

Behavioral Variations and Diet of Two Groups of the Ornate Titi Monkey (*Plecturocebus ornatus*) in Landscapes with Different Degrees of Fragmentation in the Colombian Llanos

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Abstract: Habitat loss and fragmentation affect primate behavior; however, their effects are variable and sometimes contradictory, and generalizations are difficult to make. Additionally, studies that focus on those effects do not account for the landscape in which those species live, the degree of fragmentation of those landscapes nor the possible influences on primate behavior. Using scan sampling, we studied two groups of the ornate titi monkey (*Plecturocebus ornatus*) with forest fragments in different degrees of fragmentation in the prevailing landscape. The activity budgets of the groups were different (K-W = 31.036; $P > 0.005$), with foraging and time spent moving showing significant differences between them. Thirty-five plant species were included in their diet. The most important families were Annonaceae, Burseraceae, Melastomataceae and Moraceae. The two groups were similar in their dietary composition, and their consumption of fruit was predominant (Unamas: K-W = 15.0615, $P < 0.05$; Santa Rosa: K-W = 15,1586, $P < 0.05$) compared with other food items (arthropods, leaves, flowers and others, including fungus, petioles). The time each group spent feeding on each of the food items was also significantly different (K-W = 36.0167, $P < 0.05$). The different degrees of fragmentation in the landscapes inhabited by each of the groups evidently influenced the activity patterns of those groups but not their diet in terms of their frugivory other items consumed. The time spent eating fruit can vary between groups depending on the extent of fragmentation. *Plecturocebus ornatus* can evidently adapt to fragmented landscapes in the Colombian Llanos, but the higher degrees of fragmentation present them with higher challenges regarding their activity budget and diet, and measures need to be taken to reduce possible problems such as endogamy and stress by increasing connectivity among the forest patches in the landscape.

Key words: Ornate titi monkeys, *Plecturocebus ornatus*, fragmented landscapes, Colombian Llanos, diet, behavior

Introduction

Habitat loss and fragmentation are among the main threats to primates worldwide (Estrada *et al.* 2017; Galan-Acedo *et al.* 2019). The effects of these processes on the primate's behavior have been studied by comparing groups of the same species living in fragments of different sizes and in extensive forest without considering the landscape surrounding those fragments and its possible concomitant effect (Irwin 2007; Boyle *et al.* 2009, 2012). Modifications of spatial use patterns and diet have been found in northern bearded saki monkeys (*Chiropotes sagulatus*) in Brazil (Boyle *et al.* 2009, 2012), as well as diademed sifakas (*Propithecus diadema*) in Madagascar (Irwin 2007). However, not all species respond in the same way to changes in forest fragment sizes (Gómez-Posada *et al.* 2010; Link *et al.* 2010; Gabriel 2013).

In general, primates with small home ranges and more folivorous diets seem to be better adapted to live in forest fragments than species with more frugivorous diets and large home ranges (Onderdonk and Chapman 2000). Time spent feeding is positively associated with a reduction of the size of forest fragment, while time spent moving and resting is variable and without clear patterns (Carretero-Pinzón *et al.* 2015). However, these generalizations are not always true and contradictory results have been found in some studies. For example, Link *et al.* (2006, 2009, 2012) found variations in diet but not in other activities of spider monkeys living in fragments of different sizes. Studies of ring-tailed lemurs (*Lemur catta*) and mantled howlers (*Alouatta palliata*) showed a tendency of more time spent resting and socializing in large forest fragments, while in small fragments more time was spent feeding and moving (Dunn *et al.* 2009; Gabriel 2013). This is contrary to what has been

observed for northern bearded sakis, (*Chiropotes sagulatus*) which spent more time resting and less time moving and vocalizing in small fragments (Boyle and Smith 2010).

