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Research Article

Home Range, Diet, and Activity Patterns of Common Marmosets (*Callithrix jacchus*) in Very Small and Isolated Fragments of the Atlantic Forest of Northeastern Brazil

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We evaluate the impact of very small and isolated forest fragments on the common marmosets home range, diet, and activity patterns, in the northeastern Atlantic Forest of Brazil. Three groups were studied in three forest fragments, from January to October 2010, totaling 360 hours of observations and 1,080 field-hours. Systematic observations were recorded using Instantaneous Scan Sampling, and a checklist of the items exploited was built through *ad libitum* observations. We recorded location of the groups and calculated home range. We recorded 11,639 scans and 236 *ad libitum* feeding records. 83.4% ($n = 10$) of food items were plant species, the only animal protein was from insects ($n = 2$; 16.6%), and the diet was based almost exclusively on gums. Mean home range was 5.5 ha, mean daily path length was 1,167 meters, and no differences were detected between seasons. Resting dominated their activity budget and varied between seasons. Common marmosets survived in this environment through a remarkable increase in their exploitation of tree gums (up to 98% of their feeding bouts) to compensate for the lack of food, in home ranges slightly larger than in the literature. Thus, they travelled and foraged less than expected and rested more since food was easily obtained.

1. Introduction

Common marmosets (*Callithrix jacchus*) are endemic to one of the most imperiled sectors of the Atlantic Forest, the Pernambuco Endemism Center ([1]; hereafter PEC), a hotspot's hotspot, or an even biodiversity richer area within a hotspot, in northeastern Brazil [2–4]. Current forest cover in the PEC is less than 2% of the original area [5]; more than 70% of the remaining forest fragments are less than 10 hectares in area (Mendes Pontes, in prep.), highly modified in botanical composition, and isolated by sugar-cane plantations and have reduced food availability [6–8].

Consequently, most mammalian species have been extirpated from the PEC [9, 10]. Common marmosets, however, are a highly adaptable species that thrives in secondary forests, forest borders, and even suburban areas, such as orchards and backyards [11–13]. Consequently, they are one of the few that have survived in this environment.

Despite common marmosets being considered exudativorous-insectivorous [14], they are a highly adaptable species. They range from evergreen Atlantic Forest to dry-scrub Caatinga. Depending on the habitat and the seasonality of its resources, they can focus more on fruit, gum (exudate), or animal matter [13, 15, 16]. This appears to be a function of the availability of fruit, their preferred food source [14–18].

Gummivory is a major dietary trait for a variety of primate species, including prosimians, some African cercopithecines, and especially callitrichids, the latter exploiting it from a wide variety of tree species and all year round [19]. Although gum is difficult to obtain, limited in quantity, and difficult to digest [20], high rates of gum feeding (up to 87% of feeding time) have been recorded for Brazilian Atlantic Forest

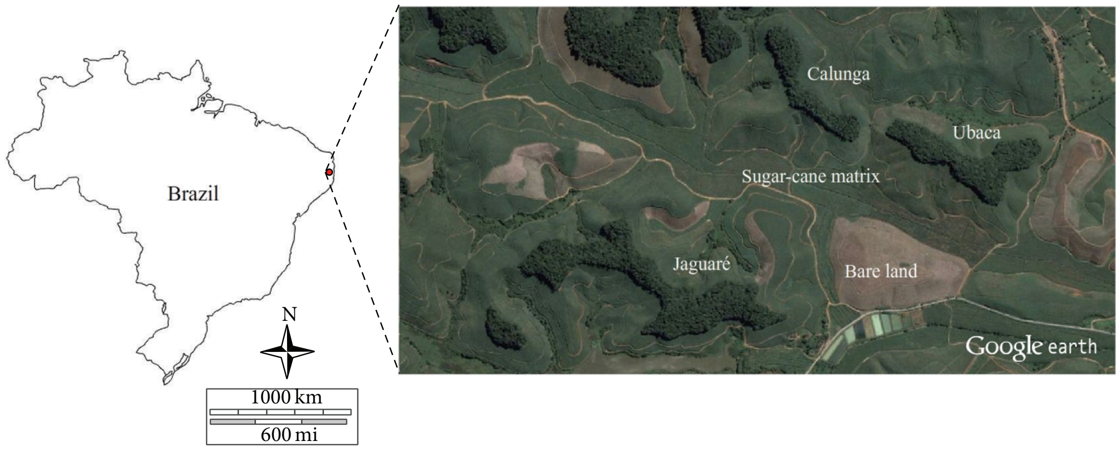

Figure 1: Location of the study site at Usina Trapiche, in the Atlantic Forest of Northeast Brazil, showing the studied fragments: (a) Jaguaré, (b) Ubaca, and (c) Calunga. Images obtained from Google Earth.

callitrichids, although fruit can be the most exploited food source [21–26].

In common marmosets the activity budget appears to be dominated by foraging and feeding, with these activities summing up to 55% of the diurnal time budget, although it varies with habitat type, distribution, abundance, seasonality of the feeding resources, and time of the day [21, 23, 27]. Common marmosets typically have activity patterns with two feeding peaks, one in the early morning and another one at the end of the afternoon, and a peak of resting in the middle of the day [12, 15, 18, 28, 29]. In both the Atlantic Forest of northeastern Brazil and the dry-scrub Caatinga forest, they often invest most of their time in foraging, especially in the dry season, and up to 50% of their time in foraging and feeding [15, 28, 30].

Home range size can be very variable in Brazilian Atlantic Forest callitrichids, ranging from 10 to 38 ha [22–26, 31, 32], and appears to be smaller in the xeromorphic semideciduous woodlands *Cerrado* and *Cerradão* [33, 34]. Common marmosets home range sizes are considerably smaller, ranging from only 1.2 to 5.2 ha [12, 15, 17, 28, 35–38], and can vary according to habitat quality and degree of human impact, with larger home ranges being recorded in areas subjected to more severe human degradation. Home range size may also vary with the availability of food resources, with larger areas being recorded during food scarcity, when animals must travel further to find food [12, 15, 38, 39].

