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Nonvolant Small Mammal (Rodentia and Didelphimorphia) Assemblages Structure in Areas Under Mining Impact in the Brazilian Amazon

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Abstract

Tropical forests are the most biodiverse ecosystems on Earth. Unfortunately, they are often degraded by large enterprises that convert large areas of continuous forest into forest mosaics or into deforested areas in order to seek economic development through infrastructure construction. This study evaluates how the assemblage of nonvolant small mammals is structured after the implementation of a bauxite mining in the Saracá-Taquera National Forest, Pará, Brazil. We tested the hypothesis that the clearings for bauxite mining produce an edge effect over the small mammal assemblage and that the size of the deforested area increases the impact's magnitude. Data collection took place through live traps from 2010 to 2012, totaling an effort of 56,220 trap nights in both impacted and pristine areas. Generalized Linear Models revealed that the size of the mined area was the main predictor explaining species impoverishment in impacted areas. Multivariate Permutational Analysis of Variance and Multivariate Dispersion Permutation Analysis revealed differences in species composition between impacted and nonimpacted sites and that these differences are due to species turnover. We recommended that concessions for land use should be rethought, especially in protected areas and when major areas are subjected to a new economic exploitation cycle.

Keywords

anthropogenic action, environmental impact, protected areas, mining, biodiversity

Tropical forests are the most biodiverse ecosystems in the world (W. Laurance, 2002). However, human activities such as large enterprises pursuing economic development by mining, road construction, agriculture, and hydropower have converted large areas of continuous forest into forest mosaics with irregular sizes and shapes, inserted into a matrix of habitat usually unsuitable for biodiversity (Benchimol & Peres, 2015; Cochrane & Laurance, 2002; Ewers & Didham, 2007; Ferreira et al., 2014; W. F. Laurance et al., 2002). This recent transformation of natural landscapes can be the main cause of increasing species extinction rates even in protected areas ((PAs) (Benchimol & Peres, 2015; Henle et al., 1996)), although the extinction debt is poorly understood (Rangel, 2012) and the time lag of occupancy after a disturbance is also very unclear and poorly known (Metzger et al., 2009; Sales et al., 2015).

In this scenario, the creation and implementation of PAs is the main strategy to prevent or diminish the impacts of the expansion of anthropogenic activities on forests (Nolte et al., 2013; Walker et al., 2009). In Brazil, National Forests are a category of PAs for which the main purpose is to promote the sustainable use of its natural resources in an attempt to combine economic development and biodiversity conservation being logging and mining

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concessions the most frequent activities (Brasil, 2000; Richardson & Peres, 2016).

During ore extraction processes, such as bauxite mining, the area is deforested, and the surface layers of the soil are completely removed (Knowles & Parrotta, 1995), which hinders natural regeneration after exploitation (Parrotta et al., 1997). The remaining forest, adjacent to mining areas, is exposed to a variety of impacts that disrupt the biotic and abiotic environmental conditions and can extend by several meters into the forest. These impacts change the structure and function of the natural assemblages and include the edge effect (Murcia, 1995; Pfeifer et al., 2017), fire susceptibility (Barlow et al., 2006; Cochrane & Laurance, 2008; W. Laurance, 2002), increased accessibility to hunters, invasion of opportunistic species, and even extinction of endemic species (Benchimol & Peres, 2015; Palmeirim et al., 2018; Santos-Filho et al., 2012).

Nonvolant small mammals are represented by the orders Didelphimorphia and Rodentia. This group of species strongly influences the structuring and maintenance of forest's species community structure, as they act as seed dispersers and predators and are primary prey for mammalian meso-carnivores, snakes, and birds of prey (Brewer & Rejmánek, 1999; Crooks & Soulé, 1999; Palomares et al., 1995; Rogers & Caro, 1998; Slade & Swihart, 1983); therefore, changes in species richness, abundance, and composition of nonvolant small mammals assemblage are also reflected in trophic chains with consequences for many ecosystem dynamics. In addition, several nonvolant small mammal species are sensitive to environmental impacts and are considered to be good bioindicators, mainly because they possess small home ranges, and both low locomotion and dispersal ability to move between remaining forest patches (Bonvicino et al., 2009; Eisenberg & Redford, 1999; Forero-Medina & Vieira, 2009; Paglia et al., 2012; Prevedello et al., 2011; Santos-Filho et al., 2012).

