



Norwegian University
of Life Sciences

Master's Thesis 2024 60 ECTS

Faculty of Environmental Sciences and Natural Resource Management
(MINA)

Long-term effects of reduced impact logging on primate assemblages in eastern Amazonia, Brazil.

Martine Søreng Landsem & Svea Wangenheim
Masters in Environment and Natural resources

Acknowledgement:

Firstly, a big thanks to Thomas Luypaert for vital last minute statistical help, also we would like to thank our supervisors Dr. Ana Cristina Mendes de Oliveira and Dr. Torbjørn Hugaasen for their help and advice while writing this thesis and for all the organization to make this trip possible.

We would also like to thank the Keilla group staff at the Rio Capim Complex, especially Marcos for all the organization and always being available, and our field guides Antonio and Domio for making sure we survived five weeks in the Amazon.

Also, a big thank to Carlos Lira Doutorado for making sure our stay in Brazil was super memorable. Also, we must thank the students at UFPA ecology lab for helping us with the data analysis, Geovana, Elisia, Lia, Marcelli, Halicia and Ana.

Universidade Federal do Pará, UFPA provided vital data for this study, and will use our collected data for future studies.

Thank you!

Norwegian University of Life science

Ås, 14. May 2024

Martine Søreng Landsem & Svea Wangenheim

Abstract

In the Amazonian rainforest, logging poses a significant threat to the ecosystem integrity. This study researches the impacts of reduced impact logging on primate species in a secluded forest area in the Northeastern Amazon biome. The objectives are to assess the trend for primate populations and primate assemblage composition and comparing these parameters over a decided time period covering 20 years (2002-2023) and dividing the data into three time periods to get a good estimate of differences over the years (Period 1, 2 and 3). However, the long-term effects of RIL are poorly studied, especially for primates. Many studies that have researched the short-term effects of RIL on vertebrates show that the populations for most the part are more or less unaffected. The data for the years 2002-2013 are from the database by Universidade Federal do Para and was gathered by walking line transects in various lengths, depending on the year. Our own data was collected by walking transect lines of 5km from October to November in 2023. In total six primate species were recorded, and the species with the most decline in observations from Period 1 to Period 3 were Red-handed howler monkey, Black tamarin, and Tufted capuchin, also being the most common species in the area. Black saki observations remained consistent over the time periods, while Collins Squirrel monkey and Kaapori capuchin observations increased over time. The mean group size increased for the Red-handed howler monkey, Black saki, Black tamarin, Collins squirrel monkey, and the Tufted capuchin, and decreased for the Kaapori capuchin. This indicates that the group sizes for most species are increasing, even though the observations of individuals are decreasing, resulting in fewer but larger groups. The encounter rate (individuals per km) declined for the Red-handed howler monkey, Black tamarin, and Tufted Capuchin, and increased for Kaapori capuchin, Black saki, and Collins squirrel monkey. Statistical calculations showed that there were significant differences among the time periods for three of the species, Red-handed howler monkey, Kaapori capuchin and Black tamarin. The results suggest that even if the mean group size and encounter rate has declined for some of the species RIL does not seem to have a heavy negative impact on primate assemblage in the area.

Table of Contents

Acknowledgement:.....	I
Abstract	II
1. Introduction.....	1
2. Methods and material.....	3
2.1 Study area	3
2.2 Line transects survey	4
2.3 Data analysis.....	6
3. Results.....	7
3.1 Primate assemblage composition.....	7
3.2 Primate population trends	10
4 Discussion	13
4.1 Primate assemblage composition.....	13
4.2 Primate population trends	14
4.3 Study limitations.....	17
4.4 Conservation implications	17
References	19

1. Introduction

The Amazon basin is home to the world's largest tropical rainforest, expanding over eight countries and covering about 40% of the South American continent (Butler, 2020). It serves as a primary regulator of the Earth's climate and as a housing of extraordinary biodiversity. Still, the Amazon suffers from a number of anthropogenic activities, such as infrastructure development, cattle ranching, and predatory extraction operations (mining, logging, and hunting). Historically, both Eastern and Southern Amazon has experienced the most deforestation and fragmentation, creating a patchwork of agricultural land, pastures, and small forest fragments. Over 50 million tropical forest fragments are believed to exist worldwide, covering an area of nearly 300 million hectares, with 50 million linear km of forest edge (Brinck et al., 2017).

Since the mid-20th century, logging in the Brazilian Amazon changed drastically from traditional hand powered logging operations, to using machines like chainsaws. About half of the global tropical forests are either already exploited for timber or are targeted for future exploits (Poker & MacDicken, 2016). As more of the land became available in the eastern Amazon, due to infrastructural changes like the Belém-Brasilia highway, forest areas also became easier to harvest (Uhl & Vieira, 1989). Even though logging is a less destructive land usage than deforestation, studies show that selective logging is a primary driver of tropical forest degradation (Asner et al., 2006; Bousfield et al., 2023).

Adopting methods like reduced impact logging (RIL) that contains guidelines intended to maximise efficiency while minimising unwanted effects, can significantly reduce the negative impacts of logging (Santos de Lima et al., 2018). RIL is a type of selective logging, which targets a specific subset of trees within the forest. Selective logging entails usually going after large, hard-wooded tree species of commercial interest (Bousfield et al., 2020). These hard-wooded tree species often produce large fruits which can be dispersed by large-bodied vertebrates (Yguel et al., 2019). Therefore, maintaining healthy mammal populations is crucial to ensure the long-term viability of timber production, ecosystem integrity of the logged forests, and forest regeneration (Rosin, 2014). However, research indicates that frugivore resources in selectively logged forests may become depleted despite modest levels of logging for the tree species depending on zoochory to be dispersed (Carvalho Jr et al., 2022).

Because of their significant contributions to ecological processes like seed dispersal, primates which are frugivores help maintain a high plant diversity in forests, and most tropical trees depend on frugivores for dispersal (Chapman et al., 2013; Correa et al., 2015). Primates and other frugivores also depend on an abundance of fruit trees as a key food source, and other ecological functions like reproduction success and population density (Correa et al., 2015; Fleming & Kress, 2011; Thompson et al., 2007). Yet, primates are among the most endangered species globally, and currently many of these species inhabit landscapes with heavy human impact (Galán-Acedo et al., 2019). Because of their significant contributions to ecological processes like seed dispersal, primates which are frugivores help maintain a high plant diversity in forests, and most tropical trees depend on frugivores for dispersal (Chapman et al., 2013; Correa et al., 2015). Primates and other frugivores also depend on an abundance of fruit trees as a key food source, and other ecological functions like reproduction success and population density (Correa et al., 2015; Fleming & Kress, 2011; Thompson et al., 2007). Yet, primates are among the most endangered species globally, and currently many of these species inhabit landscapes with heavy human impact (Galán-Acedo et al., 2019).

Several studies have investigated the effects of RIL, mainly focusing on vertebrates. Many of these studies demonstrates that the impact of RIL is low (Azevedo-Ramos et al., 2006; Laufer et al., 2015). However, these studies generally focus on the show the short-term effects of RIL with studies conducted only a few years after timber harvest. Few studies have investigated on the long-term effect of RIL, and not many have looked at the effect on primates. When studying recently altered areas after logging, the effects of habitat loss and habitat alterations can go undetected, particularly for long-lived species like primates that react more slowly to changes in their environment (Metzger et al., 2009). Studying the longer-term effects of RIL is therefore vital to further understanding the potential effects on primate assemblages.

This study took place in the Rio Capim complex, which is a large reduced-impact logging concession in the eastern Amazon. In this study, we build historical primate survey data collected since 2002 and our own newly collected (2023) data. By comparing primate assemblage data from over 20 years ago, 10 years ago and newly collected data, we can assess whether primate species composition, group encounters, and group size have changed over time. More specifically, we asked: 1) What is the current primate composition at the Rio Capim complex and how has it changed during the last 20 years? 2) Has reduced impact logging had a negative effect on the primate assemblage? We discuss our results in light of published literature.