The ornate titi monkey (*Plecturocebus ornatus*) is endemic to the Colombian Llanos. It is categorized as Vulnerable by IUCN criteria (Carretero-Pinzón *et al.* 2020), with a small distribution characterized by high deforestation in more than 50% of its range (X. Carretero-Pinzón in prep.). It is also considered Vulnerable at the national level (Henaó-Díaz *et al.* 2020). Studies focused on this species have been limited to several unpublished undergraduate theses about the species' ecology and behavior, including diet, home range and travel distances in forest fragments (Ospina 2005; Bastos-Gonzalez 2009; Quintero 2017) and three studies in an extensively forested area (Polanco 1992; Porras 2000, Rivera-Pinzón *et al.* 2014;). Its population densities, ranging from 1.07–400 ind/km² (Wagner *et al.* 2009; Defler 2010; Carretero-Pinzón, 2013) show a tendency to be higher in fragments of 1–50 ha than in fragments larger than 50 ha (Carretero-Pinzón and Defler 2016).

In fragmented areas, it seems to have higher densities in the fragment edges than in the interior (Defler and Carretero-Pinzón 2018). *Plecturocebus ornatus* can be found in fragments of gallery forest, lowland forest and *Mauritia flexuosa* swamps (Carretero-Pinzón and Defler 2019). Studies at the landscape scale have shown that the presence and abundance of *P. ornatus* is influenced by landscape scale variables at 1000-m buffer and site-scale variables dominated by cattle ranching farms (Carretero-Pinzón *et al.* 2017), while in peri-urban areas, the abundance of *P. ornatus* is influenced by landscape connectivity, fragment size, and the presence of other primate species (Ortiz-Moreno *et al.* 2022). In this study, we establish if there are differences in behavior and diet of two groups of *Plecturocebus ornatus* in landscapes with different degrees of fragmentation in the Colombian Llanos.

Methods

Study area

This study was carried out in the vicinity of the town of San Martín, department of Meta, Colombian Llanos (Figure 1). Two groups were selected in forest fragments of different sizes and surrounded by landscapes with different degrees of fragmentation. The first group was in the Las Unamas Reserve (3°34'51.93"N, 73°27'02.56"W; 300 m elevation), while the other group was located at Santa Rosa farm (3°3'30"N, 73°35'40"W; 350 m elevation). This region has two seasons, a rainy season from April to November and a dry season from December to March, with the annual precipitation averaging 3075 mm and an average temperature of 27°C (Carretero-Pinzón 2013).

Landscape characterization

Our characterization of the landscape was made using satellite images obtained from a Landsat 7 mosaic of 2010,

which was updated using Google Earth images, and satellite images Landsat 7 of 2016 to verify fragment sizes and the matrix surrounding those fragments. Matrix type, percentage of forest cover and number of fragments surrounding the groups' fragments were used to establish the fragmentation degree of the landscape studied. Landscapes with higher numbers of fragments and a low percentage of forest cover around the groups' fragments are more fragmented than landscapes with a smaller number of fragments and higher forest cover surrounding our focal fragments (McIntyre and Hobbs 1999). A buffer of 1000 m around each group's fragment was used to determine the percentage of forest cover and number of forest fragments, using ArcMap 10.2.1 (ESRI 2017). This buffer was chosen as previous studies found this to be the scale at which landscape variables influence the ornate titi monkeys' presence and abundance (Carretero-Pinzón *et al.* 2017).

Behavioral data

Behavioral data of each group were collected using scan sampling every five minutes (Altmann 1979). Each group was followed for ten days each month for at least four months. In the first two months it was not possible to collect data from Las Unamas Reserve group. The Las Unamas Reserve group was composed of four individuals (one male, one female, one juvenile and one infant), while Santa Rosa's farm group was composed of five individuals (one male, one female, one juvenile, one infant and one male that appeared in the second month of our study, possibly a subadult or adult). The presence of infants in each group helped us with female and male differentiation. Four categories were used to classify the groups' behavior: foraging when all or most individuals in the group were searching or ingesting any kind of food; moving when individuals had a defined direction and cohesive movement; resting when all individuals or most of them were sleeping and/ or resting; and social activities when groups were grooming, vocalizing, fighting, tail twining or other related behaviors (Defler 2004). A total of 3842 scan samplings (329.33 hours) of behavioral data were collected from the Santa Rosa farm group and 2664 scan samplings (253.25 hours) from the Las Unamas Reserve group.

Diet

When the focal groups were foraging, we recorded the food item and the species. We also recorded, *ad libitum*, the items and species eaten by other groups in both landscapes to complement the list of species presented in this study. Analysis and comparison of diets were based only on data from the two focal groups.

