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Key tree species for the golden-headed lion tamarin and implications for shade-cocoa management in southern Bahia, Brazil

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Abstract

The golden-headed lion tamarin *Leontopithecus chrysomelas* occurs in the Atlantic forest of southern Bahia, Brazil, where shade-cocoa agroforestry (known as *cabruca*) predominates. The economic decline of the cocoa industry has caused many landowners to convert *cabruca* into cattle pasture or diversify their plantations with other crops. These and prior anthropogenic disturbances such as habitat fragmentation are threatening lion tamarin persistence. For some lion tamarin groups, *cabruca* comprises a large part of their home range. Considering these factors, the maintenance of the biological diversity in *cabruca* favorable to golden-headed lion tamarins is of considerable interest to their long-term survival. Here we identify plant species that provide food and sleeping sites for the lion tamarins and examine their occurrence in *cabruca* plantations, in order to investigate alternatives for conservation management practices that benefit both lion tamarins and *cabruca*. We determined the total number of trees and the frequency of individuals and species used for food and sleeping sites by lion tamarins in Una Biological Reserve, Bahia, from 1998 to 2006. We used this information to compare the richness and frequency of use across habitats (*cabruca*, mature and secondary) and to create a ranking index considering various components of a tree species' utility to the lion tamarins. Lion tamarins used 155 tree species, 93 for food and 93 for sleeping sites. Fifty-five species were ranked as 'Extremely Valuable,' eight as 'Valuable' and 92 as 'Of Interest.' Of 48 families, Myrtaceae and Sapotaceae were used the most. *Cabruca* contained fewer individual trees used by lion tamarins, but the highest frequency of use per tree compared with other habitats, indicating the large influence of single trees in these plantations. Using the key tree species identified in our study in the management of *cabruca* would be of considerable benefit to the long-term survival of lion tamarins

Introduction

The golden-headed lion tamarin *Leontopithecus chrysomelas* is endemic to the Atlantic forest of southern Bahia. It is endangered due to its restricted geographic distribution and the loss, fragmentation and degradation of its forests (Rylands, Kierulff & Pinto, 2002; IUCN, 2008). Cacao *Theobroma cacao* cultivation is the predominant rural activity in the Atlantic forest of southern Bahia, and widespread in much of the eastern part of the GHLT range (Raboy, Christman & Dietz, 2004; Fig. 1). Cacao plantations require shade, and traditionally this is provided by clearing the forest understory and thinning taller trees. This agroforestry system is called *cabruca*, and a number of studies have demonstrated its efficacy in maintaining a favorable habitat matrix for the conservation of Atlantic forest biodiversity (Alves, 1990; Rice & Greenberg, 2000; Sambuichi, 2002; Pardini, 2004; Delabie *et al*., 2007; Faria & Baumgarten, 2007; Faria *et al*., 2007; Cassano *et al*., 2009). In 1990, *cabruca* plantations comprised about 40% of the original extent of moist lowland Atlantic forest in southern Bahia, whereas only about 33% of the forest cover was intact native forest (May & Rocha, 1996).

Unfortunately, the *cabruca* plantations are themselves now threatened. A collapse in cocoa prices in the early 1980s, and the emergence of witches' broom (*Moniliophthora perniciosa*) – a fungal disease that has been devastating Bahia's cocoa crops since 1989 – have resulted in landowners diversifying their crops (e.g. coffee *Coffea canephora* and oil palm *Elaeis guianeensis*) and transforming *cabruca* into cattle

