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Population-density Monitoring of the Silvery-brown Tamarin (*Oedipomidas leucopus*) in Eastern Caldas, Colombia: Third Sampling

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Abstract: Understanding population trends is key to planning and adapting conservation measures for threatened species. A number of conservation and management actions have been implemented to control deforestation and the illegal pet trade in the Caldas department of Colombia in the range of the white-footed tamarin *Oedipomidas leucopus*[1] (Vulnerable A4cd), and we have have monitored their population densities to evaluate the effectiveness of these interventions. Localities in different vegetation composition and management regimes were selected for population monitoring, using the estimated population of the silvery-brown tamarin as an indicator. In 2021, new population density estimates were obtained and compared with previous estimates from 2006–2008 and 2015. In this recent re-surveying, population densities found in the eastern Caldas region were between 18 and 129 individuals/km². No changes were found in four localities when compared to the previous surveys. In one locality there was an increase in population density from 76 to 129 ind/km². We were unable to survey one previously surveyed, so a new location was included. Our data suggest that measures to control the pet trade of this primate have been successful in this zone. We also evaluated population density differences in the distinct ecosystems: humid lowland forest; humid sub-Andean Forest, and humid lowland secondary vegetation. The population densities differed between the three ecosystems—the population density was higher in the sub-Andean humid forest.

Key words: Abundance, management, monitoring, silvery-brown tamarin, population trends

Resumen: Entender las tendencias de las poblaciones es clave para planificar y adaptar las acciones de conservación, en particular de las especies amenazadas. Dentro de la distribución del tití gris *Oedipomidas leucopus* (Vulnerable A4cd) en el departamento de Caldas de Colombia, se han implementado acciones de manejo para controlar la deforestación y la extracción ilegal de la especie para el comercio de mascotas, así como esfuerzos de monitoreo para evaluar la efectividad de estas intervenciones. Varias localidades que varían en estructura y composición vegetal y estrategias de manejo han sido previamente seleccionadas para el monitoreo de las poblaciones, utilizando la densidad poblacional del tití gris como indicador. Durante 2021, se realizaron nuevas estimaciones de densidad poblacional y se compararon con estimaciones anteriores de 2006-2008 y de 2015. En este último muestreo, las densidades poblacionales encontradas en la región oriental de Caldas estaban entre 18 y 129 individuos/km². En comparación con los muestreos anteriores, no se encontraron cambios en cuatro localidades, mientras que una localidad se encontró un aumento en la densidad poblacional de 76 a 129 ind/km². Otra localidad no pudo ser evaluada y por tanto fue excluida, por lo que se incluyó una nueva localidad en el plan de monitoreo. Parece que las medidas para controlar el comercio de mascotas de este primate han tenido éxito en esta zona. Además, evaluamos las diferencias en las densidades de población entre distintos tipos de ecosistemas, específicamente bosque húmedo basal, bosque húmedo subandino y

1 Formerly of the genus *Saguinus* Hoffmannsegg, 1839, the three northern Colombian and Panamanian bared-faced tamarins—*oedipus*, *geoffroyi* and *leucopus*—were considered sufficiently distinct by Brcko *et al.* (2022) as to warrant their placement in the genus *Oedipomidas* Reichenbach, 1862. The moustached tamarin group were likewise attributed to the genus *Tamarinus* Trouessart, 1904.

vegetación secundaria húmeda basal. Se detectaron diferencias en las densidades de población entre los tres ecosistemas. La densidad poblacional del primate fue mayor en el bosque húmedo subandino.

Palabras claves: Abundancia, manejo, monitoreo, tendencias poblacionales, tití gris

Introduction

The white-footed or silvery-brown tamarin, *Oedipomidas leucopus*, is categorized as Vulnerable A4cd on the IUCN Red List of Threatened Species (Link *et al.* 2021a). This is largely due to its occurrence in a region with one of the highest levels of anthropic transformation in Colombia. The potential range of the species has been estimated at 20,690 km², yet currently only a remnants of 10,428 km² remain (Roncancio-D. and Soto-C. 2020). Forest and secondary vegetation, occur in an area of some 1,845 km², between sea level and 1100 m, in the eastern part of the department of Caldas (municipalities of Samaná, Norcasia, Victoria and La Dorada. These forests have been reduced from an estimated 693 km² in 2002 to 558 km² in 2009 to 515 km² in 2012—a loss of more than 178 km² of suitable habitat over 10 years. Between 2012 and 2018 there was some recovery of native vegetation and currently the area of forest and secondary vegetation amounts to approximately 620 km² (33% of the region) (Colombia, IDEAM 2010, 2012, 2015, 2021). Besides the loss of its forests, the silvery-brown tamarin was the most traded primate and the second most traded mammal in the illegal Colombian pet trade between 2005 and 2009, with an estimated seizure of 519 individuals (Colombia, MADS 2012). Data provided by the regional environmental authorities, Cornare (Corporación Autónoma Regional de las Cuencas de los Ríos Negro y Nare) and Corpocaldas (Corporación Autónoma Regional de Caldas), indicate that the trafficking of silvery-brown tamarins has decreased in the past four years, with an estimated 80 individuals seized between 2020 and 2023.