In this study, we evaluate how the assemblage of nonvolant small mammals are structured after the consequences of extensive clear cutting for bauxite mining activities within a National Forest in the Brazilian Amazon. We tested the hypothesis that the distance from the forest edge and the size of the deforested area affects negatively the number of small-mammal species, and that species composition changes from impacted to nonimpacted sites.

Materials and Methods

Study Area

The study was carried out in the Saracá-Taquera National Forest (hereafter STNF; 01°20′–01°55′ S to 56°00′–57°15′ W), a Federal Protected Area located in the municipality of Oriximiná, State of Pará, on the right bank of the Trombetas River (Figure 1). The region presents a warm and humid Equatorial climate; mean annual temperature is 26 °C. The terrain has steep plateaus and slopes around it, with a maximum altitude of 140 m, and sand banks through which run streams (Knowles & Parrotta, 1995; MMA, 2001; Parrotta, 1995). Since 1979, STNF is under concession to a private company for bauxite mining. This activity includes deforestation of native areas located in plateaus and, after the depletion of mines, reforestation with seedlings of native species (Knowles & Parrotta, 1995) (Figure 1).

Data Collection

The study was carried out in the areas adjacent to the deforestation resulting from the mining activity of bauxite extraction. The impacted sites and their respective deforested sizes were the following: Almeidas (702.32 ha), Aviso (1,140.06 ha), Papagaio (418.31 ha), Periquito (369.84 ha), and Saracá (1,134.62 ha). For comparison, we studied continuous forests sites, used as a control, which were not impacted by the mining: Bela Cruz, Greig, and Monte Branco sites (Figure 1).

In the impacted sites, we installed two sets of sample units adjacent to the deforested plateaus, whereas in the nonimpacted sites, four sets of sampling unit were installed since the plateaus were not deforested. Each sample set was formed by four parallel sampling lines of 350 m each. The lines were placed at a distance of 50 m, 100 m, 250 m, and 500 m from the forest edge of impacted sites and in the continuous forest in nonimpacted sites (Figure 2). In each parallel line, we installed six pitfall traps, consisting of buckets of 64 liters spaced 50 m from one another and connected by a plastic canvas of 60 cm in height. At the end of each pitfall sequence, 10 live traps were distributed in pairs with 15 m between each pair of traps. Each pair consisted of both a Sherman ($430 \times 125 \times 145$ mm) and a Tomahawk ($450 \times 210 \times 210$ mm) traps. The traps were placed alternately on the ground and suspended to capture the maximum number of species with different habits (Pardini, 2004; Umetsu et al., 2006).

All live-catch traps were baited with small portions of an attractant made of banana, peanut powder, corn meal, and sardines. The traps were checked daily, and the baits were replaced to maintain their attractiveness (Pardini, 2004; Pardini et al., 2005; Umetsu & Pardini, 2007). The live-catch traps and the pitfalls remained open for six consecutive nights at each site. Field surveys were conducted during both rainy and dry seasons of the years 2010 and 2011 and during the rainy season of 2012, totaling five field surveys at Almeidas, Aviso, Bela Cruz, Monte Branco, Papagaio, Periquito, and Saracá, whereas, at Greig, data were collected during the dry season of 2011 and during the rainy season of 2012.

