Biodivers Conserv (2009) 18:577–603
DOI 10.1007/s10531-008-9526-x

ORIGINAL PAPER

Landscape and farm scale management to enhance biodiversity conservation in the cocoa producing region of southern Bahia, Brazil

Camila R. Cassano · Götz Schroth · Deborah Faria · Jacques H. C. Delabie · Lucio Bede

Received: 7 June 2008 / Accepted: 14 November 2008 / Published online: 11 December 2008

Abstract In southern Bahia, Brazil, large land areas are used for the production of cocoa (*Theobroma cacao*), which is predominantly grown under the shade of native trees in an agroforestry system locally known as *cabruca*. As a dominant forest-like landscape element of the cocoa region, the *cabrucas* play an important role in the conservation of the region's biodiversity. The purpose of this review is to provide the scientific basis for an action plan to reconcile cocoa production and biodiversity conservation in southern Bahia. The available research collectively highlights the diversity of responses of different species and biological groups to both the habitat quality of the *cabrucas* themselves and to the general characteristics of the landscape, such as the relative extent and spatial configuration of different vegetation types within the landscape mosaic. We identify factors that influence directly or indirectly the occurrence of native species in the *cabrucas* and the

C. R. Cassano
Instituto de Estudos Socioambientais do Sul da Bahia (IESB), Rua Major Homem Del Rey 147, Ilhéus, Bahia 45652-180, Brazil

C. R. Cassano
Departamento de Ecologia, Universidade de São Paulo (USP), Rua do Matão, Travessa 14, no 101, 05508-090 Sao Paulo, SP, Brazil

G. Schroth (✉)
Conservation International, 2011 Crystal Drive, Suite 500, Arlington, VA 22202, USA
e-mail: g.schroth@conservation.org

D. Faria
Departamento de Ciências Biológicas, Universidade Estadual de Santa Cruz (UESC), Rodovia Ilhéus-Itabuna km 16, Ilhéus, Bahia 45650-000, Brazil

J. H. C. Delabie
Laboratório de Mirmecologia, Convênio UESC/CEPLAC, Centro de Pesquisas do Cacau, C.P. 07, Itabuna, Bahia 45600-000, Brazil

L. Bede
Conservação Internacional, Avenida Getúlio Vargas 1300, 70 andar, Belo Horizonte, Minas Gerais 30112-021, Brazil

wider landscape of the cocoa region and develop recommendations for their conservation management. We show that the current scientific knowledge already provides a good basis for a biodiversity friendly management of the cocoa region of southern Bahia, although more work is needed to refine some management recommendations, especially on shade canopy composition and density, and verify their economic viability. The implementation of our recommendations should be accompanied by appropriate biological and socioeconomic monitoring and the findings should inform a broad program of adaptive management of the *cabrucas* and the wider cocoa landscape.

Keywords Atlantic forest · Biodiversity · *Cabruca* · Cocoa agroforest · Connectivity · Fragmentation · Landscape management · *Theobroma cacao*

Introduction

In the face of high rates of tropical forest loss, agroforestry based development models have been proposed as a strategy to conserve natural resources in the tropics (Izac and Sanchez 2001; Schroth et al. 2004). The cocoa tree (*Theobroma cacao* L., Malvaceae) is traditionally planted in several tropical regions under a native tree canopy after thinning the original forest (Rice and Greenberg 2000; Ruf and Schroth 2004). Cocoa plantations shaded by native trees are reportedly among the agroforestry practices with greatest potential to reconcile agricultural development and biodiversity conservation (Rice and Greenberg 2000; Schroth et al. 2004; Schroth and Harvey 2007). This is particularly relevant in southern Bahia, Brazil's main cocoa production region. Together with the northern part of the state of Espírito Santo, this region forms a center of species endemism within the Atlantic forest biome, where co-generic species from the Amazon forest and from the southern Atlantic forest are found (Brown 1982; Thomas et al. 1998). The region is exceptional for its biodiversity, and in a recent comparison of tree diversity in 22 tropical forests around the world, a forest remnant in southern Bahia was the second richest site (Martini et al. 2007). Tree endemism can exceed 25% (Thomas et al. 1998). The region also harbors several endemic species of mammals, birds (Bencke et al. 2006) and ants (Delabie et al. 1998; Lacau et al. 2004). However, a recent study estimated that only 6.5% of old growth forest remains in southern Bahia, with few remnants larger than 1,000 ha (Landau 2003).

The cocoa region of southern Bahia is defined here as the area between the Contas and Jequitinhonha Rivers (Fig. 1). Cocoa cultivation began here in the eighteenth century and peaked in the 1960s and 1970s. Over the following decades, the government's Executive Commission of the Cocoa Production Plan (CEPLAC) recommended establishing cocoa plantations by felling all native trees followed by planting cocoa seedlings together with bananas and erythrinas (*Erythrina fusca*—an exotic legume with no economic value) as shade trees. However, the lower cost of establishing cocoa groves in the traditional system—partial thinning of the forest and its under-planting with cocoa trees—resulted in the formation of extensive agroforests, known as *cabrucas* (Alger and Caldas 1994; Johns 1999) (Fig. 2). According to Sambuichi (2006), native tree density in *cabrucas* ranges from 35 to 173 trees per hectare and reaches 355 trees per hectare in abandoned plantations with their vigorous regeneration especially of pioneer species.

In the late 1980s, cocoa cultivation in Bahia entered into a period of decline triggered by falling international cocoa prices and the spread from the Amazon into Bahia of the fungus *Moniliophthora perniciosa*, causal agent of the "witches' broom" disease. The loss of

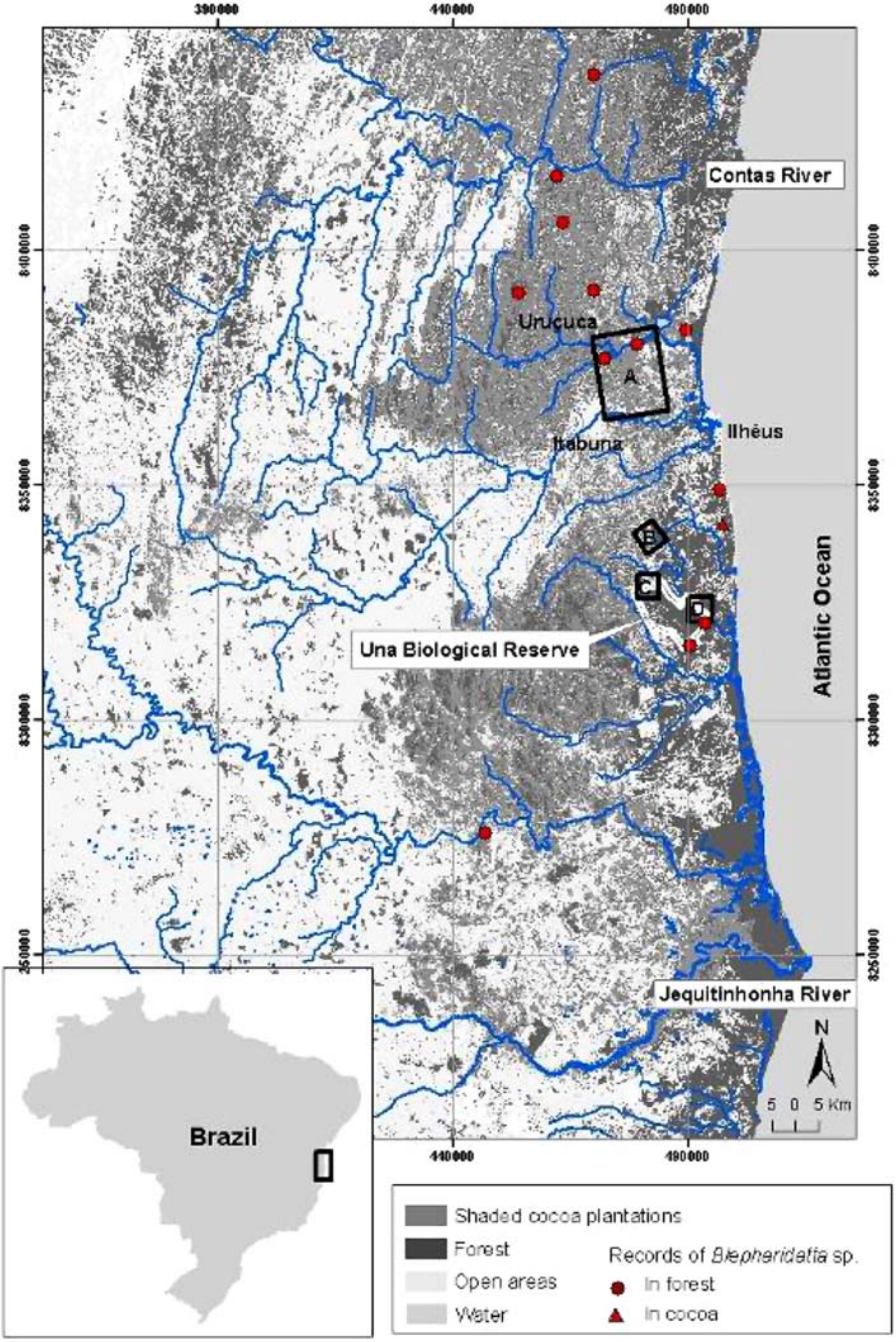


Fig. 1 The cocoa region of southern Bahia, Brazil, delimited by the Rio Contas and Rio Jequitinhonha, with the location of two landscapes with low forest cover (Ilhéus—A) and high forest cover (Una—B, C and D) where the biodiversity of *cabrucas* and forests was studied. The symbols refer to sampling locations of the endemic ant species, *Blepharidatta* sp. n (modified after Landau et al. 2003)