The severity, scope, and reversibility of habitat reduction and fragmentation, and hunting for the pet trade are recognized as the two main threats to the conservation of silvery-brown tamarins (Franco and Roncancio 2011, International Program for the Conservation of the White-Footed Tamarin, unpubl. report). We, therefore, created an action plan to mitigate the main threats based on a monitoring program that included population density surveys in several priority locations. Surveys of *O. leucopus* carried out in eight localities in eastern Caldas between 2005 and 2015 indicated densities of 37 to 149 ind/km² (Roncancio-D. *et al*. 2008, 2011, 2020; Sánchez -L. *et al*. 2013). In 2015, a resurvey of two of the initial eight localities showed declines in *O. leucopus* populations from 142 to 55 ind/km² and 125 to 40 ind/km². The population was stable in a third location, and there was an increase in numbers at a fourth location. Two of the initial sites were not re-surveyed in 2015 but two new sites were added. Landowners in the two sites where the population density of the tamarin decreased indicated that the pet trade was the cause (Roncancio-D. *et al*. 2020).

Oedipomidas leucopus inhabits tropical dry, tropical humid, tropical very humid, and premontane very humid forests. Within its range, however, the largest proportion of forest is classified as tropical humid and very humid forest. Silvery-brown tamarins are found in old growth dense forest, secondary forest in different stages of succession, and gallery forest, in small patches and more extensive ("continuous") forests. As is typical of tamarins, *O. leucopus* use mostly the middle and lower strata of the forest, between five and 10 m high. Infants have been recorded in February, March, April, May, June, August, September, October and November, suggesting reproductive activity throughout the year (Roncancio *et al.* 2012).

Here, we report on the results of the population density surveys of silvery-brown tamarins in five of six localities sampled in 2015 in eastern Caldas. We were not given permission to survey the sixth site, La Habana, so a new site, El Nepal, was included in the monitoring plan. These six localities differed in their management, ecosystems and vegetation cover (Table 1). We examined the degree to which differences in site management and differences in the extent and presence of suitable forested habitats—humid basal forest, humid sub-Andean Forest, and humid basal secondary vegetation (Colombia, IDEAM 2017)—influence silvery-brown tamarin population density. Precipitation in Humid forests ranges between 2000 and 3000 mm. The lowland forests are those between 0 and 1000 m elevation and the Sub-Andean from between 1000 and 2900 m elevation.

Methods

Study area

The distribution of *O. leucopus* in the Caldas department includes the eastern municipalities of La Dorada, Norcasia, Victoria, and Samaná (Roncancio-D. and Soto-C. 2020). Estimates of the species' population density were carried out in six localities that differ in size, shape, isolation, altitude, and vegetation cover, representing the entirety of habitat variation found in the species' preferred altitudinal range in eastern Caldas (0–1100 m) (Fig. 1; Table 1). Mean temperature and annual precipitation of the sites ranged from 19–27ºC and 1,800–4,200 mm, respectively (Hijmans *et al*. 2005). The two most distant sites were located 37 km apart. The locality of La Habana-Pozo Redondo, evaluated in 2015 (Roncancio-D *et al*. 2020), could not be re-evaluated here due to the landowner's refusal to grant access. We, therefore, included a new location, El Nepal. The other sites

