

Using population surveys and models to reassess the conservation status of an endemic Amazonian titi monkey in a deforestation hotspot

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Abstract Assessing the conservation status of species is essential for implementing appropriate conservation measures. A lack of evidence of threats, rather than showing an absence of impacts, could reflect a lack of studies on how human activities could result in species population declines. The range of Prince Bernhard's titi monkey *Plecturocebus bernhardi* is restricted to the Arc of Deforestation, a deforestation hotspot in south-eastern Amazonia. Despite this, it is categorized as Least Concern on the IUCN Red List. To reassess the conservation status of *P. bernhardi*, we carried out surveys during 2015–2017 to delimit the geographical distribution of the species and estimate its population density and abundance. We then used spatial predictive modelling to

examine future habitat and population loss within its range. *Plecturocebus bernhardi* occurs over an area of 131,295 km². Its mean group size was 2.8 individuals/group and its density 10.8 individuals/km² and 3.8 groups/km². Habitat loss was estimated to be 58,365 km² (44.5% of its current range) over the next 24 years (three *P. bernhardi* generations) under a conservative governance model of deforestation and 105,289 km² (80.2%) under a business-as-usual model. These numbers indicate that *P. bernhardi* is threatened and should be categorized as Vulnerable, at least, using the IUCN Red List criteria. We recommend the reassessment of other Least Concern primate species from the Arc of Deforestation using a similar approach.

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Introduction

Assessments of species conservation status at the global level follow the IUCN Red List categories and criteria and are fundamental for the implementation of strategies for species conservation. A taxon that does not meet any criteria for the IUCN threat categories is categorized as Least Concern (IUCN, 2012). This classification, however, does not necessarily imply that the taxon has been assessed fully for all criteria because, in most cases, there are insufficient data available regarding threats, distribution and/or population trends. When an assessment states there is no evidence of threats this does not necessarily mean studies were carried out that provide evidence the species is not in decline or not being affected by anthropogenic activities. Often the final decision rests on the judgement of specialists based on the available data (Mace et al., 2008). However, Least Concern species should be reassessed if they become exposed to threats that have not been previously recognized or investigated (McLeod, 2010; Sengupta & Radhakrishna, 2013; Erinjery et al., 2017; de la Torre et al., 2018; Silva et al., 2018).

This could be the case for mammals currently categorized as Least Concern and occurring in South America, where there is considerable concern for the conservation of habitats and species in the near future. For example, the lesser anteater *Tamandua tetradactyla* could lose > 76% of its habitat by 2050 in Bolivia because of climate and land-cover changes (Osipova & Sangermano, 2016). Such a rate of habitat reduction fulfils the criteria for a categorization as Endangered on the IUCN Red List, but this species is currently categorized as Least Concern (Miranda et al., 2014). The situation could be similar for other Least Concern xenarthrans (anteaters, sloths and armadillos) in South America, which are facing threats related not only to changes to their habitats but also to hunting, collision with vehicles, diseases and other anthropogenic factors that could cause large population decreases (Superina & Abba, 2020).

Several Amazonian primate species occurring in the Arc of Deforestation (a deforestation hotspot in south-eastern Amazonia) could potentially decline in the near future as a result of habitat loss (Silva et al., 2018, 2020; Sales et al., 2019; Rabelo et al., 2020). For example, current rates of deforestation in southern Amazonia are predicted to reduce the habitat of the marmoset *Mico chrysoleucos* by 38–54% over 18 years (three marmoset generations; Silva et al., 2018). Although c. 20% of its range is safeguarded by protected areas and Indigenous land designations (Silva et al., 2018), these rates of habitat loss are warning signs for the conservation of *M. chrysoleucos* considering the threats to the Amazon rainforest under the current government administration in Brazil. Unfortunately, however, this information was not included in the current IUCN Red List assessment and the species is still categorized as Least Concern (Röhe & Mittermeier, 2021).