2. Methods and material

2.1 Study area

This study was conducted in the Rio Capim Complex, belonging to the CBNS Company of the Keilla Group. This area is also called Cikel and is located in the municipality of Paragominas in the state of Pará (Figure 1). This area has one of the largest remnants of primary forest in the Northeast of Pará, expanding 149 908 hectares (Florestal & Na, 2005). Submontane Dense Ombrophilous Forest is the main native vegetation, with a canopy height between 25-30 meters (IBGE, 2016). According to the Köppen-Geiger climate classification the area has a tropical wet climate (Kottek et al., 2006). This means that the area has a pronounced rainy season and a dry season with less precipitation. The average annual temperature is 26,3°C, with an average precipitation of 1,800mm/year. The precipitation is less intense during the months July to October. Fieldwork for the current study was conducted from 13th of October to 16th of November and it only rained twice during these 5 weeks. Since the Rio Capim complex received FSC certification for forest management in 2001, there has only been RIL in the complex (Sist & Ferreira, 2007). Logging is done during the dry season in order to minimise harm to the forest floor. The entire concession is called a Forest Management Unit (Aide et al., 1996), and the UMF is divided into smaller sections, referred to as Annual Production Units (UPAs). These UPAs range in size from 2,000 to 5,000 hectares. At Rio Capim, each UPA has a 35-year cutting cycle. Prior to beginning the timber extraction process, two reports are created: the Annual Operational Plan (POA) and the Sustainable Forest Management Plan (Prudente et al., 2017). The POA describes the activities that will take place over the course of a year, including risk mapping, directional cutting, road planning, storage yards, and a description of every tree that has been mapped in the UPA. Two to five trees are logged per hectare in each UPA (Prudente et al., 2017). During the logging process, infrastructure such as roads, paths, and storage yards need to be maintained, and seedlings of the species identified during the tree mapping are planted post logging. Every year, the business inspects about 5,000 hectares and harvests about 150,000 cubic meters of wood. The area is a privately owned land, and all traffic into the area is monitored. Illegal activities, such as hunting or gold mining, are therefore not a threat to the wildlife inside the study area.

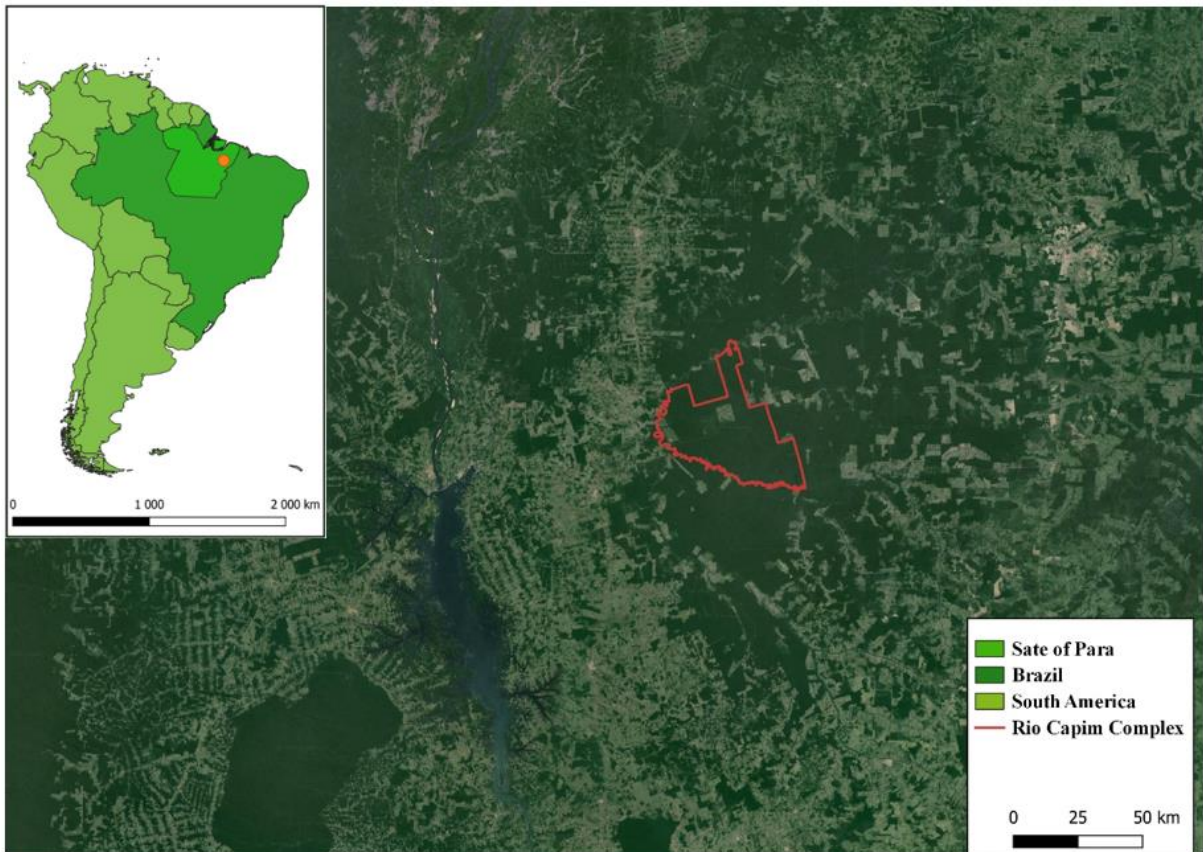


FIGURE 1: Map of the study region, including the outline of the Rio Capim Complex (CIKEL, red polygon), and reference map of South America, Brazil, and the state of Para (top left).

Satellite image from Qgis (Satellite map world, 2024).

2.2 Line transects survey

We used line transect surveys to collect data on primate assemblage structure and composition within the Cikel concession. Our transect surveys followed the general guidelines given by Peres (1999). In 2023, we performed surveys in six 5-km transect lines scattered across the concession (Figure 2C), accruing in average of 78km walked in each transect. It is vital that the observers are proficient in both identification and detection of the study species. We therefore walked all transect in teams of two, with a field assistant to help identify species. For each primate observation, we took note of the species, number of individuals, perpendicular distance from the trail, their height above the ground, and activity (e.g. foraging).

We were unable to provide density estimates for the resident primates and use this in our analyses, as survey effort differed significantly from year to year in the historical data. In most years, survey effort was not high enough to obtain credible density estimates.

A similar effort is essential for comparing data. The time Periods 1, 2 and 3 have been put together to create good representation for the sections and to have a similar combined effort in km, some years were not included because of too low effort and observations. Period 1 includes data from 2002-2004, Period 2 includes data from 2009, 2010 and 2013, and Period 3 includes our data from 2023 (Table 1). 2011 and 2012 were not included in the Period 2 section due to relatively low transect effort and low observations. Therefore, these years were excluded from the time period. Period 1 and period 2 have data from different UPAs and used shorter 1km line transects. Even though the study area is divided into several UPAs, we focus on the area as one unit and therefore do not differentiate between different trails and different UPA`s. The combined effort per section (km) is similar, and therefore these sections can be compared to see changes over time. The selected years in each time period have similar effort and observation rates.

Table 1: Total kilometres of transect surveys performed at Cikel for the years included in the three time periods used for the analysis.

