Received: 21 November 2018 | Revised: 23 April 2019 | Accepted: 25 April 2019
DOI: 10.1002/ajp.22988

RESEARCH ARTICLE

AMERICAN JOURNAL OF PRIMATOLOGY WILEY

Long-term population monitoring of the threatened and endemic black-headed squirrel monkey (*Saimiri vanzolinii*) shows the importance of protected areas for primate conservation in Amazonia

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Funding information
Conselho Nacional de Desenvolvimento Científico e Tecnológico, Grant/Award Number: 300005/2013-0; 452908/2016-7; 201475/2017-0; Ministry of Science, Technology, Innovation and Communications (IDSM/MCTIC); National Council of Technological and Scientific Development (CNPq)

Abstract

Population monitoring of endangered species is essential to the improvement of their management and conservation plans. The black-headed squirrel monkey (*Saimiri vanzolinii*) is a vulnerable species on the IUCN Red List and has extreme geographical endemism, exhibiting the smallest known distribution among Neotropical primates (ca. 870 km^2), over 90% of which occurs in white-water flooded forests within the Mamirauá Sustainable Development Reserve (MSDR), Brazilian Amazonia. To assess the effectiveness of this protected area in conserving the species, we conducted population monitoring of black-headed squirrel monkeys across five consecutive years (2009–2013) on nine trails 2 km each. Each year samples included both low and high river water periods. We used the distance sampling method, recording the distance to each observed social group as well as counting component individuals. We also calculated annual encounter rates based on the number of individuals sighted every 10 km traveled. Densities ranged from 256 individuals/km^2 (2011) to 453 individuals/km^2 (2013), and no seasonal differences were detected. Population size was estimated to be 147,848 mature individuals. Encounter rates ranged from 100 individuals/10 km (2010) to 179 individuals/10 km (2013); no significant difference among years was found. We found that *S. vanzolinii* populations remained stable throughout the years, which indicates that the MSDR has been playing an essential role on protecting this species. Due to difficulties of fulfilling assumptions of the distance sampling method, we consider the encounter rate analysis to be more effective for monitoring this and other *Saimiri* species. Given the critical endemism and worrying conservation status of *S. vanzolinii*, we suggest that monitoring of the species population should be carried out regularly.

KEYWORDS
Cebidae, distance sampling, encounter rate, flooded forests, threatened species

1 | INTRODUCTION

Monitoring of natural resources, including fauna, is an important tool for determining whether conservation efforts have the desired effect for a particular target (Elzinga, Salzer, Willoughby & Gibbs, 2011). In practice, monitoring species' populations consists of observations and repeated analyses that allow the assessment of changes over time, in relation to an initial condition, so it can be determined whether the population is growing, declining or is stable (Elzinga et al., 2011; Comiskey, Dallmeier, & Alonso, 2001; Thompson, White, & Gowan, 1998). The monitoring method used depends on the biological measure to be estimated, as well as the taxa under study. Since each species has its own particular ecological role in ecosystems, one of the criteria adopted to prioritize which taxa should be monitored is their rarity and/or threat status (Yoccoz, Nichols, & Boulinier, 2001). Results of population monitoring of threatened species, for instance, can be used as a proxy for the integrity of an entire ecosystem, as well as help to indicate which conservation and management actions represent the best strategy for a given site (Balmford, Green, & Jenkins, 2003; Hellawell, 1991; Yoccoz et al., 2001).

The Brazilian Amazon has the highest mammalian species richness and rates of endemism in Brazil. For instance, 58% of the 398 mammal species currently known in the region do not occur in any other biome in the country (Paglia et al., 2012). Primates are one of the groups with the highest mammalian species diversity, representing 93 Amazonian species (Mittermeier, 2013), of which 15 are considered threatened with extinction. For many species, there is insufficient information to allow conservation strategies to be planned (ICMBio, 2015). In this context, the creation and maintenance of protected areas are of fundamental importance, as they play an important role in primate conservation across the globe (Chape, Harrison, Spalding, & Lysenko, 2005; Naughton-Treves, Holland, & Brandon, 2005).

The genus *Saimiri* (squirrel monkeys) has one of the widest geographical distributions among primates in the Amazon biome, occurring in nine Amazonian countries in South America (Brazil, Colombia, Ecuador, Peru, Bolivia, Venezuela, Suriname, Guyana, and French Guyana) in addition to two in the tropical forests of Central America (Costa Rica and Panama; Chiou, Pozzi, Lynch-Alfaro, & Di Fiore, 2011; Lavergne et al., 2010). Lynch-Alfaro et al. (2015) designated seven species, suggesting that *Saimiri* historically maintained a lowland wetland niche, since diversification was coincident with the formation of new rivers. Squirrel monkeys can live in primary or secondary forests (Baldwin, 1985), in both upland and floodplain forests (Haugaasen & Peres, 2005; Paim, Valenta, Chapman, Paglia, & Queiroz, 2018).

Studies on social behavior and group structure of free-ranging and captive squirrel monkeys showed a wide variation in these aspects among species, including between populations of the same species from different sites (Zimbler-Delorenzo & Stone, 2011). Home range varies from 120 to 560 ha, while daily range varies from 2 to 5 km. Group size is also highly variable, ranging from 15 to 75 individuals (Boinski et al., 2002; Mitchell, 1990; Stone, 2007). Such variations are related mainly to food availability (Mitchell, 1990; Peres, 1994; Stone, 2007). For instance, *S. boliviensis* increased its home range, including the use of flooded forests to respond to fruit shortage in Western Brazil (Peres, 1994). Social interactions can be egalitarian, female dominant, or variable (male or female dominant; Boinski, 1999; Izar, Stone, Carnegie, & Nakai, 2008; Mendoza, Lowe, & Levine, 1978). Dispersal is not apparently sex-based and can be observed both in females and males (Boinski et al., 2002).

The black-headed squirrel monkey (*Saimiri vanzolinii*) is one of the threatened and endemic squirrel monkeys from Brazilian Amazonia. The species was first described more than 30 years ago (Ayres, 1986), but research on the basic aspects of its ecology and biogeography has started to be conducted only recently (Lynch-Alfaro et al., 2015; Paim & Queiroz, 2009; Paim, Silva Júnior, Valsecchi, Harada, & Queiroz, 2013). *S. vanzolinii* has the smallest known geographical distribution of any primate in the Neotropics (ca. 870 km^2) and is considered to be vulnerable to extinction in National (ICMBio: Paim, Silva Júnior, & Queiroz, 2015) and Global (IUCN Red List: Boubli & Rylands, 2008) assessments. Although the species is not a preferred hunting target, illegal timber removal, climate-change-based habitat conversion, and the risk of hybridization with congenerics represent risks to the long-term survival of this species (IPCC, 2014; Lopes, Valsecchi, Vieira, Amaral, & Costa, 2012; Lynch-Alfaro et al., 2015; Marengo & Epinoza, 2015; Paim et al., 2013; Queiroz & Peralta, 2010). Consequently, estimating population parameters and monitoring their variations over the years are essential actions to determine effective conservation strategies for *S. vanzolinii*.