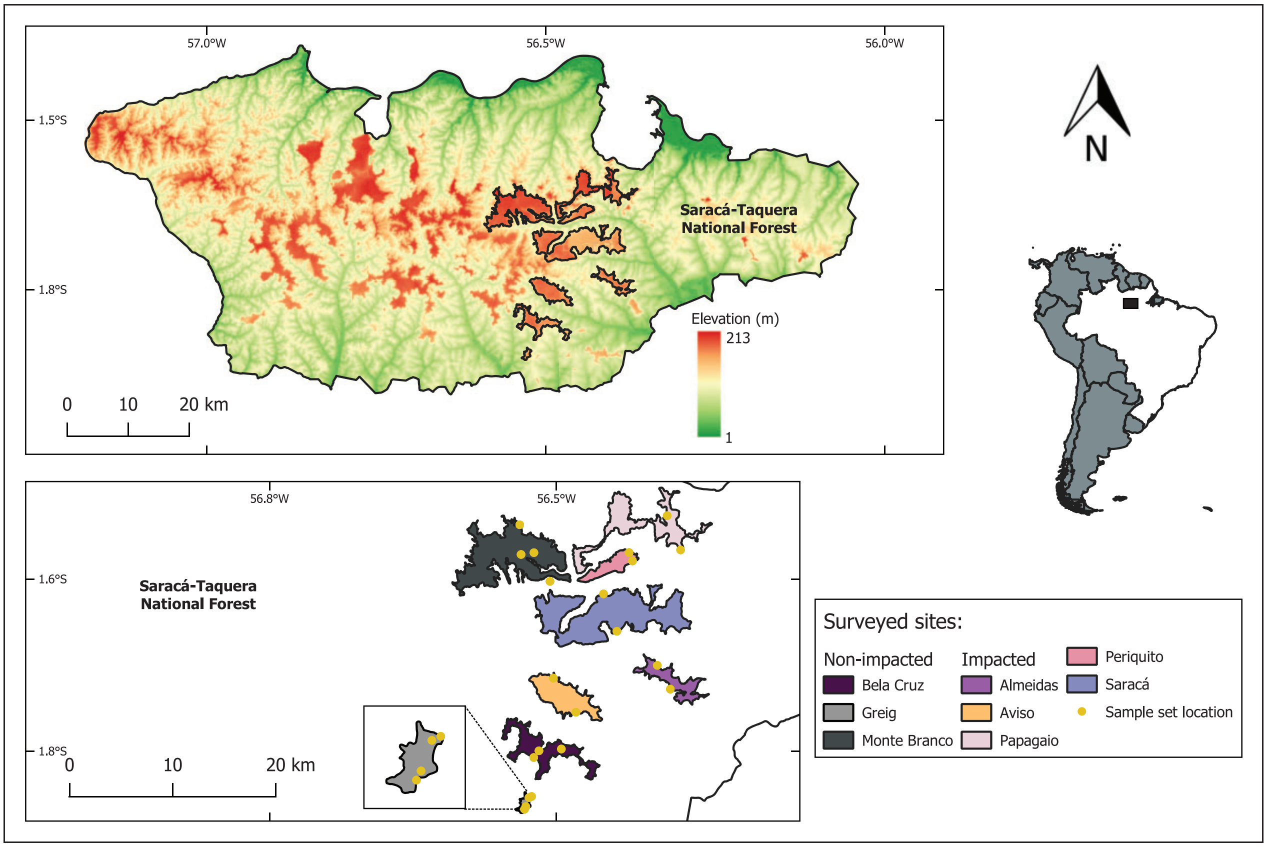

Figure 1. Saracá-Taquera National Forest in Oriximiná, Pará, Brazil. Background colors represent elevation, with reddish and green shades indicating high and low elevation, respectively. Map inset shows geographic location of each surveyed site, dark-gray, gray, and purple color represents nonimpacted sites, whereas impacted sites are represented by orange, violet, pink, light-pink, and blue colors. Yellow dots represent the location of each sampling set.

Voucher individuals of each species and those unidentified in the field were euthanized using the usual techniques of preservation of biological material (Auricchio, 2002), the others were tagged (Fish and Small Animal Tag, size 1; National Band and Tag Co., Newport, Kentucky) and released at the same capture location. Animal manipulation and marking followed ASM guidelines (Gannon et al., 2007) and was authorized by the Chico Mendes Institute of Biodiversity (ICMBIO; MMA/ICMBio license No. 009/2010, MMA/ICMBio license No. 010/2012, renov. 9 A/2010). The collected animals were deposited in the scientific collection of the Capão da Imbuia Natural History Museum, Curitiba, Paraná, Brazil.

Data Analysis

All analyses were carried out in program R version 3.5.3 (R Core Team, 2015). Using package iNEXT (Hsieh et al., 2016), we evaluated sample completeness and compared the number of species between impacted and nonimpacted sites using sample size rarefaction (interpolation) and prediction of Hill numbers by extrapolating the number of individuals twice.

We performed Generalized Linear Model using a Poisson distribution to assess the relationship between nonvolant small mammals' species richness in impacted sites, distance to edge, and the size of the deforested area (Bolker et al., 2009). Principal Coordinates Analysis (PCoA) was used to depict variation in assemblage structure between the nonimpacted and impacted sites. To test the differences in species composition between impacted and nonimpacted sites, we used a Multivariate Permutational Analysis of Variance (PerMANOVA). PCoA and PerMANOVA were performed using a Bray Curtis similarity distance matrix (Anderson, 2001). We also used a Multivariate Dispersion Permutation Analysis (PERMDISP) (Anderson, 2006) to look for differences in group's heterogeneity. Prior to these analyses, we standardized our data set to species abundance/1,000 trap nights when our sampling effort differed between impacted and nonimpacted sites. PerMANOVA and PERMDISP were performed using the *vegan* package (Oksanen et al., 2015). Finally, to verify if the dissimilarity (β-diversity) between impacted