Statistical analysis

The Kruskal-Wallis test and Multiple Range test were used to determine differences between behavior categories and food types consumed by each group as well as to establish differences between behavioral patterns and diets of the

two ornate titi monkey groups from the Santa Rosa farm and Las Unamas Reserve. The analysis was carried out using Statgraphics software.

Results

Landscape characterization

The Las Unamas Reserve landscape had a forest cover of 1630.5 ha in 16 forest fragments and 42.23 % of forest cover around the forest of the focal group, which was in a forest fragment of 151.78 ha surrounded by natural savannas (Fig. 1a). The Santa Rosa farm landscape had a forest cover of 84.9 ha in 10 fragments, and only 4.55 % of forest cover around the forest of the focal group, which was a forest fragment of 22.83 ha (Fig. 1b).

Activity budget

The activity budgets of both groups were statistically different (K-W = 31.036; $P > 0.005$; Fig. 2), with foraging and movement differing significantly between them. In the Santa Rosa farm group, there were significant differences

between foraging and all other activities, as well as between movement and resting, and movement and vocalizations. The Las Unamas Reserve group showed significant differences between foraging and movement and foraging and vocalization, and slightly higher social activity and vocalization when compared to the Santa Rosa group but not significantly different.

Diet

Table 1 shows a complete list of the species included in the diet of the ornate titi monkeys in the two landscapes. Thirty plant species were recorded while following *P. ornatus* groups and 22 additional species were recorded during *ad libitum* observations, for a total of 52 plant species recorded in the species' diet. All provided fruit, and the ornate titi monkeys also ate the flowers of *Xylopia aromatica* (Annonaceae), and *Miconia elata* and *Bellucia grossularoides* (both of the family Melastomataceae). The most important families for the *P. ornatus* groups were Annonaceae, Burseraceae, Melastomataceae and Moraceae. The dietary composition of both groups was largely similar (Table 1).

