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ORIGINAL PAPER

Recovery of species richness and conservation of native Atlantic forest trees in the cacao plantations of southern Bahia in Brazil

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Abstract The Atlantic forests of southern Bahia in Brazil present great species richness and a high degree of endemism. A large part of these native forests were transformed into cacao plantations in an agroforestry system known locally as *cabrucas*, where native trees were culled and cacao was planted under the shade of remaining trees. The present study analyzed the influence of time of implantation (age) and time of abandonment of management practices on tree species diversity of *cabruca* plantations to evaluate the capacity for conservation and recovery of species richness of native Atlantic Forest trees in *cabrucas*. Phytosociological surveys were conducted in five *cabrucas* with different conditions of age and state of abandonment. All trees, including hemiepiphytes and excluding the cacao plants, with a minimum stem diameter of 10 cm at breast height, were surveyed within a 3-ha sampling area in each plantation. A total of 2514 individual trees belonging to 293 species and 52 families were recorded in the five *cabrucas*. The Shannon diversity index varied from 3.31 to 4.22 among the *cabrucas* and was positively correlated with the time of abandonment ($r = 0.97$). The new *cabrucas* showed the highest values of estimated total richness (Chao) and the highest proportion of late successional species than the old ones. All areas preserved a very high proportion of native forest species while the three old *cabrucas* showed a higher proportion of exotic species than the two new ones. Thus the exotic species seem to replace more of the native species in the long run because of management practices and local preferences. The *cabrucas* presented also a high capacity for the regeneration of tree species richness after abandonment. Simple alterations in management practices could improve the recruitment of late successional species in these areas. Economic incentives may be necessary for the farmers to adopt management practices to retain native species which bring no economic returns.

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Introduction

The tropical Atlantic forest which extended originally all along the coastal region of the Brazil is considered to be one of the hotspots for the conservation of biodiversity on a global scale (Myers 1988; Myers et al. 2000). It is one of the most threatened biomes due to extreme fragmentation and destruction of the original vegetation. Only 7.6% of the original Atlantic Forest was still remaining in 1995 (Fundação SOS Mata Atlântica 1998). The biodiversity in some localities of the Atlantic forest is even higher than that of some Amazonian sites (Morellato and Haddad 2000) and the levels of endemism often reach up to 50% of the total and 95% in some groups (Brown and Brown 1992; Nobre 1998).

Along the 3500 km of its extension there are several distinct regions of endemism (Olivier and Santos 1991; Thomas et al. 1998; Costa et al. 2000). One such rich region extends across the southern Bahia states (Thomas and Carvalho 1997), where 300 new species and 5 new genera were identified between 1978 and 1980 (Dean 1995). It is also one of the most susceptible areas to deforestation and fragmentation where only 5–12% of the original forests still remain (Saatchi et al. 2001). In spite of the perturbations, the southern Bahia region still conserves one of the major concentrations of native tree species in east Brazil due to the cacao plantations. The cultivation of cacao was the main economic activity in this region in the early nineteenth century. During this period cacao was planted traditionally by thinning the forests and yet leaving behind enough trees to provide shade for the cacao plants in a system locally known as *cabrucas*. Estimates are that 6800 km^2 of original forests were transformed into cacao plantations in this manner and 70% of these *cabrucas* continue to exist (Franco et al. 1994), contributing to the conservation of biodiversity and the existence of complex forest formations (Johns 1999; Rice and Greenberg 2000).

In a landscape where original forest formations are rarely present or highly fragmented and insufficient to protect remaining endemic species, the *cabrucas* serve as ecological corridors and as borders protecting remaining forest fragments (Alves 1990; Dietz et al. 1996; Faria 2002; Rambaldi and Oliveira 2003; Pardini 2004; Raboy et al. 2004). In spite of its importance as a sustainable agroforestry system, the original characteristics of the *cabrucas* were destroyed when exotic shading trees were introduced in the belief that it would contribute to a higher productivity of the cacao plantations. More recently, some cacao plantations have been transformed into pastures or abandoned due to the economic crisis that hit the cacao industry beginning the late 1980's (Alger and Caldas 1994).

Comparing the few descriptions of the flora and phytosociological surveys of the *cabrucas*, reported from southern Bahia (Alvim and Peixoto 1972; Hummel 1995; Sambuichi 2002) and northern Espírito Santo states (Rolim and Chiarello 2004), it is evident that the *cabrucas* are very heterogeneous in floristic composition and structure due to the time of establishment, differences in management practices and environmental conditions. The significant presence of pioneer and early secondary species and exotic species in all *cabrucas* established at the end of the nineteenth and the beginning of the twentieth century shows that primary forest species are not being adequately protected over the long run. More detailed surveys are yet needed to evaluate the factors that determine the composition, structure and diversity of the *cabrucas* to determine their role in conserving the remaining biodiversity in the region on a sustainable basis and to define long term strategies for their management.

The principal objective of the present study was to conduct a phytosociological survey of the tree species of a few *cabrucas* in different situations in southern Bahia and characterize the existing tree species diversity among them to provide a rational basis for the conservation of native Atlantic Forest species. We focus on the influence of time of implantation and time of abandonment of management practices on diversity and other phytosociological parameters and the capacity for conservation and recovery of native tree species richness.

Study area

The five *cabrucas* which were surveyed were located between 14°41′ and 14°44′ S and 39°09′ and 39°12′ W within the municipality of Ilhéus in the southern region of the Bahia state of Brazil (Fig. 1). The climate is A_f according to the Köppen classification with an annual precipitation of up to 2000 mm, extending over 150 days. The annual potential evapotranspiration is 1200–1300 mm with relative humidity varying from 80 to 90% and a mean annual temperature between 24 and 25°C. The native vegetation is tropical rainforest. The soils are mainly Hapludults and Hapludalfs with varying levels of base saturation and soil fertility (Filho et al. 1987).