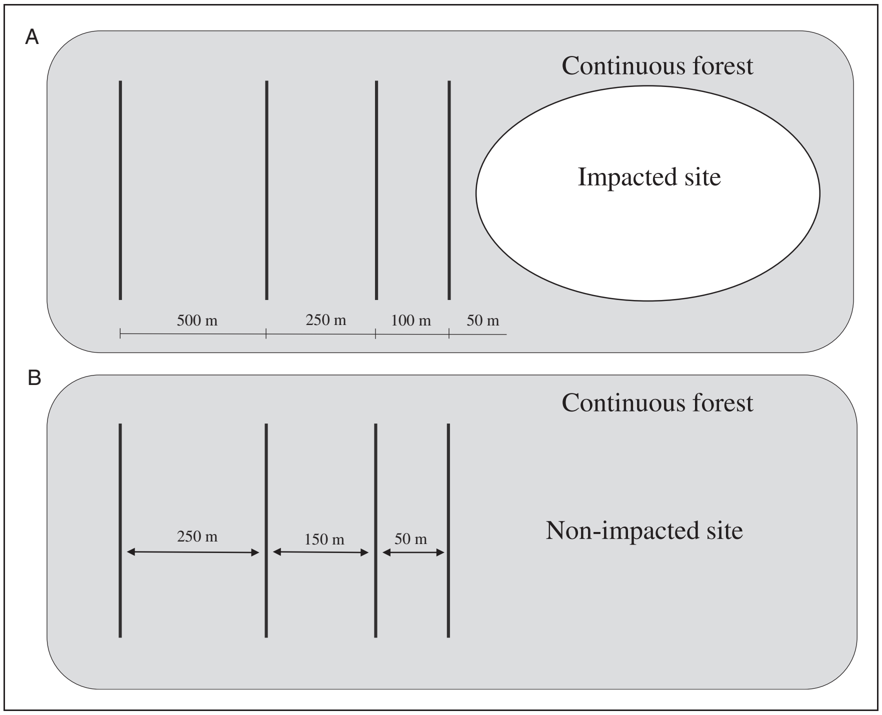

Figure 2. Schematic representation of sampling units used to assess nonvolant small mammals at Saracá-Taquera National Forest, Oriximiná, Pará, Brazil. (A) Sampling design used in impacted sites; white circle represent deforested site by mining activities, and black lines represent parallel trap lines at 50 m, 100 m, 250 m, and 500 m from forest edge. (B) Sampling design used at non-impacted sites; black lines represent trap lines at 50 m, 150 m, and 250 m from each other.

and nonimpacted was driven by species substitution (turnover) or loss of species (nestedness), we calculated β-diversity using the Jaccard presence–absence coefficient. If multiple-site β-diversity calculations based on Jaccard coefficient were sensitive to sample size, we calculated β-diversity values for all sites using a resampling procedure. We took 999 random samples from each site to have comparable measures of turnover and nestedness components. This analysis was performed using *Betapart* package (Baselga & Orme, 2012).

Results

On the basis of 56,220 trap nights, we captured 662 individuals from 18 species, 10 belonging to the order Rodentia and 8 belonging to the order Didelphimorphia (Table 1). Extrapolated curves indicated that we captured 99% of the estimated species richness for the study area; however, these did not reveal differences in species richness between impacted and nonimpacted sites (Figure 3).

The Generalized Linear Model indicated that the size of the deforested area for mining activities has a negative relationship with number of species ($\beta = -0.510$, $p = 0.003$; Figure 4). Contrary to our predictions, edge distance was not a significant explanatory variable in impacted sites ($\beta = -0.082$, $p = 0.379$).

PCoA ordination revealed strong differences between sample clusters formed by the impacted and nonimpacted sites (Figure 5), which was further confirmed by permutation tests (PerMANOVA, $R^2 = 0.27$, $F = 2.234$, $p = 0.042$; PERMDISP, $F = 0.0$, $p = 0.981$). Total Jaccard dissimilarity between surveyed sites was 63% due to species turnover and only 11% due to nestedness; pairwise comparison between impacted and nonimpacted sites revealed 22% of total dissimilarity was due to species substitution.