Time period:	Years pr section	Total km:
Period 1	2002, 2003, 2004	691 km
Period 2	2009, 2010, 2013	523 km
Period 3	2023	470 km

For Period 1 and 2 they had several shorter transects of 1km done in each UPA, with some UPA`s having up to twelve transects of 1km. The location for these UPAs is provided in Figure 2 a and b for Period 1 and 2(Figure 2a & b). Period 3 consisted of six transect lines of 5km each throughout the concession (Figure 2c). We opted to only show the UPAs for Period 1 and 2, because the exact location of the trails was not provided in the dataset. This is displayed to show a good coverage of the entire Rio Capim Complex.



2.3 Data analysis

Primate census effort varied a lot from year to year in the historical dataset from 2002-2022. Yearly comparisons of primate community composition and structure were therefore not possible. To assess potential difference between short-term, mid-term and long-term primate assemblage composition and structure, we therefore selected to poll the three initial census years (2002-04; short term) and three mid-term years (2009-10 and 2013) to obtain a similar effort to our own in 2023 (Table 1). We were unable to utilise the data from 2011 and 2012 as very few censuses were performed in the years. Hereafter, these periods are referred to as Period 1 (2002-04), Period 2 (2009-10 and 2013) and Period 3 (2023).

To detect a potential decline in group size we calculated mean number of individuals per group for each Period 1-3. We also calculated the average group size across the historical dataset. We incorporated these numbers in the changes over time section (figure 4).

As perpendicular distance from the trail was not registered in the historical data, we were unable to calculate primate density as described by (Buckland et al., 2015). We therefore calculated encounter rates (number of primate individuals encountered per km walked for each period).

An analysis of variance, ANOVA type II test together with Tukey HSD and Tukey multiple comparison post-hoc test was used to detect any significant changes in primate groups size between the periods for each species.

3. Results

3.1 Primate assemblage composition

In total, 926 primate encounters of six species were observed during surveys at Cikel conducted over a 20-year period (Table 2). The species recorded were Red-handed howler monkey (*Alouatta belzebul*; Figure 3a), Kaapori capuchin (*Cebus kaapori*; Figure 3b), Black bearded saki (*Chiropotes satanas*; Figure 3c), Black tamarin (*Saguinus niger*; Figure 3d), Collins' squirrel monkey (*Saimiri collinsi*; Figure 3e) and Tufted capuchin (*Sapajus apella*; Figure 3f). *S. collinsi* and *S. apella* are assessed as least concern, *A. belzebul* as vulnerable, *C. satanas* and *S. niger* as endangered, and the *C. kaapori* as critically endangered according to the International Union of Conservation of Nature (IUCN).

Table 2: Total number of recorded individuals and groups for all primate species observed at the Cikel from, 2002-2023. A) total number of individuals per species, B) total number of groups per species, C) mean number of individuals per group.

Species	Common name	Total ind^A	Total group^B	Mean ind^C *total mean
<i>Alouatta belzebul</i> (Linnaeus, 1766)	Red-handed howler monkey	1 436	279	5,15
<i>Cebus kaapori</i> Queiroz, 1992)	Kaapori capuchin	378	45	8,4
<i>Chiropotes satanas</i> (Hoffmannsegg, 1807)	Black bearded saki	668	84	7,95
<i>Saguinus niger</i> (É. Geoffroy, 1803)	Black tamarin	1 612	250	6,45
<i>Saimiri collinsi</i> (Osgood, 1916)	Collins' squirrel monkey	70	10	7,00
<i>Sapajus apella</i> (Linnaeus, 1758)	Tufted capuchin	1 944	258	7,53
Total:		6 108	926	

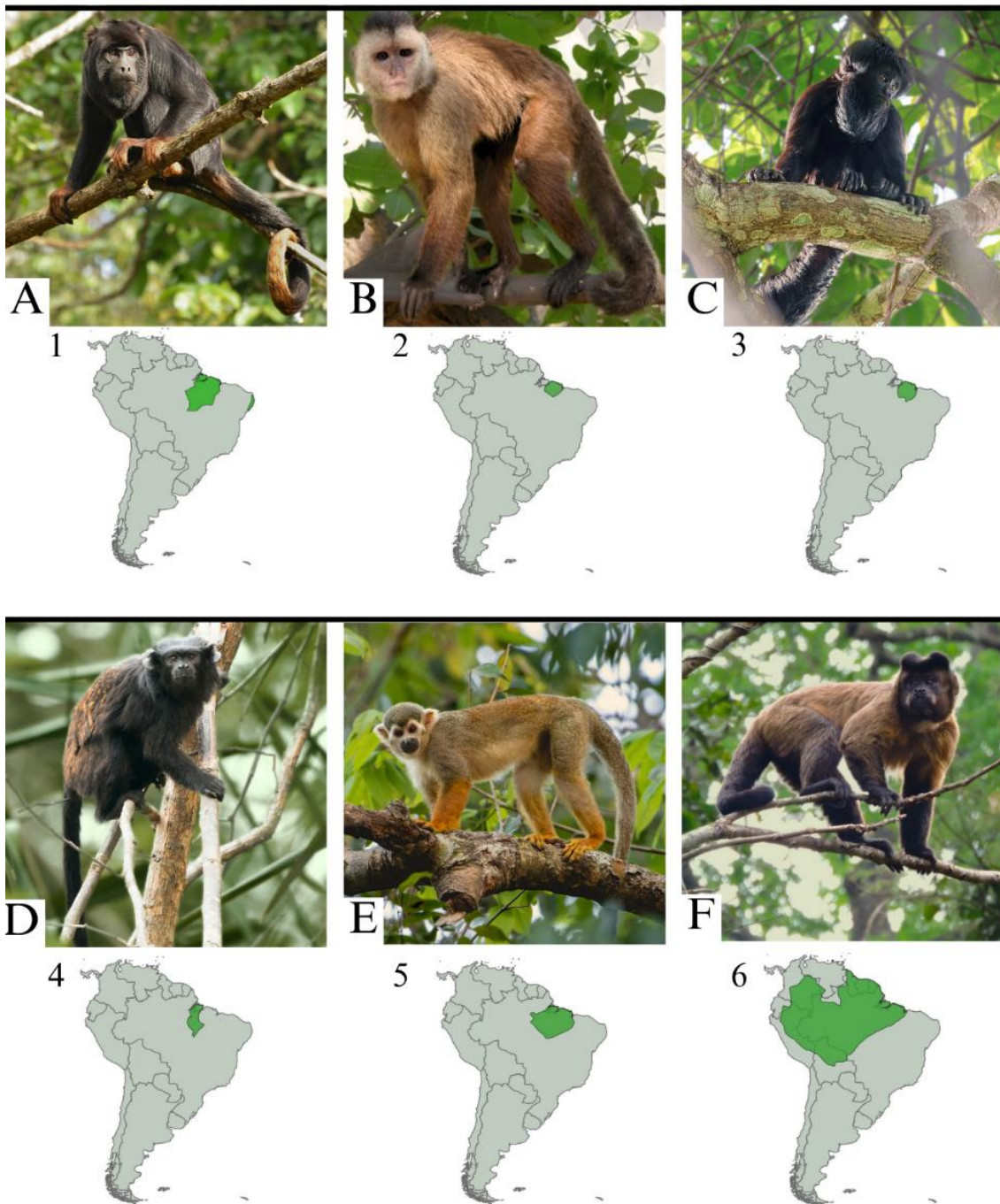


FIGURE 3: The six-primate species observed at the Cikel logging concession and their distribution according to the IUCN (accessed 25th of April 2023).

A) *Alouatta belzebul*, photo: ©flavioubaid/iNaturalist. **B)** *Cebus kaapori*, photo: ©Fabiano Melo **C)** *Chiropotes satanas*, photo: ©Nailson Júnior/iNaturalist. **D)** *Saguinus niger*, photo: ©Kurazo Mateus Okada Aguiar/iNaturalist. **E)** *Saimiri collinsi*, photo: ©Ronaldo Fransisco/iNaturalist. **F)** *Sapajus apella*, photo: ©Felipe Moreli Fantacini/iNaturalist.