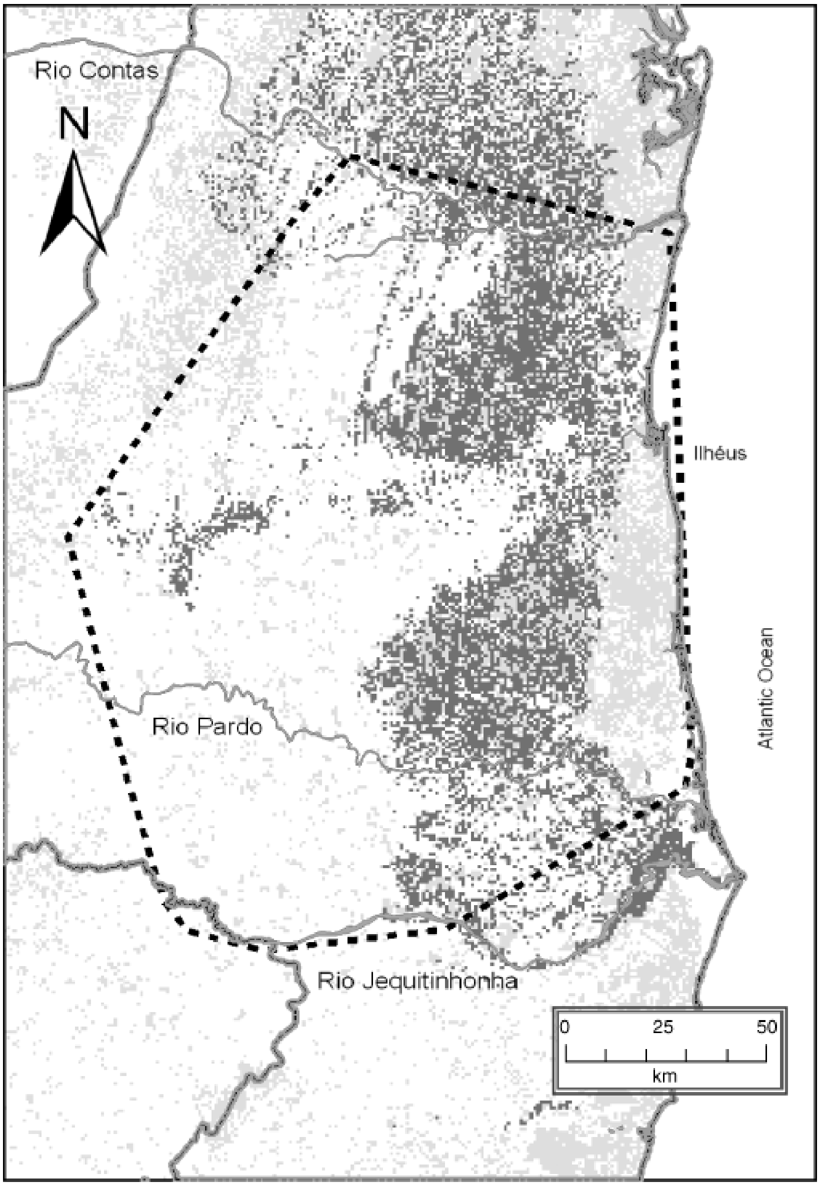

Figure 1 Geographic distribution of the golden-headed lion tamarin *Leontopithecus chrysomelas* in southern Bahia. The polygon represents the geographic range based on all published records of the species. Lighter gray areas represent areas of forest (mature or secondary); darker gray areas represent shade cocoa. This map was derived from a reclassification of Landau, Hirsch & Musinsky (2003) land cover map of southern Bahia, based on a 30 m resolution using Landsat data for 1996–1997.

pasture so as to increase revenue. Furthermore, the practice of maintaining the understory clear means that older *cabrucas* are losing their native trees due to lack of replacement following tree death (Rolim & Chiarello, 2004; Sambuichi, 2006).

Although intact primary forest has been considered indispensable for lion tamarins (Rylands, 1989, 1993, 1996), recent studies have shown that golden-headed lion tamarins are able to use degraded forests, and *cabruca* (Alves, 1990; Raboy *et al.*, 2004). Given the rapid degradation of southern Bahia's forest including *cabruca* and the endangered status of *L. chrysomelas*, a better understanding of the relationship between lion tamarin resources and the management of *cabruca* is an important conservation objective (Holst *et al.*, 2006).

In this study, we identify the tree species that provide key foods (fruit, flower, nectar, gum and animal prey) and sleeping sites (mostly tree holes) for golden-headed lion tamarins, characterize resource use across habitats and rank species according to their importance. We then examine their occurrence in the *cabruca* plantations as registered by inventories of the Executive Commission for Cacao Cultivation (*Comissão Executiva do Plano da Lavoura Cacaueira* – CEPLAC). Based on our findings, we suggest tree species and families that might be used in habitat recuperation and the creation of corridors, as well as in *cabruca* management protocols, that would favor the persistence of the lion tamarin populations in southern Bahia.

Methods

Study site

The study was carried out in the Una Biological Reserve (18 500 ha) in southern Bahia, Brazil (15°06′–12′S, 39°02′–12′W). Here, the mature and regenerating forests are broadly characterized as lowland Atlantic rainforest (Mori, 1989; Oliveira-Filho & Fontes, 2000). The annual temperatures in southern Bahia average 24–25 °C. Rainfall is aseasonal, averaging *c.* 2000 mm year^{-1} (Coimbra-Filho & Mittermeier, 1973; Mori, 1989).

Data collection

We examined the use of feeding trees (those in which the lion tamarins eat fruit, nectar, gum and flowers, and/or provided microhabitats for animal prey foraging) by three habituated groups, from March 1999 to December 2000. Records of the use of different tree species for sleeping sites were obtained in these, and an additional five groups from June 1998 to September 2006. Data were collected as part of a long-term study of wild golden-headed lion tamarins in Una Biological Reserve (Raboy & Dietz, 2004; Raboy *et al.*, 2004). The data from the eight groups were obtained from both full and partial days of observation. On full days, groups were followed from morning sleeping site to afternoon sleeping site (n = 331 days, range = 4–91 days group^{-1}). On partial days, the groups were either followed from 11:00 h until they entered their sleeping site, or from when they left their sleeping site until 13:00 h (n = 1181 days, range = 10–294 days group^{-1}). We marked each tree used for feeding or as a sleeping site, identifying them taxonomically whenever possible, and noted the habitat in which each was found (primary, secondary or *cabruca*).

Analysis

General patterns of tree use

We calculated the number of species used (overall richness) by our study groups for all resource trees and broken down by resource type (feeding and sleeping). In addition, we determined richness by family. We also calculated the total number of trees used and the total number of visits to those trees, broken down by resource type and by family.