Over 90% of the entire distribution of *S. vanzolinii* lies within the Mamirauá Sustainable Development Reserve (MSDR; Paim et al., 2013). Established at the end of the 1990s, the MSDR consists of 11,240 km^2 of white-water flooded forests (one of the forest types of Amazonian floodplains) in Central Brazilian Amazonia (Queiroz & Peralta, 2010). The creation of the MSDR was closely linked to strategies for protecting the bald-headed uacari (*Cacajao calvus*), another primate species occurring in the area, but with less threatened conservation status than *S. vanzolinii* (Ordinance 444, 2014). MSDR was the first area to officially protect white-water flooded forests in Amazonia and is widely regarded as a successful model of protection which combines biodiversity conservation with the use of natural resources by traditional human populations (Queiroz & Peralta, 2010). At the time of the reserve creation, *S. vanzolinii* had not been studied yet. Despite the worrying conservation status of *S. vanzolinii*, no population studies have been conducted on the species until the current study, and consequently, the effectiveness of this reserve in protecting the species remained unknown.

Here, we assess population trends of *S. vanzolinii* over five consecutive years through two methods to evaluate the effectiveness of the MSDR in conserving this species. We then used the experience of this long-term population monitoring to discuss advantages and disadvantages of each method, making recommendations for effectively researching the target species and other Amazonian squirrel monkeys in general.

2 | METHODS

2.1 | Study area

The study was conducted in MSDR (03°08′-02°36′S, 65°45′-67°13′W; Figure 1). Located on the mid-Solimões River, in the Central Brazilian Amazon, this is an 11,240 km^2 area of natural vegetation

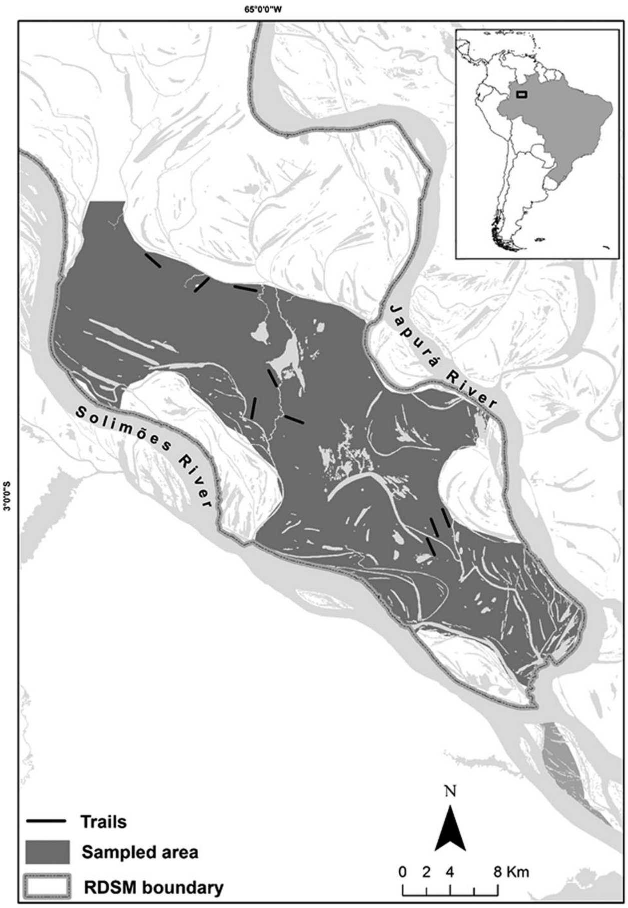

FIGURE 1 Study site location and distribution of monitoring trails. The gray area represents the geographical distribution of *Saimiri vanzolinii* within the Mamirauá Sustainable Development Reserve (MSDR)

seasonally flooded by white-water rivers (Furch, 1984; Junk, Bayley, & Sparks, 1989; Junk, Piedade, Schöngart, & Wittmann, 2012; Klammer, 1984). White-water flooded forests (hereafter *várzea* forests) represent the main type of flooded forests in Amazonia, covering 180,000 km^2 (~2.6% of the Amazon basin). This forest type is supported with a high amount of nutrient-rich suspended sediments, which are drained from Andes (Prance, 1979; Sioli, 1968), making it exceptionally productive for flora and fauna (Junk & Piedade, 1993). The river water level is the most important seasonal variable in the region, reaching an annual amplitude of approximately 10 m on average, ranging from 21.7 to 38.5 m above the sea level (Ayres, 1993; Junk et al., 1989; Ramalho et al., 2009). This annual fluctuation makes it possible to distinguish four seasons: high-water period (May–July); receding water level (August–October); low-water period (November–January); and rising water period (February–April; Ramalho et al., 2009). Due to such characteristics, collecting primate population data in this environment is challenging, especially because moving within the forest is hindered during most part of the year.

The region consists of a complex gradient of habitats differing among them according to terrain height, flooding duration, and floristic composition (Wittmann, Junk & Piedade, 2004; Ferreira-Ferreira, Silva, Streher, Affonso, Furtado, Forsberg, Valsecchi, Queiroz & Novo, 2014). There are three easily-distinguished forest habitats: (a) high *várzea*: areas of higher ground, which are subject to annual flooding for 2–4 months at depths of 1.0–2.5 m; (b) low *várzea*: areas with intermediate flood duration between 4–6 months at a depth of 2.6–5.0 m; and (c) *chavascal*: extensive areas of dense shrubby vegetation, which are flooded for 6–8 months at a depth of 5.0–7.0 m (Ayres, 1993).

Eleven primate species from five families live within the boundaries of the MSDR: Aotide (*Aotus vociferans*), Atelidae (*Alouatta juara* and *Ateles chamek*), Callitrichidae (*Cebuella pygmaea*), Cebidae (*S. vanzolinii*, *S. cassiquiarenis*, *S. macrodon*, and *Sapajus microcephalus*), and Pithecidae (*Cacajao calvus calvus*, *Cacajao calvus rubicundus*, and *Pithecia cazuzai*; Marsh, 2014; Paim et al., 2013; Rabelo et al., 2014; Valsecchi, 2005). Despite its high diversity, only *A. juara*, *C. c. calvus*, and *Saimiri* spp. have been researched since the creation of the MSDR (Ayres, 1986; Queiroz, 1995; Paim & Queiroz, 2009; Paim et al., 2013, 2017, 2018).

2.2 | Data collection

To monitor *S. vanzolinii* populations, nine trails 2-km in length each were randomly installed and georeferenced in the southeast region of the MSDR, covering the main forest types of the reserve and a representative sample of the species' geographic range (Paim et al., 2013; Figure 1). We used the distance sampling method to obtain *S. vanzolinii* densities (Buckland, Burnham, Anderson, & Laake, 1993; Buckland et al., 2001). For this, between 2009 and 2013, two observers (a researcher and a local field assistant) traversed the trails between 7:00 a.m. and 12:00 a.m., at a speed of approximately 1.0 km/h. To avoid possible effects of observers' presence (i.e., repulsion or attraction of groups on the detection rate), trails were sampled at one direction only, and re-sampled only after an interval of at least 2 days. Each trail was sampled three times a month on average during the 3 months of low-water period, and the 3 months of the high-water period.