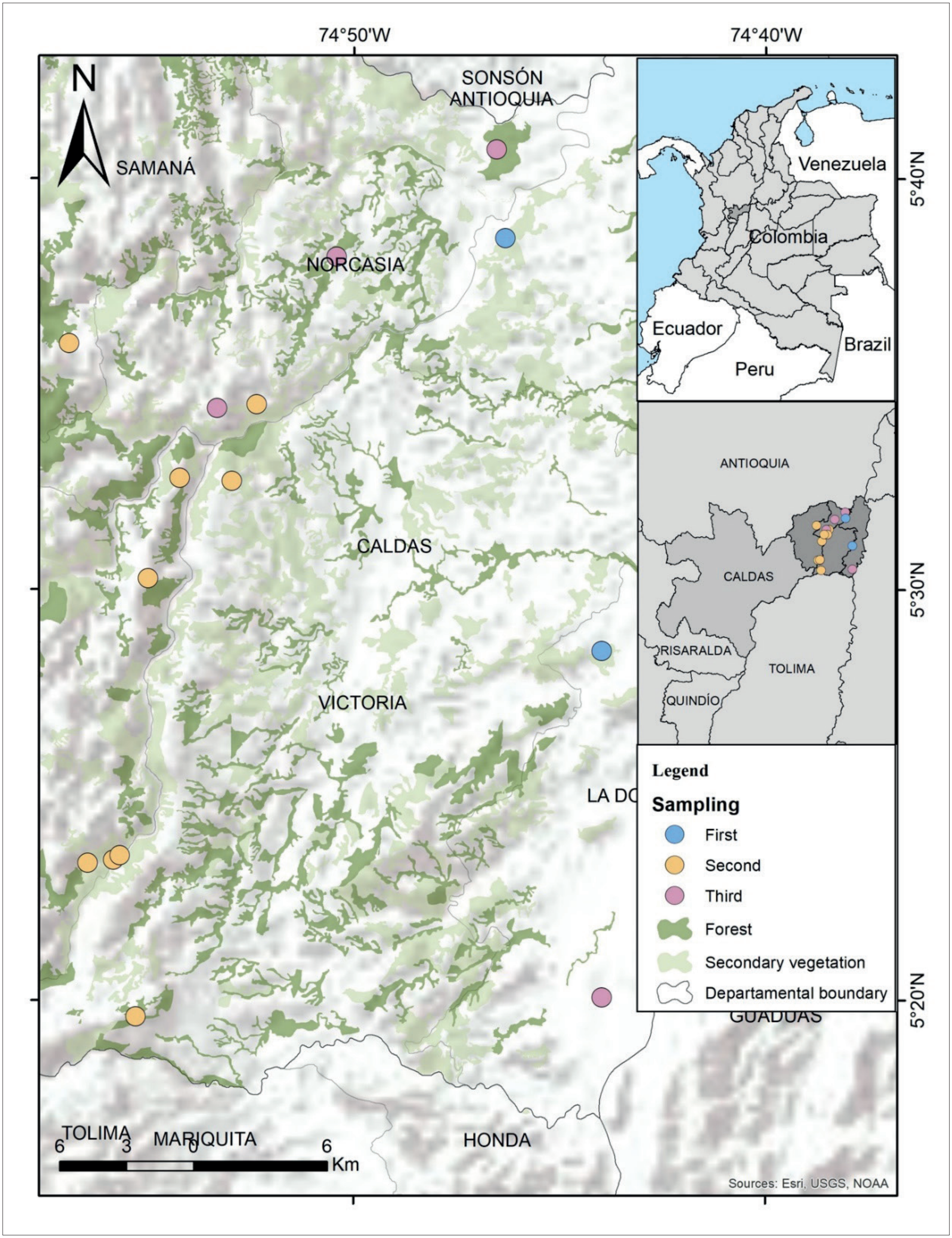

Figure 1. Study area. Shown are the localities sampled once, twice or three times to estimate the population density of *Oedipomidas leucopus*.

Table 1. Localities used to survey and estimate the population density of *Oedipomidas leucopus* in this sampling.

Locality	Area (ha)	Elevation (m)	Ecosystem: cover type* (Ideam 2017, 2021)	Management
Charca de Guarinocito	21	200	Humid basal forest: Mosaic of pastures and natural spaces	Regional protected area: preservation, restoration, sustainability use, low policy control
Río Manso Natural Reserve	313	220–340	Humid basal forest: Dense high forest, secondary vegetation	Private protected area: preservation, medium policy control
El Nepal	82.5	175–280	Humid basal secondary vegetation: secondary vegetation	Private protected area: preservation, medium policy control
Venecia-Jagual Natural Reserve	100	380–420	Humid basal forest: Dense low forest, gallery and riparian forest, secondary vegetation	Private protected area: preservation, medium policy control
Amaní	2552	250–850	Humid basal forest: Gallery and riparian forest, secondary vegetation, open high forest	Private protected area: preservation, high policy control
Bella Vista- Delgaditas-Guarinó**	431	440–1030	Humid Sub-Andean Forest and Humid basal secondary vegetation: Open high forest, mosaic of crops, pastures and natural spaces, secondary vegetation, gallery and riparian forest	Regional protected area: preservation, restoration, sustainability use, low policy control

* The ecosystem could be composed of different types of vegetation cover in each site.
** It is the same locality, but Delgaditas-Guarinó is classified as Humid basal secondary vegetation and Bella Vista as a Sub-Andean Humid Forest (Colombia, IDEAM 2017).

were: Charca de Guarinocito, Río Manso Natural Reserve, Venecia-Jagual Natural Reserve, Amaní, Bella Vista-Delgaditas-Guarinó (Table 1).

Data collection

To estimate the population density of *O. leucopus* at these six localities, we used the distance sampling method of linear transects (Buckland *et al*. 2001). This method involves counting the number of individuals seen by an observer walking along a transect and measuring the perpendicular distance to the point where the animal was observed or to the geographic center of the observed group (Buckland *et al*. 2010). Perpendicular distances were measured with an ACEGMET S9 laser. The length and orientation of the transects established in each locality depended on the size, topography, and shape of each forest (Table 2). The data were collected between 23 February and 27 June 2021. Surveys were carried out from 08:00 to 18:00 by three observers walking simultaneously along one transect each. To ensure that the probability of detection was kept constant across the entire transect, traveling speed was set at 500 meters per hour, and each time that a group of tamarins was located, observers spent no more than 15 minutes doing a complete group count.

Charca de Guarinocito. Given that the Charca de Guarinocito locality is a small (21 ha) and elongated fragment (the entire width is less than 30 m), the distance sampling method with linear transects was not used to estimate the density. Instead, a complete census count was carried out, with all the individuals inhabiting this forest patch counted. Six of us searched for and monitored tamarin groups simultaneously between 06:00 and 18:00, and confirmed the structure and composition of each group and its home range. The accumulated sampling effort in the Charca de Guarinocito was 26 observer-hours.