The *cabrucas* selected for the study varied in time of implantation (age) and time and degree of abandonment of management practices (Table 1). Information about the history of the plantations and management practices were obtained through interviews with proprietors and employees of the plantations. Three *cabrucas*, named here *old cabrucas*, were more than 70 years old (O1, O2 and O3), and two, named *new cabrucas*, was about 25 to 30 years old (N1 and N2). Because of the economic crisis in the cacao industry beginning the late 1970's, many *cabrucas* of southern Bahia were in a state of neglect. Among the *cabrucas* surveyed in the present study, only one (O1) was being properly maintained with regular weeding and fertilization (Table 1). The periodic removal of ground layer

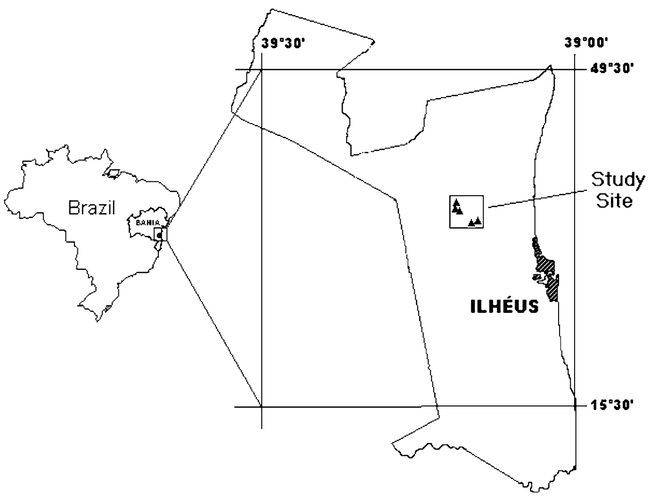

Fig. 1 Localization of the study area in southern Bahia, Brazil

Table 1 Years of abandonment of different management practices at the beginning of the study in 2001 in three old (O1, O2 and O3) and two new (N1 and N2) *cabrucas* in the southern region of Bahia in Brazil

Management practices	Old *cabrucas*			New *cabrucas*	
	O1	O2	O3	N1	N2
Mowing of ground layer vegetation	0	8 (part of the area)	8	4	15
Fertilization	0	Never practiced	Never practiced	7	15
Harvesting of cacao fruits	0	0	0	0	15

vegetation (weeding) was abandoned for four years in new *cabruca* N1 and for eight years in old *cabruca* O3. Weeding was only partially abandoned in old *cabruca* O2. The plantation N2 was totally abandoned for 15 years.

Methods

A 3-ha plot (150 × 200 m) was established in each *cabruca* for phytosociological survey. All trees, with the exception of cacao plants, with a minimum stem diameter of 10 cm at breast (1.3 m) height (DBH) or above the buttresses, were included in the survey. All hemiepiphytes with a minimum of 10 cm root DBH were also surveyed. Total diversity and evenness using Brillouin and Shannon indices (Magurran 1988) were calculated for each 3-ha plot. The Brillouin index is considered more adequate for single plot samplings. However, the Shannon index is more commonly used in vegetation surveys and was calculated to allow comparisons with other reports in the literature. The tree species richness, density and basal area per hectare (Curtis and McIntosh 1950) were calculated for each *cabruca*.

To compare the species richness of the *cabrucas* as a function of the number of individuals, rarefaction curves were constructed using the Ecosim 7.0 software (Gotelli and Entsminger 2001). Average richness values were obtained for 1000 repeated samplings of predetermined individuals using the method of independent sampling. The EstimateS 6.0 software (Colwell 2000) (Estimator Chao1, abundance based) was used to estimate the total richness of all the *cabrucas* surveyed applying the method of Chao (1984). This method uses the number of species with low abundance to estimate the number of species not included in the survey and thus the total number of species in the area (Colwell and Coddington 1994; Chazdon et al. 1998). The Sørensen (Mueller-Dumbois and Ellenberg 1974) and Czekanowski (Kent and Coker 1992) indices were calculated to compare the floristic similarity among the plantations qualitatively and quantitatively.

Results

Altogether, a total of 2514 individual trees, including hemiepiphytes, belonging to 293 species and 52 families were recorded in the five *cabrucas* investigated in the present study (Table 2). Only 13 species (4.4%) were common to all the five *cabrucas* and 174 species (59.4%) were reported from only one of the sites. The number of species in the 3 ha plots varied from 46 to 180. The mean density varied from 47 to 355 individuals ha^{-1}, and the mean basal area varied from 11.8 to 28.2 m^2 ha^{-1} among the plots (Table 3). The species

Table 2 Tree species (DBH ≥ 10 cm) encountered in a survey of 3 ha each of three old (O1, O2 and O3) and two new (N1 and N2) *cabrucas* in the southern region of Bahia in Brazil

Family/species	Number of individuals					
	O1	O2	O3	N1	N2	Total
Anacardiaceae	30	2	51	1	18	102
Spondias mombin	29	–	51	–	–	80
Tapirira guianensis	1	2	–	1	18	22
Annonaceae	4	8	2	2	8	24
Guatteria sp. 1	–	–	–	–	1	1
Guatteria sp. 2	–	2	–	–	1	3
Guatteria sp. 3	–	–	–	–	1	1
Rollinia bahiensis	–	–	–	–	1	1
Rollinia laurifolia	4	1	1	1	1	8
Rollinia mucosa	–	4	–	–	–	4
Rollinia sp. 1	–	–	–	1	–	1
Rollinia sp. 2	–	–	–	–	1	1
Xylopia frutescens	–	–	–	–	1	1
Annonaceae spp. (two species)	–	1	1	–	1	3
Apocynaceae	1	1	–	–	11	13
Himatanthus lancifolius	1	1	–	–	6	8
Lacmellea aculeata	–	–	–	–	3	3
Malouetia sp.	–	–	–	–	1	1
Rauvolfia bahiensis	–	–	–	–	1	1
Araliaceae	1	9	4	46	132	192
Oreopanax sp.				–	2	2
Schefflera morototoni	1	9	4	46	130	190
Arecaceae	1	10	51	–	4	66
Euterpe edulis	–	–	–	–	2	2
Polyandrococos caudescens	1	4	50	–	–	55
Syagrus pseudococos	–	6	1	–	2	9
Bignoniaceae	1	2	15	2	4	24
Tabebuia cassinoides	–	–	14	–	–	14
Tabebuia elliptica	1	1	1	1	4	8
Tabebuia umbellata	–	–	–	1	–	1
Tabebuia sp.	–	1	–	–	–	1
Bombacaceae	–	8	7	3	27	45
Eriotheca macrophylla	–	8	4	2	26	40
Eriotheca sp.	–	–	2	1	–	3
Quararibea turbinata	–	–	1	–	1	2
Boraginaceae	1	4	6	–	4	15
Cordia ecalyculata	1	2	1	–	3	7
Cordia superba	–	2	5	–	1	8
Burseraceae	–	3	4	–	15	22
Protium aracouchini	–	–	–	–	2	2
Protium warmingianum	–	1	–	–	9	10
Protium sp. 1	–	–	1	–	2	3
Protium sp. 2	–	–	–	–	1	1
Protium sp. 3	–	1	–	–	–	1
Protium sp. 4	–	1	1	–	–	2
Protium sp. 5	–	–	2	–	–	2
Protium sp. 6	–	–	–	–	1	1