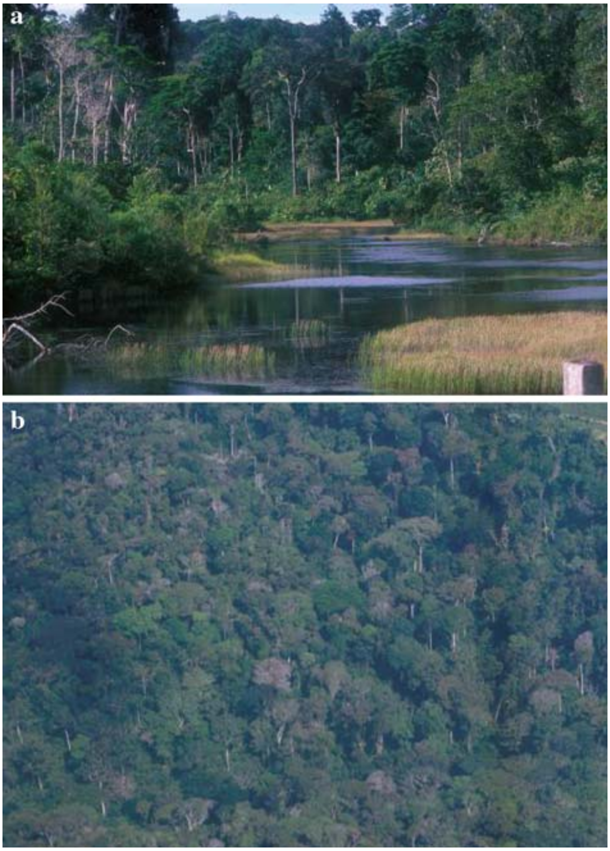


Fig. 2 Traditional cabrucas of southern Bahia, Brazil, retain much of the original forest structure. **a** *Cabruca* in the county of Una; **b** Aerial view of a *cabruca* in the same region (Photos by G. Accacio, with permission)

cocoa income led many growers to sell off their shade trees for timber (Alger and Caldas 1994; Araujo et al. 2007), while others abandoned their plantations. However, cocoa farms still occupy approximately 6,000 km^2 in southern Bahia (Landau 2003), many of which are abandoned or very extensively managed. Current recommendations by CEPLAC on techniques to rehabilitate cocoa plantations include the grafting of witches' broom resistant cocoa varieties on diseased trees and the replacement of the erythrina shade trees with rubber trees (*Hevea brasiliensis*) in order to increase and diversify farm income (Marques and Monteiro 2006).

Research in southern Bahia and other cocoa producing regions, especially Central America and parts of Africa, has shown that a significant part of the extant native flora and fauna can be conserved in traditional cocoa agroforestry systems (e.g., Rice and Greenberg 2000; Delabie et al. 2007; Faria et al. 2007; Schroth and Harvey 2007). For example, traditional cocoa agroforests with diversified native shade trees were shown to harbor a richer bird, bat and dung beetle fauna than plantain monocultures in Costa Rica (Harvey et al. 2006; Harvey and Villalobos 2007) and a richer ant fauna than pasture in Bahia (Delabie et al. 1999). However, these studies have also demonstrated that the contribution of cocoa agro-ecosystems to the conservation of biodiversity is dependent on their structure, composition and management, as well as on the quantity, quality and location of remnants of native forest habitat in the landscape (Schroth and Harvey 2007). Furthermore, there is considerable variation between species groups of conservation concern in Bahia with regard to their ability to utilize shaded cocoa plantations as habitat and to persist in the wider *cabruca* landscape (e.g., Alves 1990; Pardini 2004; Faria et al. 2007). Understanding how different elements of the local biota are influenced by site and landscape features is a necessary step for the design of conservation actions.

This article reviews the available information about the biodiversity of cocoa plantations and their landscape context in southern Bahia and identifies recommendations for management actions to improve its conservation. We first review studies that compare the biodiversity of shaded cocoa plantations with that of other vegetation types in the landscape and relate it to the composition of the landscape as a whole. Subsequently, we discuss the specific management of shaded cocoa plantations in relation to patterns of biodiversity at the site scale. We then focus specifically on endangered species of the region and highlight the contribution that *cabrucas* can make to their conservation. In the discussion we derive recommendations for the conservation management both of cocoa plantations and the wider landscape in southern Bahia, many of which are also applicable in other cocoa regions. We conclude with some research needs.

Methods

Our information sources were publications in scientific journals as well as reports, Master and Doctoral theses from several Brazilian universities. We also review studies presented at the “First Symposium on the Cocoa Production Landscape and Biodiversity of Southern Bahia” that took place at the State University of Santa Cruz, Ilhéus, Bahia, on October 8 and 9, 2007. A significant part of the body of research we present here is not available in the peer reviewed scientific literature. From a total of 52 scientific studies, we extracted information on the following biological groups: vertebrate fauna (mammals, birds, reptiles and amphibians); invertebrate fauna (butterflies, ants and parasitoids); and flora (trees, ferns and bromeliads). The geographic range of the studies varies from one or a few sites to the entire Bahian cocoa region. Most research was carried out in the counties of Una, Ilhéus and Itabuna, due in part to the location of the main cocoa research institutions there (CEPLAC, University of Santa Cruz) and in part to the importance of cocoa production for these counties. The paucity of information on most of the biological groups as well as differences between studies in survey methods prevented a formal meta-analysis.

Results

The biodiversity of shade cocoa plantations within the landscape

A main focus of biodiversity research in the cocoa region has been the county of Una surrounding the Una Biological Reserve, which was established in 1980 and is now one of the largest remaining forest blocks in the region (currently 11,000 ha). The area is still dominated by mature forest remnants (50% of the landscape) interspersed with secondary forests (15%) and *cabrucas* (5%), the remainder being mostly open pastures, crop fields and small plantations (Fig. 1). Between 1998 and 2002, researchers of the RestaUna project (http://www.restauna.org.br/) coordinated by the State University of Santa Cruz (UESC), Ilhéus, conducted an inventory of the fauna and flora of the edges and interior of large (>1,000 ha) and small forest fragments (<200 ha), as well as the *cabrucas* and secondary forests which dominate the surrounding matrix. For the purpose of the study, the latter habitat was defined as at least 15 year old forest regrowth after complete clearing of a site. This research revealed the high diversity of assemblages of all investigated biological groups (small mammals, bats, birds, leaf-litter frogs and reptiles, frugivorous butterflies, ferns and bromeliads) in the *cabrucas* and secondary forests, with species richness and abundance values comparable to those in the interior of mature forest fragments. There were, however, changes in the species composition and relative abundance of different species within each group, indicating an idiosyncratic response of each biological group to the alterations in the landscape that cocoa growing and other land uses had brought about (Table 1). Here we summarize the salient results for each taxonomic group.

Small mammals

For small mammals, the abundance of terrestrial and scansorial species that dominate the communities of the forest interior (*Oryzomys laticeps*, *Marmosops incanus* and *Monodelphis americana*) showed a relative decrease, while the abundance of three arboreal species (*Marmosa murina*, *Rhipidomys mastacalis* and *Micoureus demerarae*) increased in the disturbed habitats, i.e., forest edges, *cabrucas* and secondary forests. Two species that are typical of open environments, *Oligoryzomys* sp. and *Akodon cursor*, were found in the three disturbed habitats but were rare or absent from the forest interior (Pardini 2004). Possibly the increased richness of terrestrial small mammals in the disturbed habitats, including the *cabrucas*, narrowed the niche for the corresponding forest interior species through competition, but did not affect arboreal species (Pardini 2001).

Bats

Faria (2006), Faria et al. (2006) and Faria and Baumgarten (2007) showed that the richness and abundance of bats were higher in *cabrucas* than in natural forest. This was even true for gleaning insectivores, a feeding guild usually regarded as sensitive to habitat fragmentation (Fenton et al. 1992) and disturbance (Medellín et al. 2000). *Rhinophylla pumilio*, a dominant bat species in large forest remnants that is considered vulnerable to fragmentation (Henry and Kalko 2007) was the only species whose capture frequency was lower in *cabrucas*, where *Carollia perspicillata*, the second most abundant species in the large forest remnants, was the dominant species. This contrasting response of *R. pumilio* and *C. perspicillata* to *cabruca* versus forest was confirmed in the neighboring county of Ilhéus that is much poorer in forest and richer in *cabrucas* than Una (Faria et al. 2006). In Una, bat abundance and richness were inversely correlated to the understory density of forest patches (Faria 2002), suggesting that the simpler vegetation structure in *cabrucas* facilitated their flight (Faria et al. 2006; Faria and Baumgarten 2007). This open understory may also explain why bat species that normally use the forest canopy, such as *Artibeus jamaicencis*, *A. lituratus*, *Chiroderma villosum* and *Phyllostomus hastatus*, were caught in mist nets at 1–2 m above the ground in *cabrucas*. In another study in neighboring Ilhéus, *Artibeus obscurus*, a forest-dwelling species negatively affected by decreasing fragment size in the Una region (Faria 2006), was more abundant in cocoa plantations than in forest irrespective of their distance to forest and canopy cover, presumably due to the greater density of fruit trees such as *Ficus* spp. on which they feed (Farias and Faria 2007).

Table 1 Number of species and total recordings of small mammals, bats, birds, litter frogs and lizards, frugivorous butterflies, ferns, and bromeliads in the interior of large forest remnants and *cabrucas* in the county of Una, southern Bahia, Brazil

Biological group	Forest interior	Cabruca	Species common to both habitats	Principal changes in communities	Source
Small mammals					
# recordings	195	299		Change in the relative dominance among species	Pardini (2004)
# species	11	13	NA		
Bats					
# recordings	278	1,314		Greater richness and abundance in the cabrucas (with possible influence of the sampling method in the more open environment); change in the relative dominance between the two most common species	Faria (2002); Faria et al. (2006)
# species	18	39	16		
Birds					
# recordings	1,610	2,459		Greater richness in the *cabrucas* as effect of the invasion of species from more open environments; change in the relative abundance among species	Laps (2006)
# species	121	158	94		
Litter frogs					
# recordings	763	217		No significant change in richness, abundance or species composition	Dixo (2001)
# species	12	12	11		
Litter lizards					
# recordings	53	148		Change in the relative dominance among species	Dixo (2001)
# species	10	9	9		
Frugivorous butterflies					
# recordings	233	636		Change in the relative dominance among species	Accacio (2004)
# species	43	51	30		

Table 1 continued

Biological group	Forest interior	Cabruca	Species common to both habitats	Principal changes in communities	Source
Ferns					
# recordings	1,479	1,019		Different species composition	Paciencia and Prado (2005a, b)
# species	32	26	7		
Bromeliads					
# recordings	711	264		Different species composition	Alves (2005)
# species[a]	25	18	13		

NA data not available

[a] Species or morpho-species

Avifauna

In forest-rich Una, six typical forest bird species—the understory insectivores *Drymophila squamata*, *Herpsilochmus pileatus*, *Pyriglena leucoptera*, *Rhytipterna simplex* and the terrestrial insectivores *Conopophaga melanops* and *Formicarius colma*—were less abundant in *cabrucas* than in forest and one forest bird (*Lipaugus vociferans*, an understory frugivore) was absent from *cabrucas* (Faria et al. 2006). For birds, *cabrucas* seem to be transitional habitat where species typical of forest, fragment edges and open areas occur together, with the latter probably benefiting from the simpler vegetation structure (Faria et al. 2006).