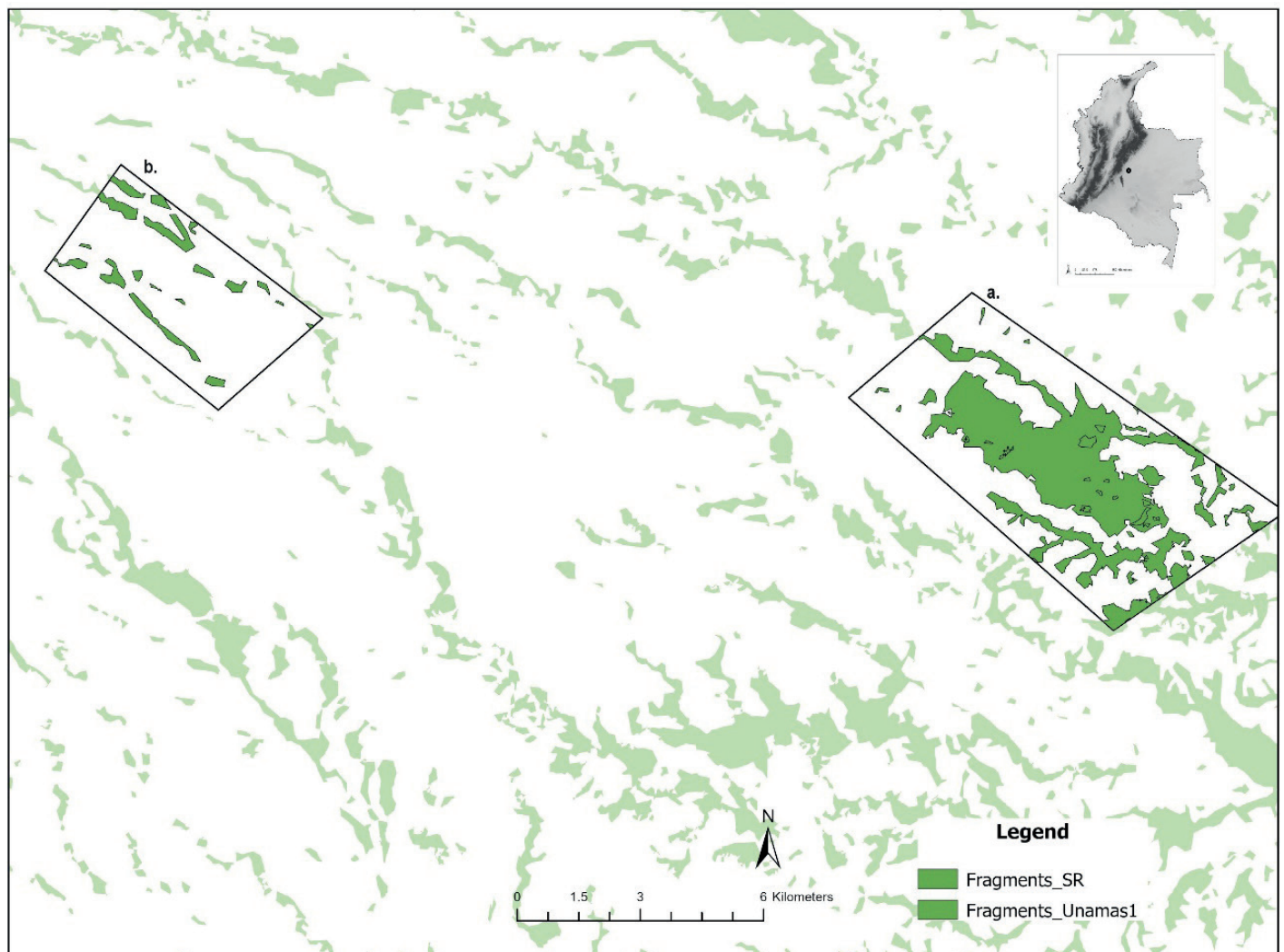


Figure 1. a. The Unamas Reserve landscape (right) and b. Santa Rosa Farm landscape (left) in the San Martín town area. Black dot in the insert shows the location of the study area in Colombia.

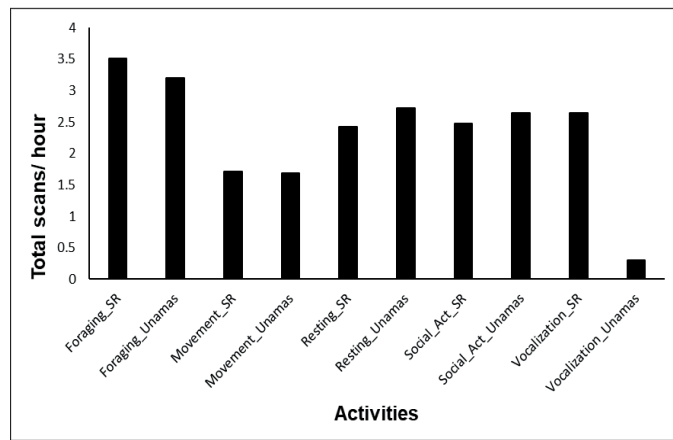


Figure 2. Total scan samples per hour by activity for the *P. ornatus* in the Santa Rosa farm (SR) and Las Unamas Reserve (Unamas) landscapes.

Fruit consumption was significantly different for both groups of *P. ornatus* (Unamas: K-W = 15.0615, $P < 0.05$; Santa Rosa: K-W = 15.1586, $P < 0.05$) when compared with other food items (arthropods, leaves, flowers and others, including fungus, petioles). It was also significantly different when comparing the two groups (K-W = 36.0167, $P < 0.05$, Fig. 3). Arthropods figured more in the Santa Rosa landscape group compared with that of Las Unamas, while the category “other” was consumed more by the Las Unamas landscape group.

Additionally, the consumption of different food items was similar from April to July, but there was a slight increase of fruit consumption in June in the Santa Rosa landscape group, with a similar rise in July in the Las Unamas

Table 1. List of species in the diet of *Plecturocebus ornatus* in fragmented landscapes of the San Martín area, Colombian Llanos.