A similar situation could exist for Amazonian titi monkeys (*Cheracebus* and *Plecturocebus*; sensu Byrne et al., 2016), for which there is little information regarding threats, distribution or populations. Of the 31 species of Amazonian titi monkeys assessed for the IUCN Red List, 19 (61%) are categorized as Least Concern, with the justification that they have relatively large ranges, occur in protected areas and/or because there is no evidence of threats to their populations. Titi monkeys are mostly frugivorous, occur in a variety of forest types (which include primary and secondary forests) and are considered tolerant of forest disturbance (Michalski & Peres, 2005; Bicca-Marques & Heymann, 2013). Nevertheless, at least seven *Plecturocebus* species occur in the Arc of Deforestation (Malhi et al., 2008), indicating they could potentially be threatened, and also unprotected.

Extensions of the known range of Amazonian titi monkeys have been reported in Brazil (Monção et al., 2008; Quintino & Bicca-Marques, 2013; Printes et al., 2018; Rocha et al., 2019), Bolivia (Martinez & Wallace, 2021) and Peru (Vermeer et al., 2011), with new reports of sympatry (Printes et al., 2018; Rocha et al., 2019) showing that

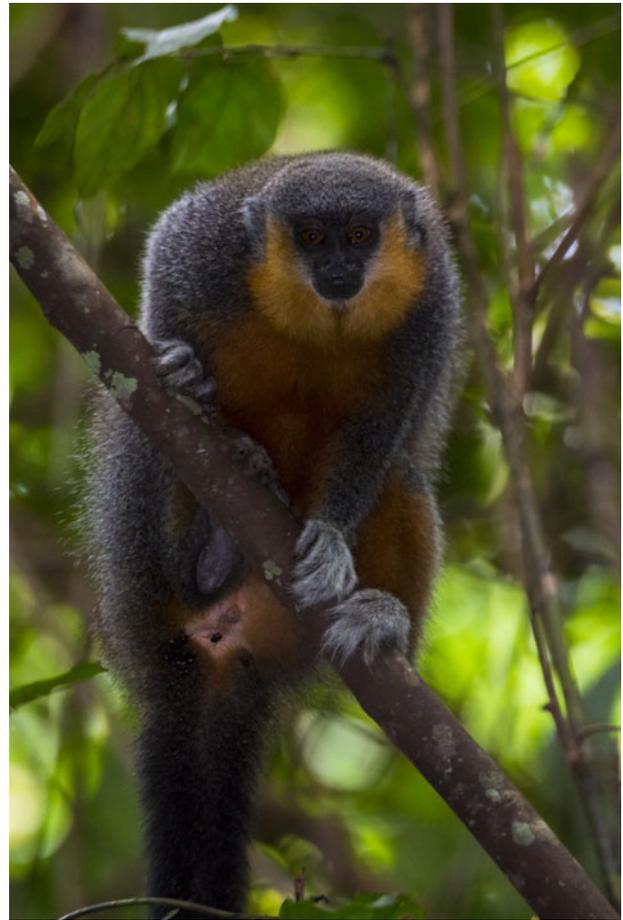


PLATE 1 Prince Bernhard's titi monkey *Plecturocebus bernhardi*. Photo: Marcelo Santana.

the geographical distribution of Amazonian titi monkeys is more complex than was previously thought. Prince Bernhard's titi monkey *Plecturocebus bernhardi* (Plate 1) is one such example. The range of the species was believed to be limited to the west by the Ji-Paraná River but new records on the west bank of this river indicate the distribution of this species is greater than previously thought (van Roosmalen et al., 2002; Monção et al., 2008; Quintino & Bicca-Marques, 2013; Silva-Diogo et al., 2018). *Plecturocebus bernhardi* is categorized as Least Concern because of its relatively large range and lack of evident threats that would result in population decline (Röhe & Boubli, 2018). However, data regarding the population of this species and the threats it faces are lacking. Here we present new occurrence data and the first population survey of *P. bernhardi*. We use predictive spatial modelling to estimate the extent of loss of its habitat and population under two future scenarios of land use (a more conservative governance scenario and a more realistic business-as-usual scenario) to reassess the conservation status of the species. This is the first study to reassess the conservation status of an Amazonian titi monkey by gathering new population data and using remote sensing information to model current and future habitat loss.