Leaf-litter herpetofauna

Dixo (2001) found no differences in total species richness or abundance of litter frogs and lizards between *cabrucas* and forest fragments between 25 and >1,000 ha in size in Una, but reported significant differences in the abundance of two lizard species, with greater abundance of *Leposoma scinconoides* and lower abundance of *Enyalus catenaci pictus* in *cabrucas* than forest. The latter species was also less abundant in secondary than in primary forest. (It should be mentioned that many species found in both habitats were rare and it is generally difficult to find significant differences for such species.)

Nymphalid butterflies

The *cabrucas* of Una harbored fewer species of the Morphinae sub-family than forest fragments between 25 and >1,000 ha in size and the abundance of two species from the Brassolinae sub-family, *Caligo idomenaeus* and *Eryphanis polyxena*, tended to be lower in *cabrucas* than in these forest fragments. Large forest species from the Euritelinae, Coloburinae and Satyrinae sub-families showed no difference in species richness between cabrucas and forest. *Cabrucas* seemed to be inhospitable to some of the species that are considered invaders of disturbed areas in the region (such as *Biblis hyperia* and *Caligo illioneus*), and only *Yphtimoides reneta* and *Hermeuptychia hermes* from this group were found in significant numbers (Accacio 2004).

Ferns and bromeliads

The fern communities of *cabrucas* in Una were poorer in numbers of species than forest interiors and some species (including those of the Hymenophyllaceae family) were missing. On the other hand, *cabrucas* were suitable for other typical forest ferns, such as *Adiantum diogoanum*, as well as fern species typical of disturbed habitat (Paciencia and Prado 2004, 2005a, b). The discovery of a new species of fern, *Adiantum discolor*, in a *cabruca* during this study (Prado 2000) highlights the importance of these agroforests for biodiversity conservation. Epiphytic bromeliads were significantly less abundant and less species rich in *cabrucas* than in forest fragments (both interior and edge; Alves 2005). Understory bromeliads from the forest interiors were found to be heavily affected by the conversion of forest to *cabrucas*: from nine species reported in the interiors of forest fragments (*Aechmea mollis*, *A. turbinocalyx*, *Areococcus paviflorus*, *Lymania globosa*, *L. azurea*, *L. south bahiai*, *Nidularium amorimii*, *Vriesea drepanocarpa* and *V. duvaliana*) none was found in *cabrucas*. All except the latter two of these species are endemic to the Atlantic forest of southern Bahia and northern Espírito Santo. Three bromeliad species

Fig. 3 Richness and abundance of different biological groups in forest fragments (FF) and *cabrucas* (CB) ▶ in a forest-rich (Una—FR) and a forest-poor (Ilhéus—FP) landscape in southern Bahia, Brazil (from Faria et al. 2007, modified)

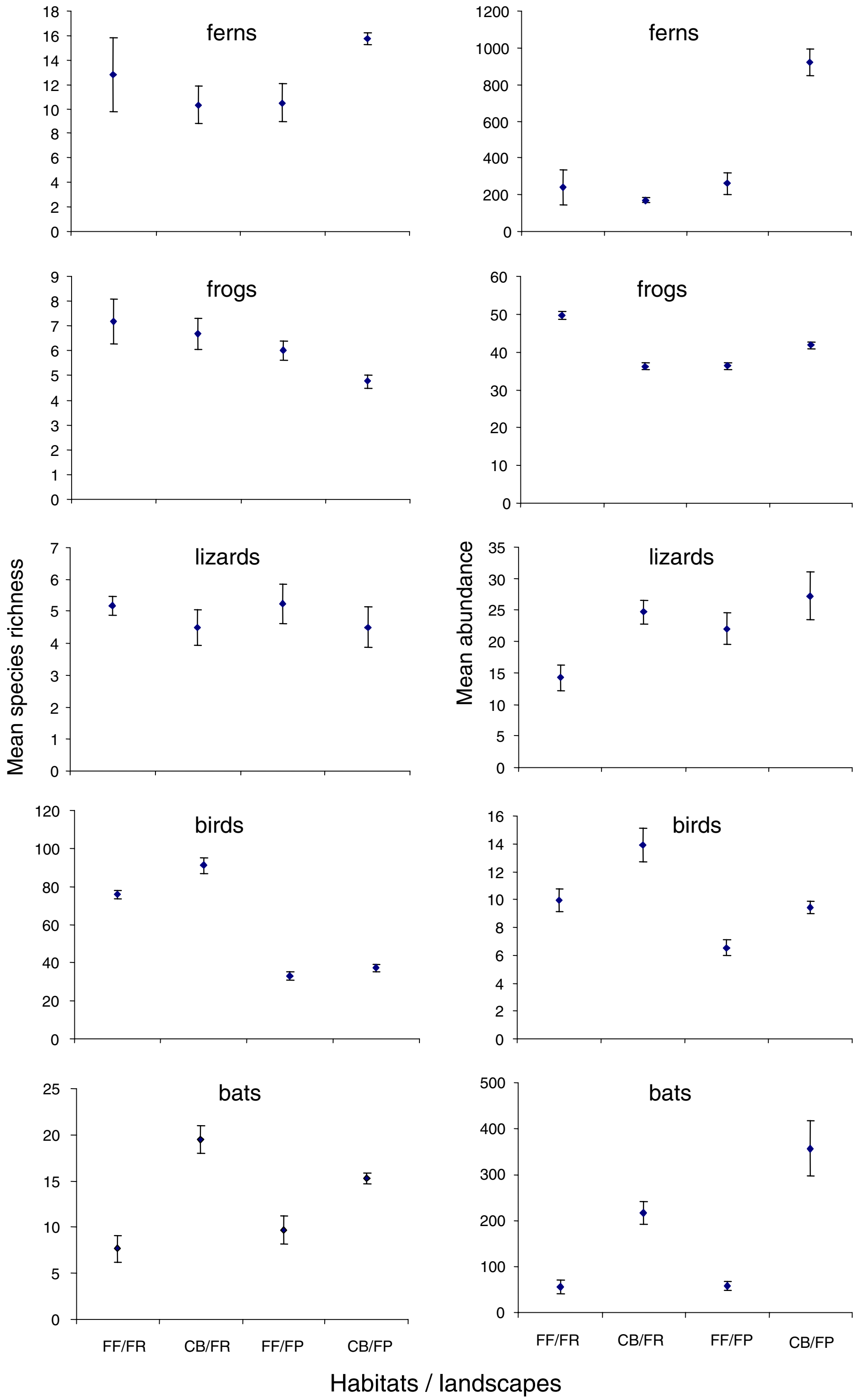
from the forest canopy (*Aechmea conifera*, *A. leonard-kentiana* and *Aechmea* sp.) were either absent or very rare in *cabrucas*, while another four canopy species (*Aechmea lingulata*, *Honhenbergia brachycephala*, *Vriesea* sp. and *V. procera*) were found exclusively in *cabrucas*. The most abundant bromeliad species in *cabrucas* was *Aechmea lingulata* whose large range stretches from Central America to southeast Brazil (Alves 2005).

The research reviewed thus far, most of which was carried out under the umbrella of the RestaUna project, thus showed that the *cabrucas* of forest-rich Una are highly species diverse, harboring about 70% of the 431 species of ferns, frugivorous butterflies, litter frogs and lizards, small mammals, birds and bats that were found in all vegetation types (including mature forest) together in this project.

In subsequent work, the same biological groups except for bromeliads were surveyed in primary forest remnants and *cabrucas* about 30–40 km further north in the county of Ilhéus (Fig. 1). Although the forests of Una and Ilhéus originally belonged to a single block before the agricultural transformation of the region, the two landscapes are now markedly different. While *cabrucas* occupy 5% and forest 50% of the Una landscape, the landscape of Ilhéus is dominated by *cabrucas* (82%) with only 5% under forest.

Overall, the biological communities were poorer in the cabruca-dominated landscape of Ilhéus than in the forest-dominated landscape of Una, with fewer species of small mammals (Ortiz et al. 2002), bats (Faria et al. 2006; Faria and Baumgarten 2007), birds (Faria et al. 2006), ferns, and litter herpetofauna (Faria et al. 2007; Fig. 3). This suggests that despite the relatively high habitat quality of the *cabrucas* that dominate the landscape, the amount of natural habitat remaining in the Ilhéus landscape is too low to retain completely the original species assemblages. Also, a greater variation in bird communities between individual forest fragments was observed in forest-poor Ilhéus than in forest-rich Una, suggesting that the connectivity provided by the *cabrucas* between forest fragments may be insufficient to allow rapid recolonization of fragments following local extinctions (Faria et al. 2007).

The important contribution of the *cabrucas* and the vital role of forest remnants for maintaining the region's biodiversity also emerge from other research. In a study by Alves (1990), the species richness of medium and large sized birds and mammals was greater in two *cabrucas* close to large forest remnants than in *cabrucas* that were distant from forest fragments, suggesting that the forest remnants served as a refuge for these animals. In this study, typical understory birds of the Formicaridae and Pipridae families were less common in *cabrucas* than in forest while ground-dwelling species of the Cracidae and Tinamidae families where almost absent, confirming that *cabrucas* offer habitat for some but not all forest birds. Among mammals, the collared peccary (*Pecari tajacu*), deer (*Mazama* sp.) and two large primates (the yellow-breasted capuchin monkey, *Cebus xanthosternos*, and the southern Bahian masked titi monkey, *Callicebus melanochir*) were rarely recorded in *cabrucas*, while small primates (Wied's black-tufted-ear marmoset, *Callithrix kuhlii*, and the golden-headed lion tamarin, *Leontopithecus chrysomelas*) as well as generalist species such as tayra (*Eira barbara*) and crab-eating racoon (*Procyon cancrivorus*) were more common. Alves (1990) reported that the occurrence of *L. chrysomelas* in *cabrucas* was positively related to the proximity of forest remnants and their size. These observations are supported by a camera-trap study where golden-headed lion


ferns
frogs
lizards
birds
bats
Mean species richness
Mean abundance
FF/FR
CB/FR
FF/FP
CB/FP
Habitats / landscapes

tamarins were recorded in five out of 20 *cabrucas* and in five out of seven forest fragments, with all *cabrucas* that harbored tamarins being close to forest remnants (Cassano 2007). On the other hand, groups of lion tamarins that live continuously in *cabrucas* without access to forest are also known (Leonardo Oliveira, personal communication, 2008). In another study comparing *cabrucas*, secondary forests and young fallows throughout the region, Neves et al. (2007) recorded *C. kuhlii* and *L. chrysomelas* in all three habitats (the two species were found in, respectively, 72 and 32% of the *cabrucas* visited), but did not find large-sized primate species such as howler monkey (*Alouatta guariba*) and yellow-breasted capuchin monkey in *cabrucas*.