Daily paths travelled by callitrichids in the Brazilian Atlantic Forest have a mean of 1,000 m, varying between 830 and 1,498 m [22–24, 31, 32, 40]. In the common marmosets in the northeastern Atlantic Forest home range varies from 912 to 1,300 m and appears to be determined by seasonal variation in fruiting, sleeping locations, and plant cover [12, 15, 37, 39].

In this study we evaluated the impact of living in very small, isolated, and highly impacted forest fragments on the common marmosets home range, diet, and activity patterns. We expected to find the studied groups of common marmosets using significantly larger home ranges, investing comparatively more time in foraging, especially in the dry season, and having a highly simplified diet, with comparatively few food items exploited, since the areas are highly impacted and the forest fragments are very small.

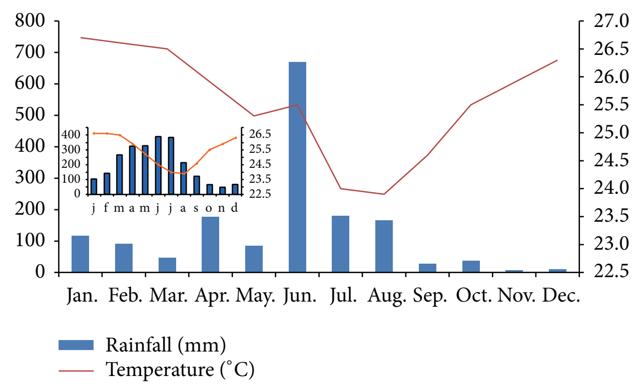

Figure 2: Temperature and rainfall in the study area at Usina Trapiche, in the Atlantic Forest of Northeast Brazil, during the study year 2010 (in comparison with the previous year 2009).

2. Methods

2.1. Study Area. The study was conducted in three forest fragments at Usina Trapiche, Sirinhaém, state of Pernambuco, Northeast Brazil, at PEC: Jaguaré (8°32′52.3″S, 35°11′44.2″W; 10 ha), Ubaca (8°32′35.37″S, 35°11′04.63″W; 8.2 ha), and Calunga (8°32′24.23″S, 35°11′33.79″W; 7.1 ha) (Figure 1), all of which are formed by submontane dense tropical rainforests preserved on steep hilltops that were not suitable for agriculture [41].

Sirinhaém has a pseudotropical to tropical hot-humid weather, with the rainy season occurring from May to September, when a maximum of 2,000 mm may be recorded in the peak of the rainy season around June [42]. The study year in Sirinhaém, nevertheless, was highly atypical, with substantial rainfall occurring in one month (Figure 2).

2.2. Studied Groups. Three social groups comprised of eight to 13 individuals were studied (one in each study site). Their

Table 1: Group composition of the three studied groups of common marmosets (*Callithrix jacchus*) in three forest fragments at Usina Trapiche, Northeast Brazil.

Group	Adult			Subadult			Juvenile			Infant			Total
	Male	Female	?	Male	Female	?	Male	Female	?	Male	Female	?	
Jaguaré	5	3					1					2*	9 (11**)
Ubaca	1	1		2	2		2					1*	8 (9**)
Calunga	5	4		1	1					2			13

*Born to the group later in the study; **number of individuals at the end of the study.

age-sex composition was determined according to Yamamoto [43]: infant (<5 months: those individuals who are carried all the time by the family members); juvenile (5–10 months: young individuals who are still carried by family members but start soliciting grooming and grooming others and also socially play with other siblings and parents); subadult (10–15 months: young individuals who are slenderer than adults but master most of the adult behavioral repertoire), and adult (>15 months).

When research began in January 2010 Jaguaré had nine individuals (in June 2010 twins were born), and there were two other adjacent groups in this fragment; Ubaca had eight individuals (in May 2010 one infant was born), and the group shared this fragment with another adjacent group; Calunga had 13 individuals and no other groups were found in this fragment (Table 1).

2.3. Checklist of Plant Species and Vegetation Structure. In each of the three studied forest fragments we sampled the vegetation in one 10 × 100 m plot (0.1 ha) situated within the group's home range, in which all trees ≥ 10 cm of diameter at breast height (DBA) were marked, identified, and counted [44]. This allowed us to calculate absolute density (number of individuals of a species per ha), relative density (density of one species as a percent of total plant density), relative dominance (dominance of one species as a percent of total plant dominance), Importance Value Index (IVI), which is the sum of relative frequency, relative density, and relative dominance, and Cover Value Index (CVI), which is the sum of relative density with relative dominance. We used FITOPAC software v.2.0 [45].

2.4. Observational Protocol. The study groups were already habituated to the constant human presence within and around the fragments, which were very small, close to houses, and crossed by paths regularly used by local people to collect forest resources. Therefore, after a maximum of five days the groups were all habituated to the presence of the observer. Each study group was followed from the time it left the sleeping tree in the morning (~05:00 h) to the time it entered the next sleeping tree in the afternoon (~17:00 h). Each group was studied during three consecutive days per month from January to October 2010, totaling 360 hours of observations (180 hours in the dry season and 180 hours in the wet season), or a total sampling effort of 1,080 hours. Due to field constraints no data from forest fragment Ubaca is available (only for the dry season).

Behavioral activities of each sighted individual in each of the studied groups were systematically recorded using Instantaneous Scan Sampling [46], with sampling units of 1 min. duration and 15 min. intervals, the latter to allow the observer to effectively move through the steep hilltops of the three studied fragments. Instantaneous scans were taken as a camera flash and conducted from left to right or vice versa depending on the position of the observer. Whenever some individuals were not visible within the 1 min. sampling units (e.g., moved out of sight while the others were feeding), the observational period was extended until all animals were sighted (up to 5 min.). In order to build a checklist of the items exploited in the diet of the individuals, we used *ad libitum* observations [46] and recorded whenever the animals were feeding.

We recorded the location of the studied groups using a Global Positioning System (GPS Garmin Map 60CSX) every 15 minutes following a scan. Recorded points were then collated for each group and group home range was estimated using *Calhome* software (California HOME Range, US Forest Service, Pacific Southwest Research Station) [47].