Table 2 continued

Family/species	Number of individuals					
	O1	O2	O3	N1	N2	Total
Caesalpiniaceae	12	17	40	41	44	154
Apuleia leiocarpa	–	1	2	–	–	3
Arapatiella psilophylla	–	–	–	4	–	4
Bauhinia forficata	3	–	–	–	–	3
Caesalpinia echinata	–	–	2	–	–	2
Chamaecrista duartei	–	–	7	–	–	7
Copaifera lucens	–	1	–	–	2	3
Copaifera multijuga	1	–	–	–	–	1
Copaifera trapezifolia	–	–	–	1	3	4
Dialium guianense	–	1	–	6	26	33
Diplotropis incexis	–	–	–	1	–	1
Hymenaea oblongifolia	–	–	–	2	2	4
Hymenaea sp.	–	2	–	–	–	2
Macrolobium latifolium	–	–	3	15	5	23
Moldenhawera blanchetiana	–	–	15	8	1	24
Senna multijuga	5	10	10	4	–	29
Swartzia acutifolia	–	–	–	–	2	2
Swartzia macrostachya	3	1	1	–	2	7
Swartzia simplex	–	–	–	–	1	1
Tachigalia paratiensis	–	1	–	–	–	1
Caricaceae	3	1	–	–	20	24
Carica papaya	2	1	–	–	–	3
Jacaratia dodecaphylla	1	–	–	–	8	9
Jacaratia heptaphylla	–	–	–	–	12	12
Cariocaraceae	–	–	–	1	3	4
Caryocar edule	–	–	–	1	3	4
Cecropiaceae	5	39	28	25	24	121
Cecropia cineaea	4	10	4	8	1	27
Cecropia hololeuca	1	28	20	15	2	66
Coussapoa microcarpa	–	1	4	2	–	7
Pourouma cecropiifolia	–	–	–	–	21	21
Celastraceae	–	1	–	–	–	1
Maytenus sp.	–	1	–	–	–	1
Couepia monteclarensis	–	–	1	–	–	1
Couepia sp.	–	–	–	–	1	1
Hirtella sp.	–	–	–	–	1	1
Hirtella triandra	–	–	1	–	–	1
Licania belemii	–	–	–	–	1	1
Parinari alvimii	–	–	–	1	–	1
Clusiaceae	–	6	10	1	11	28
Rheedia macrophylla	–	–	–	–	1	1
Symphonia globulifera	–	5	9	1	1	16
Tovomita choisyana	–	–	1	–	6	7
Vismia latifolia	–	1	–	–	3	4
Combretaceae	1	–	12	–	–	13
Terminalia brasiliensis	–	–	2	–	–	2
Terminalia sp.	–	–	10	–	–	10
Combretaceae sp.	1	–	–	–	–	1
Dichapetalaceae	–	–	3	1	6	10
Stephanopodium blanchetianum	–	–	3	1	6	10

Table 2 continued

Family/species	Number of individuals					
	O1	O2	O3	N1	N2	Total
Ebenaceae	1	–	1	–	1	3
Diospyros ebenaster	–	–	–	–	1	1
Diospyros melinonii	–	–	1	–	–	1
Diospyros sp.	1	–	–	–	–	1
Elaeocarpaceae	–	2	–	14	16	32
Sloanea guianensis	–	–	–	2	–	2
Sloanea monosperma	–	1	–	–	–	1
Sloanea obtusifolia	–	1	–	12	16	29
Euphorbiaceae	3	47	25	8	27	110
Alchornea iricurana Casar	–	7	4	1	5	17
Cnidoscolus pubescens	–	17	1	–	–	18
Drypetes sp.	–	–	–	–	2	2
Hieronyma alchorneoides	2	7	3	–	5	17
Mabea piriri	–	–	–	–	4	4
Margaritaria nobilis	1	1	15	–	5	22
Pera glabrata	–	2	2	–	–	4
Pogonophora schomburgkiana	–	–	–	–	3	3
Sapium sublanceolatum	–	–	–	2	–	2
Senefeldera multiflora	–	–	–	–	2	2
Tetrorchidium rubrivenium	–	13	–	5	1	19
Fabaceae	20	16	18	7	24	85
Andira fraxinifolia	–	1	–	–	–	1
Andira sp. 1	–	–	1	–	–	1
Andira sp. 2	–	1	–	–	–	1
Dalbergia nigra	2	–	–	–	–	2
Erythrina fusca	3	1	–	–	–	4
Erythrina poeppigiana	4	–	–	–	–	4
Lonchocarpus guillemineanus	8	2	7	–	–	17
Vataireopsis araroba	–	–	–	–	1	1
Flacourtiaceae	2	1	4	1	12	20
Banara kulmannii	1	–	2	–	2	5
Banara sp.	–	–	–	1	2	3
Carpotroche brasiliensis	1	–	2	–	1	4
Casearia commersoniana	–	–	–	–	4	4
Casearia ulmifolia	–	–	–	–	1	1
Flacourtiaceae spp. (two species)	–	1	–	–	2	3
Lauraceae	5	22	5	7	72	111
Aniba intermedia	–	–	–	–	2	2
Licaria chrysophylla	–	–	–	–	1	1
Nectandra membranacea	–	–	2	–	4	6
Nectandra sp. 1	5	22	3	1	25	56
Nectandra sp. 2	–	–	–	–	2	2
Ocotea glauca	–	–	–	–	1	1
Ocotea percurrens	–	–	–	3	9	12
Ocotea sp. 1	–	–	–	3	22	25
Ocotea sp. 2	–	–	–	–	2	2
Ocotea sp. 3	–	–	–	–	2	2
Lauraceae sp.	–	–	–	–	2	2
Lecythidaceae	5	7	26	18	30	86
Cariniana estrellensis	1	2	7	–	–	10
Cariniana legalis	3	–	4	–	–	7

