-19219-2.

Carretero, X., D. Guzman-Caro, and P. R. Stevenson. 2020. *Aotus brumbacki*. The IUCN Red List of Threatened Species 2020: e.T39915A17923405. https://dx.doi.org/10.2305/IUCN.UK.2020-2.RLTS.T39915A17923405.en. Downloaded on 23 September 2021.

Castaño, J. H., D. Cardona-Ramírez, and J. E. Botero. 2010. Ecología del mono nocturno andino (*Aotus lemurinus*) en fragmentos de bosque subandinos de Colombia. Pp. 69-90, *in* Primatología Colombiana: avances al principio del milenio, (Pereira Bengoa, V., P. R. Stevenson, M. L. Bueno, and F. Nassar-Montoya, eds.). Fundación Universitaria San Martín, Bogotá, Colombia.

Cumming, G., F. Fiona, and D. Vaux. 2007. Error bars in experimental biology. The Journal of Cell Biology 177:7–11.

Defler, T. 2020. *Aotus lemurinus*. Atlas de la biodiversidad de Colombia. Pp. 11, *in* Primates (Olaya-Rodríguez, M. H., E. Noguera-Urbano, and C. Gutiérrez, eds). Instituto de Investigación de Recursos Biológicos Alexander von Humboldt, Bogotá D. C., Colombia.

Defler, T. R., J. V. Rodríguez-M., and J. Hernández-C. 2003. Conservation Priorities for Colombian Primates. Primate Conservation 19:10–18.

Defler, T. R., and M. L. Bueno. 2010. Prioridades en investigación y conservación de primates colombianos. Pp. 193-214, *in* Primatología Colombiana: avances al principio del milenio, (Pereira Bengoa, V., P. R. Stevenson, M. L. Bueno and F. Nassar-Montoya, eds.). Fundación Universitaria San Martín, Bogotá, Colombia.

Defler, T. R. 2010. Familia Aotidae. Pp. 235-257, *in* Historia natural de los primates colombianos (Defler, T. R. ed.). Editorial Universidad Nacional de Colombia, Bogotá, Colombia.

Etter, A., and W. van Wyngaarden. 2000. Patterns of landscape transformation in Colombia, with emphasis in the Andean region. Ambio: A journal of the Human Environment 29:432-439.

Fahrig, L., *et al*. 2011. Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. Ecology Letters 14:101–112.

Fernandez-Duque, E., M. Rotundo, and C. Sloan. 2001. Density and population structure of owl monkeys (*Aotus azarai*) in the Argentinean Chaco. American Journal of Primatology 53:99–108.

Fernandez-Duque, E., and C. Huntington. 2002. Disappearances of individuals from social groups have implications for understanding natal dispersal in monogamous owl monkeys (*Aotus azarai*). American Journal of Primatology 57:219–225.

Fox, J., *et al*. 2021. Rcmdr: R Commander. R package version 2.7-2, https://socialsciences.mcmaster.ca/jfox/Misc/Rcmdr/.

Gómez-Posada, C., *et al*. 2009. Densidad y composición de grupos en tres poblaciones de mono aullador rojo (*Alouatta seniculus*) en Valle y Cauca, Colombia. Boletín Científico Museo de Historia Natural Universidad de Caldas 14:79–91.

Gonzáles-Solís, J., *et al*. 2001. Population density of primates in a large fragment of the Brazilian Atlantic rainforest. Biodiversity and Conservation 10:1267–1282.

Harcourt, A., and D. Doherty. 2005. Species-area relationships of primates in tropical forest fragments: a global analysis. Journal of Applied Ecology 42:630–637.

Hirche, A., *et al*. 2017. Population density of *Aotus* cf. *lemurinus* (Primates: Aotidae) in a subandean forest patch on the eastern slopes of the Western Andes, Region of Dapa, Yumbo, Valle del Cauca, Colombia. Primates Conservation 31:1-7.

IDEAM. 2021. Mapa de Coberturas de la Tierra. Metodología CORINE Land Cover adaptada para Colombia, escala 1:100 000 (Periodo 2018) [Map]. IDEAM–Instituto de Hidrología Meteorología y Estudios Ambientales.

Kattan, G. H., and H. Alvarez-López. 1996. Preservation and management of biodiversity in fragmented landscapes in the Colombian Andes. Pp. 3–18, *in* Forest Patches in Tropical Landscapes (Schelhas, J., and R. Greenberg, eds.). Island Press. Washington, U.S.A.

Kattan, G. 1998. Transformación de paisajes y fragmentación de hábitat. Pp. 76-82, *in* Informe Nacional sobre el estado de la Biodiversidad. Tomo 2: Causas de pérdida de biodiversidad (Chávez M. and N. Arango, eds.). Instituto Alexander von Humboldt. Bogotá, Colombia.