A total of 11,639 records were obtained with scan sampling (Jaguaré, $n = 4,375$; Ubaca, $n = 3,703$; Calunga $n = 3,561$). An additional 236 *ad libitum* feeding records were also obtained (Jaguaré, $n = 52$; Ubaca, $n = 87$; Calunga, $n = 97$). These were used exclusively for constructing the exploited food items checklist.

The studied behaviours were classified as follows:

(1) Foraging: individuals being actively searching for vegetal or animal foods, walking slowly, and scanning the environment, or turning over leaves and debris for prey.

(2) Feeding: taking to the mouth and chewing and/or swallowing any food item.

(3) Locomotion: moving through the forest without any apparent foraging behavior.

(4) Resting: when animals were motionless.

(5) Social: any interaction with members of the same or other neighbouring groups (adapted from Alonso and Langguth [15]).

Samples of reproductive and/or vegetative parts of the plant species exploited as food sources by the marmosets were collected, whenever possible, identified, and deposited in the Herbarium of the Universidade Federal de Pernambuco. Samples of the prey species were also collected whenever possible and deposited at the Zoological Collections of the same university.

2.5. Data Analysis. In order to test if there were any statistically significant differences in the exploitation of the food items by the studied groups in the different seasons we used a Pearson's chi-square test with Yates' continuity correction. We tested the exploitation of the different food items in each group separately with an exact binomial test. Since the number of feeding records of fruit, flower, and prey was low we lumped them under the category "other." We used a Spearman correlation to test for statistically significant correlations of the number of gum feeding records on the two exploited tree species, *Tapirira guianensis* and *Parkia pendula,* with the following structural variables: absolute density, relative density, relative dominance, Importance Value Index (IVI), and Cover Value Index (CVI).

We used a Kruskal-Wallis test to check for statistically significant differences in home range sizes among the three groups and, for those groups that had differences, we further used a Mann-Whitney test to check differences between two groups.

We used a Mann-Whitney test to check if any statistically significant difference existed in the size of the home range of the studied groups in the different seasons and a Spearman correlation test to check if there was any correlation between the size of their home range and the size of the forest fragment.

We used an ANOVA to test if there was any statistically significant difference in the daily path length of the studied groups. If a significant difference was found, we used the Tukey post hoc test to test if there was any statistically significant difference in the total daily path length of the studied groups in the different seasons, as well as in the total daily path length of each group separately in the different seasons.

For each group we tested if there was any statistically significant difference in the total number of behavioural records in the different seasons with a Pearson's chi-square test with Yates' continuity correction. In order to test if there was any statistically significant difference in each of the frequencies of each of the studied behaviours in the different seasons, we used an exact binomial test. All statistical tests were performed using the software R (R Core Development Team) version 3.2.

3. Results

3.1. Checklist of Plant Species and Vegetation Structure. A total of 42 plant species (of 19 families) were recorded in the three forest fragments, of which 24 (13 families) were in Jaguaré (10 ha), 16 (7 families) in Ubaca (8.2 ha), and 22 (12 families) in Calunga (7.1 ha) (Table 2). The highest diversity index was registered in Jaguaré (Shannon Index: 3.01), as was also the highest basal area (41 m^2/ha), whereas the highest equitability index was in Calunga (equitability index: 0.95) (Table 2).

In Jaguaré the species with the highest Importance Value Index (IVI = 24.4) and Cover Value Index (CVI = 20.23) was *Apuleia leiocarpa* (Caesalpiniaceae) and in Ubaca (IVI = 64.61; CVI = 58.36) and Calunga (IVI = 42.5; CVI = 37.95) (Table 2) was *Parkia pendula* (Mimosaceae). In each fragment a different species was most abundant: in Jaguaré it was *Balizia pedicellaris*, (Papilionoideae) with 50 ind./ha, in Ubaca *Parkia pendula* (70 ind./ha) and *Thyrsodium spruceanum* (Anacardiaceae) (70 ind./ha), and in Calunga *Tapirira guianensis* (50 ind./ha) (Table 2).

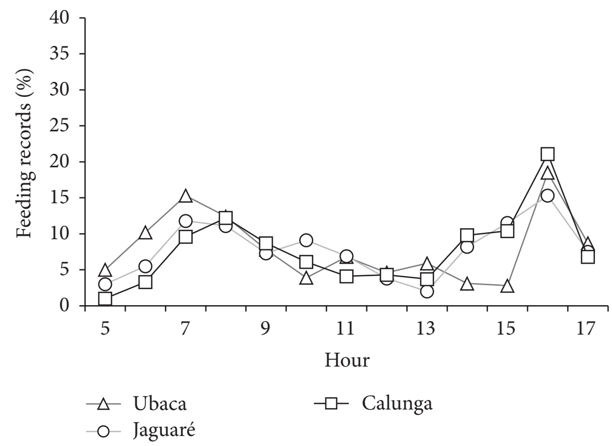

Figure 3: Distribution of the feeding records of the study groups along the day at Usina Trapiche, in the Atlantic Forest of Northeast Brazil.

3.2. Diet. During this study 83.4% (n = 10) of the food items that we recorded the common marmosets exploiting were plant species, of which 70% (n = 7) were fruit, 20% (n = 2) were gum, and 10% (n = 1) were flowers (Table 3). Only one species was introduced (*Syzygium jambolanum*, Myrtaceae). The only animal protein exploited came from insects (n = 2; 16.6%) (Table 3). Feeding bouts had two marked peaks, which occurred between 07:00 and 08:00 h and around 16:00 h. The lowest feeding bout rates for all groups were recorded between 13:00 and 15:00 h (Figure 3).

The diet of the studied groups in the three forest fragments was very similar, being based almost exclusively on gums. These were obtained solely from two tree species *Tapirira guianensis* (Anacardiaceae), whence they obtained it by gouging the trunk to cause a flow of exudate which they then licked, and *Parkia pendula* (Fabaceae), where they licked the exudate that flowed spontaneously from mature seed pods.