*Map created in Qgis

3.2 Primate population trends

During the 20-year period, the total number of groups encountered declined for three of the species (*A. belzebul*, *S. niger*, *S. apella*), whereas there was a marginal variation for two of the species (*C. kaapori*, *C. satanas*), and an increase for one species (*S. collinsi*; Tabel 3). The two-way ANOVA analysis on groups size showed a significant difference between periods for *A. belzebul* (ANOVA $F_{2,187}=4.61$, $p=0.0111$), *C. kaapori* (ANOVA $F_{2,25}=6.111$, $p=0.00691$) and *S. niger* (ANOVA $F_{2,168}=4.623$, $p=0.0111$). While the remaining species showed no significant difference *C. satanas* (ANOVA $F_{2,48}=2.636$, $p=0.082$), *S. collinsi* (ANOVA $F_{2,7}=0.378$, $p=0.698$) and *S. apella* (ANOVA $F_{2,196}=0.298$, $p=0.743$).

Tukey post-hoc test showed the significant differences in mean group size between periods. *A. belzebul* showed significant difference between Period 1 and 2 ($p=0.0472$), a marginally significant difference between Period 1 and 3 ($p=0.0521$) and no significant difference between Period 2 and 3 ($p=0.414$). *C. kaapori* had significant differences between Period 1 and 2 ($p=0.0346$), Period 2 and 3 ($p=0.00680$) and no significant difference between Period 1 and 3 ($p=0.822$). *S. niger* showed significant difference between Period 1 and 3 ($p=0.0334$), a marginally difference between Period 1 and 2 ($p=0.0563$) and no significant difference between Period 2 and 3 ($p=0.829$). For *C. satanas*, *S. collinsi* and *S. apella* the differences between periods were not significant ($p>0.05$).

Tabel 3: Total number of individuals and groups encountered at Cikel during transect surveys for each time period.

Species:	Time period 1		Time period 2		Time period 3	
	Individuals	Groups	Individuals	Groups	Individuals	Group
<i>Alouatta belzebul</i>	414	94	457	85	65	10
<i>Cebus kaapori</i>	60	9	100	8	60	11
<i>Chiropotes satanas</i>	82	15	184	22	105	14
<i>Saguinus niger</i>	532	96	318	48	189	27
<i>Saimiri collinsi</i>	9	2	8	2	53	7
<i>Sapajus apella</i>	722	103	289	40	419	56

A. belzebul group detections declined by 89% from Period 1 to 3, and the total number of individuals experienced a similar decline (84%; Table 3). However, the mean group size increased from Period 1 (4.4 individuals) to Period 3 (6.5 individuals; Figure 4A), and the encounter rate was in considerable decline from Period 1 (0.6) to Period 3 (0.14; Figure 5).

C. Kaapori experienced a 22% increase in total number of groups from Period 1 to Period 3 and had a consistent number of total individuals detected over the time periods (Table 3), meaning that the mean group size decreased from Period 1 to Period 3 (Figure 4B). However, for Period 2 there was an elevated value for mean group size (Figure 4B). The encounter rate (Figure 5) increased from 0.06 (Period 1) to 0.13 (Period 3).

For *C. satanas*, the total number of groups experienced an increase (46%) from Period 1 to Period 2, thereafter a decrease (36%) to Period 3 (Table 3). Total number of individuals increased by 124% from Period 1 to Period 2, then a decrease (42%) from Period 2 to Period 3, and an overall 28% increase from Period 1 to Period 3 (Table 3). Mean group size went from 5.47 in Period 1, to 8.36 Period 2, to 7.50 in Period 3 (Figure 4C). The encounter rate (Figure 5) showed an increase from Period 1 (0.12) to Period 3 (0.22), with a higher value in Period 2 (0.35).

S. niger experienced a decline of 71% for total number of groups and a 64% for total number of individuals from Period 1 to Period 3 (Table 3). Mean group size (Figure 4D) has increased from 5.53 (Period 1) to 7.0 (Period 3), but encounter rate (Figure 5) has decreased from 0.77 (Period 1) to 0.40 (Period 3).

The total number of groups for *S. collinsi* increased by 250% from Period 1 to Period 3, and there has been a 488% increase in total number of individuals (Table 3). The mean group size (Figure 4E) has also increased from 4.5 (Period 1) to 7.57 (Period 3). Figure 5 shows the encounter rate has increased from 0.01 (Period 1) to 0.11 (Period 3).

For *S. apella* there was a decrease in total number of groups (61%) from Period 1 to Period 2, and an increase from Period 2 to Period 3 with 40% (Table 3). The total number of individuals showed a decrease (60%) from Period 1 to Period 2, and an increase (44%) from Period 2 to Period 3. The mean group size (Figure 4F) had a steady increase over all the time periods: 7.01 (Period 1), 7.23 (Period 2), and 7.48 (Period 3).

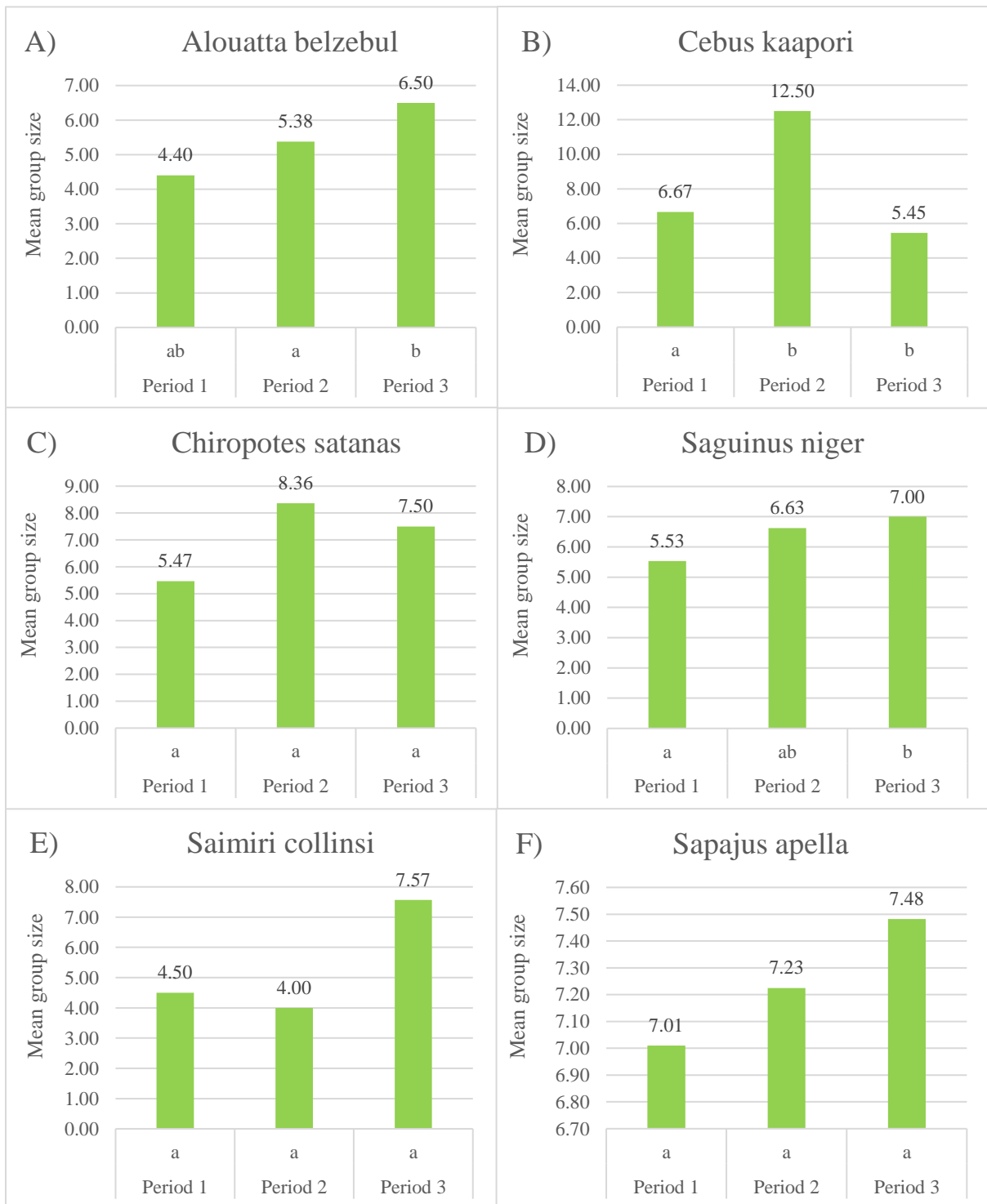


FIGURE 4: Mean group size for each species for the three time periods.