Table 2 continued

Family/species	Number of individuals					
	O1	O2	O3	N1	N2	Total
Eschweilera ovata	–	4	–	13	15	32
Eschweilera sp.	–	–	2	–	–	2
Lecythis lurida	–	–	–	2	12	14
Lecythis pisonis	1	1	13	3	3	21
Malpighiaceae	–	–	2	–	1	3
Byrsonima laevigata	–	–	2	–	1	3
Melastomataceae	–	–	6	–	6	12
Miconia calvescens	–	–	6	–	4	10
Miconia minutiflora	–	–	–	–	1	1
Miconia prasina	–	–	–	–	1	1
Meliaceae	5	19	14	2	13	53
Cedrela odorata	5	12	4	1	4	26
Guarea kuntiana	–	1	–	–	3	4
Guarea macrophylla	–	3	5	–	–	8
Trichilia lepidota	–	–	–	–	5	5
Trichilia pleeana	–	–	–	–	1	1
Trichilia quadrijuga	–	3	5	1	–	9
Mimosaceae	12	23	44	1	21	101
Albizia polycephala	10	2	2	–	1	15
Ballizia pedicelaris	–	–	–	–	5	5
Inga affinis	2	16	42	–	6	66
Inga capitata	–	–	–	–	1	1
Inga nuda	–	3	–	–	–	3
Inga thibaudiana	–	2	–	–	1	3
Parkia pendula	–	–	–	1	4	5
Mimosaceae sp.	–	–	–	–	3	3
Monimiaceae	–	–	–	–	7	7
Bracteanthus atlanticus	–	–	–	–	5	5
Siparuna sp.	–	–	–	–	2	2
Moraceae	17	161	32	15	157	382
Artocarpus heterophyllus	8	137	8	3	11	167
Brosimum gaudichaudii	–	–	1	–	–	1
Brosimum guianense	–	–	–	–	3	3
Brosimum rubescens	–	–	–	–	15	15
Brosimum sp. 1	–	–	1	–	–	1
Brosimum sp. 2	–	1	–	1	–	2
Brosimum sp. 3	–	1	–	–	–	1
Clarisia ilicifolia	–	1	–	–	–	1
Ficus broadwayi	–	–	–	1	–	1
Ficus clusiifolia	4	10	6	–	–	20
Ficus gomelleira	2	1	2	2	6	13
Ficus insipida	–	–	4	2	2	8
Ficus mariae	–	1	2	–	–	3
Ficus obtusifolia	2	–	–	1	–	3
Ficus pulchella	–	5	–	1	5	11
Ficus trigonata	–	3	2	1	–	6
Ficus sp. 1	–	–	–	1	–	1
Ficus sp. 2	–	–	1	–	–	1
Ficus sp. 3	–	1	2	–	–	3
Ficus sp. 4	1	–	–	–	–	1

Table 2 continued

Family/species	Number of individuals					
	O1	O2	O3	N1	N2	Total
Helicostylis tomentosa	–	–	2	1	113	116
Sorocea guilleminiana	–	–	–	–	2	2
Moraceae spp. (two species)	–	–	1	1	–	2
Myristicaceae	–	–	2	3	16	21
Virola gardneri	–	–	2	2	15	19
Virola sp.	–	–	–	1	–	1
Myristicaceae sp.	–	–	–	–	1	1
Myrsinaceae	–	2	–	–	1	3
Rapanea ferruginea	–	2	–	–	1	3
Myrtaceae	–	4	25	6	69	104
Compamanesia dichotoma	–	1	2	–	–	3
Eugenia flamingensis	–	–	1	–	–	1
Eugenia rostrata	–	–	–	–	10	10
Eugenia sp. 1	–	–	–	–	7	7
Eugenia sp. 2	–	–	1	–	1	2
Eugenia sp. 3	–	1	–	–	–	1
Eugenia sp. 4	–	–	–	–	2	2
Eugenia sp. 5	–	–	–	2	–	2
Marlierea strigipes	–	–	1	–	–	1
Marlierea tomentosa	–	–	–	–	1	1
Psidium sp.	–	–	1	–	–	1
Myrtaceae spp. (twenty four species)	–	2	19	4	48	73
Nyctaginaceae	–	–	12	1	49	62
Guapira hirsuta	–	–	1	–	–	1
Guapira nitida	–	–	11	–	44	55
Guapira opposita	–	–	–	–	3	3
Guapira sp. 1	–	–	–	–	2	2
Guapira sp. 2	–	–	–	1	–	1
Olacaceae	–	–	1	–	16	17
Aptandra tubicina	–	–	–	–	2	2
Tetrastylidium grandifolium	–	–	1	–	4	5
Olacaceae spp. (three species)	–	–	–	–	10	10
Phytolaccaceae	–	–	6	–	–	6
Gallesia integrifolia	–	–	6	–	–	6
Polygonaceae	–	–	1	–	1	2
Coccoloba alnifolia	–	–	1	–	1	2
Quiinaceae	–	–	–	–	1	1
Lacunaria decastyla	–	–	–	–	1	1
Rubiaceae	2	7	8	2	13	32
Alseis floribunda	–	–	–	1	–	1
Bathysa mendoncaei	–	–	–	–	6	6
Bathysa sp. 1	–	–	–	–	2	2
Bathysa sp. 2	–	–	–	–	1	1
Genipa americana	1	5	3	–	–	9
Guettarda platyphylla	1	–	1	1	–	3
Psychotria mapourioides	–	2	3	–	3	8
Simira viridiflora	–	–	1	–	–	1
Tocoyena bullata	–	–	–	–	1	1

Table 2 continued

Family/species	Number of individuals					
	O1	O2	O3	N1	N2	Total
Rutaceae	–	7	1	1	51	60
Citrus nobilis	–	–	1	–	–	1
Zanthoxylum minutiflorum	–	4	–	1	11	16
Zanthoxylum nemorale	–	–	–	–	2	2
Zanthoxylum rhoifolium	–	3	–	–	7	1
Rutaceae sp.	–	–	–	–	31	31
Santalaceae	–	–	1	–	–	1
Acanthosyris paulo–alvinii	–	–	1	–	–	1
Sapindaceae	–	–	3	1	2	6
Cupania rugosa	–	–	1	–	–	1
Cupania sp. 1	–	–	–	1	1	2
Cupania sp. 2	–	–	2	–	–	2
Cupania sp. 3	–	–	–	–	1	1
Sapotaceae	–	2	33	20	54	109
Chrysophyllum gonocarpum	–	–	–	–	1	1
Chrysophyllum lucentifolium	–	–	–	–	1	1
Chrysophyllum splendens	–	1	1	–	5	7
Ecclinusa ramiflora	–	–	3	1	2	6
Manilkara elata	–	–	–	10	–	10
Micropholis compta	–	–	–	–	2	2
Micropholis crassipedicellata	–	–	–	3	8	11
Micropholis sp.	–	–	–	–	1	1
Pouteria bangii	–	–	–	1	10	11
Pouteria beaurepairei	–	–	2	–	5	7
Pouteria cuspidata	–	–	–	–	1	1
Pouteria grandiflora	–	–	1	–	–	1
Pouteria guianensis	–	–	–	–	2	2
Pouteria procera	–	–	15	–	–	15
Pouteria reticulata	–	–	–	–	5	5
Pouteria sp. 1	–	–	–	1	2	3
Pouteria sp. 2	–	–	–	1	1	2
Pouteria sp. 3	–	–	–	1	–	1
Pradosia lactescens	–	–	–	–	2	2
Sarcaulus brasiliensis	–	1	11	–	1	13
Sapotaceae spp. (four species)	–	–	–	2	5	7
Simaroubaceae	2	19	7	1	18	47
Simaba guianensis	–	–	–	–	4	4
Simarouba amara	2	19	7	1	14	43
Solanaceae	1	–	–	1	2	4
Cestrum laevigatum	1	–	–	–	–	1
Solanum sp.	–	–	–	1	2	3
Sterculiaceae		8	8	8	27	51
Sterculia excelsa	–	8	8	8	27	51
Tiliaceae	–	1	1	1	–	3
Apeiba albiflora	–	–	1	1	–	2
Luehea divaricata	–	1	–	–	–	1
Ulmaceae	3	16	4	47	2	72
Trema micrantha	3	16	4	47	2	72