Lancia, R. A., J. D. Nichols, and K. H. Pollock. 1994. Estimating the number of animals in wildlife populations. Pp. 215-253, *in* Research and Management Techniques for Wildlife and Habitats (Bookhout T. A., ed.). Wildlife Society. Bethesda, U.S.A.

Link, A., S. De La Torre, and P. Moscoso. 2021. *Aotus lemurinus*. The IUCN Red List of Threatened Species 2021: e.T1808A17922601. https://dx.doi.org/10.2305/IUCN.UK.2021-1.RLTS.T1808A17922601.en. Downloaded on 11 May 2021

Link, A., B. Urbani, and R. A. Mittermeier. 2021. *Aotus griseimembra* (amended version of 2019 assessment). The IUCN Red List of Threatened Species 2021: e.T1807A190452803. https://dx.doi.org/10.2305/IUCN.UK.2021-1.RLTS.T1807A190452803.en. Downloaded on 23 September 2021.

Maldonado-Rodríguez, A. M. 2011. Tráfico de monos nocturnos "*Aotus*" spp. en la frontera entre Colombia, Perú y Brasil. Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales 35:225-242.

Maldonado, A., *et al*. 2020. *Aotus nancymaae*. The IUCN Red List of Threatened Species 2020: e.T41540A115578713. https://dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS. T41540A115578713.en. Downloaded on 23 September 2021.

Milner, E., and S. D. Albon. 1999. Estimating the contributions of population density and climatic fluctuations to inter annual variation in survival of Soay sheep. Journal of Animal Ecology 68:1235–1247.

Ministerio del Ambiente y Desarrollo Sostenible (MADS). 2018. Ministerio del Ambiente y Desarrollo Sostenible. https://www.minambiente.gov.co.

Mitchel, A. 2005. The ESRI Guide to GIS analysis, Volume 2: Spatial measurements and statistics. ESRI Guide to GIS analysis.

Montilla, S. O. *et al*. 2021. Activity patterns, diet and home range of night monkeys (*Aotus griseimembra* and *Aotus lemurinus*) in tropical lowland and mountain forests of central Colombia. International Journal of Primatology 42:130-153.

Naranjo, E. J. 2000. Estimaciones de abundancia y densidad en poblaciones de fauna silvestre tropical. Manejo de Fauna Silvestre en Amazonía y Latinoamérica (Cabrera, E., C. Mercolli, and R. Resquin, eds.). Instituto Interamericano de Cooperación para la Agricultura. Asunción, Paraguay.

Oksanen, J. *et al*. 2015. Vegan: community ecology package. Ordination methods, diversity analysis and other functions for community and vegetation ecologists. R package ver, 2-3.

Parques Nacionales Natrales De Colombia. 2018. Parques Nacionales Naturales de Colombia. https://www.parquesnacionales.gov.co.

Peres, C. A., and P. M. Dolman. 2000. Density compensation in neotropical primate communities: evidence from 56 hunted and non-hunted Amazonian forests of varying productivity. Oecologia 122:175–189.

Ramos-Fernandez, G., and R. B. Wallace. 2008. Spider monkey conservation in the 21st century: recognizing risks and opportunities. Pp. 351–376, *in* Spider Monkeys: Behavior, Ecology and Evolution of the Genus *Ateles* (Campbell, C. J., ed.). Cambridge University Press. Cambridge, U.K.

Roncancio, N., W. Rojas, and T. Defler. 2011. Densidad poblacional de *Saguinus leucopus* en remanentes de bosque con diferentes características físicas y biológicas. Mastozoología Neotropical 18:105–117.

Roncancio, N., K. Gómez-Cadenas, and F. Quintero. 2013. Comparisons of population density and group structure for the variegated spider monkey (*Ateles hybridus*), Serranía de San Lucas (Bolívar). Pp. 231-244, *in* Primates Colombianos en Peligro de Extinción (Defler, T. R., *et al*, eds.). Colección textos, Universidad Nacional de Colombia, Bogotá, Colombia.

Roncancio-Duque, N., *et al*. 2019. Densidad poblacional y composición de grupos de *Aotus nancymaae* en áreas de aprovechamiento de la especie para experimentación biomédica en el trapecio amazónico colombiano. Neotropical Primates 25:30-37.

Roncancio Duque, N. J. 2021. Effect of landscape modification on primate assemblages of the Magdalena River Valley, Colombia. Caldasia 43:261-273.

Santos, T., and J. L. Tellería. 2006. Pérdida y fragmentación del hábitat: efecto sobre la conservación de las especies. Revista Ecosistemas 15:3-12.

Thomas, L., *et al*. 2002. Distance sampling. Encyclopedia of Environmetrics (El-Shaarawi, A. and W. Piegorsch, eds.). Jhon Wiley and Sons, Ltd. Chichester, U.S.A.

Thomas, L., *et al*. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. Journal of Applied Ecology 47:5-14.

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