Family	Species	<i>Plecturocebus</i> group	Method
Acanthaceae	<i>Mendoncia</i> cf. <i>velloziana</i>	Landscape of Santa Rosa.	<i>Ad libitum</i> data
Annonaceae	<i>Xylopia</i> sp.	Both	Group follows
Annonaceae	<i>Guatteria ferruginea</i>	Both	Group follows
Annonaceae	<i>Xylopia aromatica</i>	Both	Group follows
Annonaceae	<i>Unonopsis</i> cf.	Both	Group follows
Annonaceae	<i>Annona</i> cf. <i>edulis</i>	Landscape of Santa Rosa	<i>Ad libitum</i> data
Annonaceae	<i>Xylopia polyantha</i>	Both	<i>Ad libitum</i> data
Araliaceae	<i>Schefflera morotonini</i>	Both	Group follows
Arecaceae	<i>Oenocarpus bataua</i>	Landscape of Las Unamas	Group follows
Burseraceae	<i>Bursera</i> cf. <i>inversa</i>	Landscape of Las Unamas	Group follows
Burseraceae	<i>Protium glabrescens</i>	Both	Group follows
Burseraceae	<i>Protium</i> sp.2	Both	Group follows
Burseraceae	<i>Bursera</i> sp.2	Both	Group follows
Burseraceae	<i>Trattinickia aspera</i>	Both	<i>Ad libitum</i> data
Burseraceae	<i>Protium llanorum</i>	Both	<i>Ad libitum</i> data
Burseraceae	<i>Protium</i> cf. <i>robustum</i>	Both	<i>Ad libitum</i> data
Convolvulaceae	<i>Maripa peruviana</i>	Landscape of Santa Rosa	<i>Ad libitum</i> data
Ebenaceae	<i>Diospyros</i> cf. <i>pseudoxylonia</i>	Both	<i>Ad libitum</i> data
Erythroxylaceae	<i>Erythroxylum</i> cf. <i>novogranatense</i>	Landscape of Santa Rosa	<i>Ad libitum</i> data
Peraceae	<i>Pera arborea</i>	Both	Group follows
Euphorbiaceae	<i>Alchornea triplinervia</i>	Both	Group follows
Fabaceae	<i>Inga fastuosa</i>	Both	Group follows
Fabaceae	<i>Inga alba</i>	Both	<i>Ad libitum</i> data
Hypericaceae	<i>Vismia cayannensis</i>	Both	Group follows
Lauraceae	<i>Ocotea oblonga</i>	Both	Group follows
Malphiaceae	<i>Byrsonima</i> sp.	Both	Group follows
Malphiaceae	<i>Byrsonima</i> cf. <i>crispa</i>	Landscape of Santa Rosa	<i>Ad libitum</i> data
Marcgraviaceae	<i>Norantea guianensis</i>	Both	<i>Ad libitum</i> data
Meliaceae	<i>Guarea glabra</i>	Landscape of Santa Rosa	<i>Ad libitum</i> data

Table 1. *Cont'd.*

Family	Species	<i>Plecturocebus</i> group	Method
Melastomataceae	<i>Bellucia grossularioides</i>	Both	Group follows
Melastomataceae	<i>Miconia napoana</i>	Both	Group follows
Melastomataceae	<i>Miconia</i> sp.	Both	Group follows
Melastomataceae	<i>Miconia trinervia</i>	Both	Group follows
Melastomataceae	<i>Miconia elata</i>	Landscape of Santa Rosa	<i>Ad libitum</i> data
Melastomataceae	<i>Mouriri</i> cf. <i>myrtilloides</i>	Landscape of Las Unamas	<i>Ad libitum</i> data
Moraceae	<i>Ficus trigona</i>	Both	Group follows
Moraceae	<i>Ficus</i> sp2	Both	Group follows
Moraceae	<i>Ficus</i> sp3	Both	Group follows
Moraceae	<i>Ficus americana</i>	Both	<i>Ad libitum</i> data
Moraceae	<i>Pseudolmedia laevis</i>	Landscape of Las Unamas	<i>Ad libitum</i> data
Myrtaceae	<i>Eugenia</i> sp.	Landscape of Las Unamas	Group follows
Myrtaceae	<i>Psidium guajava</i>	Landscape of Santa Rosa	<i>Ad libitum</i> data
Myristicaceae	<i>Virola</i> sp.	Both	Group follows
Myristicaceae	<i>Iryanthera laevis</i>	Both	Group follows
Myristicaceae	<i>Virola</i> cf. <i>sebifera</i>	Both	<i>Ad libitum</i> data
Polygonaceae	Not identified	Landscape of Las Unamas	Group follows
Salicaceae	<i>Ryania speciosa</i>	Both	<i>Ad libitum</i> data
Siparunaceae	<i>Siparuna guianensis</i>	Landscape of Santa Rosa	<i>Ad libitum</i> data
Solanaceae	<i>Solanum aturense</i>	Landscape of Santa Rosa	<i>Ad libitum</i> data
Urticaceae	<i>Urera caracasana</i>	Both	Group follows
Urticaceae	<i>Pourouma bicolor</i>	Both	Group follows
Urticaceae	<i>Pourouma guianensis</i>	Both	Group follows

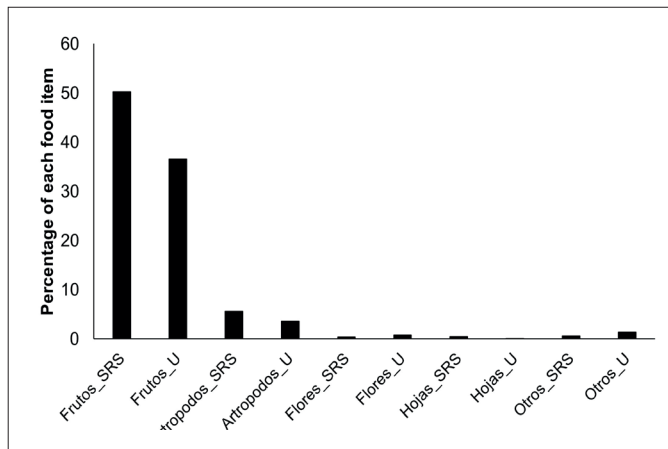


Figure 3. Percentage of food items consumed by *P. ornatus* groups in the Santa Rosa farm (SRS) and the Unamas Reserve landscapes.

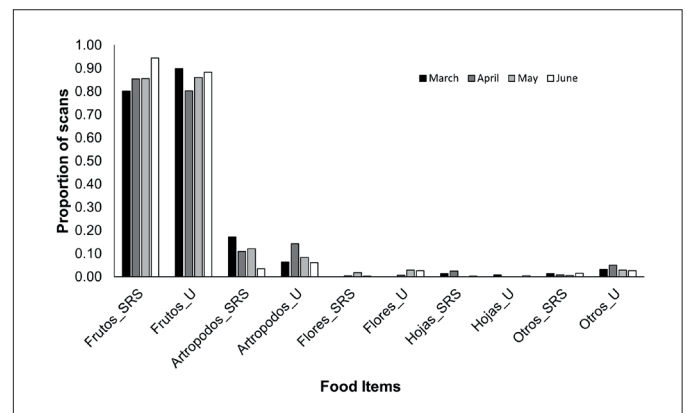


Figure 4. Proportion of scans of different food items consumed by *P. ornatus* groups in the Santa Rosa farm (SRS) and Las Unamas Reserve (U) landscapes.

landscape group. The increases were accompanied by a decrease of arthropod consumption in both areas (Fig. 4). Arthropods were consumed most in April by the Santa Rosa landscape group and in May in the Las Unamas landscape group.

Discussion

The different degrees of fragmentation in the two landscapes affect the activity patterns of the two groups but not their diets that are typically frugivorous. Landscapes with over 40% of forest cover around the focal fragment showed

patterns similar to those of extensively forested areas. Fruit consumption can vary, however, between groups living in less fragmented landscapes compared with groups living in more fragmented landscapes. Additionally, group composition and size can present variations, with bigger groups and groups with more than two adults in more fragmented landscapes.

Typical group composition and size were observed in the Las Unamas landscape (less fragmented), where the study group was characterized by a monogamic pair and its descendants (Mason 1966; Robinson 1981; Polanco 1992). The Santa Rosa landscape group had three adults. Groups with more than two adults have been reported in other species of callicebines (Pinto *et al.* 1993; Bennett *et al.* 2001; Felton *et al.* 2006). There are two explanations for the presence of three or more adults: 1) temporary aggression of young adults that were expelled from their natal groups, which does not seem to be the case in our study, as the second adult arrived two months after this study started; and 2) temporary variation in group size due to reduced dispersal opportunities (Martínez and Wallace 2007), which is possible in our case, although dispersion and movement of *P. ornatus* individuals had been observed sporadically in this area using living fences and even crossing large areas of pasture (Carretero-Pinzón 2013). This variation in group composition can have negative effects due to the possible presence of epidemics, endogamy, stress, and aggression between individuals of the same group (Mason 1966; Wagner 2009).