Deforestation and the increase in cultivated areas in the southern Bahian landscape were suggested as causal factors in the replacement of the leafcutter ant, *Atta cephalotes*, a typical species of forest environments, by *Atta sexdens*, a species more typical of degraded areas in this region (Delabie 1990; Delabie et al. 1999, 2007). Forest loss is also held responsible by these authors for the replacement of some ant genera previously recorded in *cabrucas*, such as the decrease in abundance of species of the Ponerinae and Ecitoninae sub-families and the concomitant increase in species of the Formicinae and Dolichoderinae. According to Delabie et al. (2007), several species of army ants of the genus *Eciton* can be found in *cabrucas*, provided there are contiguous forest remnants to maintain their colonies. Open areas, such as pastures and clearings, are barriers to foraging for some army ant species. A predictable consequence of the decline in army ants (*Eciton* and *Neivamyrmex*) in the cocoa region would be the disappearance of their associated fauna, especially ant birds (Delabie 1990; Delabie et al. 2007) and many invertebrates that benefit from the niches created by the periodic elimination of litter fauna along ant trails (Franks 1989).

Biodiversity conservation and cocoa management within the *cabruca* system

The conversion of forest into *cabrucas* implies a major alteration of plant species composition and forest structure, including the clearing of the forest understory which hosts most of the forest plant species (Martini 2007) and the loss of over 90% of the overstory trees (Alves 1990). Nevertheless, botanical surveys in *cabrucas* have found large numbers of native canopy tree species, including timber species such as *Cedrela odorata*, *Nectandra* sp. and *Cariniana* spp. that have become rare in unprotected natural forest due to over-use (Vinha and Silva 1982; Sambuichi 2002, 2006; Lobão 2007). For example, Sambuichi and Haridasan (2007) found 293 morpho-species of trees in five *cabrucas* in Ilhéus county, and Rolim and Chiarello (2004) inventoried 105 species in a *cabruca* in the neighboring state of Espírito Santo. Considering the extremely high tree diversity of southern Bahia (Thomas et al. 1998; Martini et al. 2007), this is an important conservation service provided by *cabrucas*. However, common management practices in *cabrucas* tend to decrease tree diversity over time. These include the progressive thinning of shade canopies—partly motivated by official recommendations to keep only 25–30 trees per hectare to maximize cocoa yields (Alvim 1966; Alvim and Pereira 1970)—and the substitution of old forest trees—typically climax and late secondary species—by faster growing pioneer and economically valuable species, often exotics (Sambuichi 2006; Mota et al. 2007; Sambuichi and Haridasan 2007). The reduction of shade tree density and diversity is likely to negatively affect habitat conditions for many fauna species that depend on the microclimate, food and other habitat conditions created by the shade canopy, although this relationship has not been well studied. For example, shade trees in *cabrucas* provide food for fruit and nectar-eating bats (Faria and Baumgarten 2007) and can be used for displacement and food by two endangered arboreal mammals, the golden-headed lion tamarin (*Leontopithecus chrysomelas*) and the maned three-toed sloth (*Bradypus torquatus*) (see following section). Greater diversity of shade trees in cocoa plantations was also positively related to parasitoid richness and abundance and thus supported natural pest control (Sperber et al. 2004).

Common management practices of *cabrucas* also impact herbaceous and understory plant species. According to Martini (2007), approximately two-thirds of the plant species in forest fragments in southern Bahia are understory species. Except for species that re-sprout after cutting, these species are eliminated by the establishment and periodic weeding of cocoa plantations, and therefore depend on natural forest areas for their conservation. Like canopy trees, understory plants are also an important basis for fauna species in *cabrucas*. Heliconias and a large number of Marantaceae, which resprout between weedings, account for the diversity and abundance of small butterflies of the Satyrinae subfamily in the *cabrucas* of Una (Accacio 2004). The leaves of *Heliconia* spp. in *cabrucas* are also used as shelter by bats (e.g., *Thyroptera tricolor*), while other bat species use termite nests and tree holes (e.g., *Lophostoma sivicolum* nests in active termite hills; Faria and Baumgarten 2007).

According to Faria et al. (2007), epiphytic ferns are less abundant in *cabrucas* than in forest, possibly because they are removed from the trees by farm workers. The pruning of cocoa trees and removal of epiphytes from their stems and branches are part of the normal cocoa management and may reduce the diversity of epiphytes in the cabruca understory (Alves 2005). Micro-climatic modifications such as lower atmospheric humidity and lack of suitable dispersers probably also reduce the richness of the bromeliad flora in *cabrucas*, although some species with a high vegetative reproduction capacity seem to do well (Alves 2005).

The suspended soil in the shade canopies of cabrucas provides a rooting substrate for bromeliads and other epiphytes (Fig. 4) and thus helps to maintain a rich fauna of ant species that are either arboreal or normally live in the litter layer, in addition to many other invertebrate species (Delabie 2003). Cocoa plantations shaded by *Erythrina* sp. are considered good ant habitat because the architecture of these leguminous trees favors the development of a great number of epiphytes (J.H.C. Delabie personal observation). The same can be said for tree snakes that use epiphytes as shelter and feeding sites (A.J.S. Argôlo, personal communication 2007).

The lower abundance or even absence of understory birds and small arboreal mammals in *cabrucas* compared to forest can partly be explained by differences in vegetation structure, especially the simplification of the understory and absence of connecting vines between understory and tree canopies (Alves 1990; Faria et al. 2006; Moura 1999). Cassano and Moura (2003) found a possible relationship between vegetation structure and small mammal diversity among cocoa plantations. They recorded five small mammal species in the simplified environment of a cocoa plantation shaded by rubber trees (*Hevea brasiliensis*, Euphorbiaceae) with complete suppression of the herbaceous stratum; seven species in a similar plantation where the herbaceous stratum was maintained; and 12 species in a *cabruca* with complex shade canopy whose understory had not been slashed for 3 years. The structural complexity of the vegetation was also suggested by Pinto et al. (1993) to be a determinant of the richness and abundance of small mammals in a comparison of native forest, an oil palm plantation, a cocoa plantation shaded by rubber trees, and a *cabruca*.

Majer et al. (1994) found that arboreal ant communities in the understory of three cocoa plantations shaded by erythrinas showed stronger dominance of species of the genera *Azteca*, *Ectatomma* or *Crematogaster* than the understory of a *cabruca*, despite similar

Fig. 4 Brazil wood tree (*Caesalpinia echinata*) with high density of epiphytes in a *cabruca* in the region of Ilhéus where *cabrucas* represent most of the tree cover in the landscape (photo by G. Schroth)

overall ant diversity. They explained the difference with greater diversity of the shade canopy, greater plantation age and no insecticide use in the *cabruca*. The *cabruca* was the only of the four plantations where the "little fire ant" *Wasmannia auropunctata* was not recorded. This species shows great capacity for population growth and colonization of new areas where other ant species were eliminated by insecticides (Delabie 1990). Insecticide use and the removal of nests of social ants in *cabrucas* are held responsible for the replacement of ants of the genus *Solenopsis* and, in the tree stratum, *Azteca* spp. by *W. auropunctata* (Delabie 1990). In a more recent study, Delabie et al. (2007) showed that *W. auropunctata* has a common but discrete presence in forest remnants where it is limited to small populations in the litter stratum, while in cocoa plantations it colonizes the tree canopies to raise sucking insects and excludes other ant species. Delabie et al. (2007) emphasized the importance of maintaining an intact litter layer in cocoa plantations because, similar to forest, this stratum concentrates the highest ant diversity. Pruning of the cocoa canopies and the reduction of their height to control infestations by the witches' broom disease are singled out for their negative effect on the arboreal ant communities which consequently cease to play their role in the biological control of herbivorous insects that damage the cocoa trees (Delabie and Mariano 2001; Delabie et al. 2007). The same authors suggested that the rarity of the forest ant *Typhlomyrmex rogenhoferi* in cocoa plantations in southern Bahia is a consequence of the rarity of fallen tree trunks where these ants build their nests (Delabie et al. 2007).

Contribution of *cabrucas* to the conservation of endangered species

Cabrucas provide habitat and resources to several endangered endemic species of the Atlantic forest and should therefore be considered in action plans for their conservation.

Mammals

At least two endangered mammal species have been recorded in *cabrucas*: the golden-headed lion tamarin (*Leontopithecus chrysomelas*; Alves 1990; Raboy et al. 2004; Cassano 2007; Neves et al. 2007) and the maned three-toed sloth (*Bradypus torquatus*; Cassano 2006). Two groups of lion tamarins that were monitored in the Una Biological Reserve used a nearby *cabruca* in their daily activities and as sleeping sites (Raboy et al. 2004). The tamarins preferentially used tree holes as shelter and the greater frequency of suitable holes seemed to be a reason why they slept more often in mature forest than in secondary forest and *cabrucas* (Raboy et al. 2004). Oliveira et al. (2007) listed 118 tree species used by these same groups of lion tamarins in the Una Biological Reserve between 1998 and 2006, with 80 species being used for food and 63 species as sleeping sites. Such information on preferred tree species could be used for improving the habitat quality of *cabrucas* and other farm areas for this endangered primate (and similarly other fauna species), thereby contributing to their more effective conservation. In addition, bromeliads of the genus *Aechmea*, including *A. conifera* and *A.* cf. *depressa*, were used as food and foraging sites by the tamarins (Nascimento et al. 2007) and were their main food item in abandoned *cabrucas* in the Una Biological Reserve (Catenacci 2008).