After detecting a social unit of *S. vanzolinii*, individuals were counted. Due to the large size of the groups and their wide dispersion, only sighted individuals were considered. For individual counting, we considered each social group (i.e., all members engaged in some activity within 100 m of each other), or subgroup (i.e., part of a social group showing temporary fission), as an independent social unit. We followed procedures presented by Peres (1999) to avoid counting same groups or individuals twice on the same sampling occasion (i.e., conducting rapid and accurate counts of individuals in a group, knowing the natural movements of the species, and standardizing a walking speed faster than would be expected by the species), since this may lead to density overestimations.

Immediately after the individuals were counted, we used a tape measure to determine the perpendicular distance of the observer to the site where the first individual was detected. During the high-water period, we used the same trails and followed the same protocol using a canoe. To find the trails during this season, we used marks such as aluminum tags and pink tape installed each 50 m, positioned above the inundation level. We measured the perpendicular distance by hammering a long wooden stem into the middle of the trail, fastening the measuring tape on its top and unrolling it perpendicularly and keeping it straight close to the water level up to the position of the first sighted individual. Due to greater difficulty in locomoting in *várzea* forests during some parts of the year, notably those of receding and rising water levels, data collection was performed only during the low- and high-water periods.

2.3 | Data analysis

We used DISTANCE 7.1 software (Thomas et al., 2010) to estimate population density in each year. Based on several models to represent the distribution of the perpendicular distances, the software calculates the Effective Strip Width (ESW), a value that takes into account the maximum width of observations and the probability of detection of individuals, with the purpose of generating a correction for data lost with the increase in perpendicular distances. As detection probability was constant across years, we gathered all data to test the various models available, selecting the one that best fit to the distribution of perpendicular distances. For this purpose, a chi-square goodness-of-fit test (GOF) was used to determine the best number of truncations as well as of perpendicular distance intervals for the adjustment of the detection function ($p > 0.05$ was considered a good adjustment). Finally, we selected the best model by comparing Akaike Information Criteria (AIC) values among models, choosing the one with the lowest AIC and lowest coefficient of variation of the density (Buckland et al., 1993). After this procedure, we stratified the density estimates per year and analyzed between-year differences by comparing the overlap of the confidence intervals. To ensure that the distance from the trail did not influence in the number of individuals counted, we performed linear regressions between perpendicular distances and log of group size independently for each year. To assess the influence of seasonal effects on the annual model, we also conducted a per-season analysis, comparing confidence intervals of the density for low- and high-water periods; the same statistical assumptions were followed to select the best model. To estimate *S. vanzolinii* population size, we multiplied the lower confidence interval value of the overall density by the size of the species geographic distribution (870 km^2), an approach recommended by the IUCN for population estimates of threatened species (IUCN, 2012). After this, we multiplied the result by the proportion of mature individuals in the group, assuming that this proportion is the same as that reported for *S. collinsi* (58%; Stone, 2006).

To compare with the distance sampling method, we calculated individual encounter rates for each 10 km covered and the respective confidence intervals for each of the 5 years of the monitoring. Calculations were computed using the formula $ER = N \times 10/L$, where ER = encounter rate, N = total number of individuals sighted, and L = total length traveled per year. For this calculation, we considered records from all tracks in a given year, since we were interested in annual and nonlocal effects. Differences among years were assessed via an analysis of variance using the Statistica 8.0 software, considering $p < 0.05$. Data were normally distributed (K-S $d = 0.18$; $p > 0.20$) and homoscedastic ($F = 2.07$; $p = 0.11$). We chose not to calculate group encounter rate, since the *S. vanzolinii*'s group social structure, which presents a fission-fusion strategy, does not allow us to determine whether social units recorded were groups or subgroups.

2.4 | Ethical note

This research complied with protocols approved by the appropriate Institutional Animal Care and Use Committee (Ethical Committee of Instituto de Desenvolvimento Sustentável Mamirauá, under protocol 009/2013). The research adhered to the legal requirements of Brazil, and to the American Society of Primatologists Principles for the Ethical Treatment of Nonhuman Primates, and compliance with all applicable laws in Brazil.

3 | RESULTS

3.1 | Density data and population size

Over the 5 years of study, 410 km were covered in total and 346 social units of *S. vanzolinii* were sampled (Table 2). We recorded 183 social units and 2,464 individuals during the low-water period (256.4 km; 0.71 social unit/km), yielding a density of 255 individuals/km^2 (confidence interval [CI]: 172–379 individuals/km^2; coefficient of variation [CV] = 18.7); and 163 social units and 2,030 individuals in the high-water period (153.6 km; 1.06 social units/km), yielding a density of 483 individuals/km^2 (CI: 365–638; CV = 13.8). Detection distances varied between 0 and 50.4 m (Figure 2). The overlap of confidence intervals between seasons was small but we considered that there were no between-season differences in density. We found no influence of the distances from the trail on the counts of group size, independently of the year ($r < 0.20$; $p > 0.7$).

The model that best fit the distribution of distances was the half-normal with three cosine adjustment terms. The value of the GOF test yielded distance classes of three meters ($X^2 = 5.686$; degrees of freedom [DF] = 12; $p = 0.931$). There was a little variation in ESW values (15.04 m, CV: 6.83%), indicating no significant variation in detection between years (Table 1).

For the 5 years of monitoring, overall density was estimated at 359 individuals/km^2 (CI: 293–439 individuals/km^2; CV = 10.2). The coefficient of variation for the overall density was 10.2%, a value considered adequate in stratified analyses (Buckland et al., 2001). We observed a decrease in density in 2011, with a subsequent rise in 2012 that continued in 2013 (Figure 3). Between-year comparisons of confidence intervals indicate that *S. vanzolinii* populations remained stable over the study years despite the lower density recorded in 2011. The total *S. vanzolinii* population size was estimated at 312,330 individuals (CI: 254,910–381,930 individuals).

TABLE 1 Selection models generated in DISTANCE 7.1 and their respective parameters

Function+adjustment term	AIC	CV (%)	*p*-GOF	ESW (m)	D (ind/km^2)	IC−(D)	IC+(D)
Half-normal+cosine[a]	1722.37	10.2	0.93	15.04	359	293	439
Hazard+simple polynomial	1723.45	12.6	0.71	15.57	347	271	444
Hazard+cosine	1723.45	12.6	0.71	15.57	347	271	444
Uniform+cosine	1723.91	10.3	0.91	15.15	356	291	437
Uniform+simple polynomial	1733.15	9.1	0.21	17.84	303	253	364
Half-normal+hermite	1756.16	8.6	0	23.33	232	196	276

AIC: Akaike information criterion; CV: coefficient of variation (%); D: density (individuals/km^2); ESW: effective strip width (m); IC−(D): lower confidence interval for density (individuals/km^2); IC + (D): upper confidence interval for density (individuals/km^2); p-GOF: probability for values of chi-square goodness-of-fit test.

[a] Selected model.

TABLE 2 Population parameters for *Saimiri vanzolinii* calculated from distances sampling. Such values are used on DISTANCE 7.1 for density estimates

	2009	2010	2011	2012	2013	Total
Number of social units	54	86	43	104	59	346
Number of individuals	547	1171	610	1462	704	4494
Distance sampled (km)	48.2	116.3	63.9	129.9	51.7	410
Average group size	13 (1, 44)	13.5 (1, 44)	14.2 (1, 66)	13.3 (1, 58)	12 (1, 39)	–

Values in parentheses indicate the minimum and maximum size of recorded social groups.