Differences in the activity pattern between the *P. ornatus* group in the less fragmented area versus the more fragmented area can be explained by differences in those forest fragments themselves. The fragment inhabited by the Santa Rosa farm group (more fragmented) had less plant richness (plant richness: 50 species, Carretero-Pinzón unpubl. data) than the forest fragment in the Las Unamas group (less fragmented landscape, plant richness: 68 species, Carretero-Pinzón unpubl. data). Therefore, groups in more fragmented areas spent more time searching for food than groups in less fragmented areas. A similar pattern has been observed in other primates living in forest fragments compared with groups living in more extensive forest, where groups in fragments spent more time searching for food (Gabriel 2013; Dunn *et al.* 2009). Regarding resting, the Las Unamas group (less fragmented area) showed a similar pattern to what had been observed in more extensive forests, with more time resting (Polanco 1992). Fragmentation seems to have an effect on activity patterns influenced by the time spent mainly in feeding and resting.

Trends observed between the groups regarding vocalizations, with more frequent calling in more fragmented landscape, can be explained by more frequent encounters with groups of *P. ornatus* as well as other primates in the Santa Rosa landscape compared with the Las Unamas landscape. Duet vocalizations, typically occurring during *P. ornatus* group encounters, were more frequent in smaller

forest fragments due to a reduced space compared with more extensive areas, and less so in fragmented landscapes also found in other studies (Mason 1966; Robinson 1979). On the other hand, a trend of more social activity shown by the group in the less fragmented landscape (Las Unamas group) seems to be related to less time spent in foraging, as this landscape would seem to have more resources available. As such, groups can spend more time resting and in social activities such as grooming. This same pattern has been recorded for other primate species in extensive forest when compared with groups of the same species in fragmented areas (Ancorenaz *et al.* 2014; Arroyo-Rodríguez and Dias 2009; McLennan and Hill 2010).

Plecturocebus ornatus is as frugivorous in fragmented landscapes as it is in extensive forests (Polanco 1992; Defler 2004). This high degree of frugivory is typical of this genus (Mason 1966; Polanco 1992; Van Roosmalen *et al.* 2002; Carrillo-Bilbao 2005). However, differences on fruit consumption between groups can be explained by differences in plant richness and floral composition found in each forest fragment. The group in the larger forest in the less fragmented landscape had a higher plant richness than the group in the more extensively and intensively fragmented landscape (Carretero-Pinzón, unpubl. data). Both groups ate several species of fast-growing plants typical of edge habitats, such as *Miconia* spp. and *Bellucia grossularoides*, and *P. ornatus* was observed visiting these edge habitats more than the interior as a result (Defler and Carretero-Pinzón 2018). Variation in the consumption of different food items over the study months can be related to variations in the plant phenology of the two landscapes, although a detailed study of phenology is needed. The higher consumption of arthropods in the Santa Rosa landscape group can be related to a higher edge effect in this area compared to Las Unamas. The abundance of arthropods, especially herbivores, higher and more diverse in the edge compared to the interior of forest fragments (Guimarães *et al.* 2014). Other primates in fragments have also been found to consume more arthropods and rest less, which seems to be a strategy in fragments to conserve energy (Donati *et al.* 2011; Dunn *et al.* 2009; Riley 2007).

Plecturocebus ornatus seems to be adapted to fragmented landscapes, perhaps because of the edge effect and secondary succession. As far as is known, members of this genus are not canopy dwellers, instead occupying the dense vegetation of the understory. An intensively fragmented landscape, however, presents them with challenges in terms of their activity budget and diet that need to be addressed. The isolation and small size of the fragments are problematic regarding endogamy and higher levels of stress. These challenges can be addressed by improving connectivity as well as increasing forest cover in the less fragmented landscape, which can increase the presence and abundance of this species (Carretero-Pinzón *et al.* 2017). Conservation actions for this species should involve reforestation, including the

plant species in their diet, to connect fragments in the highly fragmented distribution of this endemic species of Colombian Llanos.

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