A-F = subsets from Tukey HSD post-hoc test.

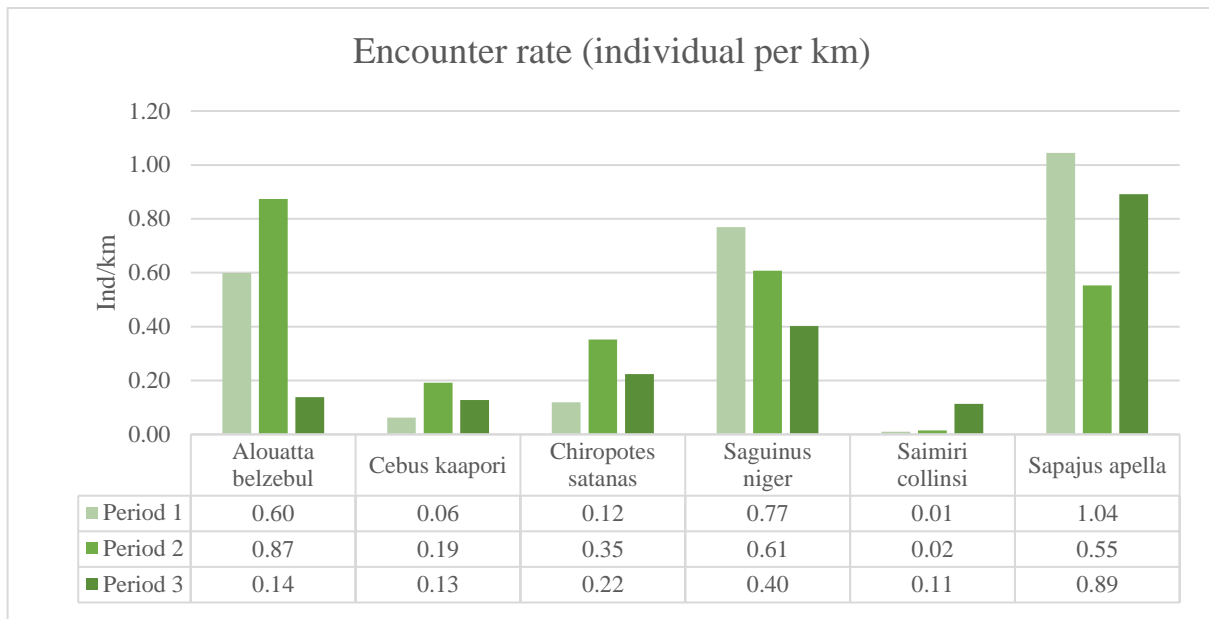


FIGURE 5: Encounter rate for each primate species at Cikel, eastern Amazonia, Brazil, for Period 1 (2002-04), Period 2 (2009-10 and 2013) and Period 3 (2023).

4 Discussion

4.1 Primate assemblage composition

Six primate species were observed at Rio Capim Complex (149 908 ha) over the last 20 years. Previous studies have reported varying primate compositions in forest fragments in The Northeastern Amazon: five species in forest fragments larger than 1000 ha, six species in fragments ranging from 1 to 100 hectares, seven species in areas spanning from 540 to 113 000 hectares (Boyle et al., 2013; Parry et al., 2007; Stone et al., 2009). This indicates that the primate species composition in the Cikel concession is similar to other fragmented areas in Northeastern Amazon. The most frequently observed species were species *S. apella*, *S. niger*, and *A. belzebul*. The presence of *S. niger* and *A. belzebul*, both endemic to the Pará region, and being listed as vulnerable on the IUCN red list, is encouraging.

During the 2023 line-transect surveys some species were seen together. *C. satanas* and *S. apella* were seen together two times in Period 3. We also saw *S. apella* with *S. niger* together two times, and *S. niger* with *A. belzebul*. Sometimes they were in the same area but in different trees, sometimes in the same tree and sometimes feeding together. There are several studies that prove the coexistence between different primate species, and that they form so called mix

species groups. Studies that show mix species groups of *S. apella* and *S. collinsi* also mention that this coexistence gives a bigger payoff for *S. collinsi*, without necessary being negative for *S. apella* (Haugaasen & Peres, 2009; Pinheiro et al., 2011). This could potentially explain the few observations of *S. collinsi* since misidentification of all species in the group can occur. *C. satanas* are in mixed species groups with *Saimiri* and *S. apella*. There is however close to no research of *S. niger* and *A. belzebul* forming mix species groups or living in close proximity, even though we observed these species together two times.

At the Rio Capim Complex, *Manilkara huberi*, *Hymenaea courbaril*, *Parkia pendula*, *Couratari oblongifolia*, and *Astronium lecointei* are the primary commercial species and the most harvested trees (Sist & Ferreira, 2007). *M. huberi* is a primate dispersed tree species (Ratiarison & Forget, 2011) and is often spread by *S. apella*. It is also part of the *A. belzebul* diet (Pinto et al., 2003). *P. pendula* is part of the diet for both *S. niger* and *S. collinsi* (Araújo et al., 2022; Oliveira & Ferrari, 2008). *C. satanas* often consume the seed from *C. oblongifolia* (Van Roosmalen et al., 1988). If these tree species are vital food sources for the six primate species in the Complex, even reduced impact logging could potentially have a negative impact on primate assemblage.

4.2 Primate population trends

The six primate species all experienced a decline for both individual and group numbers from Period 1 to Period 3. However, the mean group size increased for *A. belzebul*, *C. satanas* and *S. niger*. Using the “total mean” (Tabel 2) as a basis for comparison, we can see if the time periods follow the existing trend in total mean group sizes. If we compare the mean group size values, the “total mean value” is always higher for Period 1. Considering that the total individual and group numbers (Table 3) is high for Period 1, we assume that the group size have increased over the years. However, Table 3 shows that the number of individuals and the number of groups have decreased, and this can indicate that the group sizes have stayed consistent even though the population (both individuals and groups) has experienced a decline. The ANOVA analysis showed that there were only significant differences in mean group size for *C. kaapori* and *C. satanas* across the time periods.

For *A. belzebul*, Period 1 had the most group observations, and Period 2 the greatest number of individuals. However, in Period 3 the observations of this species had drastically declined. The mean group size had an increase in Period 3, even though the observations were far fewer than

the other time periods. This suggests that the group size is increasing, even though the total population is declining, and this is supported by the decline of the encounter rate. Their loud howling, which can be heard up to 5km away, makes it possible to know if they are present in the surrounding area. Therefore, we assume that there are more groups and individuals in the general area of Cikel than was observed in all periods, as we heard them daily, but encountered rarely. *A. belzebul* is usually observed in groups from four up to eleven individuals (IUCN, 2021a), and with all mean values being lower than 6.50 (Figure 4A), it seems that the groups in the study area are on the smaller side. The probability of occurrence of *A. belzebul*, is shown to decrease with an increased proximity to large cities, and less frequent in patches in more disturbed areas (Calle-Rendón et al., 2020)

However, *A. belzebul* are folivorous-frugivorous (Julliot & Sabatier, 1993; Mittermeier & van Roosmalen, 1981; Pinto et al., 2003), and their habitat range varies between 6-45 and 9-18 ha (Bonvicino, 1989; Pinto et al., 2003). Showing that the species can exist in smaller fragments and might be more resilient to RIL and the logging of fruit trees, due to their diet.