Using the lower confidence interval limit multiplied by the proportion of mature individuals (58%; Stone, 2006), our calculation indicates that the mature population of black-headed squirrel monkeys inhabiting the MSDR comprises 147,848 individuals.

3.2 | Encounter data

Encounter rates showed a similar trend to that found for density analysis and demonstrated population stability. The results ranged from 100 individuals/10 km (2010) to 179 individuals/10 km (2013; Figure 3). Although there was an apparent increase in *S. vanzolinii* abundance in 2013, there was no between-years difference in encounter rates ($F = 0.93$; $DF = 34$; $p = 0.46$).

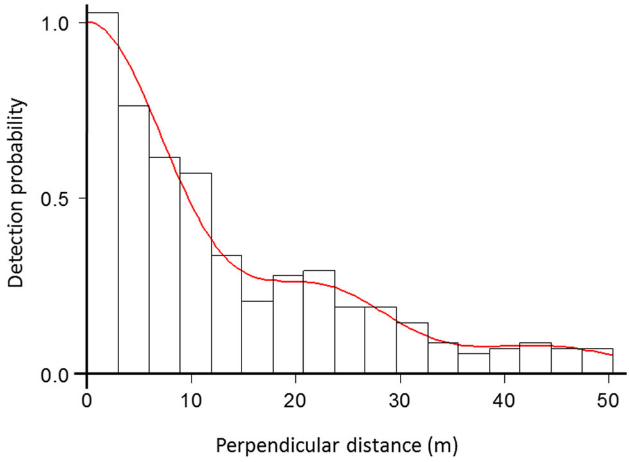

FIGURE 2 Histogram of the distribution of perpendicular distances recorded for *S. vanzolinii* between 2009 and 2013 at the Mamirauá Sustainable Development Reserve. The x-axis represents the distances sampled during the study, with interval adjusted to 3m . Y-axis represents the detection probability based on the selected model. The trend line represents the best detection function adjusted to obtained distances (half-normal cosine)

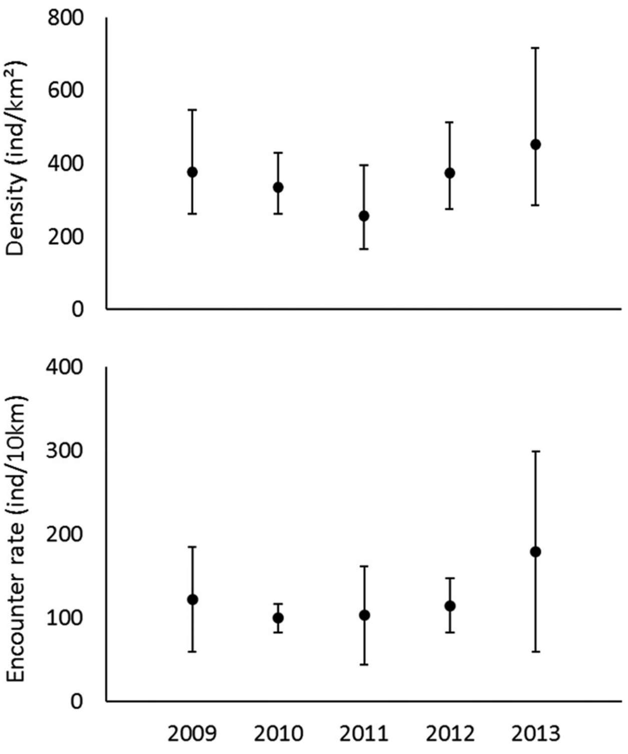

FIGURE 3 Densities (individuals/km^2) and encounter rates (individuals/10 km) of *Saimiri vanzolinii* during 5 years of monitoring. Whiskers represent 95% confidence intervals

4 | DISCUSSION

The population of *S. vanzolinii* remained stable during the monitoring period, indicating that the MSDR, which includes almost the entire geographical distribution of the species, plays an important role in its conservation. Density values were similar in 2009, 2010, 2012, and 2013, with a trend to increase in the last year. The 2011 density was lower than that of 2013. We consider that detection may have been slightly lower in 2011 due to the influence of the environmental conditions in that year. An analysis of 10 years (2005–2015) of river water level data from the MSDR indicates that 2011 and 2013 had unusual seasonal peaks. While 2011 had the second highest flood-level among the 10 years and the second greatest drought recorded in the analyzed period, 2013 showed the second lowest level of peak inundation and one of the lowest water levels recorded (Ramalho et al., 2009; Instituto de Desenvolvimento Sustentável Mamirauá, 2019; Figure 4). Flood amplitude for the years 2011 and 2013 was 13.9 and 11.2 m, respectively, showing a difference of 2.7 m between the years. In any given area, primate diet and pattern of habitat use are determined by environmental factors, that is. seasonality and food availability (Chapman, 1988; Paim, Chapman, Queiroz, & Paglia, 2017). In *várzeas* of Amazonia, the river water level is the most influential seasonal variable (Ayres, 1993; Ramalho et al., 2009), and changes in this variable are associated with fruiting peaks that affect *S. vanzolinii* feeding behavior (Paim et al., 2017). Consequently, such phenomena may influence detection in different periods of the year and between years.

Distance sampling is one of the most widely used methods for population analysis, in which accurate recording of perpendicular distances from the center of the group to the observer is the key element (Buckland et al., 1993, 2001). However, obtaining reliable central distance estimates requires good knowledge of group size and spread, as well as good visibility, factors that are hindered by low visibility in tropical forests (Marshall, Lovett., & White, 2008). An alternative is to use the record of theMarshall et al., 2008 first-sighted individual, which is almost always close to 0 m (on the trail) or near to the observer. However, this type of measurement underestimates perpendicular distances and increases the proportion of detections in smaller distance classes, leading to density overestimations (Chapman, Struhsaker, Skorupa, Snaith, & Rothman, 2010; Whitesides, Oates, Green, & Kluberdanz, 1988). Characteristics of terrain, vegetation, gradient of habitats, and animal behavior need to be considered when choosing which metric to use (Marshall et al., 2008), especially for small-sized primate species such as squirrel monkeys (*Saimiri*) with social groups that may reach up to 75 individuals (Boinski et al., 2002; Mitchell, 1990; Stone, 2007). In addition, for white-water flooded forests in particular, the limited opportunities to view animals in the canopy, the difficulty of locomotion in semi-flooded conditions, the low access to the *chavascal* because of its dense shrubby vegetation, and the impossibility of accurately determining the center of groups (Fernanda Pozzan Paim, personal observation) all contributed to the decision to measure the distance of the first individual sighted. Consequently, similar to other studies that estimated the density of *Saimiri* spp. (Table 3), it is likely that our results are overestimated.