Distance sampling is an efficient method to estimate population densities as it produces valid and more accurate estimates (i.e., with less sample variance) for a given sampling effort compared to, for example, methods that do not fit the estimation by detection probability and sampling area (Buckland *et al*. 2001; Harris and Burnham 2002; Norvell *et al.* 2003; Kissling and Garton 2006; Somershoe *et al*. 2006). For this reason, it is assumed that the population density estimates obtained with this method and with complete counts (Charca de Guarinocito) are generally comparable (Yoccoz *et al*. 2001). When partitioned by vegetation type, the humid basal forest had 80 transects with 400.08 km of sampling effort, the humid sub-Andean Forest eight transects with 34.10 km (represented only in the Bella Vista locality), and the humid basal secondary vegetation 47 transects with 356.48 km of sampling effort.

Data analyses

The population density of *O. leucopus* was estimated using the DISTANCE 7.3 release 2 software (Thomas *et al*. 2010). Each locality was analyzed independently. The analysis partitioned by vegetation type was performed at the regional level (eastern Caldas) and estimated effective strip size, probability of detection, and cluster size (defined as the number of individuals estimated per group) regionally. The input for the analysis required the label of each transect, the total sampling effort for each transect, the perpendicular distance measurements taken for each observation of tamarin groups or individuals, and cluster size. The objective

Table 2. Number of transects and sampling effort by locality.

ID	Locality	Transects	Sampling effort (km)
1	El Nepal	19	110.68
2	Venecia-El Jagual	26	128.47
3	Río Manso (Reserve)	24	93.28
4	Charca de Guarinocito	NA	NA
5	Bella Vista-Delgaditas-Guarinó	36	279.89
	• Delgaditas	11	79.9
	• Site 1 (Bellavista)	8	34.096
	• Site 2	10	85.40
	• Site 3	7	80.5
6	Amaní	30	178.33
	• Trasvase Río Manso	6	34.8
	• Los Mangos	4	29.7
	• La Clara	5	46.48
	• Sasaima	6	13.25
	• Cañaveral	2	27.4
	• Carrizales	7	26.7
	• Total	**135**	**790.65**

of the distance sampling analysis was to fit the perpendicular distances of each detection with a model function and use this function to estimate the proportion of individuals not detected in the sample (Thomas *et al*. 2002). To find the best-fit detection function, the frequency distribution of perpendicular distances was compared with six models: 1. half normal with cosine expansion series; 2. half normal with hermite polynomial; 3. uniform with cosine; 4. uniform with simple polynomial; 5. hazard-rate with cosine; and 6. hazard-rate with simple polynomial. Model selection was determined by the lowest value in the Akaike information criterion (AIC) (Burnham and Anderson 2004). The density coefficient of variation was estimated empirically from the sample variance of group size, the encounter rate, and the probability of detection (Buckland *et al*. 2015).

Comparison of population densities

A comparison of the estimated *O. leucopus* population densities in the present sampling and the estimates made in 2006–2008 and 2015 was done using a graph of confidence intervals (CI). An overlap in CIs of two density estimates of 25% or more was considered evidence of no significant difference in population densities, with a confidence level of 95% (Cumming *et al*. 2007). The encounter rate was used to compare the Amani and Bella Vista-Delgaditas-Guarinó sites. This rate is expressed as the number of records of tamarin clusters per km or meter travelled. The encounter rate, like density, is a relative measure of abundance, but it differs in that it is not unbiased to the probability of detection. It is assumed to be useful for comparing between sites with similar characteristics in vegetation structure and which were sampled by the same observers over a relatively short period of time with no high variation in weather conditions, in this case, sunny and low wind.

Results

Population density estimations

Rio Manso Natural Reserve. We recorded 52 visual detections of clusters of *O. leucopus* (Table 3). The uniform model with cosine expansion series order 1 had the lowest value of the Akaike information criterion (AIC) and the best fit of observed and expected distributions of perpendicular distances (Table 3). The effective strip width was 14.32 (95% CI = 11.95–17.15), and the probability of detection was 0.59 (95% CI = 0.49–0.71) (Table 3). The number of individuals in each cluster-detection event ranged from 1–12, with an estimated mean value (expected cluster size given the regression between the natural logarithm of the group size and the probability of detection) of 3.85 (95% CI = 3.16–4.70) (Table 4). We calculated a population density of 74.99 individuals/km² (95% CI = 47.466–118.46) and 19.47 groups/km² (95% CI = 12.82–29.58), with coefficients of variation of 23.06 and 20.3%, respectively (Table 5). The variance of the individual density was composed of the detection probability at 15.2%, the encounter rate at 66.2%, and the group size at 18.6%. The survey results of this locality and the other localities are summarized in Tables 3–6 and can be read following the previous format in the same order as the tables.

Density comparisons between re-surveys

For the Charca de Guarinocito site, an arithmetic increase in density was observed between the 2015 and 2021 surveys. In contrast, for the Río Manso Natural Reserve, the Venecia-El Jagual Natural Reserve, Amaní, and Bella Vista-Delgaditas-Guarinó, there was no statistically significant change in density (i.e., confidence intervals overlap more than 25%) with respect to the 2015 sampling (Roncancio-D. *et al.* 2011, 2020) (Fig. 2). Given the previously mentioned circumstances, no comparison could be made for the Habana-Pozo Redondo site. The recorded density at El Nepal was one of the lowest in the region (Fig. 2).