Discussion

This study showed that the deforested area required for mining activities decreases the number of nonvolant small mammal's species in impacted sites. This corroborates previous studies which demonstrated that by increasing the deforested area, the magnitude of mining activity's negative impacts on forest biodiversity are amplified (Delciellos et al., 2015; Pardini et al., 2005, 2010; Pinotti et al., 2015; Umetsu et al., 2008). Even when not located in a fragmented environment, we found that the size of the deforested area caused species loss; however, the extent of the environmental costs of this activity beyond its operational limits are still uncertain (Deikumah et al., 2014; Metzger et al., 2009; Schueler et al., 2011).

Table 1. Nonvolant small mammal species captured in impacted and non-impacted sites by bauxite mining at Saracá-Taquera National Forest, Oriximiná-Pará.

		Impacted sites					Nonimpacted sites		
	Total	Almeidas	Aviso	Papagaio	Periquito	Saracá	Bela Cruz	Greig	Monte Branco
Order Didelphimorphia									
Caluromys philander	6	0	3	1	0	0	1	0	1
Didelphis albiventris	2	0	0	0	0	0	0	0	2
Didelphis marsupialis	29	0	0	10	2	6	0	1	10
Gracilinanus emiliae	1	0	0	0	0	0	1	0	0
Marmosa demerarae	165	18	35	15	8	12	15	39	23
Marmosops parvidens	176	3	17	19	13	6	25	63	30
Monodelphis arlindoi	77	5	1	16	5	0	16	25	9
Metachirus nudicaudatus	29	3	4	0	4	9	0	0	9
Order Rodentia									
Euryoryzomys macconnelli	8	0	0	2	1	0	0	5	0
Guerlinguetus sp.	4	1	2	0	0	0	1	0	0
Hylaeamys megacephalus	30	0	0	11	4	0	3	12	0
Isothrix pagurus	2	1	0	0	1	0	0	0	0
Mesomys hispidus	7	0	0	1	0	0	0	1	5
Nectomys rattus	3	0	0	1	2	0	0	0	0
Oecomys bicolor	27	4	1	3	2	0	7	5	5
Proechimys cuvieri	70	3	1	11	6	5	11	24	9
Rhipidomys nitela	13	0	1	3	2	1	2	0	4
Zygodontomys brevicauda	13	0	0	0	2	0	1	9	1
Total individuals	662	38	65	93	52	39	83	184	108
Number of species	18	8	9	12	13	6	11	10	12

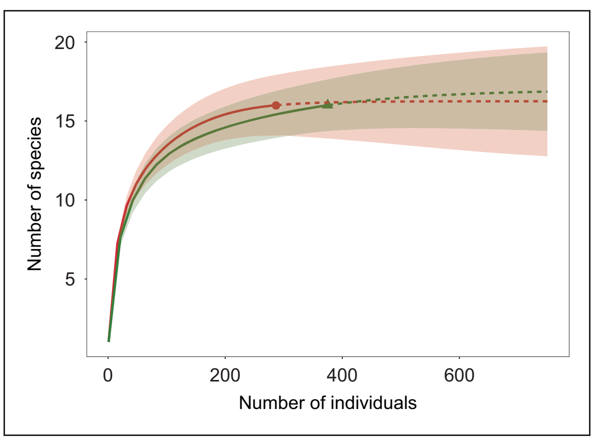

Figure 3. Species accumulation curves of nonvolant small mammals at Saracá-Taquera National Forest, Oriximiná, Pará, Brazil. Extrapolated samples are represented by dotted lines, impacted and nonimpacted sites are represented by red and green curves, respectively, and shaded area represents the 95% confidence interval.

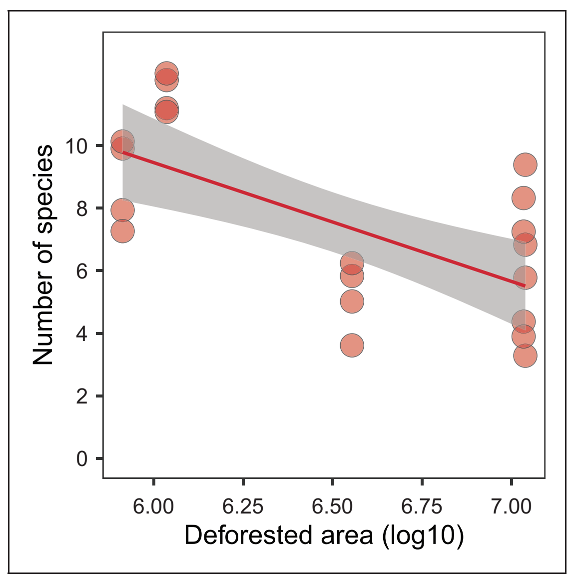

Figure 4. Relation between nonvolant small mammals' number of species and the size of deforested areas in impacted sites by bauxite mining at the Saracá-Taquera National Forest, Oriximiná, Pará, Brazil.