C. kaapori, had the highest number of group observations in Period 3, and the highest number of individuals in Period 2. This species also experienced a decrease in mean group size in Period 3, and an increase in encounter rate. This indicates that the groups are decreasing in size, and that the total population experienced a small increase. (Ferrari & Queiroz, 1994) and (Lopes & Ferrari, 1993) found that *C. kaapori* is one of the most threatened species among the Amazonian primates, and (Mittermeier et al., 2012) considered the species to be one of the most threatened primate species in the world. Our results indicate that there seems to be a positive trend for this species at Cikel. Furthermore, *C. kaapori* has a very high value for mean group size in Period 2 (Figure 4B), and in 2010 there have been three observations of groups with 20 individuals or more. Since these groups of 20 individuals has been observed on the same trail, it is possible that it was the same group, or in fact not a group solely of *C. kaapori*, as a group of this size is rare for the species. *C. kaapori* is, according to research (da Silva et al., 2022), the species with the most pessimistic prediction in future range loss, projections reaching 100% of its distribution area. Keeping this in mind when looking at our results, it seems that this study area can be important for the species future.

For *C. satanas*, Period 2 had the greatest number of observations, individuals, mean group size, and encounter rate. In contrast to Period 1, where mean group size and encounter rate was lowest. The species can form large groups, with about 40 individuals (Veiga & Ferrari, 2006). Considering the mean group sizes in this study (Figure 4C), the groups at Cikel appear to be

very small. Studies show that they can also survive in smaller secondary forest fragments, showing behavioural adaptations to habitats experiencing anthropogenic disturbances, provided there is no hunting (Ferrari, 2013; Port-Carvalho & Ferrari, 2004; Port-Carvalho, 2002; Santos, 2002; Veiga, 2006).

S. niger had the greatest group size, individuals, and encounter rate in Period 1. Their mean group size had the highest value in Period 3, and the lowest value in Period 1 (Figure 4D). This implies that the total population has declined, but that the remaining groups are larger now than they were both 10 and 20 years ago. They live in extended family groups of 4-16 individuals (IUCN, 2021d), so the mean group size indicates quite small groups in the Cikel area. Research shows a trend for smaller range in marginal or disturbed areas for the species (Egler, 1992) (Neyman, 1978), contrasting with continuous forest cover, where the ranges can exceed 100 hectares (Peres, 1993; Terborgh, 2014). Also, (Veracini, 2000) recorded a habitat range of >30 hectares in predominantly primary forest. However, *S. niger* is also shown to exhibit a preference for disturbed, marginal, and secondary forest habitats, and (Oliveira & Ferrari, 2008) observed the ecological flexibility of the species, especially their ability to adapt their behaviour to changes in distribution of resources and abundance. This ability to adapt to anthropogenic habitat disturbances (Silva & Ferrari, 2007), is most likely to be key for long-term survival of species inhabiting Amazonia (Lopes & Ferrari, 2000). This indicates that the species is affected by anthropogenic disturbances in its environment but has the ecological flexibility to adapt to the disturbances to a certain degree.

For *S. collinsi*, Period 3 had the most observations, and a mean group size similar to the total mean group size at Cikel for the past 20-years. This shows that the observation values for both Periods 1 and 2 were strikingly low (Figure 4E).

Furthermore, the increase reported (250% for groups and 488% for individuals) is somewhat misleading since the observations of this species, in both Period 1 and 2, are extremely low. *S. Collinsi* live in large groups of 25-75 individuals (Mercês et al., 2015), making the low number of observations in the study area very surprising. Despite some areas showing a population decline due to anthropogenic disturbances, particularly the Belém Area, these threats are not affecting the species as a whole (Mercês et al., 2015). Mercês (2015) found that the *C. Collinsi* is a relatively resilient species, as even in intensely fragmented areas, are able to maintain smaller populations.

S. apella had a population decline from Period 1 to 3. However, the mean group size had a steady increase over the 20-year period. Therefore, the groups are becoming larger, even though the population is declining. *S. apella* is not endangered and is the monkey species in this study with the widest range and distribution (Figure 3F). They live in groups of 15-20 individuals (IUCN, 2021e), indicating that the mean group size for this species in Cikel is small. Even though, the mean group size for *S. apella* has had a steady increase, the encounter rate (Figure 5) has declined from 1.04 (Period 1), to 0.55 (Period 2), to 0.89 (Period 3). This indicates that the group size has increased over the years, but number of observations declined in Period 2, before experiencing an increasing in Period 3. The prevalence of *S. apella* is unsurprising given its adaptability, wide distribution, and generalist diet (Gómez-Posada et al., 2019).

4.3 Study limitations

Collecting data via human observations can lead to variabilities or biases in data collection accuracy. The study area may have various levels of logging and several habitat types, influencing the behaviour and distribution of the primates in the area. The data utilised herein was collected by different people over several years, therefore error in species detection, classification, and data entry can occur.

Line-transect censuses were conducted at various times of the year with data from every month. Throughout the year, observation rates may differ due to seasonal changes. In areas with logging activity, line transects are often conducted during April – July, when there is no logging due to the rain season (Azevedo-Ramos et al., 2006). Since the line transects at Cikel were conducted in all months, the transect surveys done between February and April would naturally experience a lot more rain than the transects done between August – November.

4.4 Conservation implications

Our results show that RIL is neither very negative nor positive for the primate assemblage in the study area as of today. RIL has less primate species loss than other land uses, and this has also been shown for other large vertebrates (Azevedo-Ramos et al., 2006; Ribeiro & Freitas, 2012). However, these results can change in the future as more land area becomes logged, further depleting important fruit tree resources, and disrupting the canopy structure of forests. After the 20 years of line transect surveys at Cikel, we can with good certainty say that the area

is an especially important forest fragment for primates. Keeping in mind that much of the once existing forest in Eastern Amazonia is now deforested and/or highly fragmented. All primates in this study except for *S. apella* and *S. collinsi* are declining in the Amazon. The population of *A. belzebul* is suspected to already have declined over the period of one generation, and it is suspected to continue the decline by at least 30% over the course of the current and following generations (IUCN, 2021a). For *C. kaapori* it is assessed that the population is declined by at least 80%, based on a drastic decreasing population trend over the past three generations (IUCN, 2021b). A population reduction for *C. satanas* of at least 50% is suspected over the course of next three generations (IUCN, 2021c). There has also been a 30% decline in *S. niger* population over the last ~18 years, equalling 3 generations for the species (IUCN, 2021d). Cikel appears to act as a safe haven for *C. Kaapori*, which emphasises the importance of forest fragments. For future research, it would be interesting to see if there is a correlation between fragmented areas and the forming of new mixed species groups, especially species with no studies about them coexisting in this way. The long-term effects of RIL in logging concessions must be studied further, focusing on specific aspects of primate ecology, like diet and direct correlation between fruit tree logging and primate assemblage.

