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Abundance of Jackfruit (*Artocarpus heterophyllus*) Affects Group Characteristics and Use of Space by Golden-Headed Lion Tamarins (*Leontopithecus chrysomelas*) in *Cabruca* Agroforest

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Abstract *Cabruca* is an agroforest of cacao trees shaded by native forest trees. It is the predominant vegetation type throughout eastern part of the range of the golden-headed lion tamarins, *Leontopithecus chrysomelas*, an endangered primate endemic to Atlantic Forest. Understanding how lion tamarins use this agroforest is a conservation priority. To address this question, we documented the diet, home range size, group sizes and composition, density, number of litters and body condition of lion tamarins living in *cabruca*, and other habitats. Jackfruit, *Artocarpus heterophyllus*, was the most used species used by lion tamarins in *cabruca* and was widely available and used throughout the year. In *cabruca*, home range size was the smallest (22–28 ha) and density of lion tamarins was the highest (1.7 ind/ha) reported for the species. Group size averaged 7.4 individuals and was not significantly different among the vegetation types. In *cabruca*, groups produced one or two litters a year, and all litters were twins. Adult males in *cabruca* were significantly heavier than males in primary forest. Our study is the first to demonstrate that breeding groups of golden-headed lion tamarins can survive and reproduce entirely within *cabruca* agroforest. Jackfruit proved to be a keystone resource for lion tamarins in *cabruca*, and bromeliads were important as an animal prey foraging microhabitat. In cases where *cabruca* contains concentrated resources, such as jackfruit and bromeliads, lion tamarins may not only survive and reproduce but may fare better than in other forest types, at least for body condition and reproduction.

Keywords *Cabruca* · Agroforest · *Leontopithecus chrysomelas* · Endangered species · Jackfruit · Conservation

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Introduction

In a fragmented forest landscape, the persistence of many species depends on the ability of individuals to use the "matrix", the intervening variety of habitats in a landscape that surround forest patches (Gascon and others 2000), either to acquire resources that would be available in unaltered habitat or to disperse to other habitat fragments (Laurance 1994; Pires and others 2002). The matrix is an important component of the landscape (Gascon and others 1999), affecting within-fragment population dynamics (Fahrig 2001; Ricketts 2001) as well as metapopulation dynamics (Moilanen and Hanski 1998; Vandermeer and Carvajal 2001). The harshness of the matrix for a given species will depend on its composition and complexity. The matrix may vary from open fields such as cattle pastures that are unsuitable for an arboreal mammal, for example, to a more complex matrix resembling the original habitat that may be suitable for many species (Schroth and others 2004).

Agroforest can be defined as a dynamic and ecologically based natural resource management practice where trees and other tall woody plants are integrated with farms and agricultural landscape to diversify production for increased social, economic and environmental benefits (ICRAF 2000). Agroforests may provide biodiversity conservation benefits not present in deforested areas. Agroforestry may reduce the need for deforestation of new areas by offering a more sustainable economic activity than monocultures, which are more susceptible to pests (Schroth and others 2000). Agroforests can also provide habitat and resources for forest-dependent species that wouldn't survive in a purely agricultural landscape, or may permit species dispersal in a fragmented landscape (Schroth and others 2004). In the Atlantic Forest of southern Bahia, northeastern Brazil, the matrix that dominates the landscape is composed mainly of an agroforestry system locally known as *cabruca*, i.e. cacao plantations shaded by native trees. In the 1990s, *cabruca* comprised almost 40% of the Atlantic Forest of southern Bahia, and only 33% of the forest cover was composed of native vegetation (May and Rocha 1996). *Cabruca* has been considered as an important habitat for conserving the Atlantic Forest's biodiversity (Rice and Greenberg 2000; Cassano and others 2009) for both plants (Sambuichi 2002, 2006; Sambuichi and Haridasan 2007) and animals (Pardini 2004; Delabie and others 2007; Faria and Baumgarten 2007; Faria and others 2007).

Cabruca is the predominant habitat type throughout the eastern portion of the range of the golden-headed lion tamarin (GHLT), *Leontopithecus chrysomelas* (Raboy and others 2010) an endangered primate (IUCN 2009) endemic to Brazil's Atlantic Forest (Coimbra-Filho and Mittermeier 1973). The diet of lion tamarins consists mostly of ripe fruits, flowers, nectar, insects, small vertebrates, and occasionally gums (Rylands 1989; Raboy and Dietz 2004). They use tree holes as their main source of sleeping sites although vine tangles and palm leaves may also be used (Rylands 1989; Raboy and others 2004). The wild population estimated between 6,000 to 15,000 from a survey conducted from 1991 to 1993, lives in a fragmented landscape (Pinto and Rylands 1997) with very few patches of forest large enough to support a genetically viable population of this species in the long term (Zeigler and others 2010).

Assessing how lion tamarins use this agroforest is crucial for the conservation of this species (Holst and others 2006). Important conservation questions include whether lion tamarins live and reproduce in *cabruca*, use *cabruca* for dispersal, and whether population density is similar in *cabruca* and in native forest habitats. Other studies showed that the number of trees per hectare in *cabruca* affects the availability and use of resources by lion tamarins (Raboy 2002; Oliveira and others 2010), and consequently their biology (weight and reproduction) and ecology (home range size and habitat use).

The objectives of this study were to determine whether golden-headed lion tamarins can live and reproduce entirely within *cabruca* agroforests, and to compare density, home range, group size, and body mass of lion tamarin populations in *cabruca* and in other vegetation types. As the density and richness of trees are lower in *cabruca* than in other types of forest forest (Alves 1990; Sambuichi 2002; Sambuichi and Haridasan 2007), we expected the abundance of food to be lower in *cabruca*. Thus, we predicted that home ranges would be larger in *cabruca*, assuming that home range size is affected by availability of food resources (McNab 1963; Clutton-Brock and Harvey 1977). We expected that the density of lion tamarins would be lower in *cabruca* than in other vegetation types, as population density typically is directly related to food resource availability (Wauters and Lens 1995; Hanya and others 2005). We also expected groups to be smaller and individuals to weigh less in *cabruca* than in other vegetation types as food availability affects group size and individual weight (Kirkwood 1983; Chapman and others 1990).

Methods

Study Sites

This study was carried out in the cacao-growing region of southern Bahia, northeastern Brazil, in the municipalities of Ilhéus, Jussari, Camacan, Arataca and Una. Study sites (Fig. 1) included one public protected area (Una Biological Reserve), four private areas (Almada, Riachuelo, Santa Rita and São José farms), two private reserves (Ararauna and Teimoso) and one rural settlement (Bem Te Vi).