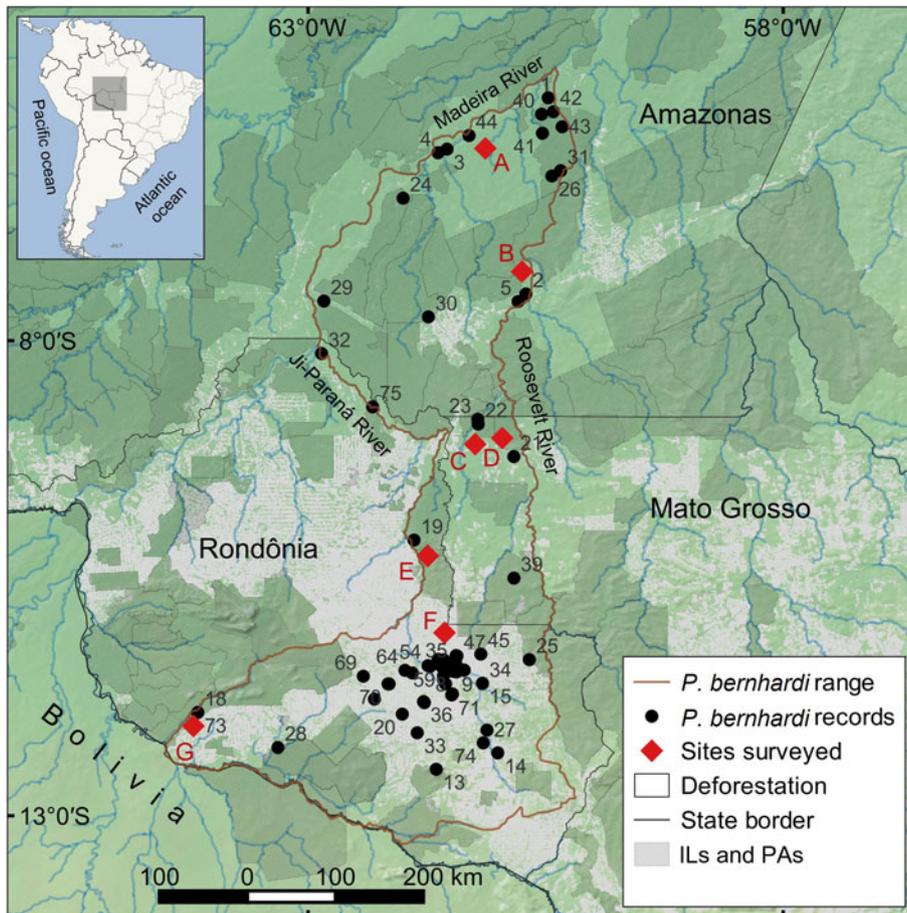


FIG. 1 The areas surveyed in this study (A–G) and the records of *P. bernhardi*. Numbers indicate the locality records of *P. bernhardi* recorded in this study and obtained from the literature (Supplementary Table 1). ILs, Indigenous lands; PAs, protected areas.

Study area

The study area is in the south of the Amazon Rainforest and encompasses the Madeira–Aripuanã interfluvium and both banks of the Ji-Paraná River to the Guaporé Valley (Monção et al., 2008; Fig. 1, Table 1). This region includes the borders between Amazonas, Rondônia and Mato Grosso states and lies in the Arc of Deforestation, a deforestation hotspot in the Brazilian Amazon as a result of the expansion of agriculture and cattle ranching, urban encroachment, logging and infrastructure projects (Carrero et al., 2020). The climate is tropical with a mean annual temperature of 28 °C and annual precipitation of 2,500–3,000 mm (Hayakawa & Rossetti, 2015). The vegetation is classified as dense lowland ombrophilous forest with seasonally flooded forests (Hayakawa & Rossetti, 2015).

