Article

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Floristic and structural variations in Lowland Atlantic Forests with different histories and their use in conservation planning[1]

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ABSTRACT - (Floristic and structural variations in Lowland Atlantic Forests with different histories and their use in conservation planning). We sought to evaluate the floristic and structural variations between three areas with distinct backgrounds in the Sooretama Biological Reserve, remnantd of Lowland Atlantic Forest in Brazil. For vegetation sampling, 30 transects were established in three different areas: post-pasture (PAS), post-fire (FIR), and preserved (PRE) remnants, totaling a sample area of 0.3ha. All individuals in the woody layer with diameter at breast height ≥ 2.5cm were sampled. Variations in floristic composition were evaluated by means of NMDS, based on the presence or absence of species. There are clear variations between the three areas evaluated, in which the PRE area presents greater species richness, floristic diversity, and basal area, with parameters similar to forests of high diversity in northern Espírito Santo and southern Bahia. The performance of inventories and monitoring of the remnants of Lowland Atlantic Forests in neglected regions are fundamental for planning conservation and enrichment measures of these vegetations
Keywords: floristic diversity, NMDS, Sooretama Biological Reserve

RESUMO - (Variações florísticas e estruturais em Floresta Ombrófila Densa de Terras Baixas com diferentes históricos de uso no planejamento da conservação). Buscamos avaliar as variações florísticas e estruturais entre três áreas com origens distintas na Reserva Biológica de Sooretama. Para amostragem da vegetação, foram estabelecidos 30 transectos em três áreas distintas: pós-pasto (PAS), pós-fogo (FIR) e remanescentes conservados (PRE), totalizando uma área amostral de 0,3ha. Todos os indivíduos da camada lenhosa com diâmetro à altura do peito ≥ 2,5 cm foram amostrados. As variações na composição florística foram avaliadas por meio do NMDS, com base na presença ou ausência de espécies. Há claras variações entre as três áreas avaliadas, sendo que a área do PRE apresenta maior riqueza de espécies, diversidade florística e área basal, com parâmetros semelhantes às florestas de alta diversidade do norte do Espírito Santo e sul da Bahia. A realização de inventários e monitoramento dos remanescentes de Floresta Ombrófila Densa de Terras Baixas em regiões negligenciadas são fundamentais para o planejamento de medidas de conservação e enriquecimento dessas vegetações.
Palavras-chave: diversidade florística, NMDS, Reserva Biológica de Sooretama

Introduction

Considered one of the largest hotspots in the world (Myers *et al* 2000), the Atlantic Forest encompasses high environmental heterogeneity, high biodiversity, and is responsible for harbor several endemic species (Salemi *et al* 2013, Thomaz 2010, ZappI *et al* 2015). Among its various vegetation types (Thomaz 2010, IBGE 2012), the Dense Ombrophilous Forest of the Lowlands (here called Lowland Atlantic Forest) stands out in the northern regions of the State of Espírito Santo and in the southern regions of Bahia (Paula & Soares 2011). Despite the biological and environmental importance, this forest ecosystem constantly suffers due to deforestation and degradation processes; currently, only 12.4% of the original vegetation remain (Rezende *et al* 2018).

Due to the flat relief and the consequent easer access, together with the high volumes of commercial tree species (Heinsdijk *et al* 1965), the ecosystem of the Lowland Atlantic Forests are targeted by agriculture, livestock, and urbanization (Paula and Soares 2011, Figueira Branco *et al* 2019), making them vulnerable to clear cut or intensive illegal logging (Rolim *et al* 2016), affecting the forest structure and exposing their biodiversity to local extinction (Thomaz 2010). These factors emphasize the importance of seeking subsidies for the definition of conservation policies (Dos Santos *et al* 2020) and to cease direct impacts on such remnants.

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The impacts on Lowland Atlantic Forests can be direct (e.g. clear cut, log or fire events) and indirect (e.g. fragmentation and edge effect) (Fernandes *et al* 2016, Joly *et al* 2014, Dias *et al* 2021), promoting changes in species composition, forest carbon stock, and impacting the structure of remaining plant communities (Pyles *et al* 2022). The remnants formed by forest fragmentation are mostly small, disturbed, and isolated (lira *et al* 2012), and they can be structured in different successional stages (Lira *et al* 2012) and successional conditions (Safar *et al* 2020, Tabarelli & Peres, Melo, 2012). Studying the composition and structure of phytosociological organization allows us to understand the responses of forests – its resistance and resilience – to the disturbances generated and how it persists (Joly *et al* 2014), thus providing important information about the successional trajectory of the forest throughout the different disturbances (Marques *et al* 2014, Rolim *et al* 2017).

Thus, we aim to compare forest sites with distinct disturbances histories of a remnant of the Lowland Atlantic Forest, seeking to verify how they change in trees species composition and phytosociological structure, also regarding about dispersion syndromes and endangered status. Considering this information, we propose some conservation measures as a pilot model that can be replicated to other remnants of Lowland Atlantic Forests in Brazil.

Materials and methods

Study Area - This study was developed in the Biological Reserve (REBIO) of Sooretama, a Conservation Unit (CU) located between the municipalities of Sooretama, Linhares, Vila Valério, and Jaguaré (40°12'W–18°54"S; 39°55'W–19°3'S), north of the State of Espírito Santo (figure 1). The Sooretama REBIO, a protected area since 1982 (Ferreira 1981), covers an area of 27,860 ha and is considered the largest remnant of this vegetation as CU in Espírito Santo (Rolim *et al* 2016).

The climate of the region is classified as humid tropical, with average annual precipitation of 1,403 mm, dry season from May to September, and an average annual temperature of 23.6 °C (Ferreira 1981). The characteristic vegetation type of the studied area is Lowland Dense Ombrophilous Forest, known as Lowland Atlantic Forest, characterized by its spaced trees, with average height above 30 m and average altitude of 50 m.a.s.l., typical vegetation of the northern region of Espírito Santo (Saiter *et al* 2016, Garbin *et al* 2017).

This study was carried out in three forest areas (figure 1) under different succession processes in the REBIO of Sooretama: FIR (fire occurrence), area that suffered purposeful fires in 1998, approximately 2,000 ha; PAS (pasture), located near the Barra Seca River, where a complete suppression of vegetation occurred in 1971 due to cattle ranching; PRE (preserved), considered the most protected area within the REBIO and defined as the reference environment for comparative purposes.