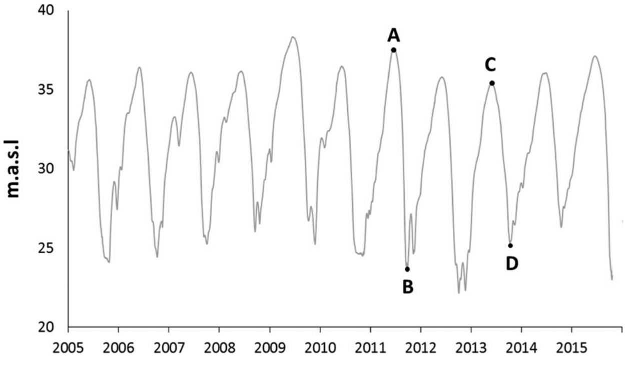

FIGURE 4 Daily water level data for the Mamirauá Sustainable Development Reserve, between 2005 and 2015. Letters A and B represent the flood and drought peaks, respectively, for 2011. Letters C and D represent such peaks, respectively, for 2013. Amplitude observed between the years varied 2.7 m. M.a.s.l : meters above sea level

For most Amazonian primate species, individual abundance is considerably higher in white-water flooded forests than in upland forests. For instance, on the mid-Juruá river squirrel monkey densities are six times higher in the white-water flooded forests than in upland forests (Peres, 1997). In the Amanã Reserve, an upland area adjacent to the MSDR, squirrel monkey densities are around 17 times lower than those estimated for this study (Table 3). Other studies estimating densities for *Saimiri* in *várzea* and upland forests using the distance sampling method also indicate higher densities in white-water flooded forests (Table 3). It should be noted that all these studies measured the distance from the first animal sighted to the observer.

Várzea forests are geologically recent (Holocene origin), and have high concentrations of nutrients due to the deposition of Andean-derived sediments (Junk & Piedade, 1993). In contrast, upland forests are poor in alluvial sediments which largely provide the macronutrients required by plants and influence primary productivity available for consumption by herbivores (Junk & Piedade, 1993; Peres, 1997). Thus, it is not surprising that primate abundance in *várzea* forests is considerably greater than in upland forests, especially for *Saimiri*, a primate genus with generalist feeding habits that may be better adapted to seasonal fluctuations of fruit availability (Haugaasen & Peres, 2005; Paim et al., 2017; Peres, 1997). Other mammals also show high populations densities in *várzeas*. For instance, bats have higher biomass of individuals in *várzea* forests than in upland forests, a result attributed to the higher fruit availability in the white-water flooded forest (Pereira et al., 2009). In addition, the MSDR has the highest density of jaguars (*Panthera onca*) among any known studied site, a result linked to high prey density of its white-water flooded forests (Ramalho, 2012).

The population size of *S. vanzolinii* was estimated at 312,330 individuals on average over a five-year period in Mamirauá Reserve. According to IUCN (2012), for threatened species conservation, it is

TABLE 3 Density estimates for *Saimiri* species in two types of environments in different areas of the Amazon

		Density (individuals/km^2)		
Species	**Locality**	**VA**	**UF**	**Reference**[a]
Saimiri spp.[b]	Juruá River Basin, AM, Brazil	118	20	Peres (1997)
Saimiri ustus	Low Purus River, AM, Brazil	116	22.9	Haugaasen and Peres (2005)
Saimiri cassiquiarensis	Quebradón el Ayo, Caparú Biological Station and Caño Pintadillo, Colombia	–	3.1–11.3[c]	Palacios and Peres (2005)
Saimiri spp.[d]	RDS Piagaçu-Purus, AM, Brazil	134.7	9	Kasecker (2006)
Saimiri cassiquiarensis	Puerto Lopez, Colombia	–	21–71	Astwood, Rodríguez, and Rodríguez (2014)
Saimiri cassiquiarensis	Amanã Reserve, AM, Brazil	–	20.5	João Valsecchi, pers. com.
Saimiri vanzolinii	Mamirauá Reserve, AM, Brazil	359	–	This study

Pers. comm.: personal communication; UF: upland forests; VA: *Várzea* forests.

[a] All papers report distance measured from the first animal sighted.

[b] *Saimiri boliviensis+Saimiri macrodon.*

[c] Lowest and highest density observed.

[d] *Saimiri ustus+Saimiri macrodon.*

appropriate to use the smallest estimate (i.e., lowest confidence interval value), as a strategy to be conservative and reinforce conservation planning. Thus, we re-estimated the population to be 254,910 individuals based on the lower confidence interval. To estimate the number of mature individuals (i.e., reproductive males and females), we considered the rate of 58% mature individuals within the groups, as indicated by Stone (2006) for *S. collinsi*. Assuming the same proportion for *S. vazolinii*, the mature population for the species would be 147,848 individuals. Based on IUCN criteria to classify a species as vulnerable (a population equal or smaller than 10,000 mature individuals), our population estimate is far higher than that recommended for including *S. vanzolinii* in this category. However, we emphasize that our values are overestimated due to the method adopted in the field for distance measurements (i.e., first animal sighted), so the true population size is likely to be considerably smaller than that calculated in this study. It is crucial to highlight that IUCN (2012) indicates that species occurring in areas smaller than 20,000 km^2 should be categorized as vulnerable. Since the geographical distribution of *S. vanzolinii* does not exceed 870 km^2 (Paim et al., 2013), this is the criterion that should be considered in any future threat assessments, both nationally and internationally, to ensure that the species is correctly classified and conservation strategies continue to be planned.

Several factors can threaten primate species, such as habitat loss, risk of hybridization and hunting (IUCN, 2012). For *S. vanzolinii*, the extreme endemism associated with the risk of hybridization with congeneric species (*S. cassiquiarensis* and *S. macrodon*) occurring in the same area poses great risks to the species permanence (Lynch-Alfaro et al., 2015; Paim & Rabelo, 2015; Paim et al., 2013). These two species are parapatric to *S. vanzolinii*, have wide geographical distributions and are considered as Least Concern by IUCN (Boubli, Rylands, de la Torre, & Stevenson, 2008). The absence of geographical barriers between these species and *S. vanzolinii* (Paim et al., 2013, 2018) pose great risks of hybridization. In fact, some mixed groups of *S. cassiquiarensis* and *S. vanzolinii*, and *S. macrodon* and *S. vanzolinii*, have already been observed close to the contact zones, suggesting the occurrence of hybrids (Paim & Rabelo, 2015). However, studies focused on molecular genetics are still needed to confirm this hypothesis.

Habitat loss due to climate change (Marengo & Epinoza, 2015) represents a critical threat for Amazonian species. Some models based on discharge and inundation extent projections in the Amazon basin indicate an increase in the mean and maximum discharge levels in large rivers, especially for the wetlands along the Solimões River where the MSDR is placed (Sorribas et al., 2016). This suggests that the whole distribution area of *S. vanzolinii* will suffer higher and longer flooding events in the future. Since the lowest forests (i.e., *chavascal*) within *várzea* are primarily selected by *S. vanzolinii* in both extreme seasonal periods (Paim, 2008), it is likely that the species could lose high amounts of suitable habitat due to this climate change scenario. Another possible situation may be an adaptation by the species for new conditions and habitats, such as selecting higher forests (i.e., low and high *várzeas*), and competing with congeneric species that inhabit such habitats. The anthropogenic disturbance caused by the traditional local people living inside MSDR may also be a threat for *S. vanzolinii*. Although a sustainable forest management plan is being executed in the MSDR, illegal logging is still common in the area (Queiroz & Peralta, 2010), and may degrade the habitats or reduce the amount of plant species used by *S. vanzolinii*. Regardless of those threats, conservation plans for *S. vanzolinii* should include medium- to long-term monitoring.