Methods

Geographical distribution

We gathered locality records from the literature and from our primate surveys carried out during 2012–2015 at seven sites in the Madeira–Aripuanã interfluvium and on both

banks of upper Ji-Paraná River (Silva-Diogo et al., 2018; Silva et al., 2020; Fig. 1, Table 1). After plotting all occurrence points using QGIS 3.20.1 (QGIS Development Team, 2021), we created a polygon with the major rivers (i.e. Roosevelt and Aripuanã Rivers to the east, Madeira River to the north and the lower Ji-Paraná River to the west) as the main barriers to the dispersal of the species within its geographical range (Amazonian rivers are considered to be barriers to the dispersal of titi monkeys; Ayres & Clutton-Brock, 1992; Boubli et al., 2015). We deducted non-forest and deforested areas from the species range to estimate the potential area of occurrence, considering that Neotropical primates are arboreal and associated with forests (Estrada et al., 2017).

Transect surveys

During January–February 2015 we carried out line transect surveys on 10 transects to estimate the population density and abundance of *P. bernhardi*. These transects were at two of the sites used for determining the species' geographical distribution (sites A and B in Fig. 1), in the northern portion of the study area. We positioned the transects randomly using QGIS, with each transect starting from a road or river.

TABLE 1 The seven sites surveyed in the Madeira–Aripuanã interfluvium and Ji-Paraná River for Prince Bernhard's titi monkey *Plecturocebus bernhardi* (Fig. 1).

Site	River	Year	Legally protected land	Latitude	Longitude
A	Low Manicoré	2012–2015	None	5°59'03"S	61°32'15"W
B	Roosevelt–Aripuanã confluence	2012–2015	None	7°31'18"S	60°40'25"W
C	Madeirinha	2015	Parque Estadual Tucumã/Estação Ecológica do Rio Madeirinha	8°52'43"S	61°13'52"W
D	Mid Roosevelt (west bank)	2015	Estação Ecológica do Rio Roosevelt	9°13'15"S	60°50'03"W
E	Mid Ji-Paraná (east bank)	2009	Reserva Biológica do Jarú	10°2'52"S	61°58'15"W
F	Upper Ji-Paraná	2014	None	11°26'38"S	61°27'44"W
G	Cautário	2014	Resex do Rio Cautário	11°54'50"S	64°09'41"W

We oriented the transects perpendicular to road or river, to account for any gradient of environmental factors or primate density from the start of the trail to the interior of the forest. The mean length of the transects was $3.07 \pm \text{SD } 0.63$ km (range 2.0–4.0 km) and we placed them at least 2 km apart to guarantee spatial independence. We surveyed the transects during 07.00–11.00 in one direction and during 14.00–17.00 in the reverse direction and considered each survey during these periods of the day as independent sampling occasions. Two observers walked along the transects at a mean speed of 1.5 km/h and counted the number of individuals in each detected *P. bernhardi* group. We measured the perpendicular distance between the centre line of the transect and the centre of each detected group, to facilitate density estimates using distance sampling (Buckland et al., 1993). Considering walks during different periods of the day as our sampling occasions, we surveyed each transect at least eight times (mean 10, range 8–12), with at least four surveys in both morning and afternoon. We implemented a 2-day break between subsequent surveys to reduce the impact of observers on the detection rate. In total we walked 271.6 km along the transects.

We estimated the population density of *P. bernhardi* using *Distance 7.1* (Thomas et al., 2010). This analysis fits detection functions to perpendicular distances, providing the probability of detecting groups and estimating the number of individuals potentially missed by the observers. Following the method used by Silva et al. (2020), we used a χ^2 test to determine the appropriate truncations and perpendicular distance intervals at $P > 0.6$. We then compared the adjustments of detection functions using the Akaike information criteria (AIC), with the models with the smallest AIC values considered as best fitting the data. We selected the model for which the density estimate had the lowest coefficient of variation (CV) when more than one function yielded a difference in AIC value (ΔAIC) < 2 . We then estimated mean abundance, A , using $A = D \times a$, whereby D is density and a is the species potential area of occurrence calculated using occurrence records (Supplementary Table 1). We calculated the 95% CI and the CV for all estimates.