Cassano (2006) monitored a female maned three-toed sloth, *Bradypus torquatus*, an endemic species of the Atlantic forest, and its offspring in a *cabruca* near the Una Biological Reserve. The sloths used the *cabruca*, which had an unusually dense canopy, as their main habitat and the most abundant tree species in the shade canopy were part of their diet (Correia et al. 2006; Barreto and Cassano 2007).

The cocoa region of southern Bahia is also the main area of occurrence of the endemic painted tree rat, *Callistomys pictus*. The *cabrucas* are probably important habitat for this rodent given that they are the main environment where the species has recently been recorded. Hollow trees and epiphytic bromeliads are apparently used as shelter. Cocoa leaves and fruits are consumed, but the species does not appear to cause significant economic damage (Moura 2005, 2008). However, this rodent is being captured and killed by farm workers, suggesting a need for local education programs to enhance the conservation of the species.

Birds

Faria et al. (2006) reported the occurrence of the pileated antwren (*Herpsilochmus pileatus*) in *cabrucas* both in the forest-dominated Una and the *cabruca*-dominated Ilhéus counties. However, in the latter area the species was very rarely found, indicating that despite its ability to utilize *cabrucas* it is vulnerable to forest loss in a landscape-scale. The *cabrucas* between Camacan and Itabuna are considered the main area of occurrence of the acrobat bird (*Acrobatornis fonsecai*), a species that was first discovered and described in a *cabruca* (Pacheco et al. 1996). Most of the subsequent recordings of the species are also linked to the *cabruca* environment and Pacheco et al. (1996) believe that the conversion of natural forest into *cabrucas* may have actually contributed to a widening of its range, including to altitudes of up to 600 m. The acrobat bird is a canopy species and observations have indicated that it forages in mixed flocks, feeding mainly on insects and nesting preferentially in legume trees which are common in *cabrucas*. The species has recently been reported from *cabrucas* near the Una Biological Reserve (André de Luca, personal communication 2007) and in the Ilhéus area (Faria et al. 2006).

Invertebrates

Cabrucas may also play a role in invertebrate conservation. The ant *Dinoponera lucida* is on the list of Brazilian fauna threatened with extinction. It is found in the southern part of the cocoa region, including in cocoa plantations adjacent to forest remnants, indicating that, as a minimum, *cabrucas* can facilitate species dispersion among forest remnants (Delabie et al. 2007). On the other hand, the rare endemic ant species, *Blepharidatta* sp. n., has been found in forest areas through much of the cocoa region, but only a single encounter in a *cabruca* has so far been reported (Fig. 1). These ants are exceptional by not having winged forms and thus depend on suitable habitat for their dispersal. If it is true that *cabrucas* do not provide suitable habitat, then these ants would be severely threatened by forest fragmentation (J.H.C. Delabie unpublished data).

While several endangered species of mammals, birds and invertebrates of the region use *cabrucas* as (secondary) habitat, for others these agroforests do not seem to offer suitable conditions. Two endangered primates of the region, the yellow-breasted capuchin monkey (*Cebus xanthosternos*) and the southern Bahian masked titi monkey (*Callicebus melanochir*), as well as the bristle-spined porcupine (*Chaetomys subspinosus*), do not seem to enter *cabrucas* (Alves 1990; Giné et al. 2006; Neves et al. 2007), reinforcing again the complementarity of forest conservation and the conservation of *cabrucas* in an integrated landscape management strategy. Still, *cabrucas* may benefit these species indirectly by helping to maintain vital ecological processes, including maintaining prey species and reducing edge effects in forest fragments.

Discussion and recommendations

Landscape management in southern Bahia cocoa region

Research in the cocoa region of southern Bahia has shown that although *cabrucas* are sub-optimal habitat for many typical forest species, they can to some extent mitigate the fragmentation and loss of natural habitat for a significant part of the regional biota. In the forest-rich landscape of Una, small forest remnants (<200 ha) have biological communities as rich and abundant as the large forest blocks, suggesting that the *cabrucas* pose no obstacle to the movements of forest species through the landscape. In the forest-poor landscape of Ilhéus, on the other hand, the *cabrucas* that dominate the landscape provide habitat for many species while the remaining forest fragments are essential for those species that cannot use *cabrucas*. Large forest remnants are then fundamental to maintaining viable populations, especially for rare, large-bodied and area-demanding species.

Research in other regions has shown that species that tolerate matrix habitat (such as *cabrucas*) are better able to survive in fragmented forest landscapes than species that do not, with the latter being particularly dependent on large, contiguous forest blocks (Laurance 1991; Gascon et al. 1999), hence the importance of an adequate system of protected areas and private forest reserves even in an overall "biodiversity-friendly" landscape like the cocoa region of southern Bahia.

Theoretical studies on forest fragmentation suggest that below 20–30% forest remnants in the landscape, species richness is negatively affected by fragmentation over and above forest loss per se (Fahrig 1998). While the lower overall diversity of the Ilhéus landscape (with 5% forest) compared to the Una landscape (with 50% forest) is in agreement with this theoretical conclusion, it is nevertheless striking that the forest-poor landscape of Ilhéus still has relatively diverse biological communities with presence of a large proportion of the native species of the region. There is no doubt that the combination of forest remnants with a matrix dominated by *cabrucas* and secondary forests are fundamental for the maintenance of these rich biological communities. Further studies are needed, however, to define limits in terms of percent cover and spatial configuration of forest remnants as well as the percent cover, configuration and characteristics of the *cabrucas* and other matrix habitat beyond which ecological processes and biodiversity would be substantially and irreversibly impaired.

While such questions await further study, some lessons clearly emerge from the existing evidence. In cocoa landscapes with still a high proportion of forest remnants (as in Una), these should be conserved to ensure the perpetuation of forest species, while *cabrucas* should be maintained in the matrix especially to provide connectivity and prevent the impoverishment of isolated, small remnants. In landscapes dominated by *cabrucas* with only little remaining forest cover (as in Ilhéus), on the other hand, the forest area should be increased to ensure the conservation of strict forest species, while the *cabrucas* should be maintained both for their essential role as habitat for many native species and to ensure a maximum of connectivity among the forest remnants. In this latter situation, adherence to current legislation requiring legal reserves (20% of each property) and areas of permanent preservation (river margins and hill slopes) of native vegetation would lead to a substantial increase of total forest cover to about 30%, in addition to the public protected areas (Faria 2007). The creation of private reserves (for which Brazilian law offers tax rebates) and expansion of public protected areas are further options to increase the total amount of forest habitat. Care should be taken to increase the proportion of natural forest in the landscape in a way that takes account of the beta diversity of natural species assemblages and is adequately stratified across underlying climatic, edaphic and topographic features. Special attention needs to be given to species with limited capacity to use *cabrucas* (Table 2). Action plans should be developed to maintain viable populations of these species in large remnants, possibly aided by dispersion corridors whose effectiveness should be monitored.

While all conversion of mature forest is illegal in the Atlantic Forest biome, the clearing of fallow land (e.g., for pasture or annual crops) should be done in such a way that forest remnants and *cabrucas* do not become isolated and that abrupt borders between forest and open areas are not unnecessarily created. Microclimatic effects and especially the increased prevalence of fire tend to progressively degrade especially small forest fragments with exposed borders (Gascon et al. 2000). Such effects can probably be reduced if forest edges are buffered by fallows, secondary forest or *cabrucas*, although the effectiveness of such spatial arrangements has not been established in Bahia.

Table 2 Species known to rarely occur in *cabrucas*

Taxon	Common name	Restrictions to use of *cabrucas*	Source
Mammals			
Cebus xanthosternos	Yellow-breasted capuchin monkey	Low probability to use *cabrucas*	Alves (1990)
Callicebus melanochir	Coastal black-handed titi		
Mazama sp.	Deer		
Pecari tajacu	Wild pig		
Chaetomys subespinosus	Bristle-spined porcupine		Giné et al. (2006)
Callistomys pictus	Painted tree rat	Relatively tolerant to the habitat modifications occurring when forest is converted into *cabruca*, but abundance in these plantations probably reduced by hunting	Moura (2005, 2008)
Didelphis marsupialis	Common oppossum		Alves (1990)
Bradypus torquatus	Maned three-toed sloth	Use of *cabrucas* dependent on the occurrence of plant species that make up its diet, density of shade trees and proximity of forest remnants	Cassano (2006)
Leontopithecus chrysomelas	Golden-headed lion tamarin		Raboy et al. (2004); Alves (1990)
Oryzomys laticeps	Forest rat	Low probability of using *cabrucas*	Pardini (2004)
Marmosops incanus			Pardini (2004)
Monodelphis americana	Three-striped short-tailed oppossum		Pardini (2004)
Rhinophylla pumilio	Bat	Low probability of using *cabrucas* when they are inserted in a landscape with little native forest	Faria et al. (2006); Faria and Baumgarten (2007)
Aves			
Lipaugus vociferans		Low probability of using *cabrucas*	Faria et al. (2006)
Drymorphyla squamata		Low probability of using *cabrucas* when they are inserted in a landscape with little native forest	
Herpsilochmus pileatus	"chorozinho-da-Bahia"		
Pyriglena leucoptera			
Rhytipterna simplex *Conopophaga melanops*			
Formicarius colma			
Formicaridae and Pipridae	Understory birds	Low probability of using *cabrucas*	Alves (1990)
Cracidae and Tinamidae	Terrestrial birds		

Table 2 continued

Taxon	Common name	Restrictions to use of *cabrucas*	Source
Reptiles and amphibians			
Enyalus catenatus pictus	Lizard	Low probability of using *cabrucas*	Dixo (2001); Faria et al. (2007)
Adelophrine pachydactyla	Litter frog		
Cycloramphus migueli	Litter frog		
Leptodactylus spixi	Litter frog		
Chiasmocleis gnoma	Littler frog		
Bothrops bilineatus	Forest pitviper	Low probability of using *cabrucas*	Argôlo (2004)
Lachesis muta	South American bushmaster		
Invertebrates			
Dinoponera lucida	Ant	Low probability of using *cabrucas*	Delabie et al. (2007)
Typhlomyrmex spp.	Ant		
Família Ecitoninae	Army ants		
Subfamília Morfidae	Fruit eating butterflies	Low probability of using *cabrucas*	Accacio (2004)
Epiphytic bromeliads			
Aechmea mollis	Understory bromeliads	Low probability of occurring in *cabrucas*	Alves (2005)
A. turbinocalyx			
Areococcus paviflorus			
Lymania globosa			
L. azurea			
L. smithii			
Nidularium amorimii			
Vriesea drepanocarpa			
V. duvaliana			
Aechmea conifera	Canopy bromeliads	Low probability of occurring in *cabrucas*	Alves (2005)
A. leonard-kentiana			
Aechmea sp.			