In the face of the threats identified for *S. vanzolinii*, we concluded that a year-long population monitoring should be carried out at regular intervals of 5 years to monitor population trends of this vulnerable species. Populational stability of *S. vanzolinii* over the monitoring period was confirmed via distance sampling and encounter rates. Although our results indicate both analyses could be used to identify variations in population size over time, we found it difficult to meet all assumptions of the distance sampling method, especially that of accurately recording the center of the group. Thus, we consider the encounter rate analysis to be simpler to apply and more effective to monitor *S. vanzolinii* populations. Furthermore, such information could help policymakers and governmental agencies to create and/or improve conservation strategies for the white-water flooded forests of Central Amazonia, benefiting not only our target species but the whole ecosystem.

ACKNOWLEDGMENTS

This research was supported by the Mamirauá Sustainable Development Institute through the Ministry of Science, Technology, Innovation and Communications (IDSM/MCTIC) and the National Council of Technological and Scientific Development (CNPq) [grant numbers 300005/2013-0; 452908/2016-7; 201475/2017-0]. We thank Dr. João Valsecchi and the Terrestrial Vertebrate Ecology Research Group for their logistical support. We thank Fernanda Roos (*In memoriam*), Louise Maranhão, Rafael Rabelo, and Ivan Junqueira for their assistance in collecting and managing data, and the Mamirauá Reserve field assistants for their support during all the stages in the field. Adrian Barnett helped with the English. We acknowledge the associate editor, Dr. Marilyn A. Norconk, one anonymous reviewer, and Dr. Fabiano de Melo for constructive comments on the manuscript.

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REFERENCES

Astwood, J., Rodríguez, J., & Rodríguez-C, K. (2014). Foraging density for squirrel monkey *Saimiri sciureus* in two forests in Puerto Lopez – Colombia. *Revista MVZ Córdoba*, *19*(2), 4158–4167. https://doi.org/10.21897/rmvz.109

Ayres, J. M. (1993). *As Matas de várzea do Mamirauá: médio Rio Solimões*. Brasília, DF: Sociedade Civil Mamirauá/CNPq.

Ayres, J.M. (1986). *Uakaris & the Amazonian flooded forests*. University of Cambridge (unpublished Doctoral dissertation).

Baldwin, J. D. (1985). The behavior of squirrel monkey (*Saimiri*) in natural environments. In L. A. Rosenblum, & C. L. Coe (Eds.), *Handbook of squirrel monkey research* (pp. 35–53). New York, US: Plenum Press.

Balmford, A., Green, R. E., & Jenkins, M. (2003). Measuring the changing state of nature. *Trends in Ecology and Evolution*, *18*, 326–336. https://doi.org/10.1016/S0169-5347(03)00067-3

Boinski, S. (1999). The social organization of squirrel monkeys: Implications for ecological models of social evolution. *Evolutionary Anthropology*, *8*, 101–112. https://doi.org/10.1002/(SICI)1520-6505(1999)8:3<101::AID-EVAN5>3.0.CO;2-O

Boinski, S., Sughrue, K., Lara, S., Quatrone, R., Henry, M., & Cropp, S. (2002). An expanded test of the ecological model of primate social evolution: Competitive regimes and female bonding in three species of squirrel monkeys (*Saimiri oerstedii*, *S. boliviensis*, and *S. sciureus*). *Behaviour*, *139*, 227–261. https://doi.org/10.1163/156853902760102663

Boubli, J. P., & Rylands, A. B. (2008). *Saimiri vanzolinii*. *The IUCN red list of threatened species 2008*. http://www.iucnredlist.org/details/19839/0. Accessed 10 February 2018.

Boubli, J. P., Rylands, A. B., de la Torre, S. & Stevenson, P. (2008). *Saimiri sciureus*. *The IUCN red list of threatened species 2008*. http://www.iucnredlist.org/details/41537/0. Accessed 15 January 2019.

Buckland, S. T., Burnham, K. P., Anderson, D. R., & Laake, J. L. (1993). *Distance sampling: Estimation of abundance of biological populations*. London: Chapman and Hall.

Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L., & Thomas, L. (2001). *Introduction to distance sampling*. Oxford: Oxford University Press.

Chape, S., Harrison, J., Spalding, M., & Lysenko, I. (2005). Measuring the extent and effectiveness of protected areas as an indicator for meeting global biodiversity targets. *Philosophical Transactions of the Royal Society of London. Series B. Biological Science*, *360*, 443–455. doi:. https://doi.org/10.1098/rstb.2004.1592

Chapman, C. (1988). Patterns of foraging and range use by three species of Neotropical primates. *Primates*, *29*, 177–194. https://doi.org/10.1007/BF02381121

Chapman, C. A., Struhsaker, T. T., Skorupa, J. P., Snaith, T. V., & Rothman, J. M. (2010). Understanding long-term primate community dynamics: Implications of forest change. *Ecological Applications*, *20*, 179–191. https://doi.org/10.1890/09-0128.1

Chiou, K. L., Pozzi, L., Lynch-Alfaro, J. W., & Di Fiore, A. (2011). Pleistocene diversification of living squirrel monkeys (*Saimiri* spp.) inferred from complete mitochondrial genome sequences. *Molecular Phylogenetics and Evolution*, *59*, 736–745. https://doi.org/10.1016/j.ympev.2011.03.025

Comiskey, J. A., Dallmeier, F., & Alonso, A. (2001). Framework for assessment and monitoring of biodiversity. In S. A. Levin (Ed.), *Encyclopedia of biodiversity* (pp. 63–73). San Diego, US: Academic Press. v3

Elzinga, C. L., Salzer, D. W., Willoughby, J. W., & Gibbs, J. P. (2011). *Monitoring plant and animal populations*. Malden, MA: Blackwell Science.

Ferreira-Ferreira, J., Silva, T. F. S., Streher, A. S., Affonso, A. G., Furtado, L. F. A., Forsberg, B. R., … Novo, E. M. L. M. (2014). Combining ALOS/PALSAR derived vegetation structure and inundation patterns to characterize major vegetation types in the Mamirauá Sustainable Development Reserve, Central Amazon floodplain, Brazil. *Wetlands Ecology and Management*, *23*, 41–59. https://doi.org/10.1007/s11273-014-9359-1

Furch, K. (1984). Water Chemistry of the Amazon basin: The distribution of chemical elements among freshwaters. In H. Sioli (Ed.), *The Amazon: Limnology and landscape ecology of a mighty tropical river and its basin* (pp. 167–199). Dordrecht, NL: Junk Publishers.

Haugaasen, T., & Peres, C. A. (2005). Mammal assemblage structure in Amazonian flooded and unflooded forests. *Journal of Tropical Ecology*, *21*, 133–145. https://doi.org/10.1017/S026646740400207X

Hellawell, J. A. (1991). Development of a rational for monitoring. In B. Goldsmith (Ed.), *Monitoring for conservation and ecology* (pp. 12–16). London, UK: Chapman and Hall.

ICMBio (2015). *Lista de Espécies Ameaçadas da Fauna Brasileira*. http://www.icmbio.gov.br/portal/faunabrasileira/lista-de-especies. Accessed 30 November 2018.