At Jaguaré the marmosets fed on gum from 12 *Tapirira guianensis* and 10 *Parkia pendula* in 97% (n = 420) of the feeding bouts, at Ubaca from 17 *Tapirira guianensis* and 10 *Parkia pendula* in 97.6% (n = 440) of the feeding bouts, and at Calunga from 18 *Tapirira guianensis* and seven *Parkia pendula* in 98.3% (n = 860) of the feeding bouts. They consumed fruits at Jaguaré (0.7% n = 3), at Ubaca (1.6% n = 7), and at Calunga (1.7% n = 15), animal prey at Jaguaré (2.3% n = 10) and Ubaca (0.4% n = 2), and flower in Ubaca (0.4% n = 2).

There was a statistically significant difference in the number of feeding bouts in the different seasons in Jaguaré (X^2 = 23.31, df = 1, p < 0.0001) and Ubaca (X^2 = 10.67, df = 1, p = 0.001), with more feeding bouts in the rainy season, but no difference was detected in Calunga (X^2 = 0.167, df = 1, p = 0.682). Gum was significantly more exploited in the

Table 2: Checklist of the plant species and vegetation structure of the studied forest fragments at Usina Trapiche, Northeast Brazil.

Forest fragment

Jaguaré

Total fragment area: 10 ha
Home range of the studied common marmoset group: 5.8 ha
Number of plant species: 24 (13 families)
Shannon Index: 3.01
Equitability: 0.94
Total basal area: 41 m^2/ha

Plant species	IVI	CVI	Abs. dens. ind./ha	Rel. dens. ind./ha	Rel. dom. (%)
Apuleia leiocarpa	24.40	20.23	40	8.33	11.90
Bowdichia virgilioides	19.97	15.81	30	6.25	9.56
Parkia pendula	19.06	14.89	20	4.17	10.72
Thyrsodium spruceanum	18.88	14.71	40	8.33	6.38
Balizia pedicellaris	18.81	14.65	50	10.42	4.23
Protium heptaphyllum	18.42	14.26	40	8.33	5.92
Enterolobium contortisiliquum	17.20	13.03	20	4.17	8.86
Eschweilera ovata	16.61	12.44	30	6.25	6.19
Unidentified 1	15.16	10.99	20	4.17	6.82
Sloanea guianensis	13.78	9.61	20	4.17	5.44
Ormosia sp.	13.54	9.37	10	2.08	7.29
Symphonia globulifera	12.06	7.90	20	4.17	3.73
Andira sp.	10.95	6.78	20	4.17	2.62
Tapirira guianensis	10.51	6.34	20	4.17	2.17
Simarouba amara	8.65	4.49	10	2.08	2.40
Pouteria sp. 1	7.30	3.13	10	2.08	1.05
Ilex cf. *sapotifolia*	7.19	3.02	10	2.08	0.94
Henrietta succosa	7.04	2.87	10	2.08	0.79
Andira fraxinifolia	7.04	2.87	10	2.08	0.79
*Caesarea*cf. *javitenses*	6.92	2.75	10	2.08	0.67
Maytenus distichophylla	6.76	2.59	10	2.08	0.51
Brosimum guianensis	6.73	2.56	10	2.08	0.48
Protium sp.	6.53	2.36	10	2.08	0.28
Pouteria sp. 2	6.51	2.35	10	2.08	0.26

Ubaca

Total fragment area: 8.2 ha
Home range of the studied common marmoset group: 5.1 ha
Number of plant species: 16 (7 families)
Shannon Index: 2.52
Equitability: 0.91
Total basal area: 27 m^2/ha

Plant species	IVI	CVI	Abs. dens. ind./ha	Rel. dens. ind./ha	Rel. dom. (%)
Parkia pendula	64.61	58.36	70	15.56	42.81
Thyrsodium spruceanum	27.20	20.95	70	15.56	5.40
Margaritaria nobilis	23.85	17.60	40	8.89	8.71
Brosimum guianensis	20.52	14.27	50	11.11	3.16
Bowdichia virgilioides	19.70	13.45	40	8.89	4.56
Dialium guianense	19.56	13.31	30	6.67	6.64
Ocotea sp.	18.17	11.92	30	6.67	5.26
Simarouba amara	15.51	9.26	30	6.67	2.60
Eschweilera ovata	15.21	8.96	20	4.44	4.52
Pouteria sp.	15.03	8.78	10	2.22	6.56
Balizia pedicellaris	14.60	8.35	10	2.22	6.13
Tapirira guianensis	10.25	4	10	2.22	1.77
Diplotropis sp.	9.26	3.01	10	2.22	0.79
Ocotea opifera	8.94	2.69	10	2.22	0.47

Table 2: Continued.

Pogonophora schomburgkiana	8.81	2.56	10	2.22	0.34
Andira fraxinifolia	8.77	2.52	10	2.22	0.30

Calunga
Total fragment area: 7.1 ha
Home range of the studied common marmoset group: 5.6 ha
Number of plant species: 22 (12 families)
Shannon Index: 2.93
Equitability: 0.95
Total basal area: 37 m^2/ha

Plant species	IVI	CVI	Abs. dens. ind./ha	Rel. dens. ind./ha	Rel. dom. (%)
Parkia pendula	42.50	37.95	40	9.52	28.43
Tapirira guianensis	22.13	17.59	50	11.90	5.68
Lecythis pisonis	18.76	14.22	10	2.38	11.84
Ilex cf. *sapotifolia*	18.17	13.62	10	2.38	11.24
Symphonia globulifera	17.73	13.19	30	7.14	6.04
Ocotea opifera	15.67	11.13	30	7.14	3.98
Stryphnodendron pulcherrimum	14.12	9.58	10	2.38	7.20
Bowdichia virgilioides	13.85	9.30	20	4.76	4.54
Eschweilera ovata	13.29	8.74	20	4.76	3.98
Cecropia pachystachya	13.20	8.66	30	7.14	1.51
Thyrsodium spruceanum	12.46	7.91	30	7.14	0.77
Balizia pedicellaris	11.27	6.73	10	2.38	4.35
Protium heptaphyllum	10.91	6.36	10	2.38	3.98
Myrcia sylvatica	10.03	5.49	20	4.76	0.73
Rheedia gardneriana	9.83	5.28	20	4.76	0.52
Pouteria sp.	9.76	5.21	20	4.76	0.45
Simarouba amara	9.05	4.51	10	2.38	2.13
Ficus sp.	8.16	3.62	10	2.38	1.24
Lecythis lurida	7.64	3.10	10	2.38	0.71
Guapira opposita	7.17	2.63	10	2.38	0.25
Brosimum rubescens	7.14	2.6	10	2.38	0.22
Vismia guianensis	7.14	2.6	10	2.38	0.22