Assessment of conservation status

We calculated the total habitat loss within the potential area of occurrence of *P. bernhardi* up to 2019. We used predictive deforestation models to assess how much habitat the species could lose over the next 24 years, which is equivalent to three titi monkey generations. This time frame of three generations is recommended for assessing population decline whether by direct observation, by measuring a decline in area of occupancy or extent of occurrence, or by measuring a decline in quality of habitat or other variables that can indicate ongoing population reduction (IUCN, 2012). We obtained data on current forest loss from MapBiomas (2020) for 1995–2019. For predicted forest loss we considered two scenarios (after Soares-Filho et al., 2006; see also Boubli et al., 2019; Silva et al., 2020): (1) A governance scenario (i.e. considering the current deforestation trends but with a 50% cap in forest loss through the current laws being effective at preventing farmers from clearing $> 50\%$ of the forest on their properties and assuming that protected areas are managed effectively). (2) A business-as-usual scenario (i.e. with the continuation of the current deforestation trends along with poor management of protected areas).

To estimate the impact of habitat loss on the population of *P. bernhardi*, we used the lower bound of the CI of the estimate of abundance, which is the recommended measure of abundance for conservation status assessments (IUCN, 2012). We then used the Red List criteria (IUCN, 2012) to assess whether *P. bernhardi* should remain categorized as Least Concern or requires recategorization.

Results

Geographical distribution We obtained 21 new locality records of *P. bernhardi* through our surveys, and 54 records from the literature (Fig. 1, Supplementary Table 1). The majority of the distribution of this species is delimited by the Aripuanã, Madeira and Ji-Paraná Rivers, but we also recorded the species on the west bank of the upper Ji-Paraná River, where its range overlaps with that of

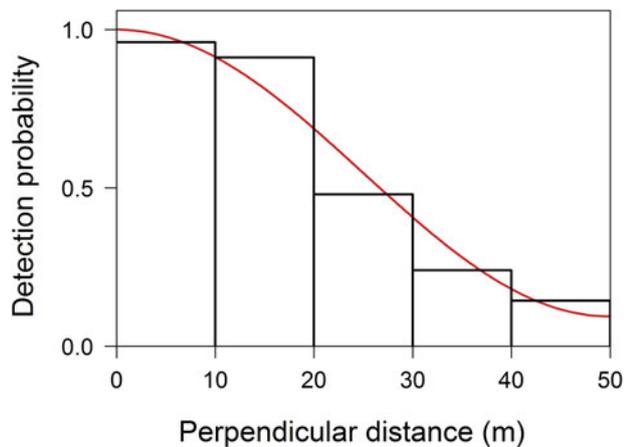


FIG. 2 Distribution of perpendicular distances of observations of *P. bernhardi* from the centre of transects in the Madeira–Aripuanã interfluvium. The trend line indicates the best detection function fitted to the distance classes.

Plecturocebus brunneus (Supplementary Fig. 1), although we did not record these species in syntopy during our surveys. In the headwaters of the Ji-Paraná and Roosevelt Rivers there is a contact zone between *P. bernhardi*, *Plecturocebus parecis* and *Plecturocebus cinerascens* (Gusmão et al., 2019) (Supplementary Fig. 1). We estimated that *P. bernhardi* potentially occurs in an area of 131,295 km² (Fig. 1) of which 49.6% is legally protected.

Population estimate We obtained 57 observations of *P. bernhardi* groups along the transects, with 161 individuals detected. The encounter rate was 0.2 groups/km (CV = 11.9). The best grouping of perpendicular distances to fit the detection curve was obtained with five intervals of 10 m each. The best detection function was uniform with one cosine adjustment term (Goodness-of-fit $\chi^2 = 0.67$, df = 3, $P = 0.88$, AIC = 163.19; Fig. 2). Mean group size was 2.8 individuals/group (95% CI = 2.5–3.2, CV = 6.5). We estimated density to be 10.8 individuals/km² (95% CI = 7.9–14.9, CV = 15.3), and 3.8 groups/km² (95% CI = 2.9–5.1, CV = 13.8), and mean abundance to be 1,365,468 individuals (95% CI = 1,037,231–1,956,296, CV = 15.3).