References

- Aide, T. M., Zimmerman, J. K., Rosario, M., & Marciano, H. (1996). Forest recovery in abandoned cattle pastures along an elevational gradient in northeastern Puerto Rico. *Biotropica*, 537-548.
- Araújo, A. C. L., Bezerra, B. M., Lima, I. M., Oliveira-Silva, L. B., Campêlo, A. d. C., & Souza-Alves, J. P. (2022). Plant community and native primate as drivers of habitat use by an exotic primate (*Saimiri* spp. Linnaeus, 1758) in an Atlantic Forest fragment. *Journal of Tropical Ecology*, 38(5), 322-330.
- Asner, G. P., Broadbent, E. N., Oliveira, P. J., Keller, M., Knapp, D. E., & Silva, J. N. (2006). Condition and fate of logged forests in the Brazilian Amazon. *Proceedings of the National Academy of Sciences*, 103(34), 12947-12950.
- Azevedo-Ramos, C., de Carvalho Jr, O., & do Amaral, B. D. (2006). Short-term effects of reduced-impact logging on eastern Amazon fauna. *Forest Ecology and Management*, 232(1-3), 26-35.
- Bonvicino, C. R. (1989). Ecologia e comportamento de *Alouatta belzebul* (Primates: Cebidae) na mata atlântica. *Rev Nordest Biol*, 6, 149-179.
- Bousfield, C. G., Cerullo, G. R., Massam, M. R., & Edwards, D. P. (2020). Protecting environmental and socio-economic values of selectively logged tropical forests in the Anthropocene. In *Advances in Ecological Research* (Vol. 62, pp. 1-52). Elsevier.
- Bousfield, C. G., Massam, M. R., Peres, C. A., & Edwards, D. P. (2023). Large-scale impacts of selective logging on canopy tree beta-diversity in the Brazilian Amazon. *Journal of Applied Ecology*, 60(6), 1181-1193.
- Boyle, S. A., Lenz, B. B., Gilbert, K. A., Sprionello, W. R., Gómez, M. S., Setz, E. Z., Reis, A. M. d., da Silva, O. F., Keuroghlian, A., & Pinto, F. (2013). Primates of the biological dynamics of forest fragments project: A history. *Primates in fragments: Complexity and resilience*, 57-74.
- Brinck, K., Fischer, R., Groeneveld, J., Lehmann, S., Dantas De Paula, M., Pütz, S., Sexton, J. O., Song, D., & Huth, A. (2017). High resolution analysis of tropical forest fragmentation and its impact on the global carbon cycle. *Nature Communications*, 8(1), 14855.
- Buckland, S. T., Rexstad, E. A., Marques, T. A., & Oedekoven, C. S. (2015). *Distance sampling: methods and applications* (Vol. 431). Springer.

- Butler, R. (2020). The Amazon rainforest: The World's largest rainforest. Retrieved December, 23, 2022.
- Calle-Rendón, B. R., de Toledo, J. J., Mustin, K., & Hilario, R. R. (2020). Drivers of primate richness and occurrence in a naturally patchy landscape in the Brazilian Amazon. *Biodiversity and Conservation*, 29(11-12), 3369-3391.
- Carvalho Jr, E. A., Hawes, J. E., & Haugaasen, T. (2022). Potential losses of animal-dispersed trees due to selective logging in Amazonian forest concessions. *Trees, Forests and People*, 9, 100316.
- Chapman, C. A., Bonnell, T. R., Gogarten, J. F., Lambert, J. E., Omeja, P. A., Twinomugisha, D., Wasserman, M. D., & Rothman, J. M. (2013). Are primates ecosystem engineers? *International Journal of Primatology*, 34, 1-14.
- Correa, D. F., Álvarez, E., & Stevenson, P. R. (2015). Plant dispersal systems in Neotropical forests: availability of dispersal agents or availability of resources for constructing zoochorous fruits? *Global Ecology and Biogeography*, 24(2), 203-214.
- da Silva, L. B., Oliveira, G. L., Frederico, R. G., Loyola, R., Zacarias, D., Ribeiro, B. R., & Mendes-Oliveira, A. C. (2022). How future climate change and deforestation can drastically affect the species of monkeys endemic to the eastern Amazon, and priorities for conservation. *Biodiversity and Conservation*, 31(3), 971-988.
- Egler, S. G. (1992). Feeding ecology of *Saguinus bicolor bicolor* (Callitrichidae: Primates) in a relict forest in Manaus, Brazilian Amazonia. *Folia primatologica*, 59(2), 61-76.
- ESRI World Topo. (2016). Qgis, Retrieved 18.03.2024 from https://services.arcgisonline.com/ArcGIS/rest/services/World_Topo_Map/MapServer/tile/{z}/{y}/{x}
- Ferrari, S. F., Boyle, S.F., Marsh, L.K., Port-Carvalho, M., Santos, R.R., Silva, S.B.B., Vieira, T.M. & Veiga, L. (2013). The challenge of living in fragments. *Evolutionary biology and conservation of titis, sakis and uacaris*, 350-358.
- Ferrari, S. F., & Queiroz, H. L. (1994). Two new Brazilian primates discovered, endangered.
- Fleming, T. H., & Kress, W. J. (2011). A brief history of fruits and frugivores. *Acta Oecologica*, 37(6), 521-530.
- Florestal, a. d. s. d. m., & Na, c. b. (2005). Ministério da educação universidade federal rural da amazônia.
- Galán-Acedo, C., Arroyo-Rodríguez, V., Andresen, E., Verde Arregoitia, L., Vega, E., Peres, C. A., & Ewers, R. M. (2019). The conservation value of human-modified landscapes for the world's primates. *Nature Communications*, 10(1), 152.

- Gómez-Posada, C., Rey-Goyeneche, J., & Tenorio, E. A. (2019). Ranging responses to fruit and arthropod availability by a tufted capuchin group (*Sapajus apella*) in the Colombian Amazon. *Movement Ecology of Neotropical Forest Mammals: Focus on Social Animals*, 195-215.
- Haugaasen, T., & Peres, C. A. (2009). Interspecific primate associations in Amazonian flooded and unflooded forests. *Primates*, 50, 239-251.
- IBGE. (2016). *Brasil - Mapas Físicos e Ambientais, vegetação*. Retrieved 06.04.2024 from <https://mapasinterativos.ibge.gov.br/sigibge/>
- IUCN. *The IUCN red list of threatened species*. IUCN. Retrieved 06.03.24 from <https://www.iucnredlist.org>
- IUCN. (2021a). *Alouatta belzebul, Red-handed Howler Monkey*. International Union for Conservation of Nature. Retrieved 05.03 from <https://www.iucnredlist.org/species/39957/190412426>
- IUCN. (2021b). *Cebus kaapori, Ka'apor Capuchin*. International Union for Conservation of Nature. Retrieved 05.03 from <https://www.iucnredlist.org/species/40019/191704766>
- IUCN. (2021c). *Chiropotes satanas, Black Bearded Saki*. International Union for Conservation of Nature. Retrieved 05.03 from <https://www.iucnredlist.org/species/39956/191704509>
- IUCN. (2021d). *Saguinus niger, Black-handed Tamarin*. International Union for Conservation of Nature. Retrieved 05.03 from <https://www.iucnredlist.org/species/160901052/192553958>
- IUCN. (2021e). *Sapajus apella, Black-capped Capuchin*. International Union for Conservation of Nature. Retrieved 05.03 from <https://www.iucnredlist.org/species/172351505/192594550>
- Julliot, C., & Sabatier, D. (1993). Diet of the red howler monkey (*Alouatta seniculus*) in French Guiana. *International Journal of Primatology*, 14, 527-550.
- Kottek, M., Grieser, J., Beck, C., Rudolf, B., & Rubel, F. (2006). World map of the Köppen-Geiger climate classification updated.
- Laufer, J., Michalski, F., & Peres, C. A. (2015). Effects of reduced-impact logging on medium and large-bodied forest vertebrates in eastern Amazonia. *Biota Neotropica*, 15, e20140131.
- Lopes, M. A., & Ferrari, S. F. (1993). Primate conservation in eastern Brazilian Amazonia. *Neotropical primates*, 1(4), 8-9.