IVI: Importance Value Index; CVI: Cover Value Index.

rainy season at both Jaguaré ($X^2 = 128.15$, $p < 0.0001$) and Ubaca ($X^2 = 65.68$, $p < 0.0001$), whereas "other" (fruit, flower, and prey) was significantly more exploited in the dry season at Jaguaré ($X^2 = 32.15$, $p = 0.022$) (no difference was detected at Ubaca, $X^2 = 5.11$, $p = 0.065$). No correlation was detected between the number of feeding bouts on the two exploited tree species (*Tapirira guianensis* and *Parkia pendula*) and their structural variables (absolute density, relative density, relative dominance, Importance Value Index (IVI), and Cover Value Index (CVI)) (Table 4).

3.3. Home Range and Daily Movements. Mean home range size of the studied groups was 5.5 ha, with a maximum of 5.79 at Jaguaré and a minimum of 5.1 at Ubaca (Table 5; Figure 4). Home range sizes were not related to the size of the forest fragment ($S = 2$, rho = 0.5, $p = 1$), and seasonal differences in home range sizes were not significant ($U = 4$, df = 4, $p = 0.406$).

Overall mean daily path length of the studied groups was $1,167 \pm 263$ m, and no statistically significant differences were detected in the daily path length among the studied groups ($F = 1.448$, $p = 0.242$) (Figure 5). No statistically significant differences were detected in the daily path length of the studied groups in the different seasons ($t = 1.98$, $p = 0.078$), nor in any of the forest fragments when considered separately (Jaguaré: $t = 0.196$, $p = 0.846$; Calunga: $t = 1.74$ $p = 0.094$; no data available for the dry season in Ubaca) (Figure 5).

3.4. Activity Budget. Overall activity budget of the studied groups of common marmosets was dominated by resting. This constituted 37.8% ($n = 1,653$) of activity at Jaguaré, 34.7% ($n = 1,294$) at Ubaca, and 31.2% ($n = 1,110$) at Calunga, whereas foraging was the least frequent activity, comprising only 7.7% ($n = 339$) of the activity budget at Jaguaré, 7.7% ($n = 286$) at Ubaca, and 10.1% ($n = 361$) at Calunga (Figure 6).

The activity budget of the common marmosets showed statistically significant differences between the different seasons in all the three forest fragments; Jaguaré ($X^2 = 138.92$, df = 4, $p < 0.0001$), Ubaca ($X^2 = 131.38$, df = 4, $p < 0.0001$), and Calunga ($X^2 = 159.42$, df = 4, $p < 0.0001$). The three studied forest fragments had significantly higher levels

Table 3: Food items consumed by the three studied groups of common marmosets (*Callithrix jacchus*) in the studied forest fragments at Usina Trapiche, Northeast Brazil, between January and October 2010.

Plant species	Status	Resource			Month when exploited		Forest fragment where exploited
		Fruit	Gum	Flower	Dry	Wet	
Anacardiaceae							
Tapirira guianensis	Native		X		Jan./Feb./Mar/ Apr./Sep./Oct.	May/Jun./ Jul./Aug.	U, J, C
Thyrsodium spruceanum	Native						
Aquifoliaceae							
Ilex cf. *sapotifolia*	Native						
Burseraceae							
Protium heptaphyllum	Native						
Cecropiaceae							
Cecropia glaziovii	Native	X			Jan./Feb.		U
Cecropia pachystachya	Native						
Celastraceae							
Maytenus distichophylla	Native						
Clusiaceae							
Rheedia gardneriana	Native						
Symphonia globulifera	Native						
Elaeocarpaceae							
Sloanea guianensis							
Euphorbiaceae							
Margaritaria nobilis	Native						
Pogonophora schomburgkiana	Native						
Fabaceae							
Andira fraxinifolia	Native						
Andira sp.	Native						
Apuleia leiocarpa	Native						
Balizia pedicellaris	Native						
Bowdichia virgilioides	Native						
Dialium guianense	Native	X				May/Jun./Jul.	J, C
Diplotropis sp.	Native						
Enterolobium contortisiliquum	Native						
Ormosia sp.	Native						
Parkia pendula	Native		X		Jan./Feb./ Mar./Apr.		U, J, C
Stryphnodendron pulcherrimum	Native						
Flacourtiaceae							
Casearia javitensis	Native						
Hypericaceae							
Vismia guianensis	Native						
Lauraceae							
Ocotea opifera	Native						
Ocotea sp.	Native						
Lecythidaceae							
Eschweilera ovata	Native	X			Jan./Feb.		U
Lecythis lurida	Native						
Lecythis pisonis	Native						

Table 3: Continued.

Plant species	Status	Resource			Month when exploited		Forest fragment where exploited
		Fruit	Gum	Flower	Dry	Wet	
Melastomataceae							
Henrietta succosa	Native			X	Feb.		U
Miconia sp.	Native	X				Apr.	J
Moraceae							
Brosimum guianensis	Native	X				Mar.	J
Brosimum rubescens	Native						
Ficus sp.	Native						
Myrtaceae							
Myrcia sylvatica	Native						
Syzygium jambolanum	Introduced	X				Jan./Feb.	U
Nyctaginaceae							
Guapira opposita	Native						
Sapotaceae							
Micropholis compacta	Native	X				Sep.	C
Pouteria sp. 1	Native						
Pouteria sp. 2	Native						
Simaroubaceae							
Simarouba amara	Native						
Animal protein							
Homoptera							
Cicadidae	Native			Insect	Mar., Apr.		J
Lepidoptera	Native			Insect	Jan.		U

Table 4: Relationship between the number of gum feeding bouts by the common marmosets on the two exploited tree species and their structural variables in the studied forest fragments at Usina Trapiche, Northeast Brazil.