Cocoa management within the *cabruca* system

The conservation of diversified and structurally complex shade canopies composed of native trees species in the *cabrucas* is important for the conservation of a large number of native tree species and as a structurally diverse habitat for many other organisms. Research is needed to establish new recommendations for shade tree densities, taking into account not only direct effects of shade on cocoa production, but also effects on production costs via suppression of weeds and biological pest control, as well as tree products (fruits, wood etc.). Incipient markets that specifically reward the conservation-friendly production of cocoa in *cabruca* systems may expand in the future. The internalization of environmental services such as carbon sequestration and contribution to the scenic beauty of the southern Bahian landscape with its high potential for tourism would create further incentives for maintaining traditional shade canopies. Guidelines need to be developed for managing the regeneration of the shade trees in *cabrucas* to prevent the gradual loss of late successional tree species and their replacement by (often exotic) pioneers. The management should ensure the persistence of endemic and endangered tree species (Fig. 4), as well as species used by endemic fauna (Table 3), and should strengthen those features of *cabrucas* that are known to contribute to their habitat quality. Hollow trees, fallen logs, termite nests, trees and branches supporting bird's nests (especially of rare species) and other structures that are used by fauna should be conserved. Epiphytes and vines should not be removed from shade trees unless they interfere with the management of the area. When thinning or pruning the canopy, it may often be possible to maintain some connectivity in the canopy to facilitate the movement of species such as sloths and other arboreal fauna, especially where *cabrucas* abut on natural habitat. Education and capacity building programs that increase cocoa farmers' ability to identify tree species and their seedlings in the field are also needed (Eduardo Mariano Neto, personal communication). Pesticides should be used only locally if at all, and preference should be given to organic practices.

Hunting is illegal throughout the Atlantic forest biome, although this law is generally not enforced. Hunting is widespread in the region and is likely to affect the density and distribution of most medium to large terrestrial mammals (Pardini 2001). Observations suggest that the farm owners' prohibition of hunting and their encouragement to keep small livestock as an alternative source of protein have potential to reduce hunting by farm workers (Santos 1999). Snakes are often killed for fear and because farm workers are often unable to distinguish poisonous from nonpoisonous species, hence the need for educational programs about the prevention of snake accidents, the harmlessness of most snake species, and the ecological importance of snakes in the control of their prey (e.g., rodents some of which can damage cocoa; Argôlo 2004). These recommendations are broadly valid for shaded cocoa (and other tree crop) systems elsewhere (Schroth et al. 2004).

Conservation of endangered species

Cabrucas should be considered priority landscape elements in action plans for the conservation of the pileated antwren (*Herpsilochmus pileatus*), the acrobat bird (*Acrobatornis fonsecai*), the golden-headed lion tamarin (*Leontopithecus chrysomelas*), the maned three-toed sloth (*Bradypus torquatus*), the painted tree rat (*Callistomys pictus*) and the ant *Dinoponera lucida*. However, with the possible exception of the acrobat bird, sufficiently large forest remnants are essential for the conservation of these species, in addition to *cabrucas*. More research is needed to establish the exact role that *cabrucas* can play in the

Table 3 Tree species recorded in *cabrucas* that are part of the diet of golden-headed lion tamarins and maned three-toed sloths or listed as endemic or endangered species

Family/species in *cabruca*	Common name	Lion tamarin diet	Sloth diet	Endemic	Threat level
Anacardiaceae					
Tapirira guianensis	pau-pombo	yes	yes		
Annonaceae					
Rollinia bahiensis				yes	VU
Apocynaceae					
Lacmellea aculeata		yes			
Rauvolfia bahiensis				yes	
Bignoniaceae					
Tabebuia elliptica		yes			
Bombacaceae					
Eriotheca sp.	imbiruçú		*E. globosa*		
Caesalpiniaceae					
Arapatiella psilophylla				yes	VU
Caesalpinia echinata	pau-brasil				EN
Dialium guianense	jitaí-preto	yes	yes		
Hymenaea oblongifolia				yes	
Macrolobium latifolium		yes	yes		
Senna multijuga	canafístula/cobi		yes		
Cariocaraceae					
Caryocar edule					
Cecropiaceae					
Cecropia spp.	embaúba		*Cecropia* sp.		
Clusiaceae					
Symphonia globulifera	guanandí	yes			
Ebenaceae					
Diospyros melinonii		yes			
Euphorbiaceae					
Mabea piriri		yes			
Fabaceae					
Dalbergia nigra	jacarandá				VU
Lauraceae					
Aniba intermedia					VU
Lecythidaceae					
Cariniana legalis	jequitiba-cipó				VU
Lecythis lurida	inhaíba				LR/cd
Malpighiaceae					
Byrsonima laevigata		yes			
Meliaceae					
Cedrela odorata	cedro roxo				VU
Mimosaceae					
Parkia pendula	jueirana-vermelha	yes			

Table 3 continued

Family/species in *cabruca*	Common name	Lion tamarin diet	Sloth diet	Endemic	Threat level
Monimiaceae					
Bracteanthus atlanticus				yes	
Moraceae					
Artocarpus heterophyllus	jaqueira	yes			
Brosimum guianense			yes		
Brosimum rubescens	condurú	yes	yes		
Ficus pulchella	figueira				VU
Ficus spp.	figueira	yes	yes		
Sorocea guilleminiana					VU
Myristicaceae					
Virola gardneri	bicuíba-vermelha		yes		
Myrtaceae					
Eugenia flamingensis				yes	
Eugenia sp.		yes			
Psidium sp.		*P. guajava*			
Polygonaceae					
Coccoloba alnifolia		*Coccoloba* sp.			
Rubiaceae					
Guettarda platyphylla		yes			
Santalaceae					
Acanthosyris paulo–alvinii					
Sapotaceae					
Chrysophyllum splendens					VU
Manilkara elata	maçaranduba	*Manilkara* sp.			EN
Micropholis compta					VU
Micropholis crassipedicellata					LR/cd
Micropholis sp.		*Micropholis* spp.			
Pouteria beaurepairei					LR/cd
Pouteria grandiflora					LR/nt
Pouteria bangii		yes			
Simaroubaceae					
Simarouba amara	Arubá	yes			

Tree species listed in *cabrucas* by Sambuichi and Haridasan (2007); lion tamarin diet after Raboy et al. (2004) and sloth diet after Cassano (2006) and Correia et al. (2006); endemicity refers to the Espírito Santo—Bahia native species center (Thomas et al. 2003); threat levels according to www.redlist.org, accessed March 18, 2008

LR Lower risk—species assessed that do not fit into threat categories (*cd* taxon whose conservation is ensured by a specific conservation program; *nt* near threatened); *VU* vulnerable; *EN* endangered

life cycles of these species and to identify management practices to increase their habitat value. Educational programs to increase the knowledge about these rare and endangered species in *cabrucas* among farm owners and workers should also be a priority.

Conclusions

This review demonstrates that *cabrucas* are utilized by a substantial part of the fauna and flora native to southern Bahia. Given the high degree of forest loss and fragmentation in parts of the region, *cabrucas* have an important role to play in biodiversity conservation by providing alternative or additional habitat for many forest species, increasing connectivity between forest fragments, and reducing edge effects to which fragments are exposed.

Conservation strategies should consider the role of *cabrucas* at two spatial scales: the local management of the plantations, and the scale of the landscape within which *cabrucas* interact with other vegetation types. The studies reviewed here indicate that where a large part of the landscape is still covered by forest remnants, the landscape as a whole, and the *cabrucas* within it, are richer in species than where much of the original forest cover has been converted into *cabrucas* and other land uses. Initiatives to conserve *cabrucas* as important habitat for many native species should thus always be seen in context with the conservation and restoration of natural forest habitat. Brazilian environmental legislation offers a legal framework to increase forest cover to 20–30% outside of protected areas, a value that, according to theoretical models, would be enough to support metapopulation dynamics in a fragmented landscape, especially where much of the remainder is covered by *cabrucas* that are sympathetically managed for conservation. Current scientific knowledge of the ecology of many species of the cocoa producing region of Bahia already allows us to identify management practices that help to maintain and increase the habitat value of *cabrucas*, although studies are needed on questions such as optimum shade tree densities and management practices to ensure the regeneration of canopy trees. Since *cabrucas* are production systems, any recommendation needs to take economic viability into account, and both costs and benefits of conservation friendly management should be monitored to inform a long-term plan of adaptive management. Long-term scientific studies are needed that relate biological diversity and the persistence of sensitive species to different combinations of *cabrucas* and natural forest in landscapes in order to determine threshold levels of deforestation and fragmentation beyond which biodiversity is significantly impaired. Further research should also be encouraged to relate variables such as the presence of food resources, shelter, vegetation structure and microclimate to the richness and composition of native species assemblages and especially the presence of sensitive forest species in *cabrucas*. It should also be remembered that no two *cabruca*s are the same. *Cabrucas* are derived from already highly heterogeneous forest through histories of establishment and subsequent plantation management that are, in combination, unique for each area. Thus, even when a list of general recommendations is set out to reconcile production and conservation, adaptation to local conditions will always be necessary, requiring ecologically educated and conscious farm owners and workers.

Finally, while this review focused on Bahia with its specific fauna, flora and culture of cocoa growing, many of our conclusions on the management of landscapes and cocoa production systems to reconcile biodiversity conservation with tree crop production are applicable to other geographical regions and add to an increasing pool of information on the biodiversity-friendly management of tropical land use mosaics (Schroth et al. 2004; Schroth and Harvey 2007).

Acknowledgments The authors thank the participants of the First Symposium on the Cocoa Landscape and its Biodiversity in Southern Bahia held at the State University of Santa Cruz, Ilhéus, on 8–9 October 2007 who contributed information and ideas to this study. Tony Gardner, Bill Laurance, an anonymous referee and the editor made very useful comments on an earlier version. This paper benefited from grants from Seeds of Change to Conservation International, and from the European Union and the Brazilian Ministry of the Environment to IESB. CRC and JHCD acknowledge their research grants from FAPESP and CNPq, respectively.