Characterizing resource trees by habitat

For each habitat, we determined the species richness, total number of individual trees, total number of visits to those trees and the average frequency of use of each species (the total number of visits to a particular species divided by the total number of individuals visited). We used randomization tests to examine the differences between habitat types for species richness and frequency of use, running separate analyses for feeding trees and sleeping sites. For species richness, we calculated the differences between habitats for the number of species present, and then randomly reassigned trees to habitat types, keeping the number of trees found in each habitat type consistent with the original data. We calculated the differences between habitats for each randomized dataset, and ran 10 000 iterations of the randomization, counting the number of datasets that had differences more extreme (positive or negative) than the original dataset. A P-value was calculated by dividing the number of more extreme differences by 10 000. We followed the same procedure for frequency of use. Again, we constrained the number of trees classified in each habitat to match the original numbers. The P-value was calculated by determining the proportion of iterations out of 10 000 that had frequency differences more extreme than the original dataset. One sleeping tree (a *Ficus gomelleira* in secondary forest) was used 276 times during the study, an abnormally high frequency considering that the next most frequently used tree was slept in 47 times. We ran analyses with and without this *Ficus* to determine its effect on differences in the frequency of use.

We used Jaccard's coefficient of similarity (Magurran, 1988) to evaluate the similarity of the plant species' composition used by the golden-headed lion tamarins as food and/or sleeping sites in the three different habitats. The Jaccard index (J) was calculated as $J = s/(a+b-s)$, where s is the number of species shared across two habitats, a the number of species in the first habitat and b the number of species in the second.

Index of tree species' value

We used four criteria to create a numerical index of the relative value of each tree species for the lion tamarins:

(1) *Versatility of function* (*maximum of six points*): We reasoned that tree species providing both sleeping sites and food are of greater value to the lion tamarins than those used for only one purpose. Each species received three points for each type of use (sleeping or food).

(2) *Attractiveness* (*maximum of six points*): The more the groups using a particular species, the greater our confidence that it would be used broadly by the lion tamarins. Food and sleeping trees were assessed separately because the number of groups observed for each differed. For food trees, we assigned one point for each of the three groups using a species (maximum of three points). For sleeping sites, we added one point if one or two of the eight study groups used the tree species. If three groups used the species, it received two points. If four or more groups used the species, it received three points.

(3) *Prevalence in habitats* (*maximum of three points*): The number of habitats in which a plant species used by the lion tamarins is found is another indication of its availability and importance as a resource. Each species received one point for each of the three habitat types where it could be found.

(4) *Availability and use patterns* (*maximum of nine points*): We reasoned that common and frequently used tree species are more valuable to tamarins than scarce and infrequently

used species. We therefore assigned an availability and use score based on three variables: the number of individuals of each species, the number of visits per species and the frequency of use for each tree species as defined above. Specifically, we calculated the mean and standard error of the mean (SEM) for each variable and assigned one point when values were below the mean–SEM, two points when values were between the mean $\pm$ SEM and three points when the values were above the mean + SEM.

Final ranking: Based on these four criteria, the maximum score for any one species was 23. We summed the points for each species and analyzed the resulting totals following the same methods outlined for criterion 4 (availability and use), categorizing scores in relation to the overall mean and SEM. We considered a species receiving a final category of 3 as 'Extremely Valuable,' 2 as 'Valuable' and 1 as 'Of Interest' for the lion tamarins. Collectively, we refer to the species in these categories as 'key.'

Comparison of key trees for lion tamarins and common shade trees

We compared data on the occurrence of trees commonly retained to provide shade in *cabruca* (CEPLAC, 1982) with our list of the key species for the lion tamarins. We calculated the per cent of species common to both lists and listed the 'Extremely Valuable' species that did or did not appear on CEPLAC's list of common *cabruca* shade trees.

Results

General patterns of tree use

The lion tamarins used 155 tree species in 49 families: 93 species for feeding (Table 1) and 93 as sleeping sites (Table 2). These totals were derived from 888 individual food trees used 1533 times, and 349 sleeping site trees used 1702 times. We were unable to identify the species of 47 of the trees. A number of unidentified species in two families Myrtaceae and Bromeliaceae were grouped into three functional units as follows: Myrtaceae gr. 'araça', Myrtaceae gr. 'murta' and Bromeliaceae gr. '*Aechmea*' (hereafter referred to as *Aechmea* spp.). From the species used for feeding, 94% were used for fruit, 5% for nectar and 1% for gum. Bromeliads were used not only for fruit but also for animal prey foraging sites.

Table 1 Characteristics of plant resource use by habitat

Habitat	No. of species	Individual trees	No. of visits	Frequency
Mature forest	44	373	675	1.79
Cabruca	42	213	393	1.84
Secondary forest	31	303	466	1.52
Total	93	888	1533	1.71

Variables include the number of species, number of individual trees, number of total visits by lion tamarins to those trees and the average frequency of use of each species by three study groups.