Tree species	Dependent variable	Independent variable	Spearman correlation coefficient
Tapirira guianensis	Number of feeding bouts X	Absolute density (ind./ha)	$S = 0$, rho = 1, $p = 0.333$
		Relative density (ind./ha)	$S = 0$, rho = 1, $p = 0.333$
		Relative dominance (%)	$S = 0$, rho = 1, $p = 0.333$
		Importance Value Index (IVI)	$S = 0$, rho = 1, $p = 0.333$
		Cover Value Index (CVI)	$S = 0$, rho = 1, $p = 0.333$
Parkia pendula	Number of feeding bouts X	Absolute density (ind./ha)	$S = 2$, rho = 0.5, $p = 1$
		Relative density (ind./ha)	$S = 2$, rho = 0.5, $p = 1$
		Relative dominance (%)	$S = 2$, rho = 0.5, $p = 1$
		Importance Value Index (IVI)	$S = 2$, rho = 0.5, $p = 1$
		Cover Value Index (CVI)	$S = 2$, rho = 0.5, $p = 1$
Tapirira guianensis and *Parkia pendula*	Number of feeding bouts X	Absolute density (ind./ha)	$S = 36$, rho = −0.03, $p = 0.957$
		Relative density (ind./ha)	$S = 36$, rho = −0.03, $p = 0.957$
		Relative dominance (%)	$S = 56$, rho = −0.60, $p = 0.242$
		Importance Value Index (IVI)	$S = 46$, rho = −0.31, $p = 0.564$
		Cover Value Index (CVI)	$S = 46$, rho = −0.31, $p = 0.564$

of resting, locomotion, and social activity in the dry season (with the exception of resting in Ubaca) and higher levels of feeding and foraging in the wet season (Table 6; Figure 6).

4. Discussion

The Atlantic Forest of northeastern Brazil has lost more than 50% of the total tree species, and one-third of these were large/very large-fruited and large-seeded species [6–8]. This suggests that there may be very little or no food available to the remaining frugivorous vertebrates. This situation is likely to be even more pronounced in very small forest fragments and may ultimately have caused the extirpation of various mammal species (including all the large-bodied ones) [9, 10, 48].

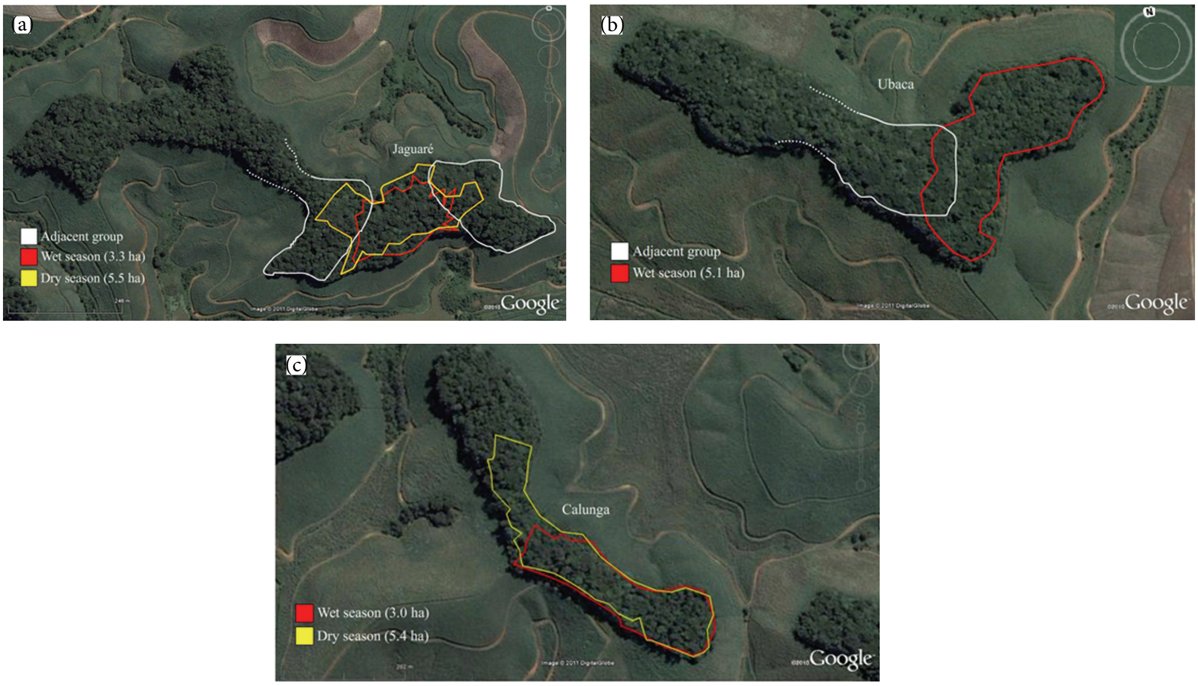

FIGURE 4: Home range of the study groups in each season at Usina Trapiche, in the Atlantic Forest of Northeast Brazil: (a) Jaguaré, (b), Ubaca, and (c) Calunga. Images obtained from Google Earth.

TABLE 5: Home range of the studied common marmoset groups at Usina Trapiche, Northeast Brazil.

Forest fragment	Area (ha)	Home range size		
		Dry	Wet	Total
Jaguaré	10	5.49	3.29	5.79
Ubaca	8.2		5.1	5.1
Calunga	7.1	5.43	3.01	5.61

The forest fragments studied here appear to represent one of the worst scenarios possible. For instance, thirty years ago Pontes and Soares [13, Unpubl. data.] recorded 52 tree species in the home range of a single group of common marmosets in a 373 ha forest fragment at Dois Irmãos Botanical Garden, an urban forest similar in structure and disturbance levels to those in the current study. In the tiny forest fragments examined in the current study, however, between 16 and 24 tree species were registered. This is only between 30% and 46% of what Pontes and Soares [13] recorded. Additionally, the common marmosets in this study had no access to human habitations and, consequently, did not benefit from the additional supply of exotic fruits from orchards and backyards (as in Pontes and Soares [13] where, in addition to the much higher number of tree species exploited by the latter, 19% of them were introduced and were providing a supplemental fruit supply).