References

Accacio GM (2004) Comunidades de Borboletas Frugívoras em Mosaico de Ambientes Florestais na Região de Una, Bahia. Doctoral Thesis, University of São Paulo, São Paulo

Alger K, Caldas M (1994) The declining cocoa economy and the Atlantic forest of southern Bahia, Brazil: conservation attitudes of cocoa planters. Environmentalist 14:107–119. doi:10.1007/BF01901304

Alves MC (1990) The role of cacao plantations in the conservation of the Atlantic forest of southern Bahia, Brazil. Master Thesis, University of Florida, Gainesville

Alves TF (2005) Distribuição geográfica, forófitos e espécies de bromélias epífitas nas matas e plantações de cacau da região de Una, Bahia. Doctoral Thesis, State University of Campinas, Campinas

Alvim PT (1966) Problemas do sombreamento do cacaueiro. Cacau Atualidades 3:3–5

Alvim PT, Pereira CP (1970) Sombra e espaçamento nas plantações de cacau da Bahia. In: XXII Reunião Anual da Sociedade Brasileira para o Progresso da Ciência: Simpósio de pesquisas sobre o cacau, pp 33–34

Araujo M, Fernandes VMA, Marques A, Souza PVN, Braga A (2007) Uso da terra e adequação ambiental da propriedade rural na região cacaueira da Bahia. In: I Simpósio sobre Paisagem Cacaueira e Biodiversidade no Sudeste da Bahia, State University of Santa Cruz, Ilhéus, 8–9 October 2007

Argôlo AJS (2004) As serpentes dos cacauais do sudeste da Bahia. Ed. Editus, Ilhéus, 260 p

Barreto RMF, Cassano CR (2007) Uso do habitat por uma preguiça-de-coleira (Bradypus torquatus) em plantação de cacau (*Theobroma cacao* L.) sombreada por árvores nativas no sul da Bahia. In: I Simpósio sobre Paisagem Cacaueira e Biodiversidade no Sudeste da Bahia, State University of Santa Cruz, Ilhéus, 8–9 October 2007

Bencke GA, Maurício GN, Develey PR, Goerck JM (2006) Áreas importantes para a conservação das aves no Brasil: Parte I—estados do domínio da Mata Atlântica, inclui áreas de Cerrado, Caatinga e Pampas. SAVE Brasil, São Paulo, 494 p

Brown KS Jr (1982) Paleoecology and regional patterns of evolution in Neotropical forest butterflies. In: Prance GT (ed) Biological diversification in the tropics. Columbia University Press, New York

Cassano CR (2006) Ecologia e conservação da preguiça-de-coleira (*Bradypus torquatus*, Illiger, 1812) no sul da Bahia. Master Thesis, State University of Santa Cruz, Ilhéus

Cassano CR (2007) Registros fotográficos de mico-leão-de-cara-dourada (*Leontopithecus chrysomelas*) em plantações de cacau no município de Una, Bahia. In: I Simpósio sobre Paisagem Cacaueira e Biodiversidade no Sudeste da Bahia, State University of Santa Cruz, Ilhéus, 8–9 October 2007

Cassano CR, Moura RT (2003) Mamíferos em sistemas produtivos de cultura permanente no entorno da Reserva Biológica de Una, Una, BA. In: II Congresso Brasileiro de Mastozoologia, Belo Horizonte

Catenacci LS (2008) Ecologia alimentar do mico-leão-da-cara-dourada (*Leontopithecus chrysomelas*, Callitrichidae, Primates) em áreas degradadas da Mata Atlântica do sul da Bahia. Master Thesis, State University of Santa Cruz, Ilhéus

Correia TL, Cassano CR, Barreto RMF (2006) Comportamento de filhote desmamado e fêmea adulta de preguiça-de-coleira (*Bradypus torquatus*), Bahia, Brasil. In: VII Congresso Internacional sobre Manejo de Fauna Silvestre na Amazônia e América Latina—CD-ROM, Ilhéus

Delabie JHC (1990) The ant problems of cocoa farms in Brazil. In: Meer RKV, Jaffe K, Cedeno A (eds) Applied myrmecology: a world perspective. Westview Press, Boulder, pp 555–569

Delabie JHC (2003) Comunidades de formigas das árvores nas formações florestais da América do Sul, com ênfase no sudeste da Bahia. In: XVI Simpósio de Mirmecologia, Florianópolis

Delabie JHC, Mariano CSF (2001) Papel das formigas (Insecta: Hymenoptera: Formicidae) no controle biológico natural das pragas do cacaueiro na Bahia: síntese e limitações. In: XIII International cocoa research conference, v 1. Cocoa Producers' Alliance, Sabah

Delabie JHC, Mariano CSF, Nascimento IC (1998) As formigas do Município de Ilhéus (Insecta: Hymenoptera: Formicidae). Especiaria 1:133–152

Delabie JHC, Nascimento IC, Mariano CSF (1999) Importance de l'agriculture cacaoyère pour le maintien de la biodiversité: étude comparée de la myrmécofaune de différents milieux du sud-est de Bahia, Brésil (Hymenoptera; Formicidae). In: XII International cocoa research conference. Cocoa Producer's Alliance, Lagos

Delabie JHC, Jahyny B, Nascimento IC, Mariano CSF, Lacau S, Campiolo S, Philpott SM, Leponce M (2007) Contribution of cocoa plantations to the conservation of native ants (Insecta: Hymenoptera:

Formicidae) with a special emphasis on the Atlantic forest fauna of southern Bahia, Brazil. Biodivers Conserv 16:2359–2384. doi:10.1007/s10531-007-9190-6

Dixo MBO (2001) Efeito da fragmentação da floresta sobre a comunidade de sapos e lagartos de serapilheira no Sul da Bahia. Master Thesis, University of São Paulo, São Paulo

Fahrig L (1998) When does fragmentation of breeding habitat affect population survival? Ecol Modell 105:273–292. doi:10.1016/S0304-3800(97)00163-4

Faria D (2002) Comunidade de morcegos em uma paisagem fragmentada da Mata Atlântica do sul da Bahia, Brasil. Doctoral Thesis, University of Campinas, Campinas

Faria D (2006) Phyllostomids bats of a fragmented landscape in north-eastern Atlantic forest, Brazil. J Trop Ecol 22:531–542. doi:10.1017/S0266467406003385

Faria D (2007) Cobertura de remanescentes florestais e plantações de cacau na paisagem da região cacaueira do sul da Bahia. In: I Simpósio sobre Paisagem Cacaueira e Biodiversidade no Sudeste da Bahia, State University of Santa Cruz, Ilhéus, 8–9 October 2007

Faria D, Baumgarten J (2007) Shade cacao plantations (*Theobroma cacao*) and bat conservation in southern Bahia, Brazil. Biodivers Conserv 16:291–312. doi:10.1007/s10531-005-8346-5

Faria D, Laps RR, Baumgarten J, Cetra M (2006) Bat and bird assemblages from forests and shade cacao plantations in two contrasting landscapes in the Atlantic forest of southern Bahia, Brazil. Biodivers Conserv 15:587–612. doi:10.1007/s10531-005-2089-1

Faria D, Paciência MLB, Dixo M, Laps RR, Baumgarten J (2007) Ferns, frogs, lizards, birds and bats in forest fragments and shade cacao plantations in two contrasting landscape in the Atlantic forest, Brazil. Biodivers Conserv 16:2335–2357. doi:10.1007/s10531-007-9189-z

Farias S, Faria D (2007) *Artibeus obscuros* e as cabrucas do sudeste da Bahia: dados preliminares. In: I Simpósio sobre Paisagem Cacaueira e Biodiversidade no Sudeste da Bahia, State University of Santa Cruz, Ilhéus, 8–9 October 2007

Fenton MB, Acharya L, Audet D, Hickey MBC, Merriman C, Obrist MK, Syme DM (1992) Phyllostomid bats (Chiroptera: Phyllostomidae) as indicators of habitat disruption in the Neotropics. Biotropica 24:440–446. doi:10.2307/2388615

Franks N (1989) Army-ants: a collective intelligence. Am Sci 77:138–145

Gascon C, Lovejoy TE, Bierregaard RO, Malcolm JR, Stouffer PC, Vasconcelos H, Laurance WF, Zimmerman B, Tocher M, Borges S (1999) Matrix habitat and species persistence in tropical forest remnants. Biol Conserv 91:223–229. doi:10.1016/S0006-3207(99)00080-4

Gascon C, Williamson GB, Fonseca GAB (2000) Receding forest edges and vanishing reserves. Science 288:1356–1358. doi:10.1126/science.288.5470.1356

Giné GAF, Le Pendu Y, Duarte JMB, Faria S, Faria D (2006) Uso do espaço pelo ouriço-preto (*Chaetomys subspinosus*, Olfers 1818) na região cacaueira do sul da Bahia. VII Congresso Internacional sobre Manejo de Fauna Silvestre na Amazônia e América Latina—CD-ROM, Ilhéus

Harvey CA, Villalobos JAG (2007) Agroforestry systems conserve species-rich but modified assemblages of tropical birds and bats. Biodivers Conserv 16:2257–2292. doi:10.1007/s10531-007-9194-2

Harvey CA, González J, Somarriba E (2006) Dung beetle and terrestrial mammal diversity in forests, indigenous agroforestry systems and plantain monocultures in Talamanca, Costa Rica. Biodivers Conserv 15:555–585. doi:10.1007/s10531-005-2088-2

Henry M, Kalko E (2007) Foraging strategy and breeding constraints of *Rhinophylla pumilio* (Phyllostomidae) in the Amazon Lowlands. J Mammal 88:81–93. doi:10.1644/06-MAMM-A-001R1.1

Izac AMN, Sanchez PA (2001) Towards a natural resource management paradigm for international agriculture: the example of agroforestry research. Agric Syst 69:5–25. doi:10.1016/S0308-521X(01)00015-4

Johns ND (1999) Conservation in Brazil's chocolate forest: the unlike persistence of the traditional cocoa agroecosystem. Environ Manag 23:31–47. doi:10.1007/s002679900166

Lacau S, Villemant C, Delabie JHC (2004) *Typhlomyrmex meire*, a remarkable new species endemic to southern Bahia, Brazil (Formicidae: Ectatomminae). Zootaxa 678:1–23