Instituto de Desenvolvimento Sustentável Mamirauá (2019). *Banco de dados fluviométrico da Reserva de Desenvolvimento Sustentável Mamirauá*. http://mamiraua.org.br/pt-br/pesquisa-e-monitoramento/monitoramento/fluviometrico/. Accessed 10 September 2018.

IPCC (2014). Climate change 2014: Synthesis report. In R. K. Pachauri, & L. A. Meyer (Eds.), *Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 2–26). Geneva, CH: IPCC.

IUCN (2012). *The IUCN Red List Categories and Criteria v. 3.1*. 2nd Edition. http://www.iucnredlist.org. Accessed 10 November 2018.

Izar, P., Stone, A. I., Carnegie, S., & Nakai, E. (2008). Sexual selection, female choice and mating systems. In P. A. Garber, A. Estrada, J. C.

Bicca-Marques, E. Heymann, & K. Strier (Eds.), *South American primates: Comparative perspectives in the study of behavior, ecology, and conservation* (pp. 157–198). New York, US: Springer Press.

Junk, W. J., & Piedade, M. T. F. (1993). Biomass and primaryproduction of herbaceous plant communities in the Amazon floodplain. *Hydrobiology*, *263*, 155–162.

Junk, W. J., Bayley, P. B., & Sparks, R. E. (1989). The flood pulse concept in river-floodplain systems. In D. P. Dodge (Ed.), *Proceedings of international large river symposium (LARS)* (pp. 110–127). Toronto, CA: Canadian Special Publication of Fisheries and Aquatic Sciences.

Junk, W. J., Piedade, M. T. F., Schöngart, J., & Wittmann, F. (2012). A classification of major natural habitats of Amazonian white-water river floodplains (várzeas). *Wetlands Ecology and Management*, *20*(6), 461–475. https://doi.org/10.1007/s11273-012-9268-0

Kasecker, T. P. (2006). *Efeito da estrutura de habitat sobre a riqueza e composição de comunidades de primatas da RDS Piagaçu-Purus, Amazônia Central, Brasil*. Instituto Nacional de Pesquisas da Amazônia (unpublished Master's thesis).

Klammer, G. (1984). The relief of the extra-Andean Amazon basin. In H. Sioli (Ed.), *The Amazon: Limnology and landscape ecology of a might tropical river and its basin* (pp. 47–83). Dordrecht, NL: Junk Publishers.

Lavergne, A., Ruiz-García, M., Catzeflis, F., Lacote, S., Contamin, H., Mercereau-Puijalon, O., … de Thoisy, B. (2010). Phylogeny and phylogeography of squirrel monkeys (genus *Saimiri*) based on cytochrome b genetic analysis. *American Journal of Primatology*, *72*, 242–253. https://doi.org/10.1002/ajp.20773

Lopes, G. P., Valsecchi, J., Vieira, T. M., Amaral, P. V., & Costa, E. W. M. (2012). Hunting and hunters in lowland communities in the region of the middle Solimões, Amazonas, Brasil. *Uakari*, *8*(1), 7–18. https://doi.org/10.31420/uakari.v8i1.120

Lynch-Alfaro, J., Boubli, J. P., Paim, F. P., Ribas, C. C., Silva, M. N., Messias, M. R., … Farias, I. P. (2015). Biogeography of squirrel monkeys (genus *Saimiri*): South-central Amazon origin and rapid pan-Amazonian diversification of a lowland primate. *Molecular Phylogenetics and Evolution*, *82*, 436–454. https://doi.org/10.1016/j.ympev.2014.09.004

Marengo, J., & Epinoza, J. C. (2015). Extreme seasonal drought and flood in Amazonia: Cause, trend and impact. *International Journal of Climatology*, *36*(3), 1033–1050. https://doi.org/10.1002/joc.4420

Marsh, L. K. (2014). A taxonomic revision of the saki monkeys, *Pithecia* Desmarest, 1804. *Neotropical Primates*, *21*(1), 1–163. https://doi.org/10.1896/044.021.0101

Marshall, A. R., Lovett, J. C., & White, P. C. L. (2008). Selection of line-transect methods for estimating the density of group-living animals: Lessons from the primates. *American Journal of Primatology*, *70*(5), 45–462. https://doi.org/10.1002/ajp.20516

Mendoza, S., Lowe, E. L., & Levine, S. (1978). Social organization and social behavior in two subspecies of squirrel monkeys (*Saimiri sciureus*). *Folia Primatologica*, *30*, 126–144. https://doi.org/10.1159/000155859

Mitchell, C. L. (1990). *The ecological basis for female social dominance: a behavioral study of the squirrel monkey*. Princeton University (unpublished Doctoral dissertation).

Mittermeier, R. A. (2013). Introduction to HMW volume 3: Primates. In R. A. Mittermeier, A. B. Rylands, & D. E. Wilson (Eds.), *Handbook of the mammals of the world* (pp. 390–396). Barcelona, ES: Lynx Edicions. v3

Naughton-Treves, L., Holland, M. B., & Brandon, K. (2005). The role of protected areas in conserving biodiversity and sustaining local livelihoods. *Annual Review of Environment and Resources*, *30*, 219–252. https://doi.org/10.1146/annurev.energy.30.050504.164507.

Ordinance 444 (2014). *Portaria No 444, December 17th, 2014*. http://www.icmbio.gov.br/sisbio/images/stories/instrucoes_normativas/PORTARIA_N%C2%BA_444_DE_17_DE_DEZEMBRO_DE_2014.pdf. Accessed 20 January 2019.

Paglia, A. P., Fonseca, G. A. B., Rylands, A. B, Herrmann, G., Aguiar, L. M. S., Chiarello, A. G., … Patton, J. L. (2012). Lista Anotada dos Mamíferos do Brasil/Annotated Checklist of Brazilian Mammals. 2nd ed. *Occasional Papers in Conservation Biology*, *6*, 1-76.

Paim, F. P. (2008). *Estudo comparativo das espécies de Saimiri Voigt, 1831 (Primates, Cebidae) na Reserva Mamirauá, Amazonas*. Universidade Federal do Pará and Museu Paraense Emílio Goeldi (unpublished Master's thesis).

Paim, F. P., & Queiroz, H. L. (2009). Diferenças nos parâmetros acústicos das vocalizações de alarme das espécies de *Saimiri* Voigt, 1831 (Primates, Cebidae) na floresta de várzea – Reserva Mamirauá. *Uakari*, *5*, 49–60. https://doi.org/10.31420/uakari.v5i1.56

Paim, F. P., & Rabelo, R. M. (2015). Methods for capturing wild squirrel monkeys in a floodplain forest: A comparison of two techniques and two species. *Neotropical Primates*, *22*, 7–11.

Paim, F. P., Silva Júnior, J. S., Queiroz, H. L. (2015). *Avaliação do risco de extinção de Saimiri vanzolinii Ayres, 1985 no Brasil. Processo de avaliação do risco de extinção da fauna brasileira*. http://www.icmbio.gov.br/portal/biodiversidade/fauna-brasileira/estado-de-conservação/7268-mamiferos-saimiri-vanzolinii-macaco-de-cheiro-de-cabeça-preta.html. Accessed 10 November 2018.