Of tree species recorded by Pontes and Soares [13], 17 species were exploited (nine for fruit, four for gum, and four for fruit and gum), with fruit representing the most exploited resource (61.5%), followed by gum (28.7%) and insect (9.8%). In a more recent study in the same 373 ha forest remnant, Silva et al. [16] found that the most exploited resource was gum (61.99%), followed by leaves, flower, seeds (9.7%), and fruit (2.9%). The lack of animal matter could

TABLE 6: Seasonal differences in the behaviors of the common marmosets in the three studied groups at Usina Trapiche, Northeast Brazil.

Forest fragment	Number of records			Significance*
	Dry	Wet	Total	
Jaguaré				
Resting	872	781	**1653**	**0.027**
Locomotion	743	651	**1394**	**0.015**
Social	301	237	**538**	**0.007**
Feeding	105	328	**433**	**<0.0001**
Foraging	148	191	**339**	**0.022**
Total	**2170**	**2205**	**4375**	
Ubaca				
Resting	610	684	**1294**	**0.042**
Locomotion	716	475	**1191**	**<0.0001**
Social	237	236	**473**	1
Feeding	144	307	**451**	**<0.0001**
Foraging	103	183	**286**	**<0.0001**
Total	**1813**	**1890**	**3703**	
Calunga				
Resting	620	490	**1110**	**<0.0001**
Locomotion	466	366	**832**	**<0.0001**
Feeding	207	498	**705**	**<0.0001**
Social	284	269	**553**	0.552
Foraging	143	218	**361**	**<0.0001**
Total	**1720**	**1841**	**3561**	

*Significant differences according to an exact binomial test in bold.

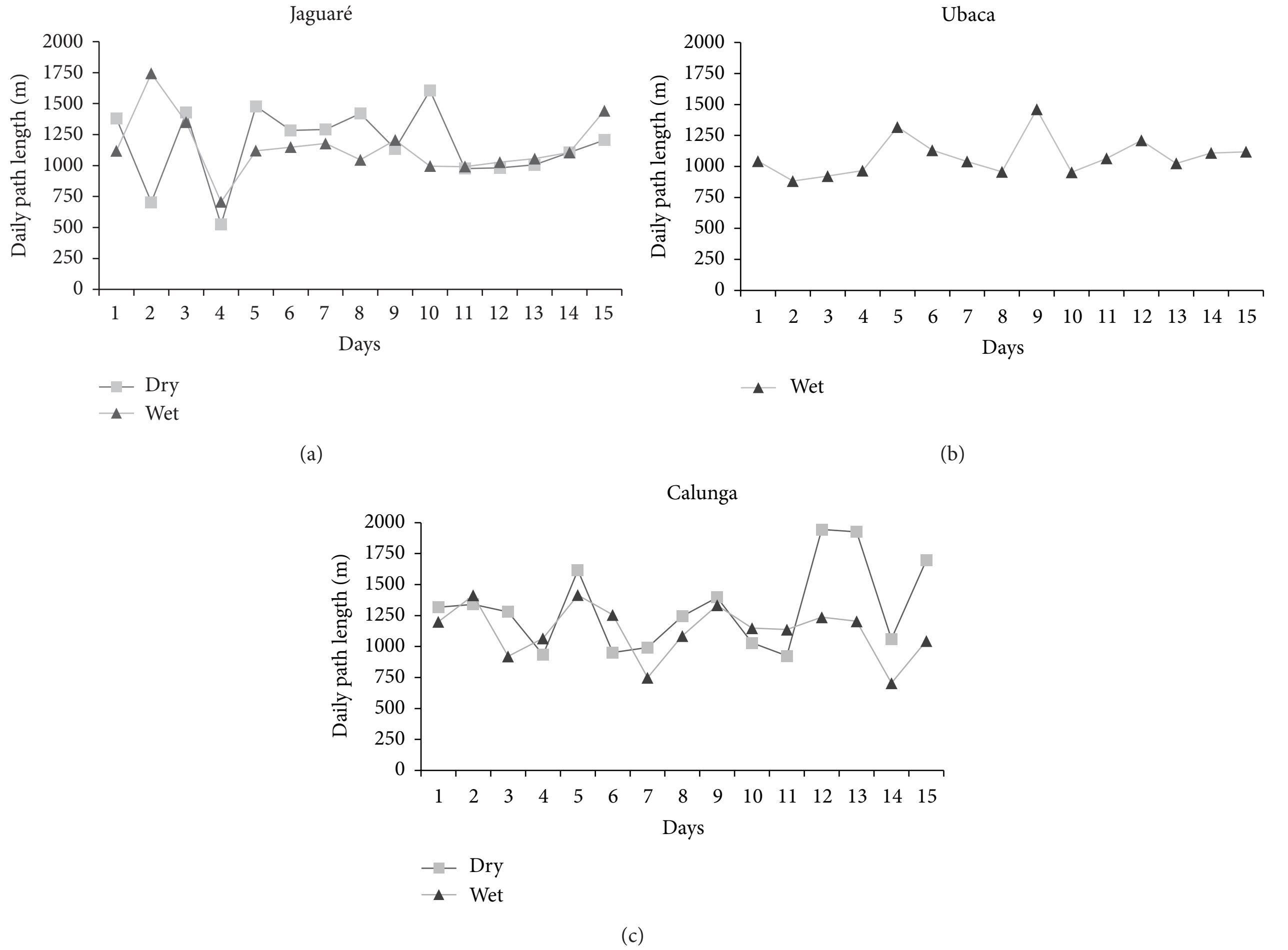

Figure 5: Daily path length of the groups throughout the study at Usina Trapiche, in the Atlantic Forest of Northeast Brazil: (a) Jaguaré, (b) Ubaca, and (c) Calunga.