Data Sampling - In the phytosociological survey, the transects method (Gentrz 1988) was used, with an allocation of 10 equidistant sample units 50 m from each other. The dimensions used were 50 × 2 m, composing 0.1 ha of sample area for each locality in this study (FIR, PAS, and PRE). In each sampling unit, all individuals with

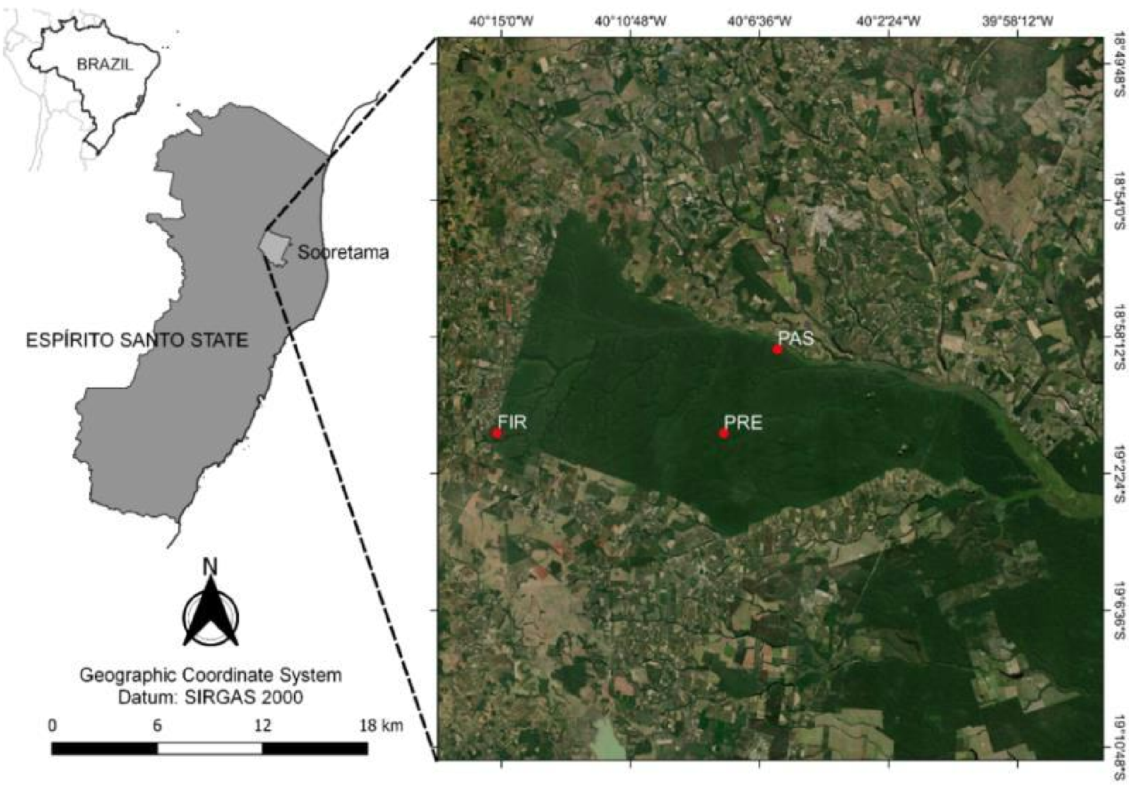

Figure 1. Location of the Sooretama Biological Reserve, municipalities of Sooretama, Linhares, Vila Valério and Jaguaré, Espírito Santo State, Brazil. PAS: pasture. FIR: fire occurrence. PRE: preserved.

DBH (diameter at breast height, measured at 1.30 m from the ground) greater than or equal to 2.5 cm were recorded. All living and dead woody individuals, including lianas, were included in the sample. The botanical material was identified by comparison with the specimens deposited in the Herbarium of the Vale Nature Reserve – CVRD, together with the curator responsible for the botanical collection. The species were classified in families recognized by Angiosperm Phylogeny Group (APG IV 2016). The life form of the species, the nomenclature, synonyms, and abbreviations of the respective authors were checked by the *Flora e Funga do Brasil* database (2022 - http://floradobrasil.jbrj.gov.br/). The species were checked for the degree of threat considering the categories "vulnerable" (VU), "endangered" (EN), "critically endangered" (CR), and "insufficient data" (DD). The national list was used, based on the database of the National Center for the Conservation of Flora (Centro Nacional de Conservação da Flora – www.cnDElora.jbrj.gov.br), and the state database according to Fraga *et al* (2019).

All samples identified at a specific level were classified according to the ecological succession group (pioneer, early secondary, and late secondary), according to the categorization proposed by Jesus and Rolim (2005). The seed dispersal syndrome (anemochory, zoochory, autochory) for each species was classified according to Van der Pijl (1982) and Judd *et al* (2009). Each species was individually researched in the literature regarding both their ecological group and the seed dispersion syndrome. Some of the species were not categorized due to the lack of information on them.

Data Analysis - For the structural analysis of the vegetation, phytosociological parameters were estimated according to Mueller-Dombois and Ellenberg (1974), with frequency, density, and dominance in their absolute and relative parameters. In order to estimate the diversity in the studied forests, the Shannon diversity indexes and the Pielou equability (Magurran 2013) were calculated using the FITOPAC 2.1 program (Shepherd 2010). To define the diameter class intervals, the formula proposed by Spiegel (1976) was used. A Veen Diagram was performed to detect the woody species that are unique to each forest type and those present in multiple forest types (Dias *et al* 2021).

The floristic composition was compared between the studied areas using the analysis of Nonmetric Multidimensional Scaling (NMDS) and similarity by the Bray-Curtis index, with abundance data. This index was used because the data set is heterogeneous, and this index assigns greater value to the shared species. NMDS is an ordering technique used to facilitate the visualization of similarities or differences between ecological data (Rabinowitz 1975). For the NMDS analysis to be considered well-adjusted, the parameter called stress must be less than 0.3. After the NMDS, the results were subjected to the One-Way ANOSIM test, at 99% probability, to verify the statistical difference between the formed groups. The analyses were carried out in R environment (R Core Team 2020).

Species richness and diversity in the three sampled environments were evaluated considering the number of individuals and sample units using individual rarefaction and extrapolation curves. Richness was constructed using the first hill number (species richness, q=0) and diversity using Shannon exponential (diversity q=1) (Chao *et al* 2014). Extrapolations were made from abundance data, considering between two and three times the total sample size by type of environment (Colwell *et al* 2012). The rarefaction/extrapolation, based on individuals and sample units, were calculated using the iNEXT package (Hsieh *et al* 2016). Rarefaction was estimated as the average of 100 replicated bootstrapping runs to estimate 95% confidence intervals. Whenever the 95% confidence intervals did not overlap, the number of species differed significantly in $p<0.05$ (Colwell *et al* 2012).

Results

A total of 841 individuals of trees were sampled in 174 morphospecies (165 species) and 53 families. About 95% of the individuals (802 ind.) were identified at a specific level, 5% at the genus (20 ind.) and family (19 ind.) level. Table 1 shows structural data by studied location.

Regarding the density representativeness of the families sampled in the three areas, we highlight the families Bixaceae (65 ind.), Euphorbiaceae (49), and Fabaceae (40) in the FIR area (table 2). In the PAS area, we found Annonaceae (71 ind.), Myrtaceae (68), and Lauraceae (23). In the PRE area, the families Myrtaceae (87 ind.), Fabaceae (51), and Euphorbiaceae (33) emerged. Together, these families represent 60% of individuals and approximately 41% of species. The families that stood out in species richness were Fabaceae (35 spp.), Myrtaceae (17),

Table 1. Synthesis of floristic and structural results obtained in this study of the Sooretama Biological Reserve, municipalities of Sooretama, Linhares, Vila Valério and Jaguaré, Espírito Santo State, Brazil. PAS: in environments pasture. FIR: after fire occurrence. PRE: preserved forest.