Landau EC (2003) Padrões de ocupação espacial da paisagem na Mata Atlântica do sudeste da Bahia, Brasil. In: Prado PI, Landau EC, Moura RT, Pinto LPS, Fonseca GAB, Alger K (eds) Corredor de Biodiversidade da Mata Atlântica do sul da Bahia. CD-ROM, IESB/CI/CABS/UFMG/UNICAMP, Ilhéus

Landau EC, Hirsch A, Musinsky J (2003) Cobertura Vegetal e Uso do Solo do Sul da Bahia–Brasil, escala 1:100.000, data dos dados: 1996–97. In: Prado PI, Landau EC, Moura RT, Pinto LPS, Fonseca GAB, Alger K (eds) Corredor de Biodiversidade da Mata Atlântica do sul da Bahia. CD-ROM, IESB/CI/CABS/UFMG/UNICAMP, Ilhéus

Laps RR (2006) Efeito da fragmentação do habitat na avifauna da região da Reserva Biológica de Una, Bahia. Doctoral Thesis, University of Campinas, Campinas

Laurance WF (1991) Ecological correlates of extinction proneness in Australian tropical rainforest mammals. Conserv Biol 5:79–89. doi:10.1111/j.1523-1739.1991.tb00390.x

Lobão DEVP (2007) Agroecossistema Cacaueiro da Bahia: Cacau Cabruca e Fragmentos Florestais na Conservação de Espécies Arbóreas. Jaboticabal, São Paulo, 108 pp

Majer JD, Delabie JHC, Smith MRB (1994) Arboreal ant community patterns in Brazilian cocoa farms. Biotropica 26:73–83. doi:10.2307/2389112

Marques JRB, Monteiro WR (2006) Adoção do sistema agroflorestal cacau x seringa—melhoria de consições de cultivo e agregação de valores. In: 28ª Semana do Fazendeiro, CEPLAC/CENEX/EMARC, Itabuna, pp 9–14

Martini AMZ (2007) Florestas não são compostas apenas de árvores: a importância do componente não-arbóreo nas florestas do sul da Bahia. In: I Simpósio sobre Paisagem Cacaueira e Biodiversidade no Sudeste da Bahia, State University of Santa Cruz, Ilhéus, 8–9 October 2007

Martini AMZ, Fiaschi P, Amorim AM, Paixão JL (2007) A hot-point within a hot-spot: a high diversity site in Brazil's Atlantic forest. Biodivers Conserv 16:3111–3128. doi:10.1007/s10531-007-9166-6

Medellín RA, Equihua M, Amin MA (2000) Bat diversity and abundance as indicators of disturbance in Neotropical rainforests. Conserv Biol 14:1666–1675. doi:10.1046/j.1523-1739.2000.99068.x

Mota L, Mariano-Neto E, Faria D (2007) Aspectos da estrutura e diversidade da flora arbórea na região cacaueira do sul da Bahia. In: I Simpósio sobre Paisagem Cacaueira e Biodiversidade no Sudeste da Bahia, State University of Santa Cruz, Ilhéus, 8–9 October 2007

Moura RT (1999) Análise comparativa da estrutura de comunidades de pequenos mamíferos em remanescente de Mata Atlântica e em plantio de cacau em sistema de cabruca no sul da Bahia. Master Thesis, Federal University of Minas Gerais, Belo Horizonte

Moura RT (2005) Observações preliminares sobre ocorrência, distribuição, biologia e ecologia do rato-do-cacau (*Callistomys pictus*), na Mata Atlântica, sul da Bahia. In: III Congresso Brasileiro de Mastozoologia, Aracruz

Moura RT (2008) *Callistomys pictus*. In: Machado ABM, Drummond GM, Paglia AP (eds) Livro Vermelho da Fauna Brasileira Ameaçada de Extinção, Ministério do Meio Ambiente, Brasília, pp 823–825

Nascimento W, Fontoura TA, Raboy BE (2007) Interação entre mico-leão-da-cara-dourada e bromélias em uma cabruca no sul da Bahia, Brasil. In: I Simpósio sobre Paisagem Cacaueira e Biodiversidade no Sudeste da Bahia, State University of Santa Cruz, Ilhéus, 8–9 October 2007

Neves LG, Cardoso N, Santos G, Raboy B (2007) Ocorrência de primatas em diversos tipos de cobertura florestal no sul da Bahia, com ênfase na cabruca. In: I Simpósio sobre Paisagem Cacaueira e Biodiversidade no Sudeste da Bahia, State University of Santa Cruz, Ilhéus, 8–9 October 2007

Oliveira LCO, Dietz JM, Raboy B (2007) Arvores importantes para o mico-leão-de-cara-dourada (Leontopithecus chrysomelas): implicações para o manejo da agrofloresta cabruca no sudeste da Bahia. In: I Simpósio sobre Paisagem Cacaueira e Biodiversidade no Sudeste da Bahia, State University of Santa Cruz, Ilhéus, 8–9 October 2007

Ortiz JV, Faria D, Baumgarten J, Pardini R (2002) Faunal responses to different habitats and landscape configurations in Southeastern Bahia: implications for ecological corridors planning. In: III Congresso Brasileiro de Unidades de Consevação, Fortaleza, pp 629–638

Pacheco JF, Whitney BM, Gonzaga LP (1996) A new genus and species of furnariid (Aves: Furnariidae) from the cocoa-growing region of southeastern Bahia, Brazil. Wilson Bull 108:397–433

Paciencia MLB, Prado J (2004) Efeitos de borda sobre a comunidade de pteridófitas na Mata Atlântica da região de Una, sul da Bahia, Brasil. Rev Bras Bot 27:641–653. doi:10.1590/S0100-84042004000400005

Paciencia MLB, Prado J (2005a) Destribuição espacial da assembleia de pteridófitas em uma paisagem fragmentada de Mata Atlântica no sul da Bahia, Brasil. Hoehnea 32:103–117

Paciencia MLB, Prado J (2005b) Effects of forest fragmentation on pteridophyte diversity in tropical rain forest in Brazil. Plant Ecol 180:87–104. doi:10.1007/s11258-005-3025-x

Pardini R (2001) Pequenos mamíferos e a fragmentação da Mata Atlântica de Una, Sul da Bahia—Processos e Conservação. Doctoral Thesis, University of São Paulo, São Paulo

Pardini R (2004) Effects of forest fragmentation on small mammals in an Atlantic forest landscape. Biodivers Conserv 13:2567–2586. doi:10.1023/B:BIOC.0000048452.18878.2d

Pinto LPS, Lamas IR, Sabato MAL, Tavares LI (1993) Inventário faunístico e Conservação da Mata Atlântica do sul da Bahia. Technical report, Fundação Biodiversitas, Belo Horizonte

Prado J (2000) A new species of *Adianturn* (Pteridaceae) from Bahia, Brazil. Brittonia 52:210–212. doi:10.2307/2666515

Raboy BE, Christman MC, Dietz J (2004) The use of degraded and shade cocoa forests by endangered golden-head lion tamarins, *Leontopithecus chrysomelas*. Oryx 38:75–83. doi:10.1017/S0030605304000122

Rice RA, Greenberg R (2000) Cacao cultivation and the conservation of biological iversity. Ambio 29:167–173. doi:10.1639/0044-7447(2000)029[0167:CCATCO]2.0.CO;2

Rolim SG, Chiarello AG (2004) Slow death of Atlantic forest trees in cocoa agroforestry in southeastern Brazil. Biodivers Conserv 13:2679–2694. doi:10.1007/s10531-004-2142-5

Ruf F, Schroth G (2004) Chocolate forests and monocultures: a historical review of cocoa growing and its conflicting role in tropical deforestation and forest conservation. In: Schroth G, Fonseca GAB, Harvey CA, Gascon C, Vasconcelos HL, Izac AMN (eds) Agroforestry and biodiversity conservation in tropical landscapes. Island Press, Washington, pp 135–150

Sambuichi RHR (2002) Fitossociologia e diversidade de espécies arbóreas em cabrucas (Mata Atlântica raleada sobre plantação de cacau) na região sul da Bahia, Brasil. Acta Bot Bras 16:89–101. doi:10.1590/S0102-33062002000100011

Sambuichi RHR (2006) Estrutura e dinâmica do componente arbóreo em área de cabruca na região cacaueira do sul da Bahia, Brasil. Acta Bot Bras 20:943–954. doi:10.1590/S0102-33062006000400018

Sambuichi RHR, Haridasan M (2007) Recovery of species richness and conservation of native Atlantic forest trees in the cacao plantations of southern Bahia in Brazil. Biodivers Conserv 16:3681–3701. doi:10.1007/s10531-006-9017-x

Santos GJR (1999) Caracterização da caça na região do entorno da Reserva Biológica de Una—BA. Final Report, Projeto Remanescentes de Florestas na Região de Una, BA, RestaUna/PROBIO, State University of Santa Cruz, Ilhéus

Schroth G, Harvey CA (2007) Biodiversity conservation in cocoa production landscapes—an overview. Biodivers Conserv 16:2237–2244. doi:10.1007/s10531-007-9195-1

Schroth G, Fonseca GAB, Harvey CA, Gascon C, Vasconcelos HL (2004) Agroforestry and biodiversity conservation in tropical landscapes. Island Press, Washington, 523 p

Sperber CF, Nakayama K, Valverde MJ, Neves FS (2004) Tree species richness and density affect parasitoid diversity in cacao agroforestry. Basic Appl Ecol 5:241–251. doi:10.1016/j.baae.2004.04.001

Thomas WW, Carvalho AMV, Amorim AMA, Garrison J, Arbeláez AL (1998) Plant endemism in two forests in southern Bahia, Brazil. Biodivers Conserv 7:311–322. doi:10.1023/A:1008825627656

Thomas WW, Jardim JG, Fiaschi P, Amorim AM (2003) Lista preliminaria das angiospermas localmente endêmicas do sul da Bahia e norte do Espírito Santo, Brasil. In: Prado PI, Landau EC, Moura RT, Pinto LPS, Fonseca GAB, Alger K (eds) Corredor de Biodiversidade da Mata Atlântica do sul da Bahia. CD-ROM, IESB/CI/CABS/UFMG/UNICAMP, Ilhéus

Vinha SG, Silva LAM (1982) Árvores aproveitadas como sombreadoras de cacaueiros no sul da Bahia e norte do Espírito Santo. Comissão Executiva do Plano da Lavoura Cacaueira, Ilhéus