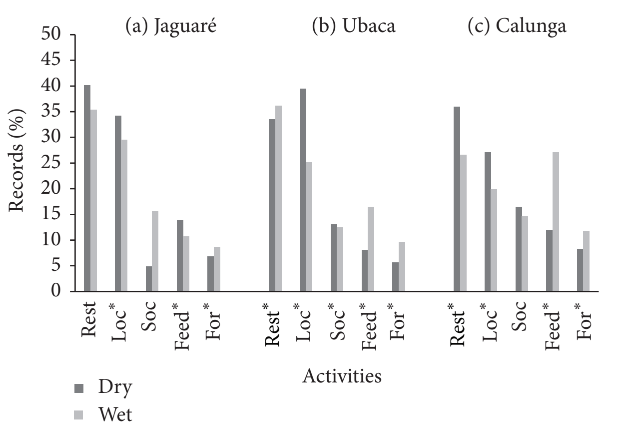

Figure 6: Activity budget of the studied groups at Usina Trapiche, in the Atlantic Forest of Northeast Brazil: (a) Jaguaré, (b) Ubaca, and (c) Calunga. Rest = resting, Loc = locomotion, Soc = social, Feed = feeding, and For = foraging. $^*p < 0.05$.

result from the systematic human impact to which these remnants have been subjected [49], which has imposed severe food constraints on the common marmosets.

In this environment, the studied groups had one of the poorest and least diverse diets of any groups inhabiting a natural habitat, not only when compared to Pontes and Soares [13], but also in comparison to other studies, either others with common marmosets [15, 50, 51] or those with other callitrichids [11, 14, 21, 26]. Their diet in these very small forest fragments was extremely simplified and based almost exclusively on tree gum (up to 98.3%), of only two tree species, *Tapirira guianensis* and *Parkia pendula*. These, it appears, were the only reliable food sources, and so there was only a very small percentage of nongum food items.

Relatively high rates of gum feeding have already been recorded in the Atlantic Forest of northeastern Brazil, both for common marmosets (~62% of feeding bouts) [16] and for other callitrichids (up to 87% of their feeding bouts [21–24]). The values presented here are, nevertheless, some of the highest ever reported for gum feeding, being higher even than those reported for common marmosets in dry-scrub *Caatinga* forest (around 50% of the feeding bouts) [30], and for *C. penicillata* in the xeromorphic semideciduous woodlands of the *Cerrado* and *Cerradão* (between 45% and 65%) [34]. This suggests that the animals in the studied fragments are living in very depauperate forest fragments, where tree species diversities were some of the lowest ever recorded for a tropical rainforest habitat, where almost no fruit or insects were available, and only two tree species provided exudates.

Thus, instead of a more typical foraging-dominated activity budget [15, 18, 28, 29], the activity pattern of the study groups had one of the highest percentages of resting ever recorded, even when compared to other callitrichids living in the much more climatically inhospitable *Cerrado* [25, 52] or at high altitudes [23]. This probably resulted from the fact that the gum is easily obtained but very difficult to digest. Gum (especially, as in the current study, when it comes from a few close-by individuals of only two species) is an easily obtained food, resulting in the three groups having one of the lowest rates of foraging ever recorded for callitrichids, leaving much more spare time for other activities, such as resting and social activities.

However, in the wet season, when *Parkia pendula* did not have pods and so was not a source of exudates, a considerable decrease in gummivory was detected, which caused an equivalent increase in foraging and feeding. The temporal patterning of feeding bouts in these small forest fragments was, nevertheless, similar to other studies, with a peak early in the morning and another one late in the afternoon and with the lowest rates being in the middle of the day, when it is common for the animals to rest [13, 15, 18, 28, 29]. These peaks have been shown to be essential for energy intake (fruit in the morning just after fast of a long night asleep) and gum just before entering their sleeping tree (with a long night ahead to digest a resource that requires fermentation) [13, 15, 19].

In primates, home range size is often greater in areas subjected to high degrees of human interference [12, 15]. This is the case in the current study in highly impacted, small, and isolated forest fragments; here home ranges reached up to 5.79 ha, slightly larger than what has been reported so far for common marmoset. Interestingly, the group at Calunga were the only one inhabiting that forest fragment and the maximum size of their home range was 5.4 ha, leaving the remaining 7.1 ha forest fragment unoccupied. Thus, we hypothesize that the home range sizes in this study may well be close to the maximum to which the animals can increase their home ranges, even though they had to rely heavily on the exploitation of gum.

Home range size of common marmosets may vary according to seasonal shifts in food availability [38, 39]. We failed to detect any statistically significant differences between wet and dry season. This is unsurprising since in the studied forests very little or no fruit was available, with the only reliable food sources being the highly predictable gum trees. The slight observable difference between the seasons, however, may have resulted from the fact that in the wet season the common marmosets concentrated their activities around gum-providing *Tapirira guianensis* clusters, whereas in the dry season they were able to exploit the more evenly distributed gum-providing *Parkia pendula* individuals.

Mean daily path travelled is generally influenced by seasonal variation in the availability of food, particularly fruit [12, 39]. In this study, daily routes travelled by the common marmosets were between 1,052 and 1,219 m and so did not differ significantly from distances reported by Alonso and Langguth [15] and Digby and Barreto [28], possibly because they did not have to travel more extensively to find food, in this case, gum trees. By the same token, we also failed to detect any statistically significant differences between wet and dry season.

5. Conclusions

This study shows that survival by common marmosets in the 21st century in these small, isolated, irregular and depauperate forest fragments of the Atlantic forest of Northeast Brazil is only achieved by a remarkable increase of the frequency with which they exploit tree gum, compensating for the almost complete lack of other food items. As a consequence of exploiting an easily obtainable food, they travelled and foraged what appears to be the least possible. These primates are probably living at the edge of what is physiologically possible for the species, doing their utmost effort to survive in this hotspot's hotspot.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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