	PAS	FIR	PRE
Density of individuals ($ind.ha^{-1}$)	2,510	2,750	3,150
Basal area ($m^2.ha^{-1}$)	14.71	22.34	31.57
Total number of families ($families.ha^{-1}$)	290	290	370
Total number of species ($spp.ha^{-1}$)	530	620	1070
Pielou equability (J)	0.77	0.72	0.90
Shannon diversity index (H´)	2.87	3.23	4.21

Table 2. List of species and families sampled in the woody layer of the Sooretama Biological Reserve, municipalities of Sooretama, Linhares, Vila Valério and Jaguaré, Espírito Santo State, Brazil, categorized by IN: total number of individuals. LF: life-form (S: shrub; T: tree; L: liana/woody vine; Ss: subshrub; P: Palm tree). EG: ecological groups (PI: pioneer; ES: early secondary; LS: late secondary.DS: dispersal syndromes (Ane: anemochory; Aut: autochory; Zoo: zoochory). Occurrence in environments (FIR: after fire occurrence, PAS: pasture, PRE: preserved forest). U: Unclassified.

Family/Species	IN	LF	EG	DS	FIR	PAS	PRE
Achariaceae							
Carpotroche brasiliensis (Raddi) A Gray	3	S/T	LS	Zoo	X		X
Anacardiaceae							
Astronium concinnum Schott	18	T	LS	Ane	X	X	X
Astronium graveolens Jacq.	8	T	ES	Ane	X	X	X
Spondias macrocarpa Engl.	2	T	ES	U			X
Tapirira guianensis Aubl.	4	T	ES	Zoo	X	X	
Thyrsodium spruceanum Benth.	7	T	ES	Zoo	X		
Annonaceae							
Annona cacans Warm.	2	T	ES	Zoo	X		X
Annona dolabripetala Raddi	9	T	ES	Zoo	X	X	
Ephedranthus dimerus J.C. Lopes, Chatrou & Mello-Silva	1	T	LS	Zoo			X
Hornschuchia citriodora D.M.Johnson	1	T	U	U			X
Oxandra espintana (Spruce *ex* Benth.) Baill.	2	S/T	LS	Zoo		X	
Pseudoxandra spiritus-sancti Maas	1	T	LS	Zoo			X
Xylopia frutescens Aubl.	68	S/T	ES	Zoo		X	
Apocynaceae							
Geissospermum laeve (Vell.) Miers	3	T	LS	Zoo			X
Himatanthus bracteatus (A. DC.) Woodson	5	T	ES	Ane		X	
Tabernaemontana salzmannii A. DC.	3	T	ES	Zoo			X
Araliaceae							
Didymopanax morototoni (Aubl.) Decne. & Planch.	1	T	ES	Zoo		X	
Arecaceae							
Allagoptera caudescens (Mart.) Kuntze	6	P	U	Zoo	X		X
Asteraceae							
Piptocarpha lundiana (Less.) Baker	1	L	ES	U			X
Bignoniaceae							
Adenocalymma validum L.G.Lohmann	3	L	PI	Ane		X	X
Handroanthus arianeae (A.H. Gentry) S. Grose	1	T	ES	U			X
Sparattosperma leucanthum (Vell.) K. Schum.	3	T	PI	Ane		X	X
Zeyheria tuberculosa (Vell.) Bureau *ex* Verl.	2	T	LS	Ane		X	
Bixaceae							
Bixa arborea Huber	65	T	PI	Zoo	X		
Boraginaceae							
Cordia acutifolia Fresen.	3	T	ES	U	X		

Continue

Table 2 (continuation)

Family/Species	**IN**	**LF**	**EG**	**DS**	**FIR**	**PAS**	**PRE**
Cordia trichoclada DC.	4	T	ES	Zoo	X		X
Burseraceae							
Protium warmingianum Marchand	3	T	LS	Zoo		X	
Capparaceae							
Monilicarpa brasiliana (Banks *ex* DC.) Cornejo & Iltis	3	S	ES	Zoo			X
Caricaceae							
Jacaratia heptaphylla (Vell.) A.DC.	2	T	ES	Zoo			X
Celastraceae							
Cheiloclinium cognatum (Miers) A.C. Sm.	1	S/T/L	ES	Zoo			X
Monteverdia distichophylla (Mart. *ex* Reissek) Biral	1	S/T					X
Chrysobalanaceae							
Exellodendron gracile (Kuhlm.) Prance	1	T	LS	U			X
Licania kunthiana Hook.f.	1	T	LS	Zoo			X
Clusiaceae							
Garcinia gardneriana (Planch. & Triana) Zappi	2	S/T	LS	Zoo			X
Tovomita umbellata Benth.	1	T					X
Combretaceae							
Terminalia mameluco Pickel	4	T	ES	Ane		X	X
Connaraceae							
Connarus detersus Planch.	1	S/T	LS	Zoo			X
Dichapetalaceae							
Stephanopodium blanchetianum Baill.	1	T	LS	Zoo			X
Dilleniaceae							
Davilla rugosa Poir.	2	L/Ss	LS	Aut		X	
Erythroxylaceae							
Erythroxylum squamatum Sw.	1	S/T	LS	Zoo		X	
Euphorbiaceae							
Brasiliocroton mamoninha P.E.Berry & Cordeiro	27	T	ES	Aut	X		X
Cunuria sp.	2	U	U	U	X	X	
Drypetes sessiliflora Allemão	1	T	LS	U			X
Joannesia princeps Vell.	35	T	PI	Aut	X	X	
Senefeldera verticillata (Vell.) Croizat	19	T	LS	U			X
Fabaceae							
Acosmium lentiscifolium Schott	2	T	LS	Ane			X
Albizia polycephala (Benth.) Killip *ex* Record	1	T	ES	Ane		X	
Apuleia leiocarpa (Vogel) J.F. Macbr.	1	S/T	ES	Ane	X		
Bauhinia forficata Link	1	T	ES	Zoo			X
Cassia ferruginea (Schrad.) Schrad. *ex* DC.	1	T	ES	Aut	X		
Copaifera langsdorffii Desf.	2	T	LS	Aut			X

Continue

Table 2 (continuation)