Compared to 2015, the differences in the number of recorded individuals per kilometer in 2021 at the Amaní sites were smaller, suggesting that the population distribution is relatively more uniform throughout the landscape. Sasaima was found to have the highest relative abundance of tamarins (0.75 individuals per km travelled). While Cañaveral had the highest number of observed individuals per kilometer in 2015 (1.48), it dropped to the second lowest in 2021 (0.36) (Table 7). At the Bella Vista-Delgaditas-Guarinó, Site 1 (Bella Vista), we recorded the highest relative abundance. This also was the only site that was found to indicate an increase in the number of groups detected per kilometer travelled. The other three sites showed decreases, but the relative abundances of detections were closer between the sites (Table 7).

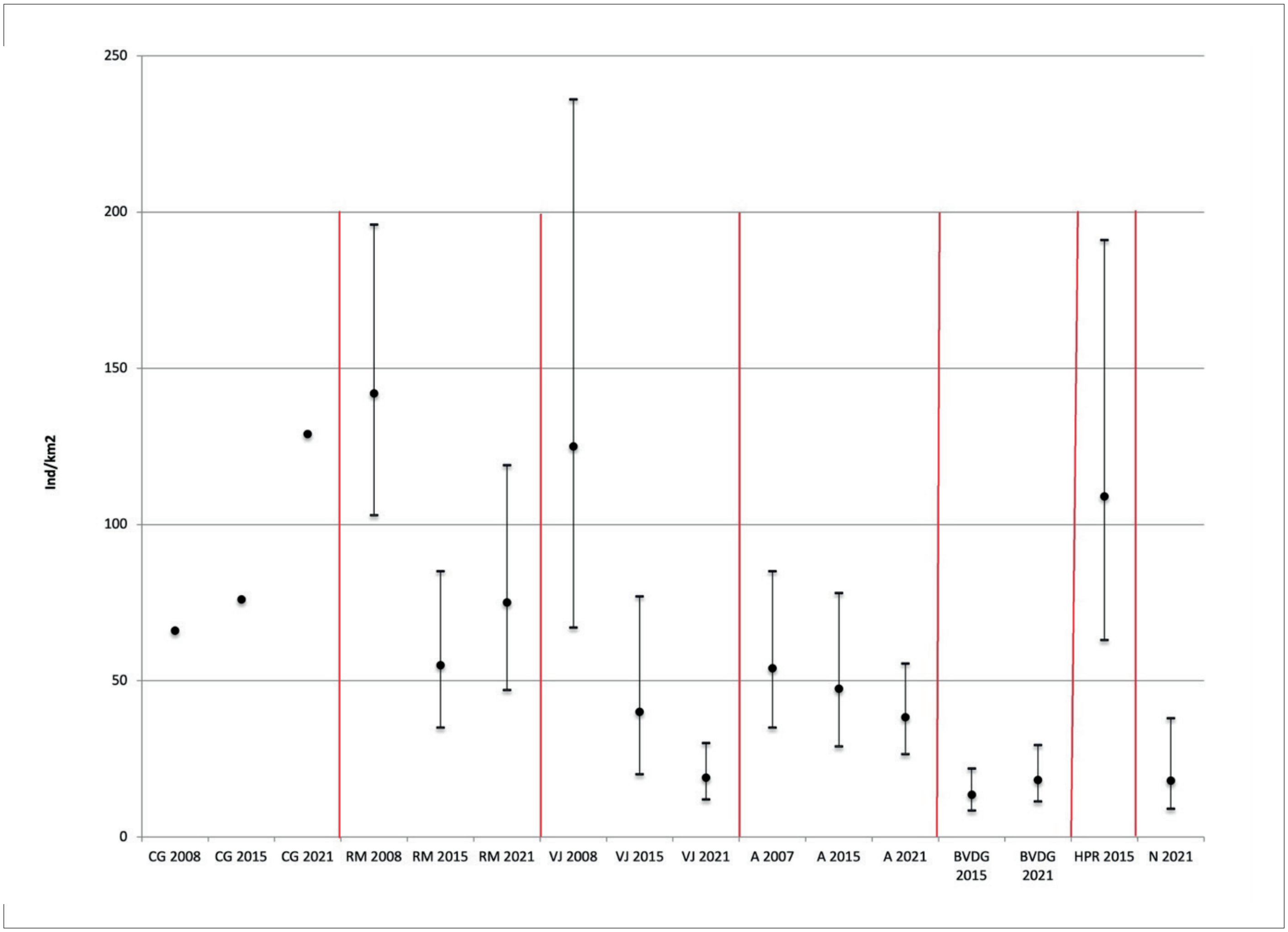

Figure 2. Population densities of *Oedipomidas leucopus* in the current sampling (2021) and previous estimates (2008, 2015) for Charca de Guarinocito (CG), Río Manso NR (RM), Venecia NR (VJ), Amaní (A), and Bella Vista-Delgaditas-Guarinó (VBDG) (Roncancio-D et al. 2011, 2020; Sánchez-Londoño 2013). La Habana (HPR) and Nepal (N) have one sampling each. When CIs of two density estimates show an overlap greater than 25%, it is considered evidence that the population densities are not significantly different, with a confidence level of 95% (Cumming *et al*. 2007).

Table 3. Fitted models based on the distribution of the frequencies of the detection distances of Oedipomodas leucopus records for each locality.

Locality	Records	Key function	Expansion series	Effective strip width	Probability of detection
Charca de Guarinocito	NA	NA	NA	NA	NA
Río Manso NR	52	Uniform	Cosine	14.32 (11.95–17.15)	0.59 (0.49–0.71)
El Nepal	13	Uniform	Cosine	12.26 (8.42–17.85)	0.61(0.42–0.89)
Venecia-Jagual NR	19	Uniform	—	16.34	1.0
Amaní	64	Half Normal	—	15.22 (12.24–18.94)	0.7 (0.49–0.76)
Bella Vista-Delgaditas-Guarinó	59	Hazard rate	—	17.93 (14.89–21.59)	0.56 (0.47–0.67)

After compiling the results from all the localities and sites, the regional population density from the 2021 re-surveying of *O. leucopus* in eastern Caldas was estimated to be 34.76 individuals/km² (95% CI = 24.12–50.1). Comparing vegetation types, there was no statistical difference but higher tamarin population densities were found in the sub-Andean Forest followed by the humid lowland forest. The humid lowland secondary vegetation had the lowest population density (Table 8).

Table 4. Estimated cluster size of *Oedipomidas leucopus* individuals for each locality (CI = Confidence Interval).

Locality	**Cluster**	**Cluster size 95% CI**	**Range**
Charca de Guarinocito	9	-	6–14
Río Manso NR	3.85	3.16–4.7	1–12
El Nepal	3.84	2.5–5.36	2–7
Venecia-Jagual NR	4.16	3.27–5.3	2–8
Amaní	3.25	2.74–3.86	1–8
Bella Vista-Delgaditas-Guarinó	3.1	2.55–3.77	1–11

Table 5. Population density of *Oedipomidas leucopus* individuals for each locality in 2021 (CV D = Coefficient of variation for the density of individuals).

Locality	**Density (ind/km²)**	**Density Confidence interval (ind/km²)**	**CV D**	**Density (cluster/km²)**
Charca de Guarinocito	129	NA	NA	14
RNSC Río Manso	75	48–119	23.06	20
El Nepal	18	9–38	36.1	5
RNSC Venecia - Jagual	19	12–30	23.9	5
Amani	38	27–56	18.8	12
Bella Vista-Delgaditas-Guarinó	18	11–29	24	6

Table 7. Comparison of relative abundances (number of records per km travelled) of *Oedipomidas leucopus* in the different sites evaluated in Amaní and Bella Vista-Delgaditas-Guarinó between 2015 and 2021.

Site	**2015**	**2021**	**Site**	**2015**	**2021**
Cañaveral	1.48	0.36	Site 1- Bella Vista	0.34	0.44
Carrizales	0.18	0.37	Site 2	0.48	0.18
La Clara	0.06	0.37	Site 3	0.25	0.19
Los Mangos	0.74	0.30	Delgaditas	0.55	0.19
Sasaima	0.26	0.75			
Trasvase Río Manso	0.35	0.40			

significant differences was not feasible due to the large confidence interval (CV = 32). In our study, we found the densities by locality varied between 18 and 29 ind/km². Without taking into account the Charca de Guarinocito locality, which has presented a persistent increase in density from 66 in 2008, to 76 in 2015, and 129 by 2021, the mean density across our study sites varied between 18 and 75 ind/km². This result is consistent with that of a 2015 estimation, that reported a silvery-brown tamarin density of between 14–109 ind/km²(Roncancio-D. *et al*. 2020). In contrast, prior samplings carried out between 2005 and 2008 recorded densities of 54–149 ind/km² (Roncancio-D. *et al*. 2008, 2011), suggesting that in some localities there was a relatively recent

Table 6. Component percentages of variance of the population density of *Oedipomidas leucopus* for each locality (NR = Natural Reserve).

Components percentages of variance	**Charca de Guarinocito**	**Río Manso Natural Reserve**	**El Nepal**	**Venecia Natural Reserve**	**Amaní**	**Bella Vista-Delgaditas-Guarinó**
Probability of detection	—	15.2	23.2	0	33.8	14.8
Encounter rate	—	66.2	59	76.7	45.6	69.0
Cluster size	—	18.6	17.8	23.3	20.6	16.2

Discussion

In this study, we carried out temporal replications of the monitoring plan for *O. leucopus* in eastern Caldas of Colombia to determine the trends in the population density of the species in some priority sites in this part of its range.

Both, the regional results and those from each vegetation type individually are within the mean values of population density (between 6–149 individuals/km²) reported for silvery-brown tamarins as a reference in its entire distribution (Roncancio-D. *et al*. 2008, 2011, 2020; Sánchez-Londoño 2013; Bonell-Rojas *et al*. 2018; De Luna and Link 2018; Roncancio-D. 2021). While the population density in the humid sub-Andean Forest is likely higher than the other two vegetation types, this forest was poorly represented in the sampling (low sample size), and thus detecting

Table 8. Regional population density (eastern Caldas) and population density partitioned by vegetation type of *Oedipomidas leucopus* in the 2021 survey (ESW = Effective strip width; p = probability of detection).

Ecosystem	**D ind/km²**	**95% CI**	**CV**	**ESW**	**p**	**Cluster size**
Regional	34.76	24.12–50.1	16.94	15.77	0.49	3.52
Humid basal forest	37.5	29.3–48.2	12.67			
Humid sub-Andean Forest	48.95	23.69–101.13	32.00			
Humid basal secondary vegetation	17.79	11.75–26.94	20.94			

crowding phenomenon in 2008, probably, after which the population densities of *O. leucopus* have been declining to their carrying capacity. On the other hand, the *O. leucopus* populations in the Río Manso and Venecia-Jagual natural reserves declined by 61% and 70%, respectively, between 2008 and 2015, probably associated with illegal pet trade (Roncancio-D. *et al*. 2020). By contrast, such declines were not evident between 2015 and 2021 and the population densities were similar. The maintenance of the population density of *O. leucopus* between 2015 and 2021 in these two localities, is likely due to successful efforts of the environmental authorities, with activities such as police control and education that reduce and, in some places, eliminate the pet trade in the species. Similarly, the sites of Amaní and Bella Vista-Delgaditas-Guarinó showed no change in their tamarin population densities across samplings (Roncancio-D. *et al*. 2020; Sánchez-L. *et al*. 2013) due to the fact that both zones are protected areas, private and public respectively, with police control, restoration activities, environmental education and other measures for their preservation. Finally, data from Charca de Guarinocito indicate a trend of increasing population size (from 14 individuals to 27 individuals) and population density (from 66 to 129 ind/km²), assuming no change in the availability of suitable habitat. Currently, there are new patches of scrubland in this locality, but we could not confirm if they are being used by the tamarins—if yes, with the same population size, the population density would be lower.

For Amaní and Bella Vista-Delgaditas-Guarinó, we could only compare the numbers from 2015 to 2021. Some sites showed an increase, others a decrease, in relative abundance. The Bella Vista site had the highest tamarin relative abundance compared to each of the other three sites at Bella Vista-Delgaditas-Guarinó. The population at Bella Vista showed an increase of more than 20% in 2021 compared to 2015. The populations at the other three sites had declined by 25–65%, which effectively offset the overall population density in this locality. The population increase at Bella Vista may have been due to the permanent presence of an environmental authority, Corpocaldas, that provides adequate control and surveillance of the implementation of management strategies for the area, which include police control, forest restoration and agreement of land use with related landowners. The declines of the tamarin population in the other three sites could be the result of improvements in forest connectivity and habitat recovery of the area. Between 2012 and 2018, the area of forest and secondary vegetation increased by14 ha, with the number of forest patches being reduced from six to five—more area, fewer patches. This led to a reduction in the effects of fragmentation (in size and isolation) in areas that had been largely deforested for agricultural expansion (Spatial statistic estimated by authors, Colombia, IDEAM 2015, 2021).

The tamarin population density estimates recorded for the localities sampled in eastern Caldas between 2005 and 2021 are high when compared with estimates from continuous forests (Roncancio-D. 2021) or those estimated for other species such as *O. geoffroyi, Tamarinus imperator, T. inustus*, *T. mystax*, *T. labiatus*, *Saguinus midas,* and *S. ursulu*s, which include studies in both fragmented and continuous landscapes, and habitats of different forest types. The densities found for these tamarin genera usually range from 20–30 ind/km² (Peres 1997; Calouro *et al*. 2018; Heymann *et al*. 2021; Link *et al*. 2021b; Mendes-Oliveira *et al*. 2021; Mittermeier *et al*. 2021; Palacios *et al*. 2021; Ravetta *et al*. 2021). Some of our estimates are five times higher. The relatively higher densities of certain primate species in fragmented landscapes have been explained as a crowding phenomenon caused by habitat reduction and fragmentation, where populations are forced to concentrate into a small space (Gestich *et al*. 2021). This situation can result in saturation of forest fragments, overexploitation of resources, increased competition, predation, and, consequently, reduced survival and reproduction rates (Lino *et al*. 2019). On the other hand, it has been suggested that some tamarin species tolerate and probably benefit from some fragmentation processes, leading to an increase in their populations where forests are maintained in succession and maintain a mosaic of forest types, secondary, edge, and primary forest (Snowdon and Soini 1988; Garber 1998). This type of forest coverage was likely the scenario that supported the evolution of the genus and to which it is best adapted (Rylands 1996).

When confined to a fragmented and isolated forest patch, the probability of a species to persist depends on its effective population size, life history traits, genetic variability, and stochastic processes (i.e., diseases, extreme climatic events) (Fahrig 2017; May *et al*. 2019). In Caldas, of the four diurnal primates originally occurring in the region only *O. leucopus* was found in La Charca de Guarinocito and Bella Vista-Delgaditas-Guarinó, and in four of the six Amaní sites (Cañaveral, Carrizales, Sasaima, and Trasvase Río Manso). The red howler, *Alouatta seniculus*, was recorded In La Clara and Los Mangos de Amaní, in Río Manso and the El Nepal Reserva Natural de la Sociedad Civil (RNSC) in addition to *O. leucopus*, with one (0.022 records/km), five (0.16 records/km), 10 (0.10 records/km), and 13 (0.12 records/km) times, respectively. For the Venecia – El Jagual Reserva Naturale de la Sociedad Civil (RNSC), *Cebus versicolor* was detected five times (0.04 records/km), a species that in 2015 had only been detected in La Habana – Pozo Redondo. The higher densities of *O. leucopus* in almost all the localities and the lower densities in the Venecia – El Jagual and El Nepal RNSCs, may be the result of density compensation by population decline of other competing species (McInerny and Etienne 2012; De Almeida-Rocha *et al*. 2017). It is likely that the disappearance or population decline of other primates and other species less tolerant of habitat loss and fragmentation, and associated factors such as hunting pressure (Jonsson *et al.* 2006, Arroyo *et al.* 2007) have decreased competition in some niche dimensions where they overlapped with *O. leucopus* (Hutchinson 1957), resulting in a greater carrying capacity for *O. leucopus* populations. This is consistent with the regression model tested for the four diurnal primates in the Magdalena medio region and with similar studies in the Amazon region (Peres and Dolman 2000; Roncancio-D. 2021).

The greater contribution of the encounter rate to the variance of the population density in all localities and vegetation types suggests that *O. leucopus* may prefer humid lowland and sub-Andean Forest. These forest types are characterized by the presence of trees of native species with a single main trunk and continuous canopy at elevations between 0 and 1800 m and with precipitation around 2000 mm per year. These preferences could be associated with the diet that include species as *Aiouea* sp., *Annona* sp., *Bellucia pentamera*, *Byrsonima spicata*, *Cecropia peltata*, *Cecropia reticulata*, *Cupania americana*, *Dicraspidia donnell-smithii*, *Didymopanax morototoni*, *Doliocarpus* sp., *Heliocarpus americanus*, at least three species of *Inga*, *Ficus killipii*, *Miconia acuminifera*, *Melicoccus* sp., *Muntingia calabura*, *Passiflora* sp., *Pera arborea*, *Piper aduncun*, *Pourouma bicolor*, *Protium* sp., *Richeria* sp., *Rollinia edulis*, *Sorocea sprucei*, *Spondias purpurea*, *Talisia* sp., *Tetrorchidium* aff. *echeverianum*, *Tococa* sp., *Trichospermum mexicanum*, and *Zanthoxylum* sp., proper of Andean native forest in the Neotropical region (Roncancio *et al.* 2012). Additionally, forests with dense, closed canopies rather than secondary vegetation, could reduce the risk of predation, for example, by birds of prey.

A high value in the coefficient of variation of density (>10%) is usually the product of sampling error, mainly due to low sample size. In this case, however, the sample size was large (135 transects), and it can be assumed, therefore, that, in this case, the natural variation of the parameter was quantified, and provides evidence that the species is making a differential use of the available habitat, either by vegetation type or vegetation cover. Future research could use cover-stratified designs to test this hypothesis. Reducing this variation would help to increase statistical power (i.e., the capacity to detect spatial and temporal changes in the measured parameter). In the case of Amaní, which showed the highest precision, the detectable change, increase or decrease (two-tailed) with a power of 0.8 and an alpha of 0.05, is 5.22 ind/km² (13.61 %) for the 38.33 ind/km² estimated in this locality. If the interest of the monitoring plan is to detect only the decline, the detectable change with the same parameters is 4.63 ind/km² (12%). In contrast, for El Nepal, which had the most imprecise estimate, the detectable change would be 6.04 ind/km² (32.82%) (two-tailed) over the estimated 18.4 ind/km², and 5.36 ind/km² (29.12%) (one-tailed). To improve the precision of the population density estimator, the number of transects should be increased until stabilizing the variance in each plant cover, vegetation type and locality. However, the established sampling design systematically covered the greatest amount of area containing suitable habitat in each of the sites, so to increase the number of transects would require a sampling design with less distance between transects. In this sense, it is important to consider that the effective sampling widths in the current study were between 12–18 m. Similarly, it would be beneficial to increase the number of kilometers travelled but this would require raising additional funds and adding additional personnel to the project. We could in future, double the present sampling and achieve the necessary precision to more reasonably detect and conclude that indeed no changes were observed in population densities. This would improve the statistical power and reduce the probability of type II errors in the rejection of the hypothesis (Lindermayer and Likens 2009; McDonald-Madden *et al*. 2010; Reynolds *et al*. 2011). Further work is necessary to identify any associations between changes in land use and tamarin population density within the framework of adaptive management. Adaptive management is defined as a structured, iterative process of robust decision-making in the face of uncertainty, with an aim to reducing uncertainty over time via system monitoring and has the goals of verifying the relationship between threats and the conservation status of the management object to make the control of these threats more cost effective (CMP 2020). The latest reference information for plant cover is the National Legend of Land Cover - CORINE Land Cover Methodology, adapted for Colombia, scale 1:100,000, 2018 period (Colombia, IDEAM 2021); but a finer scale of plant cover characterization is necessary to achieve a temporal and spatial resolution coherent with the density estimates for the region (e.g., 1:25,000).

Structured decision-making processes in wildlife management require accurate monitoring plans. However, many management plans do not include parallel monitoring plans (data collection efforts) that are necessary for explicit conservation, management, and monitoring objectives. Here we implement a monitoring plan at a regional scale that is part of the hierarchical management plan for this primate species and its associated landscape, in order to assess the effectiveness of current management strategies intended to control its two main threats. Using these results, environmental authorities and stakeholders have a more comprehensive diagnosis of the conservation status of the species and the threats it is facing, and may adapt the regional management and monitoring plans accordingly.

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