Data Collection

We captured ten lion tamarin groups in the study areas using Tomahawk live traps (48.3 × 15.2 × 15.2 cm) baited with banana and placed on platforms 1.5 m above ground (Dietz and others 1996). During capture and examination of the animals we recorded for each individual: weight, knee to heel and wrist to elbow lengths, reproductive condition, and group size and composition (age and sex of individuals in the group). We adjusted the group size and composition including any individuals seen outside the traps. Lion tamarins are cooperative breeders that live in cohesive family groups (Dietz and others 1994) and thus we assumed that individuals that remained in the vicinity of captured individuals were members of the same group. We used tooth wear to estimate the age of adult

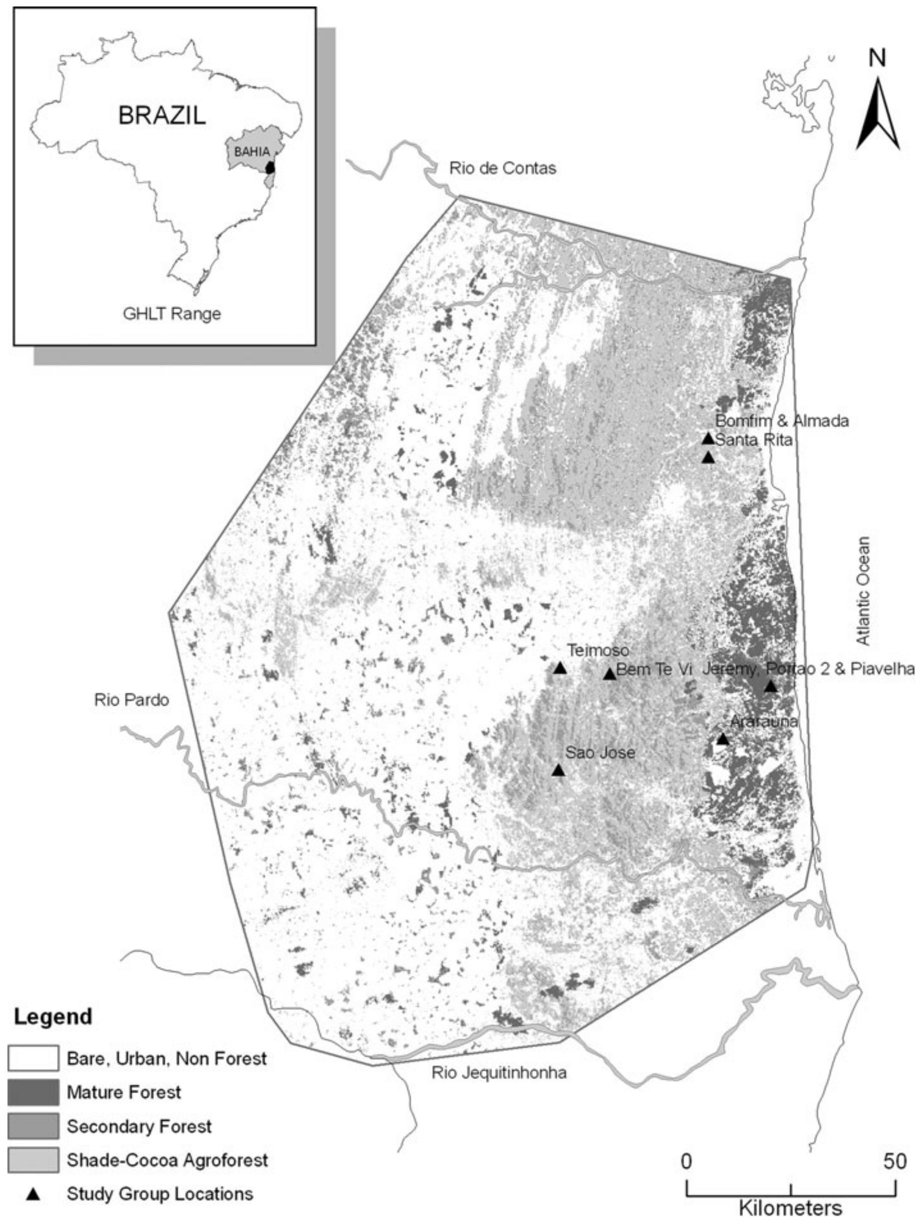

Fig. 1 Geographic distribution of golden-headed lion tamarins in southern Bahia state, Brazil and the location of the study sites. Map based on a reclassification of land cover at 30 m resolution published in Landau and others (2003) from 1996–1997 Landsat data

animals and tooth wear, body weight and dental composition to estimate ages of younger members of groups (Dietz and others 2000; Bales and others 2001).

We affixed radio-collars to one or two individuals from each group to facilitate location and monitoring. We followed the lion tamarins during complete days (from when the group left its sleeping site in the morning until when they entered a sleeping site in the evening), or partial days (either from the time they left the sleeping site until noon, or from noon until when they entered a sleeping site).

Groups were categorized post hoc according to the types and combinations of habitat occurring within their home ranges: primary forests (Una Biological Reserve: Portão 2, Jeremy and Piavelha groups); *cabruca* (municipality of Ilhéus: Almada, Bomfim and Santa Rita groups), and a mosaic of *cabruca*, primary and secondary forests (municipalities of Una, Arataca, Camacan and Jussari: Ararauna, Bem te Vi, São José and Teimoso groups, respectively) hereafter referred to as mosaic groups. For two of the primary forest groups (Jeremy and Piavelha), we used information about group size and composition, and home range size and density from Dietz and others (1996) and Raboy and Dietz (unpublished data). We defined vegetation types used by the lion tamarins using categories adapted from Catenacci and others (2009):

Primary forest: forest with little or no signs of past human disturbance, a closed canopy, trees in general at least 20 m high with large diameters, many bromeliads in a wide range of sizes and an extensive layer of vines.

Secondary forest: forest with visible signs of previous human disturbance, which has been subjected to either 'general' (recovering from complete deforestation) or 'selective' logging (recovering from the cutting of selected species).

Cabruca: forest in which the undergrowth has been cut and replaced by cacao trees.

Mosaic forest: lion tamarin home ranges that included the previous three vegetation types.