Family/Species	IN	LF	EG	DS	FIR	PAS	PRE
Dalbergia frutescens (Vell.) Britton	9	S/T	ES	Ane		X	X
Dalbergia nigra (Vell.) Allemao *ex* Benth.	3	T	ES	Ane	X	X	X
Deguelia longeracemosa (Benth.) A.M.G.Azevedo	2	T	ES	Ane			X
Dialium guianense (Aubl.) Sandwith	6	T	LS	Zoo		X	X
Goniorrhachis marginata Taub.	9	T	LS	Ane			X
Inga cabelo T.D. Penn.	1	T	ES	U	X		
Inga flagelliformis (Vell.) Mart.	3	T	ES	Ane	X		
Inga thibaudiana DC. subsp. *thibaudiana*	1	T	PI	Zoo		X	
Lonchocarpus cultratus (Vell.) A.M.G. Azevedo & H.C. Lima	3	T	ES	Zoo			X
Machaerium brasiliense Vogel	2	S/T/L	ES	Ane	X		
Machaerium fulvovenosum H.C.Lima	5	T	LS	U	X		X
Machaerium ovalifolium Glaz. *ex* Rudd	2	T	LS	U	X		
Machaerium sp.	2	U	U	U			X
Melanoxylon brauna Schott	8	T	LS	Ane	X		X
Parapiptadenia pterosperma (Benth.) Brenan	2	T	ES	Ane	X		
Peltogyne angustiflora Ducke	1	T	LS	Ane			X
Piptadenia adiantoides (Spreng.) J.F.Macbr.	4	L	U	Ane	X		X
Piptadenia paniculata Benth.	1	T	PI	Zoo			X
Poecilanthe falcata (Vell.) Heringer	1	S/T	LS	Ane	X		
Pseudopiptadenia contorta (DC.) G.P.Lewis & M.P.M. Lima	1	T	ES	Aut			X
Pterocarpus rohrii Vahl.	5	T	ES	Ane	X		X
Senegalia amazonica (Benth.) Seigler & Ebinger	1	S/L	ES	U	X		
Senegalia langsdorffii (Benth.) Seigler & Ebinger	2	S/T/L	U	U	X		
Senna multijuga subsp. *multijuga* var. *verrucosa* (Vogel) H.S.Irwin & Barneby	2	T	ES	Zoo	X	X	
Swartzia apetala var. *glabra* (Vogel) R.S. Cowan	3	T	LS	Zoo	X		X
Swartzia myrtifolia var. *elegans* (Schott) R.S.Cowan	1	T	LS	Ane			X
Swartzia simplex var. *continentalis* Urb	6	T	LS	Ane			X
Sweetia fruticosa Spreng.	2	T	LS	U	X		X
Vatairea heteroptera (Allemão) Ducke	1	T	ES	Zoo	X		
Hernandiaceae							
Sparattanthelium botocudorum Mart.	19	S/L	U	U	X	X	
Hypericaceae							
Vismia brasiliensis Choisy	2	S/T	U	U	X	X	
Icacinaceae							
Leretia cordata Vell.	1	S/T/L	U	U		X	

Continue

Table 2 (continuation)

Family/Species	**IN**	**LF**	**EG**	**DS**	**FIR**	**PAS**	**PRE**
Lamiaceae							
Vitex orinocensis Kunth	2	T	U	U	X		
Lauraceae							
Ocotea argentea Mez	2	T	LS	Zoo		X	
Ocotea fasciculata (Nees) Mez	1	S/T	LS	Zoo			X
Ocotea nutans (Nees) Mez	1	T	ES	Zoo		X	
Ocotea spectabilis (Meisn.) Mez	10	T	LS	Zoo		X	
Ocotea velutina (Nees) Rohwer	1	T	ES	U	X		
Ocotea longifolia Kunth	10	S/T	ES	Zoo		X	
Urbanodendron verrucosum (Nees) Mez	1	T	ES	Zoo			X
Lecythidaceae							
Cariniana estrellensis (Raddi.) Kuntze	1	T	LS	Ane		X	
Cariniana legalis (Mart.) Kuntze	1	T	LS	Ane			X
Couratari asterotricha Prance	6	T	ES	Ane	X		X
Lecythis lurida (Miers) S.A.Mori	6	T	LS	Zoo	X		X
Malpighiaceae							
Byrsonima cacaophila W.R. Anderson	1	T	PI	Ane	X		
Byrsonima sericea DC.	4	S/T	ES	Zoo		X	
Eriotheca candolleana (K. Schum.) A. Robyns	1	T	ES	U	X		
Eriotheca macrophylla (K. Schum.) A. Robyns	1	T	ES	Zoo			X
Guazuma crinita Mart.	2	T	PI	Ane			X
Malvaceae							
Hydrogaster trinervis Kuhlm.	2	T	ES	Zoo			X
Luehea mediterranea (Vell.) Angely	4	T	LS	Ane	X		
Pterygota brasiliensis Allemão	1	T	U	U		X	
Quararibea penduliflora (A.St.Hil.) K. Schum.	10	T	LS	Zoo			X
Melastomataceae							
Miconia cf. *cinnamomifolia* (DC.) Naudin	3	S/T	PI	Zoo		X	
Meliaceae							
Guarea pendula R.S.Ramalho, A.L. Pinheiro & T.D.Penn.	1	T	LS	Zoo	X		
Trichilia casaretti C.DC.	12	S/T	LS	Zoo		X	X
Trichilia lepidota subsp. *schumanniana* (Harms) T.D.Penn.	11	T	LS	Zoo	X	X	X
Trichilia pseudostipularis (A.Juss.) C. DC.	4	S/T	LS	Zoo			X
Trichilia quadrijuga Kunth. subsp. *Quadrijuga*	1	T	ES	Zoo			X
Trichilia silvatica C. DC.	2	S/T	LS	Zoo			X
Moraceae							
Brosimum glaziovii Taub.	1	S/T	ES	Zoo	X		
Brosimum guianense (Aubl.) Huber	1	S/T	ES	Zoo			X
Sorocea guilleminiana Gaudich.	3	S/T	ES	Zoo			X
Myristicaceae							

Continue

Table 2 (continuation)

Family/Species	IN	LF	EG	DS	FIR	PAS	PRE
Virola gardneri (A.DC.) Warb.	2	T	LS	Zoo			X
Myrtaceae							
Campomanesia espiritosantensis Landrum	1	T	LS	Zoo		X	
Campomanesia guazumifolia (Cambess.) O.Berg	10	T	ES	Zoo		X	X
Eugenia bahiensis DC.	17	T	LS	Zoo		X	X
Eugenia cf. *pisiformis* Cambess.	16	S/T	LS	Zoo	X		X
Eugenia sp1.	1	U	ES	Zoo			X
Eugenia fusca O.Berg	1	T	U	Zoo	X		
Eugenia guanabarina (Mattos & D.Legrand) Giaretta & M.C.Souza	3	T	LS	Zoo		X	X
Eugenia platyphylla O.Berg	17	T	LS	Zoo			X
Eugenia platysema O. Berg	2	T	LS	U			X
Eugenia sp2.	8	U	U	U			X
Marlierea sp.	1	U	U	Zoo		X	
Myrcia guianensis (Aubl.) DC.	1	S/T/Ss	ES	Zoo			X
Myrcia neolucida A.R.Lourenço & E.Lucas	8	T	ES	Zoo			X
Myrcia splendens (Sw.) DC.	54	T	ES	Zoo		X	X
Myrciaria floribunda (H.West *ex* Willd.) O.Berg	5	T	ES	Zoo		X	X
Neomitranthes stictophylla (G.M.Barroso & Peixoto) M.C.Souza	9	T	LS	Zoo			X
Plinia involucrata (O.Berg) McVaugh.	3	T	LS	Zoo			X
Nyctaginaceae							
Guapira opposita (Vell.) Reitz	4	S/T	LS	Zoo	X	X	X
Neea floribunda Poepp. & Endl.	2	S/T	ES	Zoo			X
Peraceae							
Pera glabrata (Schott) Baill.	3	S/T	ES	Aut		X	
Pera heteranthera (Schrank) I.M.Johnst.	1	S/T	ES	Zoo		X	
Polygonaceae							
Coccoloba cf. *densifrons* Mart. *ex* Meisn.	3	S/T/L	ES	Aut	X		X
Coccoloba warmingii Meisn.	2	S/T	ES	Aut	X		X
Rhamnaceae							
Rhamnidium glabrum Reissek	1	T	ES	Zoo	X		
Rubiaceae							
Alseis involuta K.Schum.	2	S	ES	Ane			X
Amaioua intermedia Mart. *ex* Schult. & Schult.f.	1	S/T	ES	Zoo			X
Melanopsidium nigrum Colla	1	S/T	LS	Ane			X
Rutaceae							
Dictyoloma vandellianum A.Juss.	1	T	ES	Zoo	X		
Neoraputia alba (Nees & Mart.) Emmerich *ex* Kallunki	2	T	LS	Aut			X