Reassessment of conservation status We estimated there was a loss of 36,903 km² of forest cover within the species' potential range during 1995–2019, 28.1% of the total original range of the species (Fig. 3). Only 0.5% of this deforestation occurred within protected areas or Indigenous lands. In our predictive models the habitat loss of the species over the next 24 years would amount to 58,365 km² under the governance scenario and 105,289 km² under the business-as-usual scenario (Fig. 3), 44.5 and 80.2% of the species' potential range, respectively. We estimated predicted deforestation within

protected areas and Indigenous lands would be 3.2 and 16.7% under the governance and business-as-usual scenarios, respectively. Considering the lower bound of the CI of the population abundance (1,037,231 individuals), such levels of habitat loss under the business-as-usual scenario translate into a reduction of 831,859 *P. bernhardi* individuals from the population over this period. Under both scenarios considered, the projected population reduction of *P. bernhardi* qualifies the species for categorization under a threatened category on the IUCN Red List (44.5% habitat loss indicates a categorization as Vulnerable, and 80.2% a categorization as Critically Endangered; criteria A3c, IUCN, 2012).

Discussion

Although we estimated that *P. bernhardi* has a minimum population size of 1,365,468 individuals within a large geographical range, the current rate of deforestation in the region will probably result in considerable decline over the next 24 years. Protected areas and Indigenous lands have been effective at maintaining low rates of deforestation within their borders, and these land categories are the only large forest fragments in the southern distribution of this species. Under the business-as-usual scenario, however, deforestation rates would increase considerably. This region is a hotspot of deforestation (Carrero et al., 2020) and the rate of deforestation predicted by 2050 in the Amazon rainforest (Soares-Filho et al., 2006; Nobre et al., 2016; Walker et al., 2019) could cause reductions in the populations of several primate species (Silva et al., 2018, 2020; Rabelo et al., 2020). Thus the large geographical ranges of some primates in southern Amazonia should not necessarily be used to categorize a species as Least Concern, especially when most of the distribution range of a species is within an area with an actual or potential high rate of deforestation.

There have been few studies of the ecology and behaviour Amazonian titi monkeys (e.g. Palacios et al., 1997; Bicca-Marques & Heymann, 2013; Kulp & Heymann, 2015; Martinez & Wallace, 2016) and inferences regarding their habitat preferences are based mainly on data from species in the Atlantic Forest (but see Wagner et al., 2009; Chagas & Ferrari, 2010). Nonetheless, the ecological flexibility of many Amazonian titi monkeys and their preference for secondary forests (Wagner et al., 2009) have been used to support their categorization as Least Concern. However, deforestation within the species' range, whether ongoing or predicted, is usually from activities that result in clear-cutting, leaving no continuous forests or trees that could be inhabited and used by any primate species. A similar situation was also found for the recently described *Plecturocebus grovesi* (Boubli et al., 2019) c. 230 km to the east of our study area. The species was included in the list of the 25 most threatened primates, being categorized as Critically Endangered on the IUCN