Table 2 Characteristics of sleeping-site resource use by habitat

Habitat	No. of species	Individual trees	No. of visits	Frequency
Mature forest	72	179	603	3.50
Cabruca	34	60	455	7.58
Secondary forest	20	110 (109)	621 (345)	5.64 (3.2)
Total	93	349 (348)	1702 (1435)	4.88 (4.11)

Variables include the number of species, number of individual trees, number of total visits by lion tamarins to those trees and the average frequency of use of each species by eight study groups. Numbers in parentheses are results of the analysis excluding one individual tree (OG50) that was used 276 times.

Myrtaceae and Sapotaceae were the families with the greatest number of species (28 and 16, respectively) used by the lion tamarins. Twenty species of Myrtaceae and 13 of Sapotaceae were used for feeding and 13 Myrtaceae species and nine Sapotaceae species were used as sleeping sites. These two families also accounted for the highest numbers of individual trees used by the lion tamarins (171 and 179, respectively) and the highest numbers of total visits (347 and 400, respectively).

Resource trees by habitat: feeding

We obtained habitat information for 73 of the 93 species used for feeding. Based on Jaccard's index, there was a 47% similarity of food tree species between *cabruca* and primary forest, 36.5% between *cabruca* and secondary forest and 39% between secondary and primary forest. Twenty species were present in all three habitats. Overall, bromeliads (*Aechmea* spp.), *Henriettea succosa* and *Miconia mirabilis* were the taxa providing the greatest number of individuals used for food. In primary forest, *Aechmea* spp. were the most abundant species used ($n = 44$), and *Anthodiscus amazonicus* was the species used most frequently (mean = 3.4 visits individual tree^{-1}). *Aechmea* bromeliads were also the most abundant species used for food in *cabruca* ($n = 33$), and *Diploon cuspidatum* was the species used most frequently (mean = 2.4 visits individual tree^{-1}). In secondary forest, *H. succosa* was the species with the greatest number of individuals used ($n = 61$), and *Artocarpus heterophyllus* was the species used most frequently (mean = 2.4 visits individual^{-1}).

There was no significant difference in the species richness in *cabruca* versus primary forest (difference = 3, $P = 0.98$) nor in *cabruca* versus secondary forest (difference = 10, $P = 0.074$). The lion tamarins used significantly more species of food trees in primary forest, however, than in secondary forest (difference = 13, $P = 0.038$). We found no significant difference in the frequency of use between trees in primary forest and those in *cabruca* (difference = 0.05, $P = 0.44$). Secondary forest, however, had a significantly lower average frequency of use per tree than was found for primary forest (difference = 0.29, $P = 0.001$) or *cabruca* (difference = 0.32, $P = 0.003$).

Resource trees by habitat: sleeping sites

Of the 93 tree species used by the lion tamarins as sleeping sites, we have habitat information for 84. Based on Jaccard's index, we found a 31.6% similarity of tree species used for sleeping sites between *cabruca* and primary forest, 21.0% between *cabruca* and secondary forest and 16.4%, between secondary and primary forest. In contrast to results for food species, we found just eight species that were used as sleeping sites in all three habitats. Three were among the most commonly used by the lion tamarins in general: *E. guianeensis*, *Guapira opposita* and *Manilkara maxima* (Table 3). *Rinorea guianensis* was the species most commonly used in primary forest ($n = 15$) while *G. opposita* was used most frequently ($n = 62$, mean = 5.4 visits tree^{-1}). In *cabruca*, *G. opposita* was the species with the most trees used by the lion tamarins (10 trees), and also the most frequently used 103 times (mean = 10.3 visits tree^{-1}). In secondary forest, *E. guianeensis* was the most commonly used species ($n = 87$ trees), and the most frequently used (231 times; mean-2.65 visits tree^{-1}).

There was no significant difference in the number of species used between *cabruca* and primary (difference = 38, $P = 0.10$) or secondary forest (difference = 14, $P = 0.57$). Despite this, the individual trees in *cabruca* were, on average, used more frequently than the individual trees in either primary forest (difference = 4.08, $P < 0.001$) or secondary forest (difference = 4.38, $P < 0.001$). There was no significant difference between primary and secondary forest in the average frequency of use of individual trees (difference = 0.30, $P = 0.84$), but more species were used in primary forest (difference = 52, $P < 0.001$).

Index of key tree species

The three grouped taxonomic units and a further 55 plant species were ranked as 'Extremely Valuable' for the golden-headed lion tamarins (overall score of 3). Eight species were ranked as 'Valuable' (score of 2), and the remaining 92 species were ranked as 'Of Interest' (score of 1) (Table 3).

Comparison of key trees for lion tamarins and common shade trees

CEPLAC's (1982) list of shade-tree species commonly found in *cabrucas* in southern Bahia totaled 144. Thirty-three per cent (48 either just genus and or species) were also registered in our study as being used by lion tamarins for feeding or as sleeping sites. Only 15 of the 55 species ranked as 'Extremely Valuable' for the lion tamarins were on the *cabruca* shade-tree list. Members of the Myrtaceae, the family most exploited by lion tamarins for food and sleeping sites in our study, were entirely absent from the *cabruca* shade-tree list.

Discussion

The number of species exploited for food by the three golden-headed lion tamarin groups in Una was higher than previously recorded for any lion tamarin study (Rylands, 1993; Valladares-Pádua, 1993; Dietz, Peres & Pinder, 1997; Passos, 1999; Lapenta *et al.*, 2003). This undoubtedly reflects the extraordinary diversity of tree species in the region (Thomas *et al.*, 1998). Amorim *et al.* (2008) reported 947 flowering plant species in Una Biological Reserve, and more recent inventories have increased this number to around 1200 (A. M. Amorim, pers. comm.).

In our study, the most-used species for both food and sleeping sites by the lion tamarins belonged to the Sapotaceae and Myrtaceae families. Southern Bahia has a high diversity of Sapotaceae and Myrtaceae (Mori, Carvalho & Santos, 1983; Martini *et al.*, 2007), with the latter being dominant in many wet forests in terms of both the number of species and the number of individuals (Mori *et al.*, 1983; Martini *et al.*, 2007). Therefore, the large number of species used by the golden-headed lion tamarins from these two families may be explained by preference and/or availability, but regardless, indicates the importance of these families as providing key resources for the lion tamarins.

When factoring the predominance of *cabruca* throughout the range of the golden-headed lion tamarin (Fig. 1) with findings indicating its usefulness to lion tamarins (Alves, 1990; Raboy *et al.*, 2004; present study) and the endangered status of the species, we suggest that the *cabruca* agroforest has an important role in the survival of this primate in the long term. Lion tamarins not only foraged and slept in *cabruca*, but the richness of the food and sleeping-site resources used by lion tamarins in *cabruca* was similar to that found in other habitats. However, the similarity index between primary forest and *cabruca*, the habitats that had more species in common, did not exceed 50% for either food or sleeping sites.

One of our key findings was that single trees in *cabruca* can have a significant influence on the lion tamarins' patterns of resource use. Single trees were used more frequently in this habitat (sleeping sites in particular). Other researchers have documented fewer species and individuals, and a lower density of trees overall, in *cabruca* when compared with mature forest (Sambuichi, 2002, 2006), and individual trees, therefore, may be used heavily by the lion tamarins out of necessity. Increased predation may be one of the costs of repeated use, especially in cases where predators have the capacity to learn the location of sleeping sites, as has been indicated previously for lion tamarins (Franklin *et al.*, 2007).

Despite the fact that all habitats had similar levels of plant resource richness used by the lion tamarins, the species in each habitat were dissimilar. Only 16.5% of the species exploited were found in all three habitats. Large variations in the number of individuals per species across habitats may indicate habitat-specific adaptations of the use of different plant species. For example, of 84 *E. guianeensis* individuals, only one occurred in *cabruca* and one in primary forest, the remainder occurring in secondary forest. The golden-headed lion tamarin's use of tree species found in some habitats but

Table 3 Species used for food and sleeping sites by golden-headed lion tamarins *Leontopithecus chrysomelas* at Una Biological Reserve

Species	Family	Use	Hab	SC	Cat
Myrtaceae gr. murta[a]	Myrtaceae	F; SS	C, S, P	23	3
Manilkara maxima Penn.	Sapotaceae	N; SS	C, S, P	22	3
Rinorea guianensis Aubl.	Violaceae	F; SS	C, S, P	22	3
Ficus gomelleira Kunth & Bouché	Moraceae	F; SS	C, S, P	22	3
Guapira opposita (Vell.) Reitz	Nyctaginaceae	F; SS	C, P	21	3
Elaeis guianeensis Jacq.	Arecaceae	F; SS	C, S, P	21	3
Myrcia rostrata Berg.	Myrtaceae	F; SS	C, S, P	20	3
Tapirira guianensis Aubl.	Anacardiaceae	F; SS	C, S, P	20	3
Myrtaceae gr. araça[a]	Myrtaceae	F; SS	C, S, P	20	3
Inga nutans Mart.	Fabaceae	F; SS	C, S, P	20	3
Diplöon cuspidatum (Hoehne) Cronquist	Sapotaceae	F; SS	C, P	19	3
Symphonia globulifera L.	Clusiaceae	N; SS	S, P	19	3
Musa paradisiaca L.	Musaceae	F	C, S, P	18	3
Artocarpus heterophyllus Lamark	Moraceae	F; SS	S	17	3
Ocotea nitida (meissn.) Rohwer	Lauraceae	F; SS	P	17	3
Terminalia dichotoma G. Mey.	Combretaceae	SS	C, P	17	3
Pourouma velutina Miquel	Moraceae	F	C, S, P	16	3
Pourouma guianensis Aubl.	Moraceae	F	C, S, P	16	3
Micropholis guianensis (DC.) Pierre	Sapotaceae	F	C, S, P	16	3
Miconia mirabilis (Aubl.) L. Wms.	Melastomataceae	F	C, S, P	16	3
Henriettea succosa (Aubl.) DC.	Melastomataceae	F	C, S, P	16	3
Guatteria sp.1	Annonaceae	SS	C, S, P	16	3
Anthodiscus amazonicus GL & SM	Caryocaraceae	F	C, S, P	16	3
Aechmea sp.[a]	Bromeliaceae	F	C, S, P	16	3
Eschweilera ovata (Cambess.) Miers	Lecythidaceae	SS	C, P	16	3
Manilkara logifolia (DC.) Duband	Sapotaceae	N; SS	S, P	16	3
Hydrogaster trinerve Kuhlm.	Malvaceae	F; SS	C, P	15	3
Tibouchina elegans (Gardn.) Cogn.	Melastomataceae	SS	C, S, P	15	3
Rheedia macrophylla Mart.	Clusiaceae	F; SS	C, P	15	3
Licania sp.	Chrysobalanaceae	F; SS	C, P	15	3
Compamanesia guaviroba (DC.) Kiarer	Myrtaceae	F	C, S, P	15	3
Dialium guianense (Aubl.) Sandw.	Fabaceae	F; SS	S	15	3
Tocoyena bullata (Vell.) Mart.	Rubiaceae	SS	C, P	15	3
Manilkara sp.	Sapotaceae	N	C, P	15	3
Manilkara salzmannii (A. DC.) Lam.	Sapotaceae	F; SS	C, P	14	3
Psidium cattleyanum Sabine	Myrtaceae	F; SS	C, P	14	3
Chrysophyllum splendens Spreng.	Sapotaceae	F; SS	C, P	14	3
Philodendron willianisii S.D. Hooker	Araceae	F	C, S, P	14	3
Miconia sp.	Melastomataceae	F	C, S, P	14	3
Chrysophyllum sp.	Sapotaceae	F; SS	P	14	3
Emmotum nitens (Benth.) Miers	Icacinaceae	SS	C, P	14	3
Hortia arborea Engl.	Rutaceae	F; SS	P	13	3
Parkia pendula (Willd.) Benth.	Fabaceae	G; SS	C, P	13	3
Virola gardneri (A. DC.) Warb.	Myristicaceae	SS	C, P	13	3
Lacmellea aculeate (Ducke) Monach	Apocynaceae	F	S, P	13	3
Pradosia bahiensis Teixeira	Sapotaceae	F	C	13	3
Eugenia rostrata O. Berg	Myrtaceae	F; SS	P	13	3
Macrolobium latifolium Vog.	Fabaceae	F; SS	P	13	3
Gomidesia langsdorffii O. Berg.	Myrtaceae	SS	C, S, P	13	3
Diplotropis purpurea (L.C. Rich) Amshoff	Fabaceae	SS	P	13	3
Lecythis pisonis Cambess.	Lecythidaceae	SS	C, P	12	3
Sclerolobium densiflora Benth.	Fabaceae	SS	C, S, P	12	3
Protium heptaphyllum (Aubl.) Marchand	Burseraceae	F; SS	C	12	3
Passiflora quadrangularis L.	Passifloraceae	F	C, S	12	3
Compomanesia guazumifolia (Camb) O. Berg	Myrtaceae	SS	S	12	3
Pradosia lactescens (Vell.) Radlk.	Sapotaceae	SS	C, P	12	3
Couepia sp.	Chrysobalanaceae	SS	C	12	3
Albizia polycephalum (Benth) Killip ex Rec	Fabaceae	SS	S	12	3

Table 3. Continued.

Species	Family	Use	Hab	SC	Cat
Hyeromina alchorneoides Allemao	Euphorbiaceae	SS	C, S, P	11	2
Humiria balsamifera (Aubl.) J. St.-Hil.	Humiriaceae	SS	C, P	11	2
Rheedia sp.	Clusiaceae	F	C, P	11	2
Passiflora sp.	Passifloraceae	F	C, S, P	11	2
Lecythis lurida (Miers) Mori	Lecythidaceae	SS	P	11	2
Eriotheca sp.	Malvaceae	SS	P	11	2
Licania hypoleuca Benth.	Chrysobalanaceae	SS	C	11	2
Inga edulis Mart.	Fabaceae	F	S	11	2
Himatanthus bractethus (Vahl) Woodson	Apocynaceae	SS	C, P	10	1
Byrsonima laevigata (Poir) DC.	Malpighiaceae	F	C,P	10	1
Nectandra sp.1	Lauraceae	SS	C, P	10	1
Randia armata (Sw.) DC.	Rubiaceae	SS	P	10	1
Pterodon emarginatus Vogel	Fabaceae	SS	P	10	1
Pterocarpus rhorii Vahl	Fabaceae	SS	P	10	1
Pouteria reticulata (Eichler) Eyma	Sapotaceae	SS	P	10	1
Parinari littoralis Prance	Chrysobalanaceae	SS	C	10	1
Myrcia thyrsoidea Berg.	Myrtaceae	F	P	10	1
Buchenavia grandis Ducke	Combretaceae	SS	C	10	1
Andira anthelmia (Vell.) J. F. Macbr.	Fabaceae	SS	P	10	1
Aegiphila sellowiana Cham.	Verbenaceae	SS	C	10	1
Aspidosperma polyneuron Muell. Arg.	Apocynaceae	SS	S, P	10	1
Terminalia brasiliensis (Camb. Ex A. St-Hil) Eichl.	Combretaceae	SS	P	10	1
Ficus insipida Willd.	Moraceae	SS	P	10	1
Attalea funifera Martius	Arecaceae	SS	S	10	1
Duguetia magnolioidea Maas	Annonaceae	F	C, S	9	1
Trichilia quadrijuga H.B.K.	Meliaceae	F	C, P	9	1
Psidium guajava L.	Myrtaceae	F	S,P	9	1
Tachigali multijuga Benth.	Fabaceae	SS	P	9	1
Miconia rimalis Naudin	Melastomataceae	F	P	9	1
Balizia pedicellaris (DC) Barneby & J. W. Grimes	Fabaceae	SS	P	9	1
Arapatiella psilophylla (Harms) R. S. Cowan	Fabaceae	SS	P	9	1
Tetrastylidium brasiliense Engl.	Olacaceae	SS	P	8	1
Eugenia mandioccencis Berg.	Myrtaceae	F	P	8	1
Maytenus sp.	Celastraceae	SS	P	8	1
Nectandra sp.	Lauraceae	F	C	8	1
Virola oficinalis (Mart.) Warb.	Myristicaceae	SS	C	8	1
Trichilia magnifoliola T. D. Penn.	Meliaceae	F	C	8	1
Tovomita sp.	Clusiaceae	SS	P	8	1
Stachyarrhena harleyi Kirk.	Rubiaceae	F	P	8	1
Sloanea sp.	Elaeocarpaceae	SS	P	8	1
Senefeldera multiflora (Mart.) Muell. Arg.	Euphorbiaceae	SS	P	8	1
Schoepfia cf. *obliquifolia* Turcz.	Olacaceae	F	P	8	1
Pouteria grandiflora (A. DC.) Baehni	Sapotaceae	SS	P	8	1
Pouteria bangii (Rusby) Penn.	Sapotaceae	F	P	8	1
Pogonophora schomburgkiana Miers ex Benth.	Euphorbiaceae	SS	P	8	1
Plinia sp.	Myrtaceae	SS	P	8	1
Peltogyne angustiflora Ducke	Fabaceae	SS	P	8	1
Ocotea sp.	Lauraceae	SS	C	8	1
Nectandra sp.2	Lauraceae	SS	P	8	1
Myrcia sp.1	Myrtaceae	SS	P	8	1
Myrcia sp.	Myrtaceae	SS	P	8	1
Micropholis venulosa (Mart. & Eichl.) Pier	Sapotaceae	F	C	8	1
Miconia hypoleuca (Benth.) Triana	Melastomataceae	F	P	8	1
Manilkara rufula (Miquel) Lam.	Sapotaceae	N	P	8	1
Mabea piriri Aubl.	Euphorbiaceae	F	C	8	1
Inga thibaudiana DC.	Fabaceae	F	C	8	1
Inga affinis Benth.	Fabaceae	F	C	8	1
Hymenaea coubaril L.	Fabaceae	SS	P	8	1

Table 3. Continued.

Species	Family	Use	Hab	SC	Cat
Guettarda platyphylla Muell. Arg.	Rubiaceae	F	P	8	1
Eugenia sp.	Myrtaceae	SS	P	8	1
Combretum sp.	Combretaceae	SS	P	8	1
Calyptanthes brasiliensis Spreng.	Myrtaceae	SS	P	8	1
Brosimum rubescens Taub.	Moraceae	F	P	8	1
Brosimum guianense (Aubl.) Huber	Moraceae	SS	P	8	1
Annona salzmannii A. DC.	Annonaceae	F	C	8	1
Couepia grandiflora (Mart. & Zuc.) Ben. Ex Hook.	Chrysobalanaceae	SS	P	8	1
Trichilia pleena (A. Juss.) C. CD.	Meliaceae	SS	P	8	1
Terminalia sp.	Combretaceae	SS	P	8	1
Theobroma cacao L.	Sterculiaceae	F	C	8	1
Talisia elephantipes Sandw	Sapindaceae	F		8	1
Syzygium jambos (L.) Alston	Myrtaceae	F		8	1
Sprucella crassipedicellata (Mart. & Endl.) Pires	Sapotaceae	F		8	1
Simarouba amara Aubl.	Simaroubaceae	F	S	8	1
Ocote insignis Mes	Lauraceae	SS	S	8	1
Neomitranthes sp.	Myrtaceae	F		8	1
Neea floribunda Poepp. & Endl.	Nyctaginaceae	F	S	8	1
Myrciaria sp.	Myrtaceae	F		8	1
Myrcia cf. *bergiana* Berg.	Myrtaceae	F		8	1
Myrcia cauliflora (C. Mart.) O. Berg.	Myrtaceae	F		8	1
Myrcia acuminatissima Berg.	Myrtaceae	F		8	1
Mendoncia blanchetiana Prof.	Mendonciaceae	F		8	1
Marlierea obversa Legrand	Myrtaceae	F		8	1
Marlierea cf. *claussemiana* (Gardner) Kiaerskou	Myrtaceae	F		8	1
Macoubea guianensis Aublet	Apocynaceae	F		8	1
Gurania sp.	Cucurbitaceae	F		8	1
Guapira cf. *obtusata* (Jacq.) Little	Nyctaginaceae	F	S	8	1
Gomidesia sp.	Myrtaceae	F		8	1
Ficus sp. 1	Moraceae	F	S	8	1
Ficus sp.	Moraceae	F	S	8	1
Eugenia sp. 1	Myrtaceae	F		8	1
Eugenia cerasiflora Miquel	Myrtaceae	F		8	1
Dyopyros cf. *miltonii* P. Cavalcante	Ebenaceae	F		8	1
Croton macrobotrys Baill.	Euphorbiaceae	F		8	1
Cordia magnoliaefolia Cham.	Boraginaceae	F		8	1
Coccoloba sp.	Polygonaceae	F		8	1
Bowdichia virgilioides Kunth	Fabaceae	SS		8	1
Guarea macrophylla Vahl	Meliaceae	SS		8	1
Margaritaria nobilis L. f.	Euphorbiaceae	SS		8	1
Myrcia falax (Rich.) DC.	Myrtaceae	SS		8	1
Tabebuia obtusifolia (Cham.) Bureau	Bignoniaceae	SS		8	1

[a]Indicate cases where more than one species in a family were used by lion tamarins but not identifiable to the species level. We grouped these as one taxonomic unit for the analyses.

Hab, habitat; Cat, overall importance ranking category; SC, score; SS, sleeping site; F, fruit; N, nectar; G, gum; P, primary forest; C, *cabruca* agroforest; S, secondary forest.

not others supports prior suggestions that the lion tamarins may thrive in habitat mosaics of varied composition (Raboy *et al.*, 2004), as long as necessary resources can be found in them.

Recommendations for conservation

We suggest that conservation measures on behalf of golden-headed lion tamarins in southern Bahia include the cultivation and conservation of the 55 resource trees that we have ranked as ‘Extremely Valuable.’ Most of these served both for food and sleeping sites, were available in multiple habitats and were used frequently. Additionally, individual trees (regardless of species) supporting large bromeliads should be retained wherever possible (Coimbra-Filho & Mittermeier, 1973; Rylands, 1989, 1993). Epiphytic bromeliads are an extremely important animal prey foraging site, and also supply fruits and sleeping sites for lion tamarins (Dietz *et al.*, 1997; Prado, 1999; Raboy *et al.*, 2004).

The low congruence between our list of key golden-headed lion tamarin species and those commonly left standing as shade trees for cocoa plantations in southern Bahia is a concern, especially given the complete lack of Myrtaceae as a preferred shade tree. The plant families most frequently encountered in *cabruca* in southern Bahia were Anacardiaceae, Moraceae, Fabaceae, Caesalpiniaceae, Mimosaceae, Lecythidaceae, Euphorbiaceae, Lauraceae, Meliaceae and Annonaceae (Sambuichi & Haridasan, 2007). Myrtaceae and Sapotaceae, the families most widely exploited by golden-headed lion tamarins in our study, are less commonly found in *cabruca*. Managers gradually replace trees of these families with exotic species supplying commercial fruit crops. Moreover, native tree seedlings of these families are slow growing and are consequently easily eliminated during periodic clearance of undergrowth (Sambuichi & Haridasan, 2007).

A number of *cabruca* management practices can be identified that would improve the suitability of *cabruca* for lion tamarins. The first is the selective retention of key species listed in this study (those that provide food and sleeping sites to GHLTs) to serve as shade trees in *cabruca*. Promoting the permanence of Myrtaceae and Sapotaceae species in *cabruca* would be particularly favorable to the lion tamarins. The second is increasing the overall density of trees in *cabruca*, again favoring the cultivation of those known to be propitious for lion tamarins. Increasing tree density will also support greater local diversity and act as an effective refuge for many tropical forest organisms (Rice & Greenberg, 2000; Williams-Guillén *et al*., 2006; Delabie *et al*., 2007; Vaughan *et al*., 2007). These aforementioned actions require oversight when choosing the trees to be felled, selecting saplings for retention and in planting and fostering the successful growth of particular species.

Economic incentives to plant and protect such ‘eco-friendly’ trees may be necessary (Acharya, 2006; Ashley, Russell & Swallow, 2006), given that agronomic recommendations for *cabruca* management tend toward decreasing rather than increasing plant density (Johns, 1999) and prioritizing profits to the detriment of sustainability (Sambuichi & Haridasan, 2007). Critical to the implementation of such measures is to promote an increased public awareness of the potential of *cabruca* to protect southern Bahia biodiversity.

We provide a template for using science-based findings on an endangered species as a way to guide agroforestry management choices. Our methods of ascertaining tree importance offer increased practical application for habitat conservation and recuperation by identifying the relative importance of plant resource species to a focal animal species based on a series of factors in relation to their use and function. *Cabruca* has a long history in southern Bahia, and in the face of the current crises including low cocoa prices and fungal disease, this agroforestry system is now undergoing much scrutiny and reform. Examples include assessment of tree spacing, examining solutions for natural tree death and of the use of commercially valuable exotics. In parallel with these efforts to improve the economic return from *cabruca*, we emphasize that management options exist to promote the persistence of endangered species.

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