Continue

Table 2 (continuation)

Family/Species	IN	LF	EG	DS	FIR	PAS	PRE
Ravenia infelix Vell.	2	T	LS	Zoo			X
Zanthoxylum acuminatum subsp. *juniperinum* (Poepp.) Reynel	2	T	ES	Ane		X	
Salicaceae							
Casearia commersoniana Cambess.	2	S/T	LS	Zoo			X
Casearia sp.1	3	U	U	U	X	X	X
Casearia sp.2	1	U	U	U		X	
Casearia javitensis Kunth	1	S/T	LS	Aut		X	
Macrothumia kuhlmannii (Sleumer) M. H. Alford	1	T	LS	Zoo			X
Sapindaceae							
Allophylus petiolulatus Radlk.	1	S/T	ES	Zoo			X
Cupania oblongifolia Mart.	5	T	ES	Zoo		X	
Cupania rugosa Radlk.	5	T	LS	Zoo	X	X	X
Melicoccus espiritosantensis Acev.-Rodr.	1	T	U	Zoo			X
*Pseudima frutescens (*Aubl.) Radlk.	1	S/T	LS	Zoo			X
Serjania cf. *glutinosa* Radlk.	1	L	U	Zoo	X		
Sapotaceae							
Chrysophyllum gonocarpum (Mart. & Eichler *ex* Miq.) Engl.	1	T	LS	Zoo			X
Chrysophyllum lucentifolium Cronquist.	4	T	LS	Zoo			X
Micropholis sp.	3	U	U	U		X	
Pouteria aff. filipes Eyma	1	T	LS	Zoo			X
Pouteria bapeba T.D.Penn.	1	T	LS	Zoo	X		
Pouteria guianensis Aubl.	2	T	LS	Zoo			X
Pouteria macrophylla (Lam.) Eyma	1	T	LS	Zoo			X
Pouteria psammophila (Mart.) Radlk.	2	T	LS	Zoo	X		
Pouteria sp.	1	U	U	U			X
Pouteria venosa subsp. *amazonica* T.D.Penn.	1	S/T	LS	Zoo	X		
Solanaceae							
Solanum pseudoquina A.St.-Hil.	5	T	U	Zoo	X		
Solanum sooretamum Carvalho	16	T	PI	Zoo	X		
Trigoniaceae							
Trigonia eriosperma (Lam.) Fromm & Santos	2	S/L	U	Zoo			X
Urticaceae							
Cecropia hololeuca Miq.	3	T	PI	Zoo	X		
Verbenaceae							
Aegiphila integrifolia (Jacq.) Moldenke	4	S/T	PI	Zoo	X		
Violaceae							
*Rinorea bahiensis (*Moric.) Kuntze	6	T	LS	Ane			X
Vochysiaceae							
Qualea megalocarpa Stafleu	1	T	LS	Ane			X

Sapotaceae (10), Annonaceae, Lauraceae, and Malvaceae, with seven species each. Together, these families add up to 48% of the sampled species. In total, 31 species were into some category of threat of extinction (table 3), with 29 at the state level and 15 at the national level. The VU category was the most representative considering the two lists. For the State of Espírito Santo, the species classified as DD were also quite expressive. Three species appeared as CR, the category of greatest threat.

The predominant diaspores dispersion syndrome in both areas was zoochoric; responsible for 50% of the species sampled in the FIR area, 79% in the PAS area, and approximately 56% in the PRE area. Over 20% of the species were classified as anemochoric and 6% autochoric (most was observed in the FIR area). Regarding the ecological group, approximately 40% of the classified species in the FIR area belong to the group of pioneers; 67% of the sampled individuals in the PAS area were of

Table 3. List of endangered species found in sampling the woody layer in Sooretama Biological Reserve, municipalities of Sooretama, Linhares, Vila Valério and Jaguaré, Espírito Santo State, Brazil. TC: threat category. BR: Brazilian list (CNCFlora). ES: Espírito Santo State list. DD: data deficient. VU: vulnerable. EN: endangered. CR: critically endangered.

Family	Specie	TC	
		BR	ES
Bignoniaceae	*Handroanthus arianeae* (A.H.Gentry) S.Grose	EN	EN
	Zeyheria tuberculosa (Vell.) Bureau *ex* Verl.	VU	-
Chrysobalanaceae	*Exellodendron gracile* (Kuhlm.) Prance	EN	EN
Connaraceae	*Connarus detersus* Planch.	-	DD
Erythroxylaceae	*Erythroxylum squamatum* Sw.	-	VU
Euphorbiaceae	*Drypetes sessiliflora* Allemão	-	DD
Fabaceae	*Apuleia leiocarpa* (Vogel) J.F.Macbr.	VU	VU
	Dalbergia nigra (Vell.) Allemão *ex* Benth.	VU	VU
	Inga cabelo T.D.Penn.	DD	VU
	Machaerium fulvovenosum H.C.Lima	-	VU
	Machaerium ovalifolium Glaz.	-	DD
	Melanoxylon brauna Schott	VU	CR
Lecythidaceae	*Cariniana legalis* (Mart.) Kuntze	EN	EN
	Couratari asterotricha Prance	EN	EN
Malpighiaceae	*Byrsonima cacaophila* W.R.Anderson	-	VU
Malvaceae	*Eriotheca candolleana* (K.Schum.) A.Robyns	-	DD
Meliaceae	*Trichilia quadrijuga* Kunth	-	DD
Moraceae	*Brosimum glaziovii* Taub.	-	DD
Myrtaceae	*Campomanesia espiritosantensis* Landrum	CR	CR
	Eugenia fusca O.Berg	-	EN
	Neomitranthes stictophylla (G.M.Barroso & Peixoto) M.C. Souza.	-	VU
Polygonaceae	*Coccoloba warmingii* Meisn.	-	DD
Rhamnaceae	*Rhamnidium glabrum* Reissek	VU	DD
Rubiaceae	*Alseis involuta* K.Schum.	VU	VU
	Melanopsidium nigrum Colla	VU	-
Sapindaceae	*Melicoccus espiritosantensis* Acev.-Rodr.	EN	EN
	Pseudima frutescens (Aubl.) Radlk.	-	VU
Sapotaceae	*Pouteria bapeba* T.D.Penn.	CR	CR
	Pouteria guianensis Aubl.	-	DD
	Pouteria macrophylla (Lam.) Eyma	-	DD
Violaceae	*Rinorea bahiensis* (Moric.) Kuntze	-	VU

early secondary species; and almost 50% of the sampled individuals in the PRE area belong to the group of late secondary species, demonstrating the highest degree of sucessional stage. Overall, 90% of the species sampled in the three areas are trees, the other 10% is distributed among shrubs, subshrubs, lianas, and palm trees (table 2).

Regarding the structural data, the phytosociological tables present the sets of the ten species with the highest importance value (IV) for the areas FIR (table 4), PAS (table 5), and PRE (table 6). In the FIR area, the *Joannesia princeps* Vell and *Bixa arborea* Huber, with hold the highest IV, were present in almost all the sample units in that area. The *B. arborea* presented higher density (24%) than *J. princeps* (12%), but *J. princeps* presented higher relative dominance (29%) since its individuals have a high basal area due to their large diameter and were better distributed in the area, appearing in eight of the ten sample units.

In the PAS area, two species dominated in sampling, *Myrcia splendens* (Sw.) DC., which stood out with at least one specimen in each sampling unit, not being found in the other areas considered in this study, and *Xylopia frutescens* Aubl., which was also found in almost all sample units in the area. *X. frutescens* presented IV (22%) and DoR (31%), higher than *M. splendens* (11% and 4%, respectively), demonstrating that the latter has individuals with smaller basal area.

The species with the highest IV in the PRE area were *Goniorrhachis marginata* Taub (6.4 %) and *Astronium concinnum* Schott (5.8%). Both species presented some individuals with DBH greater than 25 cm. Unlike the

Table 4. Phytosociological descriptors of the 10 most important species of the woody layer sampled in burned area (FIR) in the Sooretama Biological Reserve, municipalities of Sooretama, Linhares, Vila Valério and Jaguaré, Espírito Santo State, Brazil, classified in descending order of IV: importance value. NI: number of individuals. RD: relative density. RF: relative frequency. Rdo: relative dominance.

Species	NI	DR	RF	RDo	IV
Joannesia princeps	34	12.36	6.06	29.13	15.85
Bixa arborea	65	23.64	3.79	17.18	14.87
Solanum sooretamum	16	5.82	6.06	2.02	4.63
Brasiliocroton mamoninha	14	5.09	5.30	3.26	4.55
Sparattanthelium botocudorum	15	5.45	3.79	1.94	3.73
Annona dolabripetala	8	2.91	3.79	1.97	2.89
Thyrsodium spruceanum	7	2.55	1.52	3.05	2.37
Luehea mediterranea	4	1.45	3.03	1.78	2.09
Allagoptera caudescens	3	1.09	2.27	2.84	2.07
Melanoxylon brauna	5	1.82	3.03	1.27	2.04
Totais	171	62.18	38.64	64.44	55.09

Table 5. Phytosociological descriptors of the 10 most important species of the woody layer sampled in pasture area (PAS) in the Sooretama Biological Reserve, municipalities of Sooretama, Linhares, Vila Valério and Jaguaré, Espírito Santo State, Brazil, classified in descending order of IV: importance value. NI: number of individuals. RD: relative density. RF: relative frequency. Rdo: relative dominance.

Species	NI	DR	RF	Rdo	IV
Xylopia frutescens	68	27.09	7.69	31.2	22.00
Myrcia splendens	53	21.12	8.55	3.57	11.08
Byrsonima sericea	4	1.59	2.56	13.60	5.92
Astronium concinnum	10	3.98	4.27	7.03	5.10
Ocotea longifolia	10	3.98	5.13	4.31	4.47
Campomanesia guazumifolia	9	3.59	5.13	1.16	3.29
Terminalia mameluco	2	0.8	1.71	6.89	3.13
Ocotea spectabilis	10	3.98	4.27	0.73	3.00
Himatanthus bracteatus	5	1.99	4.27	1.88	2.71
Tapirira guianensis	5	1.99	3.42	1.95	2.45
Totais	176	70.11	41.87	72.32	63.15

Table 6. Phytosociological descriptors of the 10 most important species of the woody layer sampled in preserved area (PRE) in the Sooretama Biological Reserve, municipalities of Sooretama, Linhares, Vila Valério and Jaguaré, Espírito Santo State, Brazil, classified in descending order of IV: importance value. NI: number of individuals. RD: relative density. RF: relative frequency. Rdo: relative dominance.

Species	NI	DR	RF	Rdo	IV
Goniorrhachis marginata	9	2.86	2.22	14.11	6.40
Astronium concinnum	7	2.22	2.67	12.69	5.86
Astronium graveolens	4	1.27	1.33	7.70	3.43
Pterocarpus rohrii	3	0.95	1.33	7.80	3.36
Senefeldera verticillate	19	6.03	2.67	0.63	3.11
Eugenia platyphylla	17	5.40	3.11	0.46	2.99
Melicoccus espiritosantensis	1	0.32	0.44	8.20	2.99
Brasiliocroton mamoninha	13	4.13	2.22	1.87	2.74
Eugenia bahiensis	15	4.76	3.11	0.23	2.70
Eugenia cf. pisiformis	15	4.76	3.11	0.18	2.69
Totais	103	32.7	22.21	53.87	33.28

FIR and PAS areas, the structural distribution in the phytosociological table of the PRE area demonstrated a non-oligarchic organization, where the importance value of the species had very close values.

The Veen diagram shows the exclusive and shared species for the studied areas (figure 2a). Only seven species were common to the three areas, showing a difference in forest composition according to the anthropic interferences suffered. Of the sampled species, 41% were found only in the PRE area, a number higher than the exclusive species of the FIR and PAS areas (18 and 16%, respectively). The NMDS, using the sample units with abundance data of species, suggested the formation of three distinct groups (Figure 2b), which was confirmed by the One-Way ANOSIM test, which presented $p<0.05$, with stress of 0.16.

The diametric distribution showed a higher concentration of individuals in the smallest diameter class (DBH ≥ 2.5 cm < 7.5 cm), ca. 44%, with reduction in subsequent classes, resulting in the typical "inverted J" pattern, presenting a variation in the PRE area (figure 3). In this same area, 39 individuals with DBH above 25 cm were sampled, mostly represented by species of the Fabaceae family (41%), and more than 50% of these species are late secondary. The mean diameter of the individuals sampled in the PRE area (12.3 cm) was higher than those of the FIR and PAS areas (7.7 and 8.5 cm, respectively).

The rarefaction and extrapolation curves calculated for the richness and diversity of species indicated that the sampling was satisfactory for the evaluation of the three areas (figure 4). The PRE area presented greater richness

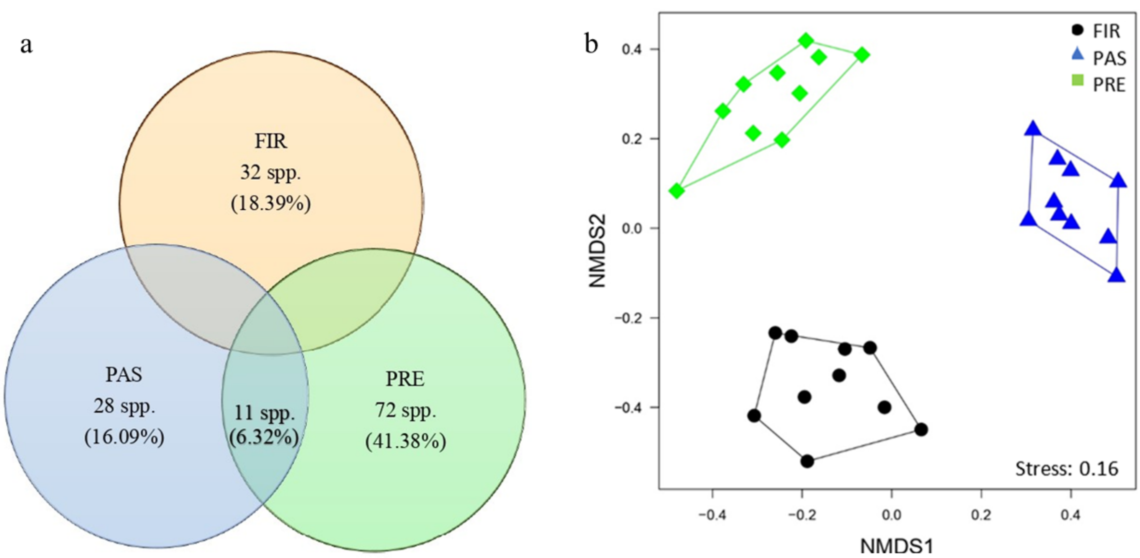

Figure 2. Venn diagram of the species sharing the different environments in the Sooretama Biological Reserve, municipalities of Sooretama, Linhares, Vila Valério and Jaguaré, Espírito Santo State, Brazil. (2a) and Nonmetric multidimensional scaling (NMDS) of the floristic links in environments, PAS: pasture. FIR: fire occurrence. PRE: preserved (2b).

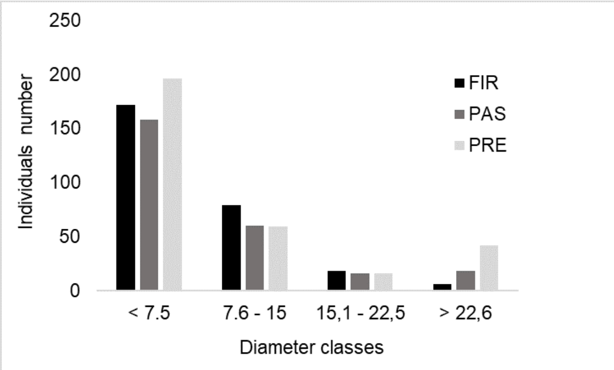

Figure 3. Distribution of individuals of the woody layer by diameter in environments sampled in remnants of dense ombrophilous lowland forest in the Sooretama Biological Reserve, municipalities of Sooretama, Linhares, Vila Valério and Jaguaré, Espírito Santo State, Brazil. PAS: pasture. FIR: fire occurrence. PRE: preserved.

and diversity of species, different from the PAS area based on the number of individuals (Fig. 4a, 4c). Similar richness patterns were observed between the FIR and PAS areas, but with difference between these environments and the PRE area according to rarefaction and extrapolation curves based on the sample units (Fig. 4b, 4d).

Discusion

Monitoring the conditions of Atlantic Forest fragments is a determining tool to control the activities that are unsustainable to natural environments and to guide actions toward mitigating impact and promoting forest recovery (Dias *et al* 2021). In this sense, the Lowland Atlantic Forests, which have high biomass productivity due to vegetation and species richness, are exceptional in carbon retention and biodiversity (Strassburg *et al* 2010). The results show that there are clear variations between the three areas evaluated, in which the PRE area presents greater species richness, floristic diversity, and basal area, with parameters similar to forests of high diversity in northern Espírito Santo and southern Bahia. The performance of inventories and monitoring of the remnants of Lowland Atlantic Forests in neglected regions are fundamental for planning conservation and enrichment measures of these vegetations.

The families Fabaceae, Myrtaceae and Sapotaceae with the highest species richness, are also the most representative in studies conducted in northern Espírito Santo State (e.g., Rolim *et al* 2016, Dias *et al* 2021, Alves-Araújo *et al* 2022) and southern Bahia State (e.g., Martini *et al* 2007, Magellan 2018). Present in the most diverse Brazilian biomes, Fabaceae is one of the families with

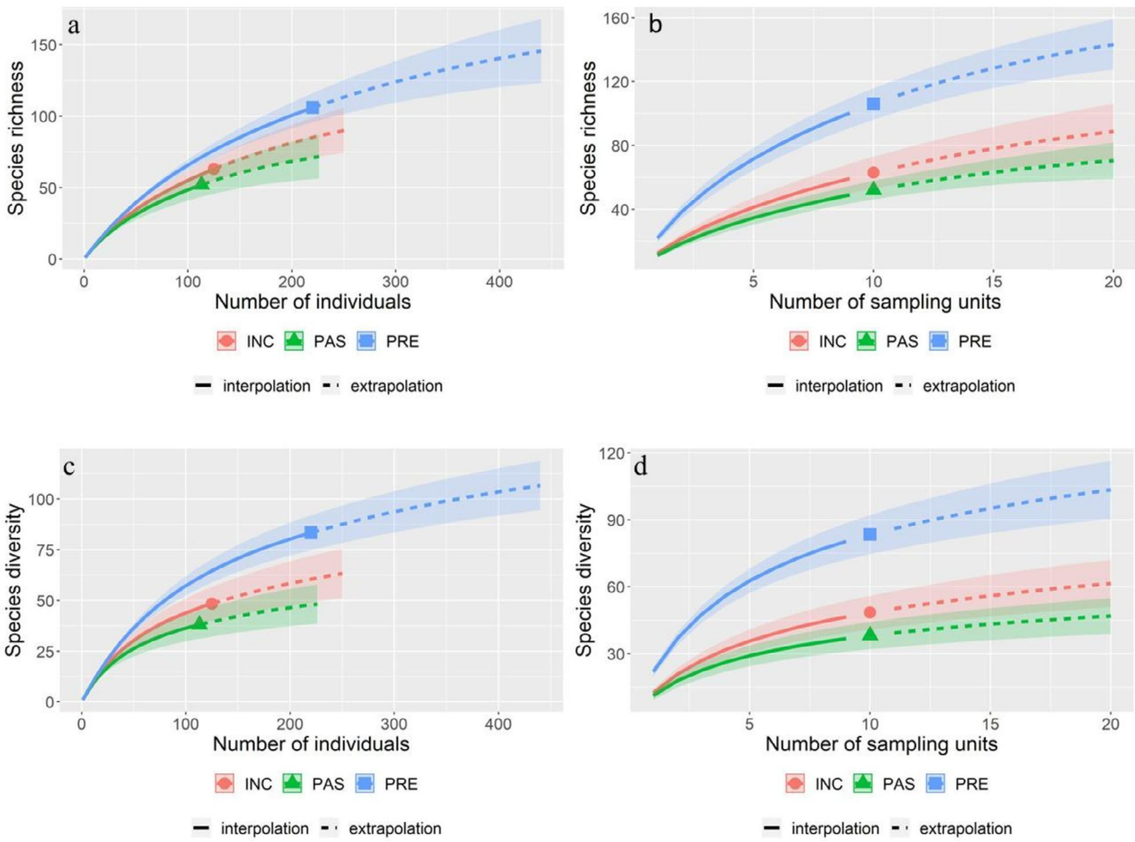

Figure 4. Rarefaction (solid line) and extrapolation curves (dashed lines) based on the number of individuals (a, c), sample units (b, d), species diversity and species richness for different areas sampled at Sooretama Biological Reserve, municipalities of Sooretama, Linhares, Vila Valério and Jaguaré, Espírito Santo State, Brazil. The rarefaction and extrapolation curves represent mean values and standard deviation with 95% confidence intervals. PAS: pasture. FIR: fire occurrence. PRE: preserved.

the highest species richness and abundance in the country (Klippel *et al* 2015, De Amorim *et al* 2016). Moreover, the rate of endemic species of large legumes has grown in recent years according to the scientific description of new species (e.g., Lewis *et al* 2017, Carvalho *et al* 2022), most of which are considered rare in nature (e.g., Fontana *et al* 2019). Myrtaceae is also one of the most important families in the Atlantic Forest since it presents high species richness, most of which are endemic to this biome (Lucas & Bünger, 2015).

The REBIO of Sooretama is home to many endangered species, we found 22 endangered tree species. Together with the Vale Nature Reserve, it forms one of the largest vegetation sets of coastal lowlands in Brazil (Ribeiro *et al* 2022), with a leading role in the conservation of endemic and threatened species. Some of the main reasons for the risk of extinction of tree species are the fragmentation processes associated with the loss of habitat quality (Martinelli & Moraes 2013). Thus, the presence of threatened species of the Atlantic Forest evidences the need to preserve the remnants forest to protect the species against extinction (Pscheidt *et al* 2018, Amorim *et al* 2019).

The number of rare species, those with only one specimen recorded in this sample (Zani *et al* 2012), represent 38.5% of richness and 7.9% of the total sampled individuals, most of which were found in the PRE area. Forests of more advanced stages of development are expected to have more rare species due to a greater trend of increasing biodiversity (Santos, Serafim & Sano 2012, Paula & Soares 2011). Kageyama *et al* (1998) stated that rare species require extensive areas to maintain their populations, and the fragmentation process is an aggravating factor for the loss of such species. However, we must point out that a 0.3 ha sampling in megadiverse forests, such as those studied, may overestimate the number of rare species in the sampling due to sample size (Phillips *et al* 2003).

With the highest importance value (IV) in the fire occurrence area (table 3), the species *J. princeps* and *B. arborea*, were also among the most important in the study conducted by Lopes *et al*. (2022) in the Semidecidual Seasonal Forest of the Rio Doce State Park, in the phase of natural regeneration after 30 years of fire, as well as in the study by Rolim *et al* (2017), indicating its importance in the colonization of areas after disturbances. Both species are pioneers and easily found in the areas under regeneration in the studied region. The presence of the *B. arborea* species is an indication of food availability for the local fauna, since this species has zoochoric dispersion, contributing to the maintenance of local biodiversity (Lorenzoni-Paschoa *et al* 2019).

In the Pasture area (table 4), the species *M. splendens* and *X. frutescens* dominated in the sampling. The genus *Myrcia* is among those with the highest species richness in the Atlantic Forest (Lucas *et al* 2011, Souza *et al* 2019). Demanding in light, *M. splendens* is a canopy species (Higuchi *et al* 2008), widely dispersed by animals and important for succession of the secondary forest in restoration (Arantes *et al* 2014). Widely distributed in tropical regions (Lopes & Mello-Silva 2014**)**, the genus *Xylopia* is often sampled in environments that have experienced disturbances and are in a poorly developed successional stage (De Paula *et al* 2009). In a study conducted by Dias *et al* (2021), evaluating the impact of the edge effect in the Lowland Dense Ombrophilous Forest, in the Biological Reserve of Córrego Grande, *M. splendens* and *X. frutescens* were sampled and were also among the most abundant species.

The species with the highest IV in the preserved area (PRE) were *G. marginata* and *A. concinnum.* From the Fabaceae family, the species *G. marginata* is commonly found in regions of well-preserved forests, being native and endemic to the southeast and northeast regions of the country (Lima *et al* 2021), in the ombrophilous and seasonal tropical forests of the Atlantic Forest (Silva-Luz and Pirani 2021). In turn, the *A. concinnum* is a late secondary species, commonly found in northern Espírito Santo (Paula & Soares 2011).

The results show that the PRE area has a greater diversity, presenting a high richness of species when compared with the areas FIR and PAS. Approximately 76% of the total species sampled were found in only one of the three environments, presenting species that are exclusive to each area, in accordance to previous land use and successional stage (Braga *et al* 2015).

Regarding the evaluation of the seed dispersal syndrome, the zoochoric species were predominant (50%), demonstrating the importance of this group for the restoration of the areas that suffered disturbance in an integrated way with the fauna, as well as for the maintenance of forests (Camargos 2013). The predominance of species with this type of dispersal reflects one of the characteristics of plant communities in tropical forests, which in general have a higher occurrence of this syndrome (Tabarelli & Peres 2002, Oliveira *et al* 2011). Possibly, the PRE area contributed with the dispersion of zoochoric species to the two disturbed areas evaluated (FIR and PAS), considering that the fauna of more conserved areas plays a fundamental role in the dispersive process (Hawes *et al* 2020).

The floristic diversity (H') for the PRE area (4.21), although lower, is close to the values found by Dias *et al* (2021 - 4.86) and Magalhães (2018 – 4.75) in the Lowland Atlantic Forest of northern Espírito Santo and southern Bahia, which are places considered highly diverse (Ribeiro *et al* 2022). The areas FIR (H'=3.23) and PAS (H'=2.87), on the other hand, showed low floristic diversity due to their low species richness. Plant communities that generally have low species richness and diversity are characterized by the dominance of a few species and by high levels of disturbance, which may limit the establishment of some species (Pickett *et al* 1987). Low diversity may also be related to factors such as habitat fragmentation and degradation, as well as other unfavorable environmental conditions for the establishment and maintenance of native species. Fragmentation can reduce biodiversity by limiting the size of viable populations and increasing the risk of extinction, as well as changing species composition and reducing habitat connectivity (Young *et al* 2005). This lack of diversity can negatively impact the ecosystem and its ability to provide ecosystem services (Liu & Ferry Slik, 2014). Therefore, it is important to adopt adequate restoration and conservation measures to increase the diversity and resilience of these areas in succession (Rey Benayas *et al* 2009).

The floristic dissimilarity obtained between the three areas studied in REBIO, according to the NMDS, showed distinct clusters among the areas (figure 2 b). This highlights that the different disturbances histories, promoted by the different forms of vegetation suppression and use, influence the floristic composition and resilience since passively regenerated forests present floristic and structural composition distinct from the surrounding preserved forests and according to their recovery time and the type of disturbance (Lugo & Helmer 2004, Safar *et al* 2020;).

The diametric distribution presented a pattern ("inverted J," figure 4) that is expected for native forests (Souza *et al* 2012). Thus, it was possible to observe that the lower diametric class presented higher density of individuals for the forests analyzed. The higher concentration of individuals in the first diametric classes indicates the presence of many young individuals in the community, which may be related to previous disturbances. This result shows that forests are moving towards self-support, since they have a contingent of regenerating individuals for the upper diametric classes. The presence of pioneer and small diameter species in the FIR and PAS areas indicate that most populations may be in the initial phase of establishment (Souza *et al* 2012). However, the high number of individuals, within the preserved area, in their initial classes suggests that the community achieved self-sustainability, and the individuals present in the understory can replace those that die (Dias *et al* 2021).

Conclusions

In this study, we were able to show how the different levels of anthropic interference determined the forest sucessional process. Comparing the vegetation structure in association with species composition and their functional attributes contribute to understanding the resilience of the ecosystem after natural and anthropic disturbances, which are important attributes for decision-making focused on management from different perspectives of successional stages, conservation, and ecosystem recovery. In disturbed areas, measures such as nucleation and enrichment of species can help in the restoration of these vegetations with low diversity. These models can be replicated to other remnant areas of Lowland Atlantic Forests, as inventories and monitoring plans are deployed in those locations.

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