Paim, F. P., Chapman, C. A., Queiroz, H. L., & Paglia, A. P. (2017). Does resource availability affect the diet and behaviour of the Vulnerable squirrel monkey, *Saimiri vanzolinii*? *International Journal of Primatology*, *38*, 572–587. https://doi.org/10.1007/s10764-017-9968-7

Paim, F. P., Silva Júnior, J. S., Valsecchi, J., Harada, M. L., & Queiroz, H. L. (2013). Diversity, geographic distribution and conservation of squirrel monkeys, *Saimiri* (Primates, Cebidae), in the floodplain forests of central Amazon. *International Journal of Primatology*, *34*, 1055–1076. https://doi.org/10.1007/s10329-018-0659-6

Paim, F. P., Valenta, K., Chapman, C. A., Paglia, A. P., & Queiroz, H. L. (2018).). Tree community structure reflects niche segregation of three parapatric squirrel monkey species (*Saimiri* spp.). *Primates*, *59*, 395–404. https://doi.org/10.1007/s10329-018-0659-6

Palacios, E., & Peres, C. A. (2005). Primate population densities in three nutrient-poor Amazonian terra firme forests of South-Eastern Colombia. *Folia Primatologica*, *76*, 135–145. https://doi.org/10.1159/000084376

Pereira, M. J. R., Marques, J. T., Santana, J., Santos, C. D., Valsecchi, J., Queiroz, H. L., … Palmeirim, J. M. (2009). Structuring of Amazonian bat assemblages: The roles of flooding patterns and floodwater nutriente load. *Journal of Animal Ecology*, *78*, 1163–1171. https://doi.org/10.1111/j.1365-2656.2009.01591.x

Peres, C. A. (1994). Primate responses to phenological changes in an Amazonian terra firma forest. *Biotropica*, *26*, 98–112. https://doi.org/10.2307/2389114

Peres, C. A. (1997). Primate community structure at twenty western Amazonian flooded and unflooded forests. *Journal of Tropical Ecology*, *13*, 381–405. https://doi.org/10.1017/S0266467400010580

Peres, C. A. (1999). General guidelines for standardizing line-transect surveys of tropical forest primates. *Neotropical Primates*, *7*, 11–16.

Prance, G. T. (1979). Notes on the vegetation of Amazonia III. The terminology of Amazonian forest types subject to inundation. *Brittonia*, *31*, 26–38. https://doi.org/10.2307/2806669

Queiroz, H. L. (1995). *Preguiças e guaribas: Os mamíferos folívoros arborícolas do Mamirauá. Sociedade Civil Mamirauá*. Brasília, DF: Sociedade Civil Mamirauá e CNPq.

Queiroz, H. L., & Peralta, N. (2010). Protected areas in an Amazonian Várzea and their role in its conservation: The case of mamirauá Sustainable Development Reserve (MSDR). In J. J. Wolfgang, M. T. F. Piedade, F. Wittmann, J. Schöngart, & P. Parolin (Eds.), *Amazonian floodplain forests: Ecophysiology, biodiversity and sustainable management* (1., 210, pp. 465–483). London, UK: Springer.

Rabelo, R. M., Silva, F. E., Vieira, T., Ferreira-Ferreira, J., Paim, F. P., Dutra, W., … Valsecchi, J. (2014). Extension of the geographic range of *Ateles chamek* (primates, Atelidae): Evidence of river-barrier crossing by an amazonian primate. *Primates*, *55*, 167–171. https://doi.org/10.1007/s10329-014-0409-3

Ramalho, E. E. (2012). *Jaguar (Panthera onca) population dynamics, feeding ecology, human induced mortality, and conservation in the várzea floodplain forests of Amazonia*. University of Florida (unpublished doctoral dissertation).

Ramalho, E. E., Macedo, J., Vieira, T. M., Valsecchi, J., Calvimontes, J., Marmontel, M., & Queiroz, H. L. (2009). Ciclo hidrológico nos ambientes de várzea da Reserva de Desenvolvimento Sustentável Mamirauá – médio Rio Solimões, período de 1990 a 2008. *Uakari*, *5*(1), 61–87.

Sioli, H. (1968). Hydrochemistry and geology in the Brazilian Amazon region. *Amazoniana*, *1*, 267–277.

Sorribas, M. V., Paiva, R. C. D., Melack, J. M., Bravo, J. M., Jones, C., Carvalho, L., … Costa, M. H. (2016). Projections of climate change effects on discharge and inundation in the Amazon basin. *Climatic Change*, *136*, 555–570. https://doi.org/10.1007/s10584-016-1640-2

Stone, A. (2006). Foraging ontogeny is not linked to delayed maturation in squirrel monkeys (*Saimiri sciureus*). *Ethology*, *112*, 105–115. https://doi.org/10.1111/j.1439-0310.2005.01121.x

Stone, A. I. (2007). Responses of squirrel monkeys to seasonal changes in food availability in an Eastern Amazonian forest. *American Journal of Primatology*, *68*, 1–16. https://doi.org/10.1002/ajp.20335

Thomas, L., Buckland, S. T., Rexstad, E. A., Laake, J. L., Strindberg, S., Hedley, S. L., … Burnham, K. P. (2010). Distance software: Design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology*, *47*(1), 5–14. https://doi.org/10.1111/j.1365-2664.2009.01737.x

Thompson, W. L., White, G. C., & Gowan, G. C. (1998). *Monitoring vertebrate populations*. San Diego, CA: Academic Press.

Valsecchi, J. (2005). *Diversidade de mamíferos e uso da fauna nas Reservas de Desenvolvimento Sustentável Mamirauá e Amaná – Amazonas – Brasil*. Universidade Federal do Pará and Museu Paraense Emílio Goeldi (unpublished master´s thesis).

Whitesides, G. H., Oates, G. F., Green, M. S., & Kluberdanz, R. P. (1988). Estimating primate densities from transects in a West African rain forest: A comparison of techniques. *Journal of Animal Ecology*, *57*, 345–367. https://doi.org/10.2307/4910

Wittmann, F., Junk, W. J., & Piedade, M. T. F. (2004). The várzea forests in Amazonia: Flooding and the highly dynamic geomorphology interact with natural forest succession. *Forest Ecology and Management*, *196*, 199–212. https://doi.org/10.1016/j.foreco.2004.02.060

Yoccoz, N. G., Nichols, J. D., & Boulinier, T. (2001). Monitoring of biological diversity in space and time. *Trends in Ecology & Evolution*, *16*, 446–453. https://doi.org/10.1016/S0169-5347(01)02205-4

Zimbler-Delorenzo, H. S., & Stone, A. I. (2011).). Integration of field and captive studies for understanding the behavioral ecology of the squirrel monkey (*Saimiri* sp.). *American Journal of Primatology*, *73*, 607–622. https://doi.org/10.1002/ajp.20946

How to cite this article: Paim FP, El Bizri HR, Paglia AP, Queiroz HL. Long-term population monitoring of the threatened and endemic black-headed squirrel monkey (*Saimiri vanzolinii*) shows the importance of protected areas for primate conservation in Amazonia. *Am J Primatol*. 2019;e22988. https://doi.org/10.1002/ajp.22988