Groups that lived mostly in primary forests were studied during three periods: from August 1992 to June 1994 (Piavelha), from September 1994 to July 1995 (Jeremy), and from March 2005 to April 2006 (Portão 2). All groups in *cabruca* and mosaic forests were studied from April 2008 to September 2009. For all groups, we recorded group location at 20-min intervals either using maps with marked trails (groups Jeremy, Piavelha and Portão 2) or using GPS (all others). For both *cabruca* and mosaic groups, we also collected information about use and location of feeding trees. Whenever possible we identified feeding trees to the species level. Group size and the presence of infants were recorded daily. Whenever possible we also collected information on size, location and composition of non-focal groups observed while following focal groups or during encounters with conspecifics.

Data Analysis

Diet

Habituation to human observers varied from high (*cabruca* groups) to medium or low (mosaic groups) which made it difficult to record feeding activities of mosaic groups. Thus our data on feeding come mainly from *cabruca* groups. We calculated the number of feeding tree species (overall richness) used by the study groups living in *cabruca* and in mosaic forest. We also calculated the total number of visits to feeding trees. We recorded the type of substrate used by the lion tamarins when foraging for animal prey and the time spent in this activity.

We used Jaccard's coefficient of similarity (Magurran 1988) to evaluate the similarity of food-plant species used by lion tamarins in *cabruca* groups and in mosaic groups. We also compared the plant species consumed by these above-mentioned groups with the list of plant species consumed by lion tamarins in *cabruca* reported in Oliveira and others (2010). The Jaccard index (J) was calculated as $J = s/(a + b - s)$, where s is the number of species shared across two areas, a is the number of species found exclusively in the first area and b is the number of species found exclusively in the second. We estimated mean and standard error of the mean (SEM) for the total number of individual trees used by the lion tamarins. We considered species for which the number of individuals was higher than the mean + SEM to be the most important species for the lion tamarins in *cabruca* (as in Oliveira and others 2010). We recorded the geographic location of all individual food trees used by lion tamarins as well as the month when each individual tree was used.

Home Range

We excluded the São José group from all analyses except size and condition, because it was composed of two dispersing adult males and thus was not a breeding group. We estimated home range size using the minimum convex polygon method (Mohr 1947). Home range sizes were compared using one way ANOVA followed by least squares mean t-tests for multiple comparisons using a significance level of $P < 0.05$.

Density

We estimated lion tamarin density by dividing the number of individuals in each group by the group's home range size. We considered only exclusive home ranges (with no overlap among group home ranges) in the calculation of density. We compared densities among all vegetation types using one-way ANOVA followed by least squares mean comparisons using a significance level of $P < 0.05$.

Group Sizes and Composition

Group size and composition varied over the study period. Thus, we estimated the sizes of each group considering the average of group size recorded on each day of observation. We evaluated differences in group size among the three different vegetation types using one-way ANOVA.

Size and Condition of the Lion Tamarins

We compared the mean weights of adult individuals in each group using one way ANOVA followed by least squares mean comparisons using a significance level of $P < 0.05$. We evaluated the condition of individual males and females by analyzing residuals of a regression (Packard and Boardman 1988) between individual weight and knee-heel length. We selected the residuals and used one way ANOVA to compare the means of the residuals followed by least square means t-tests for multiple comparisons using a significance level of $P < 0.05$. For those analyses we considered only adult individuals, identified according to tooth wear.

Results

Diet

Overall, our study groups used 43 plant species from 24 families (Table 1). *Cabruca* groups used 26 plant species while mosaic groups used 23 species. We identified 35 taxa of trees at least to genus level. From these, 22 (12 in *cabruca* and 17 in mosaic forest) were also represented in the list of key tree species identified in Oliveira and others (2010). We were unable to identify 19 individual feeding trees (15 from mosaic groups and four from *cabruca* groups). In *cabruca*, the families Bromeliaceae, Mimosaceae and Moraceae were dominant in number of species and number of individuals. The three species used most frequently belonged to the Moraceae and Mimosaceae families. We recorded only two species belonging to the Myrtaceae and Sapotaceae families.

There was a 35% similarity of food-tree species between *cabruca* and mosaic, 32% between mosaic and the *cabruca* species listed in Oliveira and others (2010) and 15% between the species used by *cabruca* groups and the list of *cabruca* species used by the lion tamarins in Oliveira and others (2010). Seven species were present in the diet of the groups from both *cabruca* and mosaic forest.

Jackfruit (*Artocarpus hetrophyllus*) was the dominant species in the diet of individuals in both habitats combined (33.5% of total food tree individuals used) as well as in *cabruca* and mosaic habitats (37.5 and 21.3%, respectively). *Ficus gomelleira*, (10.4%) and *Inga affinis* (9.3%) were the second and third most-used plant species, respectively. Fruits of jackfruit were available and consumed throughout the year by all three groups that lived in *cabruca* (Table 2). The level of dominance of *A. heterophyllus* in the diet of lion tamarins varied among study groups in *cabruca* comprising 55, 33 and 25% of the fruits consumed by Almada, Bomfim and Santa Rita groups, respectively. For mosaic groups, *A. heterophyllus* comprised 60, 52, 14.3 and 2.1% (Bem te Vi, São José, Teimoso and Ararauna groups, respectively). In the latter groups, it was consumed mostly in *cabruca* and to a lesser extent in secondary forest. However, differences in sample size, degree of habituation of the groups and changes in home range may have affected the results obtained in mosaic forest. For example, we recorded only five individual trees used by the Bem te Vi mosaic group (three of them were *A. heterophyllus*); the São José mosaic group shifted its home range to a *cabruca* area with an abundance of jackfruit trees.

In *cabruca*, the three most important plant species represented 79, 76 and 54.5% of the fruits consumed by the Almada, Bomfim and Santa Rita groups, respectively, and were widespread inside the home ranges of these groups (Fig. 2a–c). Bromeliads were the most common foraging sites for animal prey in both *cabruca* (96.7%) and mosaic forest (80.6%) followed by tree bark (Table 3). For some groups, bromeliads were the only substrate used for foraging for animal prey. The lion tamarins spent up to 220 min a day foraging for animal prey in *cabruca* areas and up to 98 min a day in mosaic forest areas. Considering the time that lion tamarins spent in feeding behavior (both fruits and animal prey foraging) they spent 61 ± 11.1% foraging in bromeliads in *cabruca* and 35.7 ± 12.6% in mosaic forest.

Home Ranges

The average home range size for all study groups was 83 ha, ranging from 22 to 197 ha (Table 4). We observed a significant difference in home range size in the three vegetation types ($F = 5.70$, df $= 8$, $P = 0.041$). The average home range size for groups that used *cabruca* exclusively was significantly smaller compared to groups from primary forests ($P = 0.018$), but not different from mosaic groups ($P = 0.525$). Home range size also differed between mosaic groups and primary forest groups ($P = 0.044$). The smallest home range sizes reported for the species (22 and 28 ha) occurred in two of the three *cabruca* groups. We observed that 80% of the home range of one group (Bomfim) overlapped the home range of another group (Almada), both living in *cabruca*.

Density

The overall mean density in our study was 0.12 individuals per hectare. The average density of tamarins in *cabruca* areas was 0.17 individuals/ha (range: 0.1–0.21 individuals/ha), the highest density recorded for the species. The average density in mosaic groups was 0.13 individuals/ha (range: 0.08–1.8 individuals/ha) and 0.06 individuals/ha in primary forest (range: 0.04–0.11 individuals/ha). Although those ranges suggest a difference in lion tamarin densities in the three vegetation types, the differences were not statistically significant ($F = 4.36$, df $= 8$; $P = 0.067$). However, the density recorded in *cabruca* was significantly higher than the density recorded in primary forest groups ($P = 0.027$).

Based on differences in size and composition, we estimated that the range of each of our study groups was bordered by one to six neighboring groups. *Cabruca* groups were bordered by the highest number of neighbors (3–6), while in two of the mosaic groups (Teimoso and São José) we observed no neighbor groups (i.e., no observed encounters with conspecifics) and for one group (Bem te Vi) we observed only one encounter with conspecifics. We observed encounters with at least four different groups of

Table 1 Plant species used for food by lion tamarins in *cabruca* and mosaic forest with the total number of individuals of each tree species used and the total number of visits to each tree species

Scientific name	Family	Ind		N of visits	
		C	M	C	M
Artocarpus heterophyllus Lamark[a]	Moraceae	106	17	227	27
Ficus gomelleira Kunth & Bouché[a]	Moraceae	38	0	83	0
Inga affinis Benth.[a]	Mimosaceae	28	6	37	6
Duguetia magnolioidea Maas[a]	Annonaceae	20	1	27	1
Celtis glycycarpa Mart. ex Miq.	Ulmaceae	16	1	39	1
Musa paradisiaca L.[a]	Musacae	8	6	8	6
Sarcaulus brasiliensis (A.DC.) Eyma.JPG	Sapotaceae	11	0	26	0
Hohenbergia blanchetii (Baker) EM ex Mez	Bromelidae	9	0	9	0
Hohenbergia disjuncta L.B.Sm	Bromelidae	8	0	10	0
Cecropia hololeuca Miq.	Cecropiaceae	8	0	9	0
Miconia mirabilis (Aubl.)L. Wms.[a]	Melastomataceae	0	6	0	6
Symphonia globulifera L.[a]	Clusiaceae	3	3	4	4
Spondias venulosa Mart. Ex Engl.	Anacardiaceae	5	0	5	0
Tapirira guianensis Aublet[a]	Anacardiaceae	5	0	13	0
Macoubea guianensis Aublet[a]	Apocynaceae	0	4	0	5
Theobroma cacao L.[a]	Sterculiaceae	3	1	3	1
Aechmaea sp.[a]	Bromeliaceae	0	2	0	3
Carica papaya L.	Caricaceae	2	0	2	0
Chondrodendron microphyllum (Eichl)Mol	Menispermaceae	0	2	0	3
Eugenia cauliflora DC.[a]	Myrtaceae	0	2	0	4
Lacmellea aculeate (Ducke) Monach[a]	Apocynaceae	0	2	0	2
Myrtaceae sp1	Myrtaceae	0	2	0	2
Myrtaceae sp3	Myrtaceae	0	2	0	2
Protium sp.[b]	Burseraceae	0	2	0	2
Syngonium sp.	Araceae	2	0	2	0
Ampelocera glabra Kuhlm	Ulmaceae	0	0	0	0
Anacardiaceae sp.	Anacardiaceae	0	1	0	2
Bactris ferruginea Burret	Arecaceae	0	1	0	1
Aechmea lingulata (Linnaeus) Baker[b]	Bromelidae	1	0	1	0
Coffea Arabica L.	Rubiaceae	1	0	1	0
Cordia nodosa Lam[b]	Boraginaceae	1	0	5	0
Elaeis guianeensis Jacq.[a]	Arecaceae	1	0	1	0
Ficus sp.[a]	Moraceae	0	1	0	3
Inga edulis Mart.[a]	Mimosaceae	1	0	1	0
Micropholis gardneriana (ADC)Pier JPG[b]	Sapotaceae	0	1	0	2
Myrtaceae sp2	Myrtaceae	1	0	1	0
Passiflora haematostigma Mart exMart.JPG	Passifloraceae	0	1	0	1
Persea Americana Mill.	Lauraceae	1	0	1	0
Pourouma velutina Miq.[a]	Moraceae	0	1	0	1
Protium heptaphyllum (Aubl.) Marchand[a]	Burseraceae	0	1	0	5
Quararibea turbinata Pohl.	Bombacaceae	1	0	5	0
Sapotaceae sp.	Sapotaceae	1	0	1	0
Soroceae sp.	Moraceae	0	1	0	1
Unknown	Unknown	4	15	4	20
Total		285	82	523	109

Veg, vegetation type; Ind, N of individuals; Freq, frequency of use; %, relative abundance, C, *cabruca*; M, mosaic

[a] Species also recorded on the list of key species for the lion tamarins presented in Oliveira and others (2010)

[b] Genus also recorded in the list of key species for the lion tamarins presented in Oliveira and others (2010)

Table 2 Percentage of each plant-food species used by the three groups of golden-headed lion tamarins in *cabruca* agroforest over the period of study (May 2008 to November 2009), with the total number of individuals and species used per month

Species	2008								2009								
	M (2)	J (5)	J (6)	A (4)	S (6)	O (3)	N (3)	D (4)	J (4)	F (6)	M (7)	A (11)	M (5)	J (7)	J (7)	A (3)	S (6)
Artocarpus heterophyllus	67	40	64	62	60	67	88	92	71	38	29	14	15	23	60	60	68
Ficus gomelleira		27	7	10	33	33			29	44	18	2	10	19	20	20	19
Inga affinis											14	18	20	8			
Duguetia magnolioidea		13									2	14	20	15			
Bromeliaceae		7	7	5						19	10	8		4			
Celtis glycycarpa											4	16	5				
Sarcaulus brasiliensis												10	25	12			
Musa paradisiaca				5	3						2	1				20	13
Cecropia hololeuca	33							8			6	4					
Spondias venulosa				5							4	3					
Tapirira guianensis			7								2	3			10		
Symphonia globulifera			7								2	3			10		
Syngonium sp.				10													
Carica papaya		7												4			
Inga fogifolia												2					
Myrtaceae sp1											2	1					
Elaeis guianeensis							13										
Quararibea turbinata															10		
Cordia nodosa													1				
Persea americana					3												
Inga edulis		7															
Ficus sp.											2						
Myrtaceae sp2											2						
Coffea arabica														4			
Theobroma cacao				5													
Unknown			7								2	2	5	4			
Total individuals	3	15	14	21	30	6	8	12	7	16	49	93	20	26	10	5	31
Total species consumed	2	6	6	7	4	2	2	2	2	2	14	15	7	10	4	3	3

In parentheses is the sample effort in days of observation for each month

lion tamarins inside the overlap area of the groups Almada and Bomfim (Fig. 3).

Group Sizes and Composition

Group sizes varied from 3 to 15 individuals (Table 5) and averaged 7.4. There was no difference in group size among the three vegetation types ($F = 0.51$, df $= 8$, $P = 0.624$). We observed that all groups but one contained at least one reproductive female, one to four adult males and other individuals (subadults, juveniles and infants) probably related to them (Table 6). Two reproductive females were recorded in one group (Ararauna) at the first capture, and no reproductive females were observed in the Santa Rita group, although one adult female joined the group a few weeks after the capture.

We observed individuals of all age classes, including newborn infants (born in the study period), in all study groups. We recorded the birth of ten litters (20 infants) of seven reproductive females during the study (Table 7). Groups in both *cabruca* and mosaic forest produced one litter per reproductive season and in all birth events the reproductive female gave birth to twins. The Ararauna group, with two reproductive females, produced litters of twins 1 week apart.

Size and Condition of the Lion Tamarins

The average weight of adult individuals was 653 g for *cabruca* groups, 614 g for mosaic groups and 586 g for primary forest groups. We found differences in the weights of adult males living in the three vegetation types ($F = 4.54$,

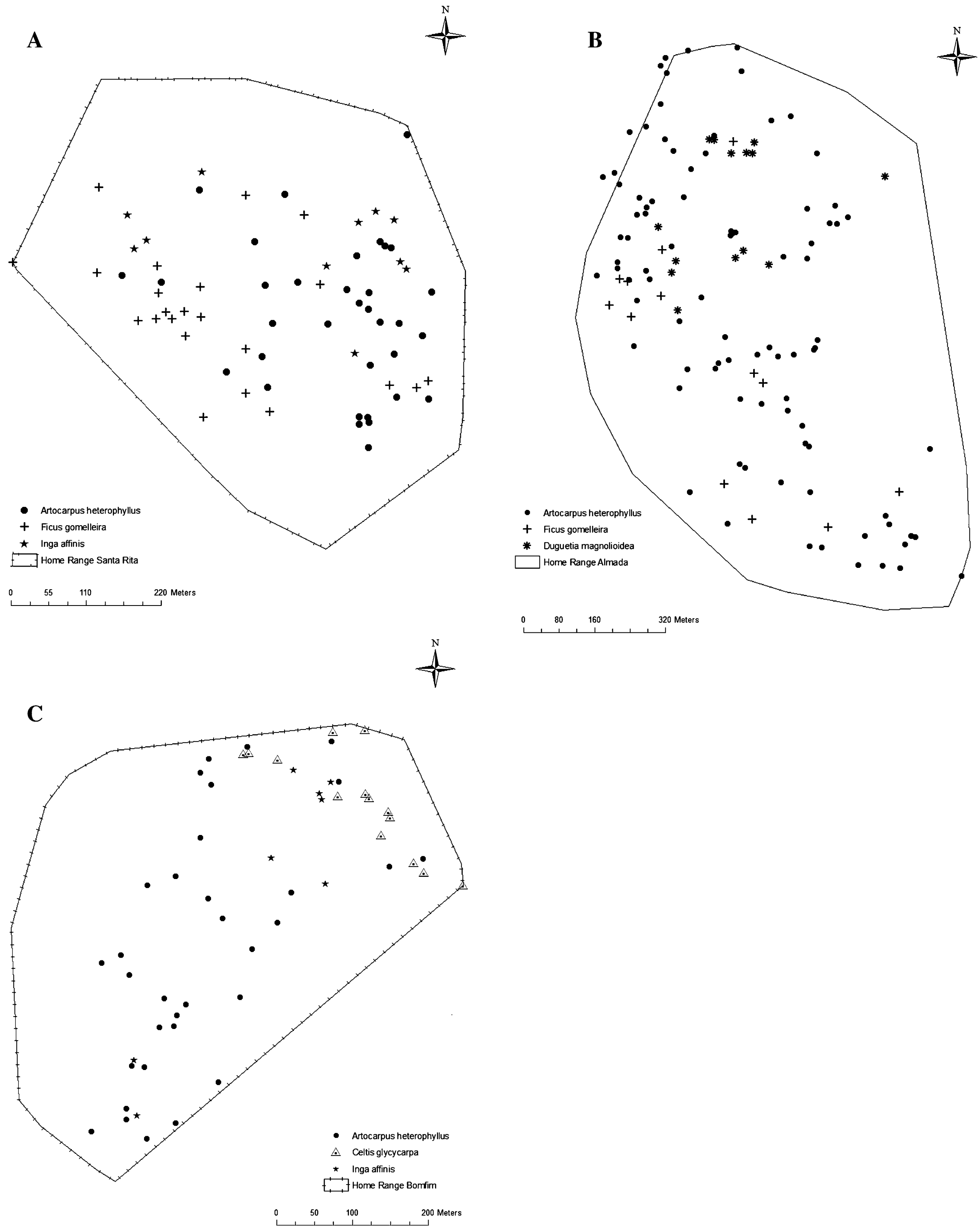

Fig. 2 **a** Distribution of the three most used plant species inside the home range of the Santa Rita *cabruca* group, **b** distribution of the three most used plant species inside the home range of the Almada *cabruca* group, and **c** distribution of the three most used plant species inside the home range of the Bomfim *cabruca* group

$\mathrm{df} = 24, P = 0.023$). Males from *cabruca* were heavier than males from primary forest ($P = 0.013$) and mosaic ($P = 0.026$); however, males from primary forest and mosaic forest did not differ significantly ($P = 0.573$). We found no difference in the weights of adult females in the three vegetation types ($F = 0.07, \mathrm{df} = 12, P = 0.929$). The regression between weight and knee-heel length, performed in order to evaluate the body condition of the lion tamarins was significant for males ($r^2 = 0.35, F_{1,\ 28}, P = 0.001$) but not for females ($r^2 = 0.005,\ F_{1,\ 14},\ P = 0.791$). The

Table 3 Foraging substrates used by the lion tamarin groups for animal prey

Substrate	*Cabruca*			Mosaic		
	Almada	Bomfim	Santa Rita	Ararauna	Teimoso	São José
Bromeliads	159 (93%)	127 (100%)	290 (97.3%)	55 (100%)	25 (69.4%)	3 (75%)
Tree bark	10 (5.8 %)	–	4(1.3%)	–	7 (19.4%)	1 (25%)
Palm	1 (0.6%)	–	2 (0.7%)	–	3 (8.3%)	–
Leaves	–	–	2 (0.7%)	–	1 (2.8%)	–
Other	1 (0.6%)	–	–	–	–	–

Numbers represent the total number of observations and in parenthesis is the percentage that each substrate was used

Table 4 Home range sizes, vegetation type and sample effort for the study groups

Group	Vegetation type	Home range size (in hectares)	Sample effort (in days)
Almada	*Cabruca*	84	64
Bomfim	*Cabruca*	22	24
Santa Rita	*Cabruca*	28	66
Ararauna	Mosaic	65	32
Bem te Vi	Mosaic	65	15
Teimoso	Mosaic	64	60
Jeremy	Primary	129	48
Piavelha	Primary	93	61
Portão 2	Primary	197	62

Home range size was estimated using minimum convex polygon method. Sample effort included complete and partial days of observation

residuals of the regression were not significantly different for females among the different vegetation types ($F = 2.17$, df = 16, $P = 0.153$). However, the residuals of the regression were significantly different for males ($F = 5.37$; df = 30, $P = 0.010$). Males from *cabruca* and primary forest were significantly different ($P = 0.003$) although neither males from *cabruca* and mosaic forest nor from mosaic and primary forest were different ($P = 0.132$ and $P = 0.119$, respectively).

Discussion

Our study is the first to demonstrate that breeding groups of golden-headed lion tamarins can survive and reproduce in home ranges entirely within *cabruca* agroforests. This observation is important for the conservation of this species for two reasons. It increases the estimated total amount of habitat that may be used by the species, and thus the estimated number of individuals in the wild. It also suggests that lion tamarins can use *cabruca* for dispersal among forest patches previously considered as isolated. For both these reasons, populations may be less vulnerable to the negative genetic and demographic effects of habitat fragmentation in areas where *cabruca* connects native forests.

Shaded agroforest systems are important for arboreal mammals, especially for primates, functioning as a refuge, and feeding and breeding areas (Estrada and others 2005; Vaughan and others 2007). Primate species have been recorded living and reproducing in shaded agroforest systems in other places [the mantled howler monkey, *Alouatta palliata* in shaded coffee plantations, (McCann and others 2003; Muñoz and others 2006); *Alouatta palliata* in shaded cocoa (Muñoz and others 2006); *Alouatta palliata* (Williams-Guillén and others 2006); *Alouatta palliata* and the Geoffroy's spider monkey, *Ateles geoffroyi* in shaded cocoa and shaded coffee (Estrada and Coates-Estrada 1996)].

Diet

The diet of groups that lived exclusively in *cabruca* comprised few plant species from the Myrtaceae and Sapotaceae families. The species from these two families are the most important in the diet of the lion tamarins (Oliveira and others 2010). These two families are usually rare or absent in *cabruca* probably because the majority of Myrtaceae and Sapotaceae species are slow-growing climax species typically found in low density and thus the probability of these seedlings being eliminated by weeding in *cabruca* is very high (Sambuichi and Haridasan 2007). In contrast, the three tree species most frequently used by lion tamarins in *cabruca* are typically abundant in this agroforest. Both *A. heterophyllus* and *Ficus* spp. have been reported as very abundant if not the dominant species in

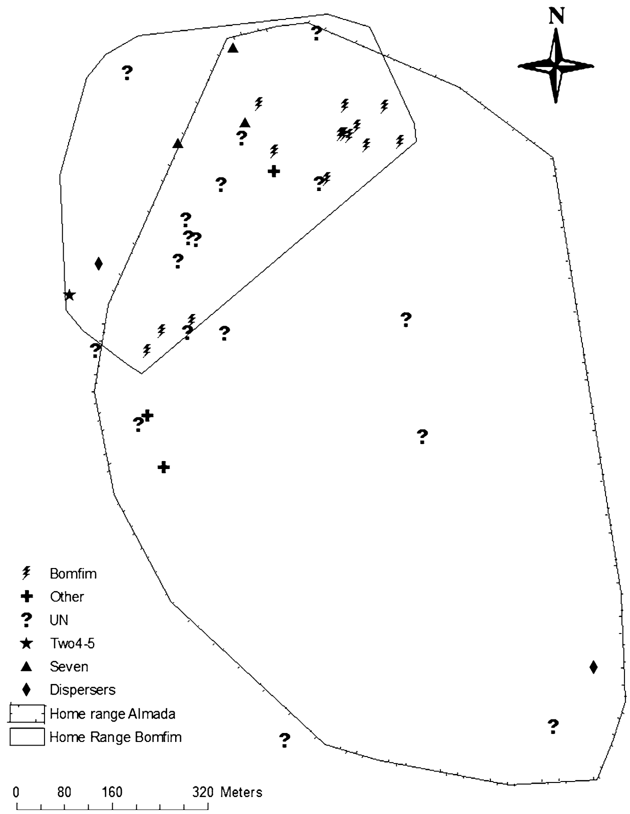

Fig. 3 Conspecific encounters in the ranges of the Almada and Bomfim *cabruca* groups. Results suggest that at least five reproductive groups are located in the area of overlap of these two home ranges

Table 5 Range and average number of individuals in each study group of lion tamarin in the three vegetation types

Group	Vegetation type	Range of individuals per group	Average group size
Almada	*Cabruca*	5–12	8.3
Bomfim	*Cabruca*	3–5	4.7
Santa Rita	*Cabruca*	3–6	5.3
Ararauna	Mosaic	8–15	11.8
Bem te Vi	Mosaic	7–8	7.7
Teimoso	Mosaic	2–7	5.2
Jeremy	Primary	4–7	5.1
Piavelha	Primary	9–12	9.8
Portão 2	Primary	6–9	7.3

cabruca areas (Hummel 1995; Sambuichi 2002, 2006; Sambuichi and Haridasan 2007). Species of the genus *Inga* are also common in *cabruca* (Sambuichi 2002; Vinha and Silva 1982) and because they are fast-growing they are used by agroforest owners when they need to improve shade in *cabruca* areas (Sambuichi and Haridasan 2007).

Table 6 Composition of the study groups at first capture

Group	Alm	Bom	Sta	Ara	BTV	Tei	Jer	Pia	Por
Reproductive ♀	1	1	–	2	1	1	1	1	1
Adult ♀	1	–	–	–	–	1	1	1	1
Adult ♂	4	3	2	4	3	1	1	3	2
Sub adult ♀	1	1	–	1	1	–	–	–	–
Sub adult ♂	1	–	2	1	1	–	1	2	1
Juveniles	–	–	1	2	2	2	2	2	–
Infants	2	–	–	–	–	–	–	–	–
Total	10	5	5	10	8	5	6	9	5

Composition was estimated by summing individuals captured plus those individuals observed outside the traps

Alm Almada, *Bom* Bofim, *Sta* Santa Rita, *Ara* Ararauna, *BTV* Bem te Vi, *Tei* Teimoso, *Jer* Jeremy, *Pia* Piavelha, *Por* Portão 2

Table 7 Number of litters and offspring for each reproductive female in each study group over the period of study

Group	Habitat type	Number of reproductive seasons	Number of litters	Total number of offspring
Almada	*Cabruca*	2	2	4
Bomfim	*Cabruca*	1	1	2
Santa Rita	*Cabruca*	2	2	4
Ararauna[a]	Mosaic	1	2	4
Bem te Vi	Mosaic	1	1	2
Teimoso	Mosaic	2	2	4
Jeremy[b]	Primary	2	–	–
Piavelha	Primary	4	2	3
Portão 2	Primary	3	2	3
Total			8	20

Reproductive seasons from February to March and October to December (Bach and others 2001)

[a] The group had two reproductive females that both had twins with a week between birth events

[b] No available information about litter size

Artocarpus heterophyllus was the only species present in the diet of all study groups in mosaic and *cabruca* forest. Jackfruit is an exotic species introduced into cacao plantations of southern Bahia and its edible fruits are widely used by local people (Correia 1975). Each jackfruit tree may produce up to 100 fruits a year, with individual fruits weighing up to 40 kg (Correia 1975). This species has high recruitment rates, is the dominant species in number of individuals and biomass in many areas (Abreu 2008; Cunha and others 2006) and has been considered an invasive species in some regions of Brazil (Abreu 2008; Horus 2010). The distribution pattern of *A. heterophyllus* may be either equally spaced or clumped (Boni and others 2009), and we observed both patterns in our *cabruca* study areas.

In our study areas, *A. heterophyllus* fruits were available all year. In the Amazon, higher fruit production is expected from January to March and July to September (Falcão and others 2001).

In contrast with our assumption that *cabruca* would contain fewer resources than other vegetation types, we found that our study areas of *cabruca* provide a superabundant and reliable food source for tamarins, specifically jackfruit. We believe that jackfruit is a keystone resource in *cabruca* in which it occurs, providing the food resources necessary to sustain breeding groups of golden-headed lion tamarins.

Bromeliads were also an important resource for lion tamarins in *cabruca*. In *cabruca* areas bromeliads comprised 96.8% of all lion tamarin animal foraging sites. Previous studies also reported bromeliads as the principal foraging substrate for animal prey but with lower percentage of use, 50% of the records in (Rylands 1989), 76.6% in (Raboy and Dietz 2004), 81.7% in (Catenacci 2008) and 86% in (Guidorizzi 2008) than in this study. However, contrary to other studies (Raboy and Dietz 2004; Catenacci 2008; Guidorizzi 2008; Oliveira and others 2010), fruits of bromeliads were not consumed frequently by lion tamarins in our study. Guidorizzi (2008) correlated the high consumption of fruits from bromeliads to a lower abundance and availability of food resources in his study area. Fruits of bromeliads are rich in carbohydrates and poor in protein and minerals (Catenacci 2008) and it is possible that the low consumption of bromeliads in our study is related to high abundance of jackfruit, that is rich in carbohydrates. We believe that lion tamarins gained energy mainly from the temporally and spatially abundant jackfruit, which allowed them to spend more time foraging in bromeliads to obtain fat and protein from animal prey.

Home Range Sizes and Density

Contrary to what we expected, home range sizes were smaller and the density of lion tamarins was higher in *cabruca* compared to other vegetation types. Previously reported home range sizes for lion tamarins range from 40 to 200 ha (Rylands 1989; Dietz and others 1996). Many factors can affect estimates of home range size including the methods to estimate home ranges, duration of observation, and biological characteristics such as individual body size, group size and composition and biomass (Milton and May 1976; Clutton-Brock and Harvey 1977; Terborgh 1983; Chapman 1990; Dietz and others 1997; Lehmann and Boesch 2003; Benson and others 2006). However, none of these seem to be a reasonable explanation for differences in home range sizes reported in our study because group sizes and composition, duration of the study and the methods were the same.

Food availability and density of animals can also affect home range size. Although we did not quantify the availability of food resources in *cabruca*, we observed high spatial and temporal abundance of jackfruit, which probably affected the size of home ranges of the *cabruca* groups. Home range size has been reported to be negatively correlated with food availability (Mares and others 1982; Litvaitis and others 1986; Herfindal and others 2005). As availability of food resources increases, individuals can acquire sufficient resources for survival and reproduction within a smaller area (Benson and others 2006). Boutin (1990) experimentally tested this hypothesis and observed a decrease in home range for terrestrial mammals with an increase in resources abundance. This may explain the smaller home range sizes of *cabruca* and mosaic groups, in which three of four groups used jackfruit as the main fruit resource. However, the relationship between food availability and home range size is difficult to demonstrate because food supply and population density are often positively correlated (Wauters and Lens 1995; Heydon and Bullon 1997; Hanya and others 2005). As availability of food resources increases, more individuals are able to exploit them for survival and reproduction. Thus, abundance of jackfruit in *cabruca* may affect home range size directly (individuals need to travel less distance to find adequate food) or indirectly, by permitting increased density of lion tamarins in the area. High population densities, in general, result in smaller home range sizes (Forsyth and Smith 1973; Maza and others 1973) as shown for lion tamarins (Dietz and others 1996; Kierulff and others 2002) and in our study.