Table 2 continued

Family/species	Number of individuals					
	O1	O2	O3	N1	N2	Total
Urticaceae	–	–	–	2	–	2
Urera caracasana	–	–	–	2	–	2
Verbenaceae	4	–	–	11	–	15
Aegiphila sellowiana	–	–	–	6	–	6
Citharexylum myrianthum	4	–	–	–	–	4
Gmelina arborea	–	–	–	5	–	5
Violaceae				2	17	19
Rinorea guianensis	–	–	–	2	17	19
Unidentified (six species)	–	–	–	2	5	7
Total	142	475	526	306	1065	2514

Table 3 Phytosociological parameters for tree communities (DBH ≥ 10 cm) encountered in a survey of five *cabrucas* in the southern region of Bahia in Brazil

Cabruca	Density (ind. ha^{-1})	Basal area (m^2 ha^{-1})	Number of species (3-ha plot)	Number of families (3-ha plot)
O1	47 (±17)	11.8 (±2.9)	46	25
O2	158 (±30)	18.3 (±1.1)	85	32
O3	175 (±41)	23.5 (±1.3)	113	40
N1	102 (±29)	15.7 (±3.3)	82	35
N2	355 (±54)	28.2 (±3.4)	180	45

richness, density and basal area for different diameter classes showed a strong correlation with the time of total abandonment of weeding practices in the *cabrucas* (Figs. 2–4).

Native species accounted for 97.3% of the total species surveyed. The category of late secondary/climax species shows the greatest proportion of species in all plots (Table 4). The new *cabrucas* show the highest proportion of late secondary/climax species and the smallest proportion of pioneer/early secondary and exotic species than the older ones. In the same age category, the *cabrucas* abandoned without weeding for longer periods showed the largest proportion of late secondary/climax species and the smallest proportion of pioneer/early secondary and exotic ones. The older *cabrucas* showed the largest relative abundances of individuals of exotic species, and 4–6 introduced species accounted for 12.0–33.1% of individuals. The relative abundance of individuals in the other categories was correlated with the time of abandonment of weeding (Fig. 5). The abundance of late successionals increased, and of early successionals decreased, with the time of abandonment.

Spondias mombin and *Artocarpus heterophyllus* were the most abundant exotic species in the survey, showing also the highest values of basal area in the older *cabrucas*. The most abundant early successional species was *Trema micrantha* and *Schefflera morototoni*. Among the late successional species, *Sloanea obtusifolia*, *Sterculia excelsa*, *Pterocarpus rohrii*, *Simarouba amara*, *Eryotheca macrophylla* and *Lecythis pisonis* showed the highest values of basal area in the survey.

The Shannon diversity index varied from 3.31 to 4.22 in the plots (Table 5) and was positively correlated with the time of total abandonment of weeding ($r = 0.97$). The new plantations showed the highest values of estimated total richness (Chao) (Table 5) and

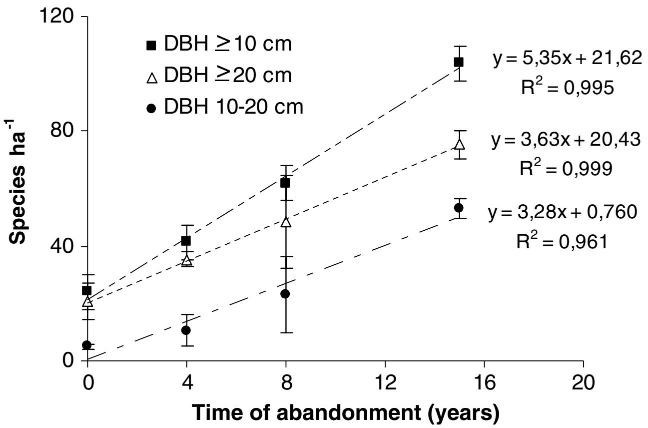

Fig. 2 Tree species richness as a function of time of total abandonment of weeding in four *cabrucas* surveyed in southern Bahia, Brazil

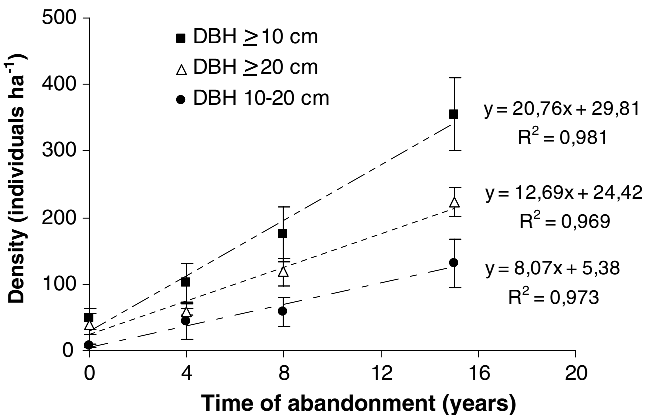

Fig. 3 Tree density as a function of time of total abandonment of weeding in four *cabrucas* surveyed in southern Bahia, Brazil

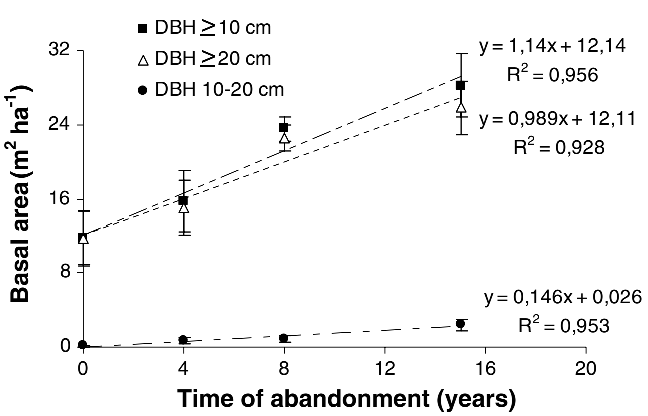

Fig. 4 Basal area of trees as a function of time of total abandonment of weeding in four *cabrucas* surveyed in southern Bahia, Brazil

Table 4 Percentage of species (S) and relative abundance of individuals (A) with DBH ≥ 10 cm of different categories of trees encountered in a survey of 3-ha each of three old (O1, O2 and O3) and two new (N1 and N2) *cabrucas* in the southern region of Bahia in Brazil

Category	Old *cabrucas*						New *cabrucas*			
	O1		O2		O3		N1		N2	
	S	A	S	A	S	A	S	A	S	A
Exotic species	13.0	33.1	4.7	30.3	3.5	12.0	2.4	2.6	0.6	1.0
Pioneer/Early secondary species	34.8	35.2	20.0	28.6	11.5	23.8	11.0	43.5	8.3	17.7
Late secondary/ Clímax species	52.2	31.7	75.3	41.1	85.0	64.3	86.6	53.9	91.1	81.3

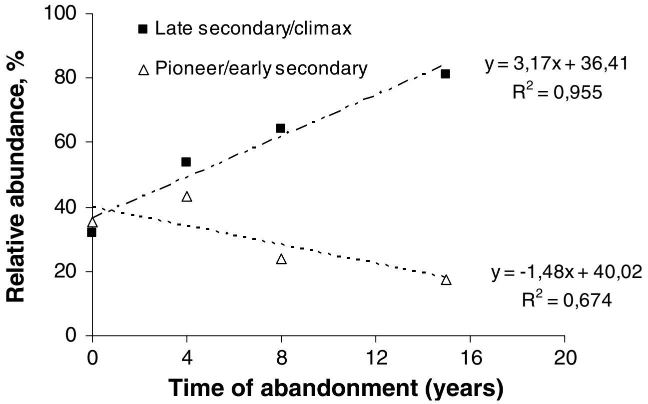

Fig. 5 Relative abundance of species by successional classes of trees (DBH ≥ 10 cm) as a function of time of total abandonment of weeding in four *cabrucas* surveyed in southern Bahia, Brazil

lower stabilization of the species-individuals curves (Fig. 6). Plots O1 and O3 showed the highest values of equitability (Table 5). The highest values of similarities, both qualitative and quantitative, were between the old *cabrucas* O2 and O3 (Table 6). The new *cabruca* N2 was the least similar to other *cabrucas*. The older *cabrucas* were more similar among themselves than to the new *cabrucas*.

The families *Myrtaceae*, *Moraceae* and *Sapotaceae* showed the highest number of species in the total survey (Table 1). The richness of Myrtaceae in the plots was strongly correlated with the time of abandonment of weeding (Fig. 7). The number of species of Sapotaceae was highest in the new *cabruca* areas, and also showed a high correlation with the time of abandonment of weeding (Fig. 8). The richness of Moraceae was high in all the plots, showing no correlation with the time of abandonment.

As far as the stem diameter distribution was concerned, only plantations O2 and O3 did not show significant differences using the Kolmogorov–Smirnov test. In the areas where the weeding practice was abandoned there was a high concentration of individuals with DBH ≤ 20 cm, especially in the early stages of abandonment (Fig. 9).

Discussion

Of the total of 179 species identified up to the species level in the present survey (Table 1), only 111 species were reported to occur in the conservation reserves of the cocoa region of

Table 5 Diversity, evenness and total estimated richness in a survey of 3-ha each of three old (O1, O2 and O3) and two new (N1 and N2) *cabrucas* in the southern region of Bahia in Brazil

	Shannon index		Brillouin index		Estimator Chao
	H'	Evenness	*HB*	Evenness	Richness
Old *cabrucas*					
O1	3.31	0.87	2.91	0.76	72
O2	3.34	0.75	3.09	0.70	144
O3	3.99	0.85	3.70	0.78	156
New *cabrucas*					
N1	3.54	0.80	3.20	0.73	164
N2	4.22	0.81	3.98	0.77	228

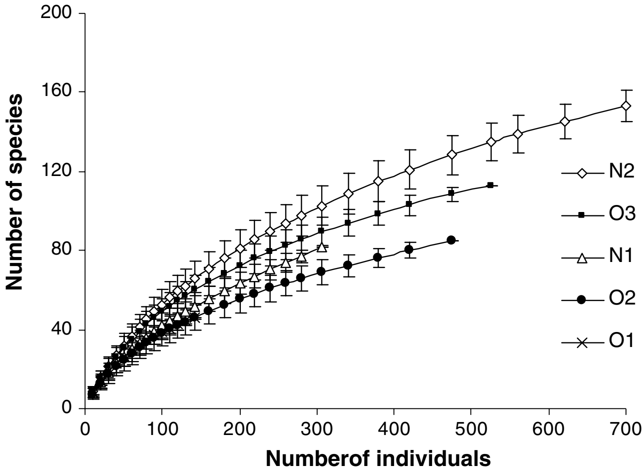

Fig. 6 Curves of rarefaction of the number of species as a function of individuals sampled for old (O1, O2 and O3) and new (N1 and N2) *cabrucas* in southern Bahia, Brazil. Mean and 95% confidence intervals for 1000 random samplings of individuals

Table 6 Similarity indices of Sørensen* (lower triangle, numbers in bold font) and Czekanowski** (upper triangle, numbers in normal font) encountered in a survey of 3-ha each of three old (O1, O2 and O3) and two new (N1 and N2) *cabrucas* in the southern region of Bahia in Brazil

		Old *cabrucas*			New *cabrucas*	
		O1	O2	O3	N1	N2
Old *cabrucas*				Czekanowski		
O1	Sørensen	–	20.1	29.0	12.9	7.5
O2		**0.46**	–	32.0	24.1	18.8
O3		**0.39**	**0.47**	–	20.9	16.7
New *cabrucas*						
N1		**0.27**	**0.36**	**0.33**	–	23.0
N2		**0.21**	**0.34**	**0.36**	**0.37**	–

*Qualitative, varies from 0 to 1; **Quantitative, varies from 0 to 100

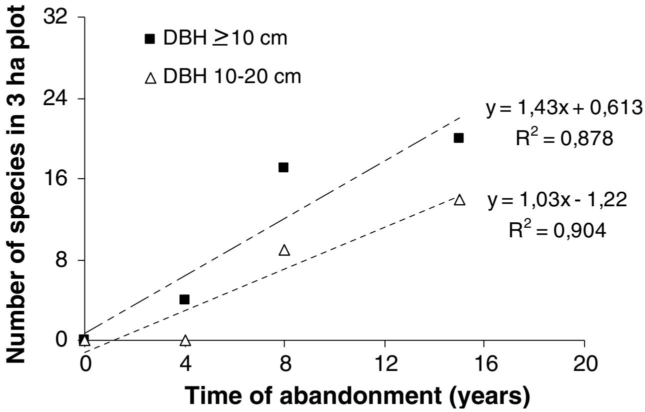

Fig. 7 Species richness of *Myrtaceae* trees as a function of time of total abandonment of weeding in four 3 ha plots of *cabruca* surveyed in southern Bahia, Brazil

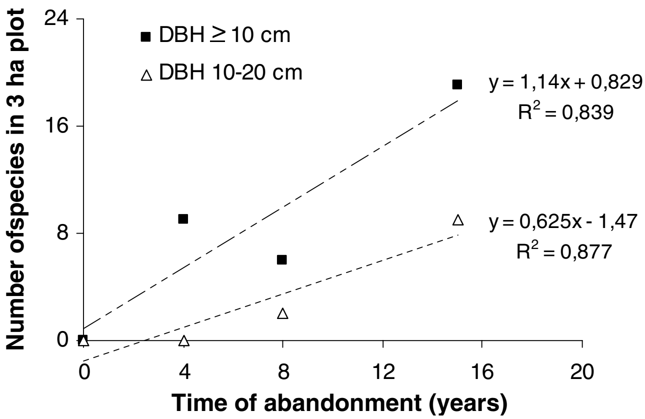

Fig. 8 Species richness of *Sapotaceae* trees as a function of time of total abandonment of weeding in four 3 ha plots of *cabruca* surveyed in southern Bahia, Brazil

Bahia in earlier studies. Seventy three of these species occur in the Una Biological Reserve (Amorim et al. in press), 67 species in the Serra do Conduru State Park (Thomas et al. in press), and 54 species occur in the Serra do Teimoso Private Reserve (Amorim et al. 2005). Vinha and Silva (1982) reported 142 tree species from *cabrucas* of which only 129 were described up to the species level and 73 were found in the present survey. Rolim and Chiarello (2004) reported the occurrence of 105 species in a *cabruca* in the neighboring state of Espírito Santo, south of Bahia, of which 31 were common to the *cabrucas* reported in the present study.

The large number of unidentified species in the present study attests to the lack of detailed surveys in the native forests and the large number of endemic species yet to be identified. There was also the limitation that in some cases we could not collect adequate herbarium specimens for detailed identification because we could not return to collect reproductive parts when the trees produced inflorescence.

The tree diversity in the surveyed *cabrucas* should be considered high. The Shannon index values reported here are in the same range of values (3.0–4.3) reported for native

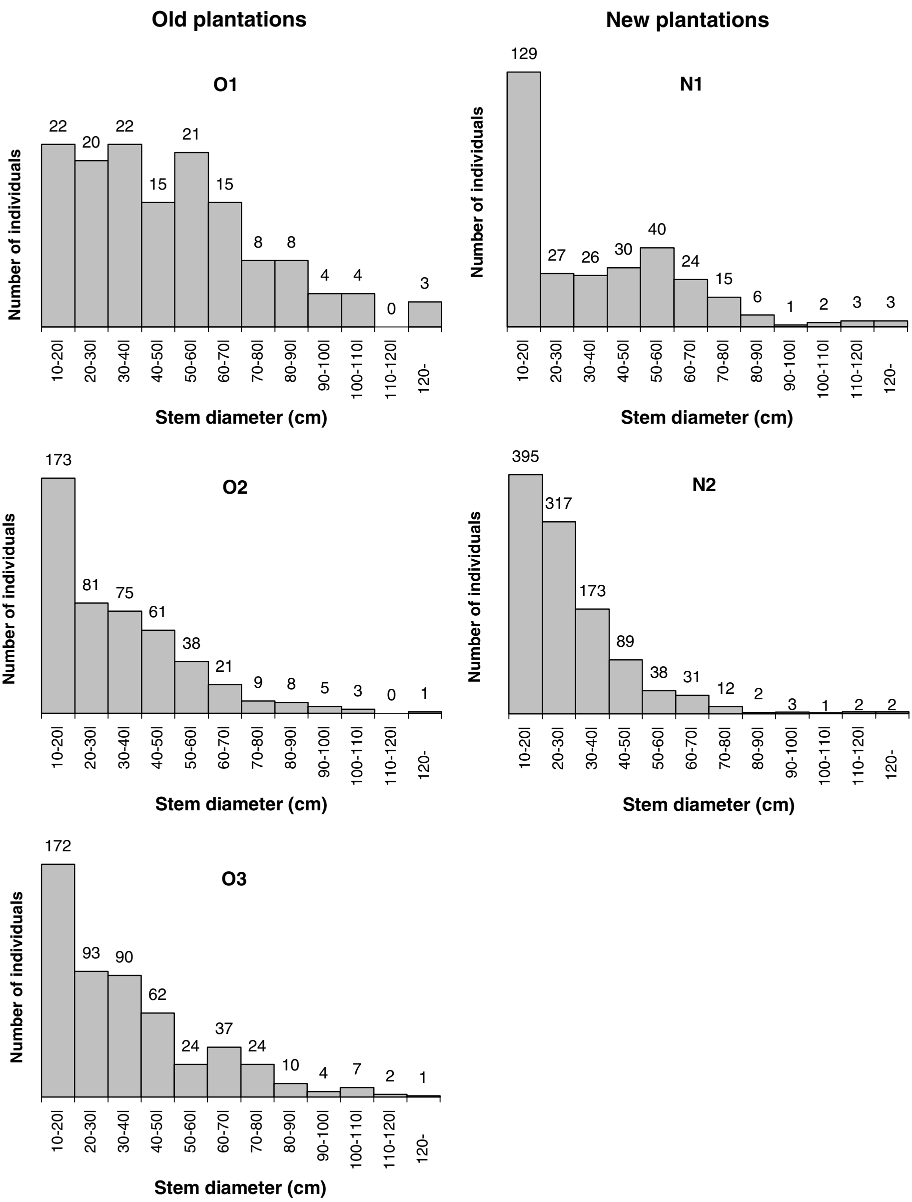

Fig. 9 Distribution of tree diameter (DBH or above the buttresses) for old and new *cabrucas* in southern Bahia, Brazil

Atlantic Forests. The abandonment of the management practices improved the diversity in most of plots, but there was a great diversity even in the *cabruca* O1 where all regular management practices were being maintained. Hummel (1995) and Sambuichi (2002) reported Shannon index of 3.06 and 3.35 for old managed *cabrucas* in the region. This is surprisingly high especially for an agroforestry system which has been in place for a considerable length of time and suffered strong perturbations along several decades. This high diversity in the *cabrucas* reflects the high diversity in the original native forests. Mori et al. (1983a, b) reported 178 species among 600 individuals surveyed in a natural forest and Thomas et al. (in press) 270 species in one hectare for DBH ≥ 10 cm. Also, we found low similarity among most of the surveyed *cabrucas* in spite of their relative proximity. Low floristic similarity is common among adjacent areas of tropical forests of the Amazon and the Atlantic regions (Vinha et al. 1976; Tavares et al. 1979; Mori et al. 1983a; Campbell et al. 1986, 1992; Scudeler et al. 2001). In many cases abundant species encountered in an area could have a very restricted geographical distribution (Scudeler et al. 2001).

The large variation in the tree density among the *cabrucas* is a feature already observed by Alvim and Peixoto (1972) who reported densities varying from 25 to 323 individuals ha^{-1} and by Alves (1990) who reported values from 35 to 133 individuals ha^{-1} for DBH ≥ 10 cm. The amount of shading in cacao plantations depends on management practices adopted by the farmers. To improve the cacao production the agronomic recommendation is to leave only 25 trees ha^{-1} but for economic reasons even in well managed areas the farmers rarely observe this guideline (Johns 1999). In the last few decades economic crisis and the consequent abandonment of cultivation practices have also contributed to this great variation. The variation in density among the plots in the present survey can be mostly explained by differences in the time and degree of abandonment of management practices. Some variation in density is inherent in the native forests of the region. Mori et al. (1983a) reported 891 individuals ha^{-1} and Thomas et al. (in press) found 988 individuals ha^{-1} while Alves (1990) estimated densities varying from 596 to 830 individuals ha^{-1} for DBH ≥ 10 cm. The density of trees in the *cabrucas* reflects the intensity of thinning of forest trees during the implantation of the cacao plantations and is influenced, along the course of time, by the equilibrium between tree mortality and recruitment.

The strong positive correlation of the phytossociological parameters with the time of abandonment of weeding (Figs. 2–4) shows the importance of this management practice in reducing the richness, density and basal area of the *cabrucas* by controlling the tree recruitment. During weeding, almost all the new seedlings are removed, leaving a few to attain maturity only when it is considered necessary to substitute dead trees. The seedling species that are selected to survive depends on the choice of the farm workers. Generally they are able to identify seedlings of some of the most common species, and seedlings are selected for edible fruits or for good quality wood. In case of immediate necessity for improved shading, they could select early successional species such as *Inga* spp., *Senna multijuga* and *Albizia polycephala*. The seedlings of rarer species and trees which are not of economic importance are generally weeded out. Fast growing species take advantage whereas slow growing species have little chance to survive the periodicals weeding events to attain maturity. The weeding not only reduces the diversity by reducing the total density of trees and limiting the recruitment in general, but also by selecting some species in detriment of others.

The largest density and basal area of exotic species found in the three old plantations show the tendency for these species to dominate to the detriment of native species with the passing of time. *Spondias mombin* dominates in two of the old plantations (O1 and O3) and *Artocarpus heterophyllus* in the other (O2). These two species were introduced in the cacao plantations of southern Bahia from very early times and are among the most important species in other *cabruca* surveys (Alvim and Peixoto 1972; Hummel 1995; Sambuichi 2002; Rolim and Chiarello 2004). These are fast growing species and their edible fruits are widely used by local people. Also, the higher proportion of early successional and exotic species found in the old *cabrucas* than in the new ones support the thesis that these species are slowly substituting the late successional species in the *cabrucas*.

The families more frequently encountered in the surveys of *cabrucas* in southern Bahia are *Anacardiaceae*, *Moraceae*, *Fabaceae*, *Caesalpiniaceae*, *Mimosaceae*, *Lecythidaceae*, *Euphorbiaceae*, *Lauraceae*, *Meliaceae*, and *Annonaceae* (Alvim and Peixoto 1972, Hummel 1995, Sambuichi 2002). All these families are also reported in the present work. Mori et al. (1983a, b) reported that the more important families in the Atlantic forest segments they studied were *Myrtaceae*, *Sapotaceae*, *Caesalpiniaceae*, *Lauraceae*, *Chrysobalanaceae*, *Euphorbiaceae*, *Bombacaceae*, *Lecythidaceae*, *Melastomataceae*, and *Moraceae*. Oliveira-Filho and Fontes (2000) also suggested that *Myrtaceae* is the most important family in all formations of native Atlantic forests. This high importance of *Myrtaceae* is a feature of the Atlantic coastal forests with many endemics species, a feature not common in other neotropical forests. It is common in the forests of Australia and Madagascar (Gentry 1988). Some of the more common families of the Atlantic forest are less favored in *cabrucas*. The majority of species of *Myrtaceae*, *Sapotaceae* and *Chrysobalanaceae* are climax species. These have slow growth and are mostly rare, and the probability of these seedlings being eliminated by the farm workers is very high. Some species do not regenerate well in more open areas. Moreover, many of the *Myrtaceae* species are of small and medium size in the native forest (Mori et al. 1983a) and are felled during establishment of cacao plantations. Other less favored families in the *cabrucas* are *Bombacaceae* due to the poor quality of their wood and *Melastomataceae* because of the small size of their trees.

The *Moraceae* family presented a large number of species in all the *cabrucas* due to the presence of the genera *Ficus* as earlier reported by Hummel (1995) and Sambuichi (2002). These species appear to be more common in disturbed areas than in native forests. Mori et al. (1983a) did not report this genus in their survey of native Atlantic forests and Tavares et al. (1979) encountered only one species with low frequency. They are in general fast growing species with many stranglers which escape weeding.

The increase of species richness with the time of abandonment of weeding in the 10–20 cm diameter class (Fig. 2) manifested principally after the fourth year. Otherwise, the difference in species richness between the old plot O1 (not abandoned) and the new plot N1 (four years of abandonment) is greater in the ≥20 cm DBH class. Thus four years of abandonment was not sufficient to cause a significant increase in richness in this DBH class, this difference can be attributed mostly to the influence of the time of implantation (age) in reducing the species richness of the old plantation. Similar results were observed for the families *Myrtaceae* and *Sapotaceae* (Figs. 7 and 8) indicating a negative influence of *cabruca* age and a positive influence of weeding abandonment. This also demonstrates forest resilience after abandonment of management practices for these two important Atlantic Forest families.

These results reinforce the hypothesis that the cultivation practices applied in the *cabrucas* are not adequate for conservation purposes. The *cabrucas* are loosing species richness and are being dominated by exotic and early successional tree species as was be previously pointed out by Sambuichi (2002) and Rolim and Chiarello (2004) in earlier surveys. The fast increase in richness with the abandonment shows that the *cabrucas* have a high capacity for tree species regeneration and simple alterations in the management practices can improve the conservation of late successional species. As the amount of well preserved forests is very small in the cocoa region, the conservation of tree species in the *cabrucas* is important to reduce the risk of extinction especially of the rarer and endemics species. It is possible that some of these species have significant populations preserved only in the *cabrucas*. The results also show that the *cabrucas*are very suitable for fast forestry restoration to enlarge the forest cover in the region. However, economic interests are often contrary to conservation needs. The pressure to destroy the reminiscent forests is strong and the agronomic recommendations for *cabruca* management in general priorize profits in detriment of sustainability. To change this, farmers should be encouraged to retain native tree species in cacao plantations which could be efficient providing shade (Ewell 1986; Myers 1986) and at the same time conserving biological diversity (Phillips 1997). Environmental education is important but economic incentives are fundamental to assure biological conservation.

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