No consequences of the edge effect on nonvolant small mammals were detected. This is probably because the remaining area is still large continuous forest (Delciellos et al., 2015), considering the consequences of the edge effect are aggravated by site area, the impact level, the degree of isolation, the size and the shape of the matrix, adjacent area quality, and forest fragmentation level (Delciellos et al., 2015; Ewers & Didham, 2006; Prevedello et al., 2013; Prevedello & Vieira, 2010). As these factors are not characteristic of the studied

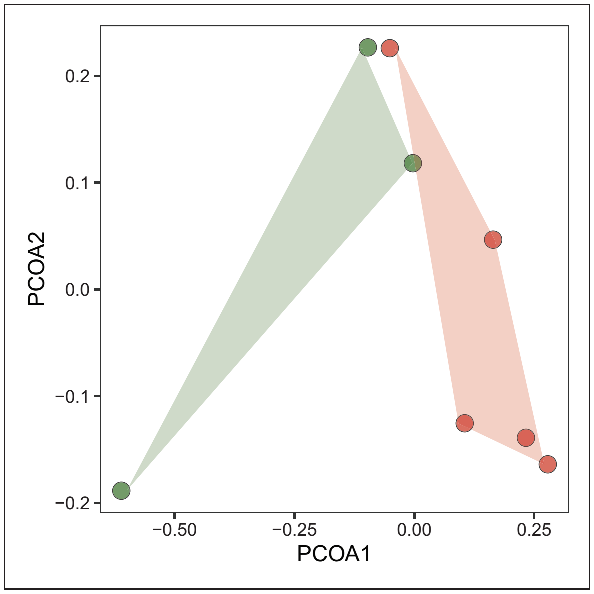

Figure 5. Principal Coordinates Analysis (PCoA) ordination of nonvolant small mammals' composition in impacted (red circles) and non-impacted (green circles) sites by bauxite mining at the Saracá-Taquera National Forest, Oriximiná, Pará, Brazil.

areas, the absence of these aggravating factors may have neutralized larger impacts. However, De Araújo and Espırito-Santo Filho (2012) and De Araújo et al. (2014) used the same areas in their studies and found edge effects for galling insects, with greater species richness near the edge of the forest. This can be explained by the different ways in which taxonomic groups respond to changes caused by the edge effect (Pfeifer et al., 2017).

Our study revealed that most of the species dissimilarity was due to species turnover highlighting a high diversity and heterogeneity even at a local scale. This makes the impacts of deforestation more severe since each location was unique in terms of species composition. In this way, forest changes can mean, in the long term, irreplaceable species losses as mining progresses, because there may be unique species in each site, which can result in local extinctions (Kerr & Currie, 1995; Rangel, 2012). Therefore, the unprecedented Brazilian government attempts to reclassify, downsize, and to open PAs for mining exploitation is a threat to the Amazon and its biodiversity (De Marques & Peres, 2015; Schueler et al., 2011) as the strengthening of forest reserves are critical in trying to reduce and mitigate species losses and changes in assembly structure (Metzger et al., 2009; Nolte et al., 2013).

Conservation Implications

The sustainable exploitation of natural resources within of Brazilian National Forests is permitted by law (Brazil, 2000). However, this study has shown that there are deleterious effects of biodiversity in areas adjacent to mining within the boundaries of the STNF. In this context, we emphasize that for the conservation of tropical forests, it is necessary to analyze and rethink land use concessions, especially within PAs such as National Forests, the main objective of which is to protect biodiversity against the devastating anthropic processes that are largely neglected by Brazilian environmental policy. Currently, PAs in Brazil face major problems with a misguided policy, a consequence of aggressive economic development that puts at risk the delicate functionalities in the different existing PA's categories, weakening them. Bills for further opening, reduction, and even elimination of PAs for future mining operations are lacking in planning to mitigate any damage and have problematic consequences that disrupt the Amazon biome (De Marques & Peres, 2015; Ferreira et al., 2014; W. F. Laurance et al., 2001). Contrary to what happens with Brazilian environmental policy, it is necessary to strengthen PAs to reduce environmental changes, which are fundamental to both conservation of the world's largest tropical forest and human well-being.

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Declaration of Conflicting Interests

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