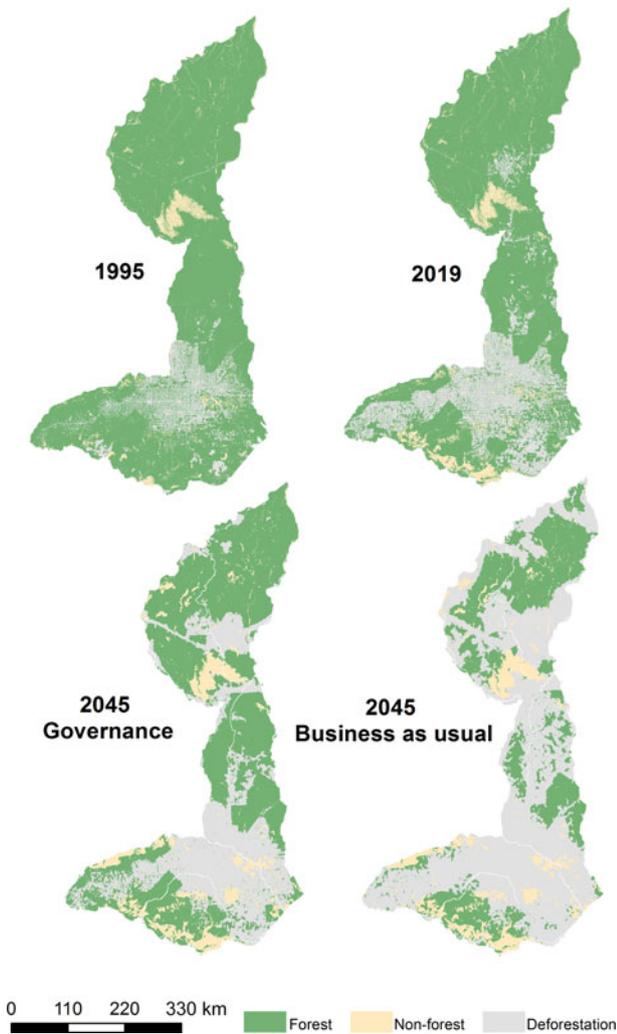


FIG. 3 The accumulated (1995–2019) and predicted habitat loss according to different scenarios of deforestation within the geographical range of *P. bernhardi*.

Red List based on criteria A3c (i.e. population reduction projected, inferred or suspected to be met in the future; Boubli et al., 2020). Questions regarding how Amazonian titi monkeys will cope with habitat fragmentation and what the genetic consequences of population reduction will be in these scenarios remain unanswered.

Based on our analysis and given the increasing rates of deforestation in the Brazilian Amazon, we recommend that *P. bernhardi* should be categorized at least as Vulnerable on the IUCN Red List. In addition to habitat loss, several other anthropogenic activities could further affect *P. bernhardi*. For example, greater contact with people in remnant forest could increase the transmission of pathogens, including diseases with high fatality rates such as yellow fever, which have been reducing populations of non-human primate species in southern Brazil significantly, including titi monkeys (de Melo Mares et al., 2020; Berthet et al., 2021; Fernandes et al., 2021). In addition, fragmentation could provide new points of access to the forest for hunters and

increase the harvest of wild animals (Renó et al., 2016). The scenario described here for *P. bernhardi* therefore also raises concerns for the conservation of other species in highly impacted landscape of the southern Amazon. Examples include marmosets and titi monkeys that are currently categorized as Least Concern (e.g. *M. chrysoleucos*, *Mico intermedius*, *P. cinerascens*) or Data Deficient (*Plecturocebus miltoni*, *Plecturocebus vierai*), but that have large portions or even the entirety of their ranges lying in the Arc of Deforestation.

Although legally protected lands are essential for the conservation of Amazonian species, their integrity and effectiveness are at risk under the policies of the current government in Brazil (Pereira et al., 2019, 2020; Diele-Viegas et al., 2020; Paiva et al., 2020; Pelicice & Castello, 2021). Initiatives being promoted by the government and by politicians associated with agribusiness are weakening environmental regulations for controlling deforestation, resulting in a new wave of forest loss (Magnusson et al., 2018; Andrade et al., 2021; Mataveli et al., 2021; Ruaro et al., 2021). Such initiatives include the proposed bills PL490/2007 and PL191/2020, allowing mining and hydro-power dams within Indigenous lands, and the so called land-grabbing bills PL2633/2020 and PL510/2021, which grant an amnesty to land-grabbers and invaders that irregularly occupy exploited and deforested federal lands (Aleixo & Junior, 2022). Consequently, activities that increase deforestation in the southern Amazon such as land grabbing, illegal logging, mining and fire are being facilitated against a backdrop of impunity and a lack of governance (Azevedo-Ramos et al., 2020; Cardil et al., 2020; Pereira et al., 2020; das Neves et al., 2021; Mataveli et al., 2021). Even a small number of misguided and irresponsible policy decisions can significantly worsen an already difficult future scenario for Amazonian primates (Estrada et al., 2018; Carvalho et al., 2019; Sales et al., 2019). The increasing economic and development pressures on this biome threaten not only titi monkeys but all species currently categorized as Least Concern in this region.

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Author contributions Study design: FES, HREB; data collection: FES, LPL, ACG, ODdS, JCD, MIS; data analysis: FES, LGP, CLBF, HREB; interpretation of results and writing: all authors.

Conflicts of interest None.

Ethical standards This research abided by the *Oryx* guidelines on ethical standards. There were no human subjects, experimentation with animals or collection of specimens associated with this work. This research adhered to Brazilian law governing primate research and the principles of the American Society of Primatologists for the ethical treatment of primates.

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