Our study groups in *cabruca* had the highest densities reported for the species (average 0.12 and 0.17 for the whole study and for *cabruca* groups respectively). Other studies reported densities varying from 0.05 (Dietz and others 1996), 0.07 (Rylands 1989; Guidorizzi 2008), to up to 0.11 individuals per hectare in a compilation of unpublished data in Una Biological Reserve (Holst and others 2006). This affirmation is supported by the observed overlap of home ranges (almost 80%) of two groups (Almada and Bomfim), and the high number of encounters with different groups of conspecifics inside this overlap area. We also observed a high number of encounters on the exclusive parts of the home range of these two groups and higher numbers of encounters in *cabruca* groups compared to mosaic groups.

Group Sizes and Composition

In contrast with what we expected, group sizes were similar across vegetation types and similar to others studies (Rylands 1989; Pinto 1994; Dietz and others 1994, 1996; Raboy and Dietz 2004; Guidorizzi 2008) in different vegetation types. Variation in group size may be affected by many factors. For example, Pinto (1994) suggested that human activities in unprotected areas might have caused the smaller group sizes found in his study. On the other hand, Chapman (1990) proposed that patch characteristics (e.g. size, density and distribution) may limit group size. Patch size would limit the number of individuals that could exploit such a patch, while patch density would affect group feeding efficiency, and patch distribution would affect the distance that animals must travel to find food (Chapman 1990). Spatial distribution of resources will affect path length (the distance groups must travel each day) which may also act to constrain group size (Wrangham and others 1993; Janson and Goldsmith 1995; Chapman and others 1995; Chapman and Chapman 2000). However, the results of our study did not support either hypothesis. We found no correlation between group size and degree of protection. The group sizes were similar in private reserves and productive farms. Also, despite the high availability of food resources (specifically jackfruit) found in *cabruca*, groups that lived there were no larger than those in other types of vegetation. One possible constraint on lion tamarin group size in *cabruca* is the limited number of suitable sleeping sites. As tamarins in a group sleep together, mainly in tree holes (Rylands 1989; Dietz and others 1996; Raboy and Dietz 2004), it would be necessary to have trees with DBH large enough to support large groups of tamarins. Another possible explanation is that group sizes in *cabruca* may be limited by predation, especially in *cabruca*, where predation risk is high (unp. data).

The reproductive success of lion tamarins in *cabruca* is greater than the average reported for the species in other areas. In *cabruca* groups all litters consisted of twins in every reproductive season. Reproductive female lion tamarins may produce 1–2 offspring per litter, and up to two litters per year (Dietz and others 1994; Holst and others 2006). Holst and others (2006) reported females having four offspring a year (two litters of twins) in just 8% of years, although higher values were reported by others. Dietz and others (1996) observed 13 litters (20 infants) from seven reproductive females in which 54% were twins and 46% singletons. Similarly, Bach and others (2001) reported two litters per year for only 27% of reproductive females. The high availability of food in *cabruca* may affect the number of litters and offspring produced by lion tamarins in *cabruca*, as has been shown for other species elsewhere (Epple 1970; Kirkwood 1983; Chapman and others 1990) and for lion tamarins (Kleiman 1983). The presence of groups with offspring of several consecutive litters in *cabruca*, and with similar or higher number of litters and offspring per year than in other vegetation types indicates that golden-headed lion tamarins can live and reproduce in this agroforest.

Size and Condition of the Lion Tamarins

The lion tamarins in *cabruca* were larger and heavier compared to other vegetation types. Availability and quality of food may affect primate weight and population biomass (Kirkwood 1983; Knott 1998; Brugiere and others 2002), including callitrichid primates (Epple 1970). In our study, most of the fruit consumed by lion tamarins living in *cabruca* consisted of jackfruit. These fruits are rich in carbohydrates and were available year round in *cabruca*. In addition, lion tamarins spent a large amount of time foraging for animal prey, which are sources of protein and fat, as mentioned before. Diets rich in carbohydrates and protein may result in increased weights and sizes of lion tamarins using these agroforests. Another possible explanation for the heavier weight of lion tamarins in *cabruca* may be the effect of the density of tamarins in these areas. Scheffer (1955), using data from a variety of mammal species, suggested that an increase in aggressive contact among individuals in a high density environment might result in selection for larger and stronger individuals. In our study, the heaviest and largest tamarins were in *cabruca* areas, where the density was highest. In those areas we observed frequent aggressive encounters, as expected due to higher densities of tamarins. However, we don't have enough information to address this hypothesis.

In contrast with reports by other authors (Coimbra-Filho and Mittermeier 1973; Alves 1990), we found that lion tamarins can live in *cabruca* agroforest that is not associated with native forest. If *cabruca* agroforests contain a concentrated food source, such as jackfruit, and bromeliads, lion tamarins may not only survive and reproduce but may fare better than in other forest types, at least in terms of body condition and reproduction.

Conclusion and Recommendations

Our results show that lion tamarins can live and reproduce in some types of *cabruca* agroforest, with demographic and ecological aspects apparently similar to groups that live in native forest habitats. However, *cabruca* areas, even those close to each other, vary in richness and density of overstory trees (Sambuichi and Haridasan 2007) and consequently in forest structure. Understanding how or whether lion tamarins use the range of available *cabruca* types would help to refine 1991–1993 estimates of the number of lion tamarins in the wild [6,000–15,000 (Pinto and Rylands 1997)]. *Cabruca* was not considered in this estimation, though the total area of different land cover types was not exact. The precision of population size estimates is critical in modeling estimates of species viability and in making management recommendations (Lacy 2000).

Our results highlight the importance of detailed species knowledge as a basis for developing management recommendations and certification criteria for biodiversity friendly land use systems. Conservation and appropriate management of *cabruca* agroforest can contribute to the conservation of golden-headed lion tamarins and probably to that of many other endangered species as well. We suggest that changes in management of *cabruca* would improve the conservation status of this endangered primate. At the local scale, tamarins in *cabruca* would benefit from retention or planting of tree species known to be important as sleeping sites or for foraging, and by increasing the density of these trees in *cabruca* (Oliveira and others 2010). Cacao farmers should be encouraged to cultivate organic cocoa, which brings a better price and consequently would decrease the pressure to remove cacao in favor of more profitable types of crops. Economic incentives should be given to farmers that adopt a biodiversity-friendly management of *cabruca*. This could be accomplished by creating a certification of biodiversity-friendly cacao, which also might result in a better market price. Finally, independent of any management strategy, retention of traditional *cabruca* should be favored over clear-cutting for conversion to any agricultural monocultures or to cattle pasture.

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