- Lopes, M. A., & Ferrari, S. F. (2000). Effects of human colonization on the abundance and diversity of mammals in eastern Brazilian Amazonia. *Conservation Biology*, 14(6), 1658-1665.
- Mercês, M. P., Alfaro, J. W. L., Ferreira, W. A., Harada, M. L., & Júnior, J. S. S. (2015). Morphology and mitochondrial phylogenetics reveal that the Amazon River separates two eastern squirrel monkey species: *Saimiri sciureus* and *S. collinsi*. *Molecular phylogenetics and evolution*, 82, 426-435.
- Metzger, J. P., Martensen, A. C., Dixo, M., Bernacci, L. C., Ribeiro, M. C., Teixeira, A. M. G., & Pardini, R. (2009). Time-lag in biological responses to landscape changes in a highly dynamic Atlantic forest region. *Biological Conservation*, 142(6), 1166-1177.
- Mittermeier, R. A., Schwitzer, C., Rylands, A. B., Taylor, L. A., Chiozza, F., Williamson, E. A., & Wallis, J. (2012). The World's 25 Most Endangered Primates.
- Mittermeier, R. A., & van Roosmalen, M. G. (1981). Preliminary observations on habitat utilization and diet in eight Surinam monkeys. *Folia primatologica*, 36(1-2), 1-39.
- Neyman, P. F. (1978). Aspects of the ecology and social organization of free-ranging cotton-top tamarins (*Saguinus oedipus*) and the conservation status of the species. *The biology and conservation of the Callitrichidae*, 39-71.
- Oliveira, A. C. M., & Ferrari, S. F. (2008). Habitat exploitation by free-ranging *Saguinus niger* in eastern Amazonia. *International Journal of Primatology*, 29, 1499-1510.
- Parry, L., Barlow, J., & Peres, C. A. (2007). Large-vertebrate assemblages of primary and secondary forests in the Brazilian Amazon. *Journal of Tropical Ecology*, 23(6), 653-662.
- Peres, C. (1993). Diet and feeding ecology of saddle-back (*Saguinus fuscicollis*) and moustached (*S. mystax*) tamarins in an Amazonian terra firme forest. *Journal of Zoology*, 230(4), 567-592.
- Pinheiro, T., Ferrari, S. F., & Lopes, M. A. (2011). Polyspecific associations between squirrel monkeys (*Saimiri sciureus*) and other primates in eastern Amazonia. *American Journal of Primatology*, 73(11), 1145-1151.
- Pinto, A. C., Azevedo-Ramos, C., & de Carvalho Jr, O. (2003). Activity patterns and diet of the howler monkey *Alouatta belzebul* in areas of logged and unlogged forest in Eastern Amazonia. *Animal Biodiversity and Conservation*, 26(2), 39-49.
- Poker, J., & MacDicken, K. (2016). Tropical forest resources: facts and tables. *Tropical forestry handbook*, 3-45.

- Port-Carvalho, M., & Ferrari, S. F. (2004). Occurrence and diet of the black bearded saki (*Chiropotes satanas satanas*) in the fragmented landscape of western Maranhão, Brazil. *Neotropical primates*, 12(1), 17-21.
- Port-Carvalho, M. a. F., S. F. (2002). Estimativas da abundância de cuxiú-preto (*Chiropotes satanas satanas*) e outros mamíferos não-voadores em fragmentos antrópicos de floresta da região Tocantina, Amazônia oriental. *Congresso Brasileiro de Zoologia*, 531-532.
- Prudente, B. S., Pompeu, P. S., Juen, L., & Montag, L. F. (2017). Effects of reduced-impact logging on physical habitat and fish assemblages in streams of Eastern Amazonia. *Freshwater Biology*, 62(2), 303-316.
- Ratiarison, S., & Forget, P. M. (2011). Fruit availability, frugivore satiation and seed removal in 2 primate-dispersed tree species. *Integrative Zoology*, 6(3), 178-194.
- Ribeiro, D. B., & Freitas, A. V. (2012). The effect of reduced-impact logging on fruit-feeding butterflies in Central Amazon, Brazil. *Journal of insect conservation*, 16, 733-744.
- Rosin, C. (2014). Does hunting threaten timber regeneration in selectively logged tropical forests? *Forest Ecology and Management*, 331, 153-164.
- Santos de Lima, L., Merry, F., Soares-Filho, B., Oliveira Rodrigues, H., dos Santos Damaceno, C., & Bauch, M. A. (2018). Illegal logging as a disincentive to the establishment of a sustainable forest sector in the Amazon. *PloS one*, 13(12), e0207855.
- Santos, R. R. D. (2002). Ecologia de cuxiús (*Chiropotes satanas*) na Amazônia Oriental: Perspectivas para a conservação de populações fragmentadas. *Satellite map world*. (2024). Qgis, Google. <http://www.google.cn/maps/vt?lyrs=s@189&gl=cn&x={x}&y={y}&z={z}>
- Silva, S., & Ferrari, S. (2007). Notes on the reproduction, behaviour and diet of *Saguinus niger* (Primates: Callitrichidae) in a forest remnant at the National Primate Centre, Ananindeua Pará. *Biol Geral Exper*, 7, 19-28.
- Sist, P., & Ferreira, F. N. (2007). Sustainability of reduced-impact logging in the Eastern Amazon. *Forest Ecology and Management*, 243(2-3), 199-209.
- Stone, A. I., Lima, E. M., Aguiar, G., Camargo, C. C., Flores, T. A., Kelt, D. A., Marques-Aguiar, S. A., Queiroz, J. A., Ramos, R. M., & Silva Júnior, J. S. (2009). Non-volant mammalian diversity in fragments in extreme eastern Amazonia. *Biodiversity and Conservation*, 18, 1685-1694.
- Terborgh, J. (2014). *Five New World primates: a study in comparative ecology* (Vol. 46). Princeton University Press.

- Thompson, M. E., Kahlenberg, S. M., Gilby, I. C., & Wrangham, R. W. (2007). Core area quality is associated with variance in reproductive success among female chimpanzees at Kibale National Park. *Animal Behaviour*, 73(3), 501-512.
- Uhl, C., & Vieira, I. C. G. (1989). Ecological impacts of selective logging in the Brazilian Amazon: a case study from the Paragominas region of the state of Pará. *Biotropica*, 98-106.
- Van Roosmalen, M. G., Mittermeier, R. A., & Fleagle, J. G. (1988). Diet of the northern bearded saki (*Chiropotes satanas chiropotes*): a neotropical seed predator. *American Journal of Primatology*, 14(1), 11-35.
- Veiga, L. (2006). Ecologia e comportamento do Cuxiú-Preto (*Chiropotes Satanas*) na paisagem fragmentada da Amazônia Oriental.
- Veiga, L. M., & Ferrari, S. F. (2006). Predation of arthropods by southern bearded sakis (*Chiropotes satanas*) in eastern Brazilian Amazonia. *American Journal of Primatology: Official Journal of the American Society of Primatologists*, 68(2), 209-215.
- Veracini, C. (2000). Dados preliminares sobre a ecología de *Saguinus niger* na Estação Científica Ferreira Penna, Caxiuanã, Pará, Brasil. *Neotropical primates*, 8(3), 108-113.
- Yguel, B., Piponiot, C., Mirabel, A., Dourdain, A., Hérault, B., Gourlet-Fleury, S., Forget, P.-M., & Fontaine, C. (2019). Beyond species richness and biomass: Impact of selective logging and silvicultural treatments on the functional composition of a neotropical forest. *Forest Ecology and Management*, 433, 528-534.



Norges miljø- og biovitenskapelige universitet
Noregs miljø- og biovitenskapelige universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway