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Impacts of Slash-and-Burn Cultivation on the Soil and Vegetation of the Atlantic Forest in Southeastern Brazil

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Abstract
Conflicts among transnational enterprises, full protection conservation units, and slash-and-burn agriculturalists have historically centered on whether this practice threatens local ecosystems. Our research in the Atlantic Forest (Southeast Brazil) was designed to identify the potential effects of slash-and-burn on soils and vegetation. We collected samples in old cropping areas that have lain fallow for 8, 15, and 60 years. We analyzed the morphological, physical, and chemical properties of the soil samples. We collected vegetation data in 10 × 10 m plots, identified tree species and calculated their basal area. Our morphological and physical data indicate that the soils are not compacted and that the aggregate stability degree increases with time. The chemical data suggest that slash-and-burn practices have not changed the pH or reduced soil fertility, while the vegetation data indicate a long-term recovery. Since our results show sustainable use of slash-and-burn cultivation we recommend land legislation should be designed to safeguard agricultural communities' livelihoods.

Keywords Slash-and-burn · Fallow · Soil · Vegetation · Conservation units · *Alto Ribeira* Touristic State Park (PETAR) · Atlantic Forest · Southeastern Brazil

Introduction

In the wake of institutional dismantlement and privatization policies in Brazil since the 1990s, transnational governance has increased over the environmental agenda and policies (Diegues, 2008). In 2021, the São Paulo State government-initiated concession of the *Alto Ribeira* Touristic State Park (PETAR) to private institutions. PETAR is one of the most important conservation units in Southeast Brazil and its concession affects the livelihoods of multiple local communities who have inhabited the areas for centuries. The initiative overlaps already existing conflicts between local communities and full protection policies and presents new challenges to a local population that has historically faced private and state pressures since the park's foundation (Silveira, 2008).

PETAR is in the Brazilian Atlantic Forest, which has faced intensive deforestation since colonial monoculture systems were introduced in the sixteenth century (Morellato & Haddad, 2000; Oliveira & Engermann, 2011). Since then, the introduction of further deforestation drivers such as mining and urbanization have threatened the forest and its inhabitants (Silveira, 2008). PETAR encompasses an area that survived deforestation, including traditional communities that developed in "the interstices" of colonial monoculture and macro economy (Oliveira & Engermann, 2011), practicing traditional slash-and-burn.

The community of *Ribeirão dos Camargo* (Fig. 1), whose territory is partially in PETAR, is composed of forest-dependent farmers descended from non-manorial settlers (mainly African and European) who migrated to the interior of the forest as a response to the economic crisis caused by the exhaustion of the gold mines in the eighteenth century (Pedroso et al., 2014). These settlers formed a multi-ethnic community of subsistence farmers practicing slash-and-burn agriculture learned from Indigenous and Quilombolas (forest communities developed by runaway slaves) populations.

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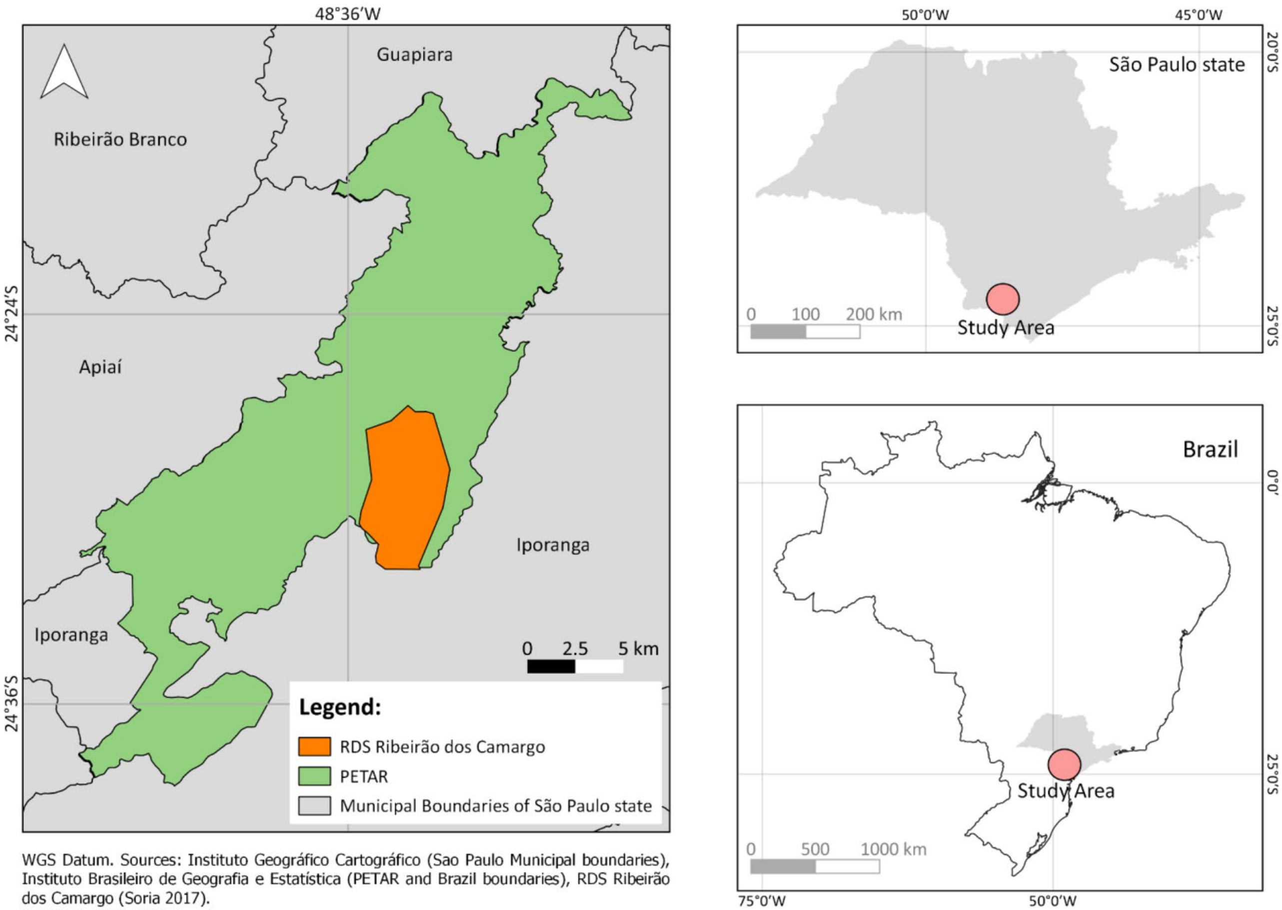


WGS Datum. Sources: Instituto Geográfico Cartográfico (Sao Paulo Municipal boundaries), Instituto Brasileiro de Geografia e Estatística (PETAR and Brazil boundaries), RDS Ribeirão dos Camargo (Soria 2017).
MENDES, BTFA 2022 (org.)

Fig. 1 Location of the suggested Sustainable Development Reserve

In 2000, PETAR was designated a Full Protection State Park, which strengthened laws against slash-and-burn management practices (*Sistema Nacional de Unidades de Conservação da Natureza,* 2000). Since then, communities have constantly fought and negotiated with the park authorities for relative tenure rights and access for active engagement in local tourism. The current concession process between State government and private bodies risks outsourcing decision making to managers not necessarily familiar with the environmental or sociological nature of the area, potentially exacerbating the challenges imposed by full protection laws and reversing advances already achieved.

Despite private and state pressures, the farmers of *Ribeirão dos Camargo* have been seeking a legislative change of the status of their territory from a Full Protection State Park to a Sustainable Development Reserve (RDS) (Fig. 1) (*Sistema Nacional de Unidades de Conservação da Natureza,* 2000; Pedroso, 2014). A Sustainable Reserve is a "natural area that is home to traditional populations whose livelihoods are based on sustainable systems of exploitation of natural resources, developed over generations and adapted to local ecological conditions and play a fundamental role in the protection of nature and in the maintenance of biological diversity" (*Sistema Nacional de Unidades de Conservação da Natureza,* 2000).

In this context, supporting communities' sustainable slash-and-burn rights in these areas starts with recognition of central role of the concept of sustainability in local practices. We use the concept of *traditional knowledge* (Diegues, 2019) since it encapsulates management *knowledge* and *know-hows* of natural dimensions farmers' territory accumulated over generations. Still, local knowledge is not static, but rather historically evolving (Pottier, 1999) and changing, promoting forest and agricultural management that includes forest recovery as an important component of communities' livelihoods.

Hence, sustainability towards slash-and-burn agriculture is taken as a socio-environmental concept. Slash-and-burn is described by Kleinman et al. as sustainable management meeting "near-term human needs" and respecting "long-term social, economic, and ecological limits" (1995: 236). Studies at Ribeira Valley have shown the need of addressing sustainability not only through environmental, ecological, and natural resources perspectives, but also through the socio-economic cultural reproduction of local communities and forest-dependent peoples (Diegues & Viana, 2004). Hence, our approach to sustainability focuses on long-term ecological features of slash-and-burn management that need to be respected to attend local near-term human needs and recognize the necessity of further studies to evaluate sustainability through a socio-economic perspective as well.

Slash-and-burn is a crop management technique widely practiced in moist and wet forested landscapes around the world (Felipim et al., 2004). The management regime is divided into three stages: conversion, cropping, and fallow (Felipim et al., 2004; Kleinman et al., 1995). The first stage involves clearing the forest vegetation where crops will be introduced. Cut vegetation typically remains in situ until it is dry enough for burning, which promotes near-term benefits in terms of inputs of soil nutrients. In the study community, the cropping stage happens through tillage without machines or chemical fertilizers, other than these from burning. The third stage should allow the recovery of soil properties and forest vegetation through the return of soil nutrients and biological processes.

Research has pointed to the system's sustainability in terms of vegetation and soil recovery after burning (Ribeiro Filho et al., 2018; Sillitoe & Shiel, 1999). The introduced biomass from ash and litter have been extensively analyzed as an interface between soil and vegetation in the system, providing soil nutrients for the crop and to further vegetation regeneration (Lessa et al., 1996; Oliveira, 2008; Sillitoe & Shiel, 1999). The proximity to seed banks during fallow is also taken as a factor that encourages slash-and-burn sustainability (Ribeiro Filho et al., 2018). The necessity of fallow periods adapted to each environment has been extensively studied as an essential factor to ensure soil and vegetation recovery (Lawrence & Schlesinger, 2001; Sommer et al., 2004).

Still, recovery here is not taken as a return to forest conditions as if the area were not managed. In fact, conservation is understood here through alternatives that promote diversity along with cultural diversity (Diegues, 2019) of those who historically depend on the forest. Thus, we hypothesize that soil and vegetation properties re-establish old-growth Atlantic Forest conditions over time, providing necessary food and forest resources to the community's livelihood. Our objective is to provide indicators of soil-vegetation recovery over ancient cropping areas of *Ribeirão dos Camargo Cabocla* as a contribution to the debate on the legitimacy of a RDS for the community's territory.

Materials and Methods

Study Area

Ribeirão dos Camargo is located at Iporanga (Fig. 1), a small city in the Ribeira Valley of the Atlantic Forest, a mixed Rain a Semi-deciduous Forest originally covering an area of 1.1 million km^2 of which only 98,000 km^2 remained by 2000 (Morellato & Haddad, 2000; Oliveira-Filho & Fontes, 2000). Despite deforestation, it is the second largest South American forest in area (Oliveira-Filho & Fontes, 2000). Its remaining fragments have biodiversity levels per area higher than those of the Amazon Forest (ibid). Our study area has high annual levels of pluviosity and lacks a dry season due to continuous oceanic wet masses reaching the mountainous features (Morellato & Haddad, 2000; Oliveira-Filho & Fontes, 2000).

The specific crop sites are in steep hills and ridges intersected by tributaries of the Ribeira de Iguape. Such landforms are sustained by metamorphic rocks, especially meta siltstones and phyllites (Fundação Florestal, Secretaria Estadual de São Paulo, 2016). These lithologies are associated with old shear zones related to the Braziliano Orogeny – 800–550 m.y.a. (Brito Neves et al., 2014), and belongs to the Açungui Supergroup, Ribeira belt, and Mantiqueira Province. The predominant soils are dystrophic, low-activity clay *Cambissolos* (Inceptisols), with medium to clayey texture, developed over metapelites (Fundação Florestal, Secretaria Estadual de São Paulo, 2016). This pedological cover supports secondary submontane vegetation, which comprises the Atlantic Tropical Forest. Despite the deforestation that has occurred in the area since the sixteenth century, there is medium to high tropical forest vegetation (more than 15 m), with open canopy and high levels of alteration due to ancient crops (ibid.).

The region's climate is influenced 60% of the year by the Polar Atlantic Mass and for 40% by the Atlantic Tropical Mass (Fundação Florestal, Secretaria Estadual de São Paulo, 2016). The area is subject to a mean precipitation index of 1500 to 2000 mm/year (Lepsch et al., 1990), a mean annual temperature of 20 °C, average minimum temperature of 12 °C, and average maximum temperature of 27 °C (CBH-RB, 2016). The frequency of anticyclones produces a colder and less rainy season from May to September, and a hotter and rainier season from October to April. However, this seasonal variability does not change the continuum characteristics of high pluviometry and humidity, providing water surplus throughout the year in the PETAR.

Methods

With the assistance of members of the community, we selected three old cropping areas to perform the studies.

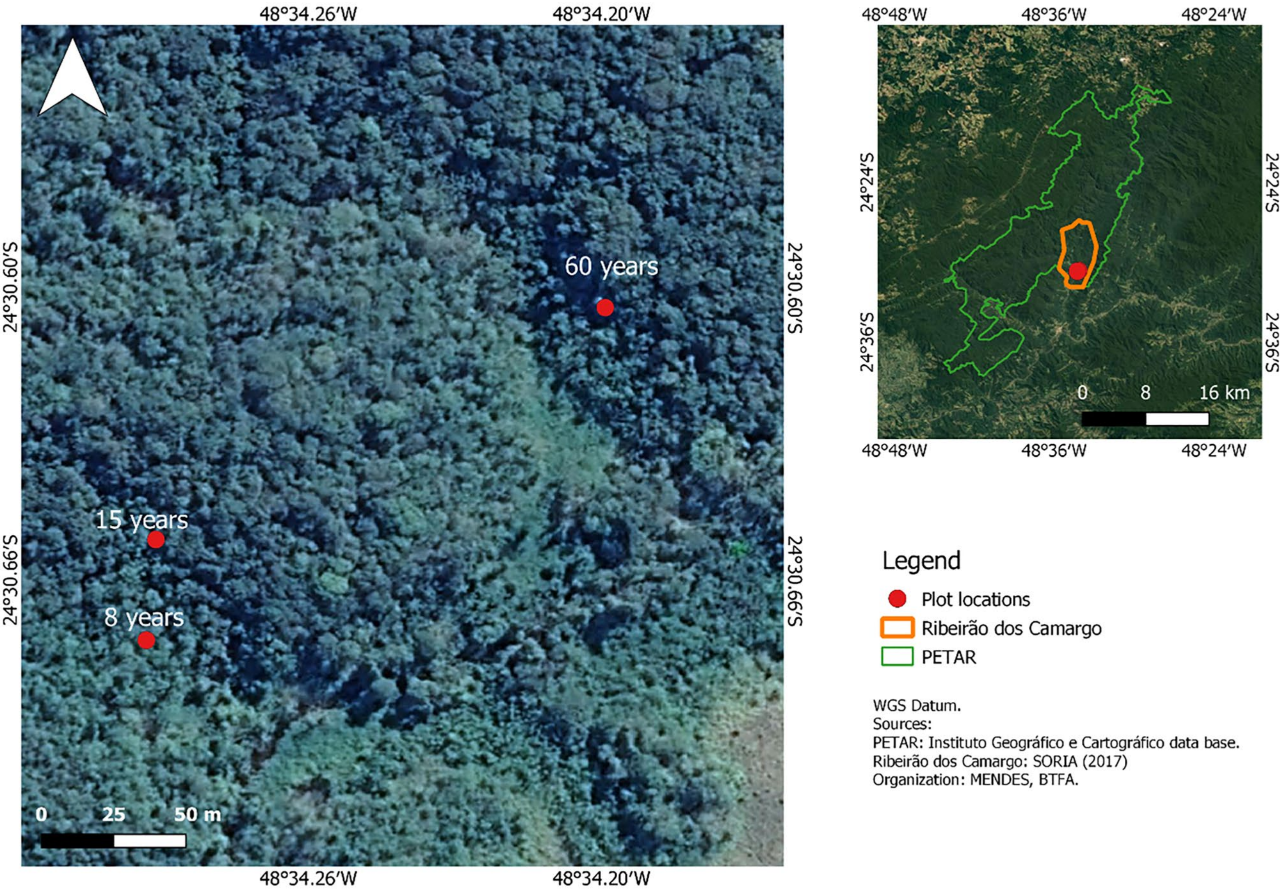
The local farmer, Benedito de Almeida, directed us to a slope where areas with similar geological, geomorphological, and pedological characteristics (Fig. 2) have lain fallow for 8, 15, and 60 years. We cut a trench 60 cm deep (Hénin et al., 1976) in each of these areas to analyze the morphological features of one soil profile in each of the areas. For morphological analysis, we followed Hénin et al. (1976) and Santos et al. (2015), describing the following characteristics of the soil horizons: color, texture, structure (type, size, grade), moisture consistency, transitions between horizons, roots (size, abundance) and soil fauna.

In addition, we collected triplicates of soil samples of each horizon to analyze the physical (bulk density, porosity, particle size, and aggregate stability) and chemical parameters (pH in H_2O, pH in $CaCl_2$, pH in KCl, P, N total, Organic Carbon (OC)), and the exchangeable cations (Na^+, K^+, Al^3, $Al^+ + H^+$, Ca^{2+}, and Mg^{2+}). We used this physical data to evaluate soil compaction due to management, whereas we used the chemical data to analyze soil nutrition.

We determined the macro, micro, total porosity, and bulk density by collecting undisturbed samples in volumetric rings, which we put on Büchner funnels in the laboratory (Manfredini et al., 1984). The particle-size analysis was performed through the pipette method for silt and clay content determination, whereas sand content was measured by sieving, according to Camargo et al. (2009). We established the aggregate stability—resistance of soil macroaggregate structures to disturbances (USDA, 1996)—by sieving under water (Grohmann, 1960) and over the superficial horizons, where the aggregates are more developed (in the horizons below, no pedological structures were identified).

The pH-H_2O was measured, respectively, in a 1:1 soil–water ratio (Burt & Staff, 2014). Available P were extracted with Mehlich 1 solution (0.05 M HCl + 0.0125 M H_2SO_4) and quantified by colorimetry. Total N was determined by sulphuric digestion using the Kjeldahl flask technique (Claessen, 1997). The organic carbon (OC) was determined by wet oxidation in $K_2Cr_2O_7$ solution and titration with Fe $(NH_4)_2(SO4)_2.6H_2O$ (Walkley & Black, 1934).

Exchangeable Ca^{2+}, Mg^{2+} and Al^{3+} were extracted with 1 M KCl; the two first cations were determined by atomic absorption spectroscopy (AAS) and the later cation was quantified by titration with 0.025 M NaOH, using



WGS Datum.
Sources:
PETAR: Instituto Geográfico e Cartográfico data base.
Ribeirão dos Camargo: SORIA (2017)
Organization: MENDES, BTFA.

Fig. 2 Location of the three cropped studied areas bromothymol blue as the indicator (Cantarella et al., 2001). The exchangeable K^+ and Na^+ were extracted with Mehlich 1 (0.05 M HCl + 0.0125 M H_2SO_4) and measured by flame photometry (Cantarella et al., 2001; Silva et al., 2009). Exchangeable $H + Al^{3+}$ were extracted by 1 M KCl and 0.5 M $(CH_3COO)_2Ca \cdot H_2O$ at pH 7 and quantified by titration with 0.025 M NaOH, using phenolphthalein as indicator (Quaggio & Raij, 2001). The results of the chemical analyses were used to calculate cation exchange capacity (CEC) $(Ca^{2+} + Mg^{2+} + Na^+ + K^+ + H^+ + Al^{3+})$, total of basic cations (S) $(Ca^{2+} + Mg^{2+} + Na^+ + K^+)$, base saturation (V%) $[(S \times 100) / CEC]$, and Al saturation (m%) $[(Al^{3+} \times 100) / (Ca^{2+} + Mg^{2+} + K^+ + Na^+ + Al^{3+})]$ (EMBRAPA, 1997).

For an exploratory analysis of the vegetation of each cropping area, fixed plots of 10 × 10 m were used for a summer and a fall collection, as it is traditionally done in Brazilian forestry descriptions (Freitas & Magalhães, 2012). Two vegetation collections were done over summer (November 2018) and fall (April 2019) respectively.

Plant identification was made primarily through the community's local names. Then, the diameters at breast height (dbh) of tree species with a dbh bigger than 1.5 cm were collected. The choice of focusing on tree species was made based on the broader literature regarding their successional stages in the area. The chosen dbh considers regenerating and mature arboreal individuals. After that, exsicates were produced and identified at the Municipal Herbarium of São Paulo city. The species nomenclature followed Flora Brasil (2020), and the fallen trees were not identified, although their dbh were collected.

We subsequently identified the species as threatened and non-threatened based on the publications of Secretariat of the Environment of São Paulo state (SMA) (*Lista oficial das espécies da flora ameaçadas,* 2016) and of the Ministry of Environment of Brazil—MMA (*Lista Oficial das Espécies da Flora Brasileira Ameaçadas de Extinção,* 2008). In addition, we determined the successional stage classification of the arboreal species between pioneer and non-pioneer, according to Gandolfi et al. (1995), Barretto and Catharino (2015), Pereira et al. (2013), Marmontel et al. (2013), Coelho et al. (2016), and Moura (2016). All the individuals had their basal area (Freitas & Magalhães, 2012) calculated, and further evaluated according to pioneer and non-pioneer individuals in each plot.

Results

Soil Analysis

The pedological cover of the three analyzed cropping areas (fallow periods: 8, 15, and 60 years; Figs. 2 and 3) present similar morphological characteristics in terms of shallow and incipient soil profiles (Table 1), with a sequence of A-Bw-C horizons, all classified as Cambisols (IUSS Working Group WRB, 2015). They are generally light colored, more commonly yellowish brown (10YR 5/4; 7.5YR 5/4) in the A and light yellowish-brown or light brown in the Bw. The texture is silty clay loam in the fallow period of 8 years and varies from clay to silty clay in the 15 and 60 fallow periods. The structure is mostly subangular blocky in the A and B horizons, and massive in the C horizon. However, granular structure was observed in the A horizon in the 60-year cropping area.

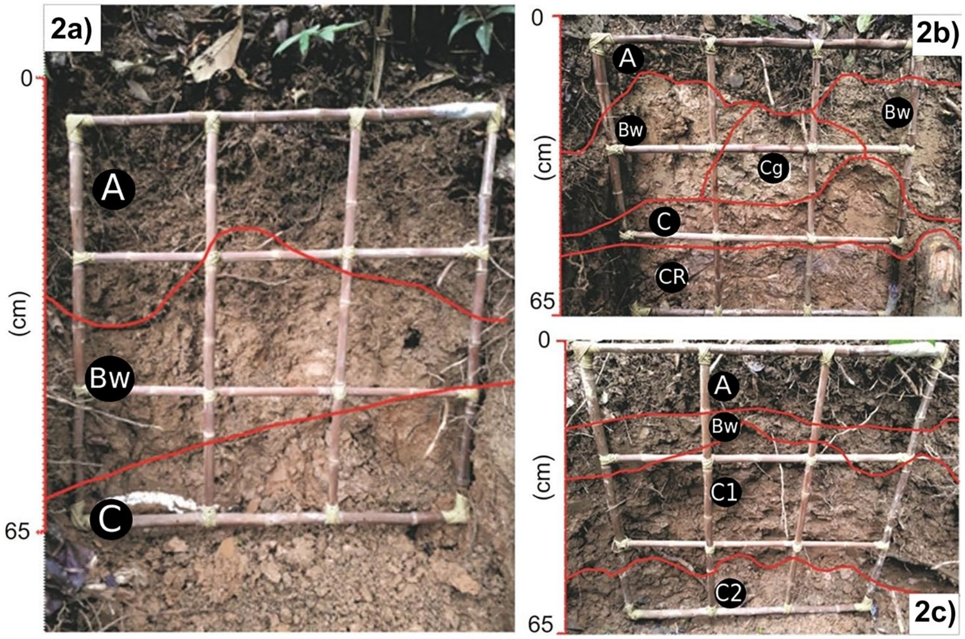


Fig. 3 Soil profiles of the 8 (2A), 15 (2B), and 60 (2C) years areas

Table 1 Morphological description of the 8-year set aside soil

Previous crops in all the areas: Rice and corn												
Fallow period	**Slope**	**Horizon**	**Depth (m)**	**Color**	**Texture**	**Structure**			**Wet consistence**	**Transition**	**Roots**	**Observations**
						Type	**Class**	**Grade**				
8 years	32°	A	0 to 0.37	10 YR 5/4	Silty clay loam	Subangular blocks with some sharp edges	Thin	Moderate to strong	Sticky and slightly plastic	Diffuse	Prevalence of fine ramified roots. They are scattered predominantly horizontally. A few thicker roots, of 1 to 4 cm.	Ants, coprolites, worms, and organic matter were found.
		Bw	0.34 to 0.56	10 YR 6/4	Silty clay loam	Subangular blocks with some sharp edges	Medium	Moderate to strong	Sticky and plastic	Clear	Rare fine ramified roots.	2 cm milky angular quartz was found, along the profile with centimeter cavities with eventual fulfillment of coal. Presence of biogenic microaggregates.
		C	0.52 to 0.65	7.5 YR 6/4	Silty clay loam	Massive			-	-	Rare thicker roots.	Clay skin on the face of peds.
15 years	32°	A	0 to0.15	7.5 YR 5/4	Silty clay	Subangular blocks	Thin	Strong	Sticky and plastic	Clear	Prevalence of fine ramified roots from 0.7 to 0.8 cm. A few thicker roots, of 1.5 to 3.5 cm.	Presence of coal, stains and concretions.
		Bw	0.11 to 0.40	10 YR 6/3	Clay	Subangular blocks	Medium	Weak	Sticky and plastic	Abrupt	Scattered fine ramified roots.	Pink stains derived from the rock.
		Cg	0.15 to 0.41	5 YR 5/4	Silty clay	Massive			Sticky and plastic	Abrupt	Scattered rare fine ramified roots.	Clear stains related to hydromorphic features.

Table 1 (continued)

Previous crops in all the areas: Rice and corn

Fallow period	**Slope**	**Horizon**	**Depth (m)**	**Color**	**Texture**	**Structure**			**Wet consistence**	**Transition**	**Roots**	**Observations**
						Type	**Class**	**Grade**				
		C	0.40 to 0.52; 0.41 to 0.51	5 YR 5/6	Silty clay	Massive			-	Abrupt	-	Slightly altered rock with a visible metamorphic foliation.
		CR	0.51 to 0.65	10 R 3/2	Silty Clay	Massive			-	-	-	-
60 years	32°	A	0 to 0.12	7.5YR 4/3	Silty clay	Granular	Medium	Moderate	Sticky and plastic	Clear	Roots are numerous and divided between thicker individuals and fine ramified roots.	Leave fragments slightly degraded; presence of coal, coprolites and worms.
		Bw	0.12 to 0.20	10YR 4/4	Silty clay	Subangular blocks	Medium	Moderate	Sticky and plastic	Diffuse	One thicker root of 4.5 cm, which is a preferred channel for water flows.	-
		C1	0.20 to 0.40	7/5 YR 5/4	Silty clay	Angular blocks	Coarse	Moderate	Sticky and plastic	Clear	Rare, mostly fines.	Clay skin on the face of peds.
		C2	0.40 to 0.65	Matrix 5YR 5/6; Mottles 5YR 6/1	Silty clay loam	Massive			Sticky and plastic	Clear	Rare thicker roots.	Grayish millimeter-sized stains.

Table 2 Particle-size (g kg^{-1})*

Fallow period	Horizon	Sand							Silt	Clay
		0.053–0.0625	0.062–0.125	0.125–0.250	0.250–0.5	0.5–1	1–2	TOTAL	0.002–0.053	< 0.002
8 years	A	16.7	126.2	35.6	9.5	6.6	3.2	197.8	448.8	353.4
	Bw	9.3	119.1	32.1	6.1	5.1	6.3	177.9	426.2	395.9
	C	47.2	92.4	39.2	5.8	3.8	2.2	192.1	419.6	388.2
15 years	A	4.5	87.2	32.8	11.6	9.2	5.7	151.1	411.2	437.7
	Bw	4.7	63.8	37.2	11.4	8.4	4.1	129.6	315.8	554.6
	Cg	8.1	68.6	25.2	5.9	4.3	2.8	114.9	428.6	456.5
	C	3.7	50.0	26.7	7.3	3.9	2.4	94.0	455.6	450.4
	CR	3.2	37.9	15.2	11.2	5.2	2.0	74.7	477.5	447.8
60 years	A	4.7	50.2	13.2	9.1	7.1	3.0	87.4	495.1	417.4
	Bw	4.4	47.1	5.6	3.0	2.0	3.6	65.7	469.7	464.6
	C1	3.8	47.4	7.6	2.8	0.8	1.2	63.6	426.8	509.6
	C2	41.0	71.1	30.5	5.1	3.0	3.0	153.8	399.7	446.4

*All measurements were made within a SE margin of 2%

The clay content slightly increased from the 8 to the 15 and 60 cropping areas. These slight variations are partially accompanied by porosity and bulk density changes, since the bulk density of A and Bw horizons indicate a decrease from the 8-year soil to the 60-year. In contrast, porosity and aggregate stability suggest an increase with the fallow period (Tables 2 and 3).

Similarly, the chemical data (Table 4 and 5) confirm the relative homogeneity of morphological and physical attributes of the soils. Such data indicate that the pedological cover is highly acidic (pH $H_2O < 4.7$), leached, and presents low fertility, with a low concentration of Ca^{2+}, Mg^{2+}, P, total N, and organic matter. The total amounts of basic cations ($S < 12.3$ mmol$_c$ kg^{-1}), the base saturation ($V\% < 18.3\%$) and CEC values (< 70.4 mmol/kg) are small in all horizons. Overall, the highest values of S and V% are in the surface horizons (A). S and V% suggest higher values in the 8-year set-aside zone, a decrease in the 15-year zone, and a slight increase in the 60-year zone (Table 4). The Al^{3+} is the only exchangeable cation that suggests significant increases over time, especially in the A horizon. Such characteristics agree with aluminum saturation (m%) values, which indicate high concentration of Al (> 81%) in the sorption complex of all horizons.

Table 3 Bulk Density, Porosity, and Ped Stability Degree (ped size average)*

Fallow period	Horizon	Bulk density Kg dm^{-3}	Total of pores (%)	Micropores (%)	Macropores (%)	Ped size Average (mm)
8 years	A	0.96	63.69	36.14	27.55	3.19
	Bw	1.42	46.36	38.09	8.27	3.24
	C	1.41	46.89	39.09	7.80	-**
15 years	A	0.87	67.05	46.15	20.9	3.35
	Bw	1.34	49.51	44.64	4.87	3.29
	Cg	1.37	48.33	43.58	4.75	-**
	C	1.34	49.52	43.46	6.06	-**
	CR	1.48	44.26	41.26	3	-**
60 years	A	0.78	70.42	33.28	37.14	3.35
	Bw	1.27	52.08	39.08	13.00	3.34
	C1	1.3	50.95	40.18	10.77	-**
	C2	1.24	53.06	38.57	14.49	-**

*All measurements were made within a SE of 2%

**Ped size Average was calculated for measurements of aggregate stability. Therefore, only horizons A and B were analyzed, since horizons C is an alterite with very weak structures, highly influenced by rock's original features

Table 4 Chemical Data*

Fallow period	Horizon	Na	K	Ca	Mg	Al	N	OC	OM	P	Al + H	S	CEC	V	m	pH
		mmol kg^{-1}					mg kg^{-1}	g kg^{-1}		mmolc kg^{-1}			mmol$_c$kg	%	%	-
8 years	**A**	0.77	2.15	2	4	49.17	1960	21	36	< 2	110.93	8.92	58.09	15.36	84.64	4.14
	Bw	0.71	1.07	2	6	51.77	2660	30	52	4	84.33	9.78	61.55	15.89	84.11	3.88
	C	0.64	0.94	< 0.1	1	53.43	1274	10	18	< 2	80.07	2.68	56.11	4.78	95.22	4.3
15 years	**A**	0.6	2.03	< 0.1	1	57.17	875	5	9	< 2	90.73	3.73	60.90	6.12	93.88	4.26
	Bw	0.31	0.46	< 0.1	1	51.43	1078	4	7	< 2	54.93	1.87	53.30	3.51	96.49	4.58
	Cg	0.43	0.67	< 0.1	1	55.00	1141	5	8	< 2	69.00	2.20	57.20	3.85	96.15	4.58
	C	0.31	0.39	< 0.1	1	53.20	973	5	9	< 2	66.13	1.80	55.00	3.27	96.73	3.58
	CR	0.41	0.61	< 0.1	1	64.23	994	5	8	< 2	72.27	2.12	66.35	3.20	96.8	3.74
60 years	**A**	0.86	2.11	< 0.1	2	65.30	1596	14	24	2	118.93	5.07	70.37	7.20	92.8	3.82
	Bw	0.65	0.46	< 0.1	1	45.27	1316	9	16	1	91.40	2.21	47.48	4.65	95.35	4.68
	C1	0.72	0.67	< 0.1	1	63.93	1372	7	12	1	91.40	2.49	66.42	3.75	96.25	4.18
	C2	0.57	0.72	2	9	54.37	3150	30	51	9	72.13	12.29	67.26	18.27	81.73	4.02

*All measurements were made within a SE of 12%

Vegetation Analysis

The vegetation analysis classified species as pioneer (P), non-pioneer (NP), and non-identified (NI) (see Tables 5 and 6). Non-identified species were considered, and their basal areas were calculated (Tables 6, 7, 8, 9). The 8 and 15-year set-aside areas present a similar number of species (21 and 20, respectively), whereas the 60 years' area has slightly more species (25). The 60-year set-aside area has significantly more non-pioneer species (14) and individuals (45). Moreover, the quantity of pioneer species and individuals increases from the 8 years area (27 and 46) to the 60 years area (18 and 75), and the non-pioneer species moderately decrease from the 8 (7) to the 15 years area (6) but increase in non-pioneer individuals (from 13 to 16).

The number of young individuals ($1.5 < \text{dbh} < 5$ cm) is similar to the number of older ones (dbh > = 5 cm) in the three plots (Table 6). To make a general analysis on the disposition of the pioneer and non-pioneer species inside each plot (Table 7), the relative density, as well as the relative dominance for pioneer, non-pioneer, and non-identified species (Tables 8, 9 and 10), were calculated. The data indicate a basal area of 30.21 m^2 ha^{-1} in the 8-years plot, 19.93 m^2 ha^{-1} in the 15-year and 46.6 m^2 ha^{-1} in the 60 years.

Greater numbers of non-pioneer species (14) and basal area (46.6 m^2/ha) are concentrated in the 60-year set-aside area, whereas the pioneers lie mainly in the 8 (11) and 15 years (10) set-aside areas. Furthermore, in the total species of all plots, the basal area is slightly prominent among the pioneer species, whereas the number of non-pioneer individuals among all plots is higher than that of non-pioneers.

Discussion

The morphological and physical data of the soil cover indicate that slash-and-burn causes weak impacts on soil, as demonstrated especially by the bulk density and aggregate stability data. The bulk density in all soil horizons of the three areas is lower than 1.43 kg dm^{-3}, indicating that the management adopted did not induce compaction. As comparison, the bulk density is considerably higher in cultivation of *pupunha* palm, reaching values of 1.93 kg/dm^3 (Santos & Manfredini, 2018) in clay to silty clay in *Cambissolos* (Cambisols) in neighboring areas at Iporanga/SP.

In the same way, aggregate stability (Table 3) suggests a gradual soil recovery over the fallow period. Furthermore, an increase of the clay content likely enhances aggregate stability due to the binding effects of the clay minerals (phyllosilicates) and Fe and Al oxides in the soils (Totsche et al., 2018). Forest regeneration, especially in the 60 years fallow period, likely triggers an increase of soil fauna (i.e. earthworms), whose role on the aggregation was studied in Atlantic Forest soils (Diogo Filho & Queiroz Neto, 2018).

The studied soils are classified as strongly acidic (Table 4) (Gandolfi et al., 1995). Although the CEC is considered high, the Al^{3+} is the main cation in the exchangeable complex in most of the horizons (Table 4). These characteristics can inhibit root growth and interfere in nutrient availability (Lourenço et al., 2021; Osaki et al., 1997; Watanabe & Osaki, 2006). On one hand, high acidity can be related to the systematic replacement of nutrients (Ca^{2+}, Mg^{2+}, K^+, and Na^{2+}) in the soil colloids by H^+ and Al^{3+}. This could be associated with the high hillslope declivity and precipitation rates in the study area, which contributes to the strong leaching of basic cations (Martins, 2010). On the other hand, some studies (e.g. Lourenço et al., 2021; Osaki et al., 1997; Watanabe & Osaki, 2006) have

Table 5 Identified species per plot

Family/*Specie*	Popular Name	60 years	15 years	8 years	SC
PTERIDOPHYTE					
Cyatheaceae		**6**	**2**	**7**	
Cyathea corcovadensis (Radd) Domin	Samambaiaçu	6	2	7	NP
ANGIOSPERMS					
Annonaceae		**1**	**0**	**4**	
Guatteria australis A.St.-Hil	Calão de rede	1	0	4	P
Aquifoliaceae		**1**	**0**	**0**	
Ilex theezans Mart	Canela	1	0	0	P
Arecaceae		**8**	**7**	**1**	
Bactris setosa Mart	Tucunheiro	0	1	0	NP
Euterpe edulis Mart	Juçara	8	6	1	NP
Boraginaceae		**0**	**0**	**1**	
Cordia sellowiana Cham	Cabaça	0	0	1	P
Celastraceae		**5**	**0**	**0**	
Monteverdia cf. *schumanniana* (Loes.) Biral	Pau d'arco	5	0	0	NP
Elaeocarpaceae		**4**	**0**	**0**	
Sloanea cf. *guianensis* (Aubl) Benth	Sai porco	4	0	0	NP
Euphorbiaceae		**0**	**1**	**3**	
Alchornea cf. *triplinervia* Mull. Arg	Tapieiro	0	1	3	P
Fabaceae		**4**	**3**	**0**	
Bauhinia sp.	Pata de vaca	4	0	0	NI
Schizolobium parahyba Vell. (Black)	Guapuruvu	0	3	0	P
Lauraceae		**4**	**7**	**2**	
Endlicheria paniculata (Spreng) J. F. Macbr	Canela	0	6	1	NP
Nectandra oppositifolia Ness & Matt	Canela branca	1	0	0	P
Ocotea brachybotrya (Meisn) Mez	Canelinha	1	1	0	NP
Ocotea dispersa (Nees & Mart) Mez	Canela	0	0	1	NP
Ocotea teleiandra (Meisn.) *Mez*	Canela preta	2	0	0	NP
Melastomataceae		**0**	**8**	**5**	
Leandra variabilis Radd	Pixirica	0	6	0	P
Miconia cinnamomifolia (DC.) Naudin	Nhocatirão	0	1	2	P
Tibouchina pulchra (Vell.) Cogn	Nataoeiro	0	1	3	P
Meliaceae		**5**	**1**	**0**	
*Cabralea canjerana (*Vell.*)* Mart	Cajarana	2	0	0	NP
Guarea macrophylla Vahl	Cafeeiro bravo	3	1	0	P
Myrtaceae		**3**	**1**	**4**	
Eugenia subavenia O. Berg	Camarinheiro	2	0	2	NP
Myrcia splendens (Sw.) DC	Fruto de pombo	0	0	2	P
Eugenia cf. *malacantha* D. Legrand	Araçá	1	0	0	NP
Eugenia sp.	Canela	0	1	0	NI
Myristicaceae		**1**	**0**	**0**	
Virola gardneri (A. DC.) Warb	Bucuveiro	1	0	0	NP
Nyctaginaceae		**0**	**1**	**0**	
Guapira opposita (Vell.) Reitz	Canela	0	1	0	P
Peraceae		**2**	**2**	**0**	
Pera glabrata (Schott) Poepp. Ex. Baill	Tabucuva	2	2	0	P
Piperaceae		**0**	**1**	**1**	
Piper cf. *malacophylla* (C. Prest) C. DC	Jaguarandi	0	1	1	NI
Phyllanthaceae		**0**	**0**	**3**	
Hieronyma alchorneoides Allemão	Ricurana	0	0	3	P
Polygonaceae		**0**	**3**	**0**	

Table 5 (continued)

Family/*Specie*	Popular Name	60 years	15 years	8 years	SC
Coccoloba sp.	Coração de Bugre	0	3	0	NI
Olacaceae		**1**	**0**	**0**	
Heisteria silvianii Schwacke	Casco de areia	1	0	0	NP
Rubiaceae		**7**	**3**	**0**	
Bathysa australis (A. Sr-Hil.) K. Schum	Folha larga	5	3	0	P
Psychotria sutterella Müll.Arg	Fruto de pombo	2	0	0	NP
Rutaceae		**2**	**0**	**0**	
Esenbeckia grandiflora Mart	Canela de cotia	2	0	0	NP
Salicaceae		**8**	**0**	**2**	
Casearia sylvestris Sw	Árvore de macaco	0	0	1	P
Casearia obliqua Spreng	Rabo de burro	8	0	1	NP
Sapindaceae		**5**	**3**	**0**	
Allophylus petiolulatus Rad/K	Canela	0	1	0	P
Cupania olongifolia Mart	Cavatã	5	2	0	P
Solanaceae		**0**	**0**	**3**	
Solanum cf. swartzianum Roem. & Schult	Canela	0	0	3	P
Urticaceae		**0**	**0**	**3**	
Pourouma guianensis Aubl	Imborana	0	0	3	P
Vochysiaceae		**0**	**0**	**2**	
Vochysia bifalcata Warm	Guaricica	0	0	2	P

CS Successional Classification, *P* Pioneer, *NP* Non-pioneer, *NI* Non-identified

Table 6 Structure and Diversity Parameters of each Plot

	DBH	Sampled individuals	Number of identified species	Density	Dominance
8-year set-aside	1.5 > dbh < 5	19	15	1900	1.63
	> = 5	27	14	2700	28.56
	Total	46	21	4600	30.18
15-year set-aside	1.5 > dbh < 5	27	15	2800	1.28
	> = 5	24	14	2300	18.64
	Total	51	20	5100	19.93
60-year set-aside	1.5 > dbh < 5	38	15	3800	3.68
	> = 5	37	15	3700	42.96
	Total	75	25	7500	46.63

pointed possible benefits of aluminum to well-adapted trees, using the element to improve nutrient uptake, excluding or accumulating the elements in its leaves as a survival strategy. In addition, species that accumulate aluminum seems to be demand lower levels of other essential nutrients (Watanabe & Osaki, 2006), such as some species found at this work's plots: *Alchornea triplinervia* (8 and 15 years-old plot) and *Pera glabrata* (15 and 60 years-old plots) (Lourenço et al., 2021).

Table 7 Successional Stages

		NP	P	NI	Fallen individuals	Total
8-year set aside	**Total of individuals**	13	27	6	0	46
	Total of species	7	11	3	0	21
15-year set aside	**Total of individuals**	16	22	8	5	51
	Total of species	6	10	4	*	20
60-year set aside	**Total of individuals**	45	18	12	0	75
	Total of species	14	8	3	0	25

*The toppled individuals were not identified

Table 8 8-year set aside

	NP	P	NI	Total
Ab total $m^2\ ha^{-1}$	5.29	23.47	1.46	30.21
Abe/Ab8years (%)	17	78	5	100
ne/ni8years	0.28	0.59	0.13	1

Abe sum of the basal areas of each stage of ecological succession, *Ab8years* sum of the basal areas of the 8-year set-aside zone, *ne* number of species of each stage of ecological succession in the 8-year set-aside zone, *ni8years* number of individual of the 8-year set-aside zone

In this study, higher macronutrients concentration (N total, K^+, Ca^{2+} and Mg^{2+}) is verified only in the A and Bw horizons of the 8 years area, possibly due to the more recent burn. The macronutrients availability (N total, K^+, Ca^{2+}, and Mg^{2+}) and the pH patterns are like those found in Cambisols pre and post slash-and-burn in the soils of another local community in the PETAR (Ribeiro Filho et al., 2018), as well as in other Cambisols of the Atlantic Forest (Gandolfi et al., 1995). This suggests that, although management causes chemical changes over the pedological cover, they are subtle, since strong acidity, low base saturation and high levels of Al^{3+} are typical and natural soil characteristics of this Biome (e.g., Gandolfi et al., 1995; Ribeiro Filho et al., 2018). Therefore, this study proposes that the nutrient inputs from slash-and-burn are key elements for vegetation recovery, following the conclusions of other research performed in the area (Lessa et al., 1996; Ribeiro Filho et al., 2018; Oliveira, 2008). Over time, this recovery would reestablish the closed-system between soil-litter-vegetation that allows the continuous nutrient provision to the forest vegetation, despite soil infertility (Martins, 2010; Oliveira, 2008).

Moreover, the study areas present similar values of basal areas per hectare when compared to other areas of Atlantic Forest (Table 11). The comparison of the basal area of our findings and these in the literature indicates characteristics of young to old secondary forests in the plots of 8 and 15-years of fallow (Table 11). The value per hectare found in the 60 years area (46.6 $m^2\ ha^{-1}$), along with its predominance of non-pioneers species, can be seen as an indicator of an old growth forest. Also, the incidence of *Euterpe edulis* (all the plots) and *Eugenia malacatha* D. Legrand (60-year plot) indicates the regeneration of threatened species (*Lista Oficial das Espécies da Flora Brasileira Ameaçadas de Extinção* 2008; Fundação Florestal, Secretaria Estadual de São Paulo, 2016). The first species is planted by the community after the final harvest as a strategy to improve regeneration and is considered an indicator of well conserved forests (Moreno et al., 2003). *Eugenia malacatha* D. Legrand was identified with uncertainty levels. If these data are correct, it indicates not only that the forest is being restored, but also that it contributes to the re-establishment of species highly threatened with extinction.

Table 9 15-year set-aside

	NP	P	NI	Fallen individuals	Total
Abe total $m^2\ ha^{-1}$	2.48	10.58	2.1	4.77	19.93
Abe/Ab15years (%)	12	53	11	24	100
ne/ni15years	0.31	0.43	0.16	0.1	1

Abe sum of the basal areas of each stage of ecological succession, *Ab15years* sum of the basal areas of the 15-year set-aside zone, *ne* number of species of each stage of ecological succession in the 15-year set-aside zone, *ni15years* number of individual of the 15-year set-aside zone

Table 10 60-year set-aside

	NP	P	NI	Total
Abe total $m^2\ ha^{-1}$	28	8.6	10	46.6
Abe/Ab60years (%)	60	20	20	100
ne/ni60years	0.6	0.2	0.2	1

Abe sum of the basal areas of each stage of ecological succession, *Ab60years* sum of the basal areas of the 60-year set-aside zone, *ne* number of species of each stage of ecological succession in the 60-year set-aside zone, *ni60years* number of individuals of the 60-year set-aside zone

There is a large range of studies of successional levels of Atlantic Forest tree species (e.g.: Gandolfi et al., 1995; Marmontel et al., 2013; Pereira et al., 2013; Barretto & Catharino, 2015; Coelho et al., 2016; Moura, 2016). Analyzing vegetation indicators through these parameters can be useful, in considering differences of light and shade demanding species, which is an important variable considering canopy dynamics during recovery (Gandolfi et al., 1995; Barretto & Catharino, 2015). In this regard, the data suggest higher numbers of non-pioneer species and individuals in the later plot (60 years) as an indicator of recovery. Nonetheless, broader perspectives on the analysis of forest regeneration highlight the importance of considering the variability of species according to site-specific species composition in surrounding areas and environmental impacts on species determination (Norden et al., 2015).

Norden et al. (2015) points out that local environmental factors are a bigger determinant on successional processes than standing age. In this regard, regeneration is not a linear or uniform process (ibid.). Its inherent unpredictability is considered when analyzing the 15-year plot basal area (Table 9). The 15-year plot was subject to tree falling and the forest gap should influence forest composition. The high hillslope declivity, natural erosion, and mass movement are natural contributors to trees falling in the Atlantic Forest (Fundação Florestal, Secretaria Estadual de São Paulo, 2016). Gandolfi et al. (1995) state that clearings increase

Table 11 Literature comparison of Density and Dominance values found for the Atlantic Rainforest

Author	Fallow Period (years)	Location (City/State)	Altitude (m)	Previous use	Stage of Ecological Succession	DBH (cm)	Basal Area (m^{2}ha^{-1})
Barretto and Catharino (2015)	-	Marsilac (Sao Paulo)	750—775	Farming and forest extraction of timber and palm heart	Mature	> 4.8	49.3
	-	Morro Grande (Sao Paulo)	850	Farming	Mature	> 4.8	44.5
	-	Itapevi (Sao Paulo)	880	Mostly conserved forest since the 1940s, except for a fire in the 1960s	Mature	> 4.8	44.5
Kurtz and de Araújo (2000)	-	Paraíso (Rio de Janeiro)	200	Grassland and subsistance agriculture	Climax or advanced secondary forest	> 5	57.2
Ruschel et al. (2009)	> 30	São Pedro de Alcântara (Santa Catarina)	-	Grassland	Intermediate secondary forest	> 5	25,6
	> 50		-	Grassland	Advanced secondary forest	> 5	33,3
Moreno et al. (2003)	-	Campos dos Goytacazes (Rio de Janeiro)	50	Monoculture and grassland	Well conserved secondary forest	> 10	41.9
	-		250	Monoculture and grassland	Well conserved secondary forest	> 10	34.8
This research	8	Iporanga (Sao Paulo)	189	Slash and Burn	Young secondary	1.5 > dbh < 5	1.63
						> = 5	28.56
						> 1.5	30.18
	15		156			1.5 > dbh < 5	1.28
						> = 5	18.64
						> 1.5	19.93
	60		138		Old-secondary to old-growth	1.5 > dbh < 5	3.68
						> = 5	42.96
						> 1.5	46.63

the canopy opening, encouraging light-demanding species (i.e., pioneers in the authors' terms). Openings in the area might also raise leaching rates due to higher rain exposure, which must contribute to smaller values of basic cations and organic matter in the area (Table 9). Thus, multi-functional analysis in terms of topography and climate effects on soil chemical properties and vegetation seems to be important for deeper studies of regeneration in the area.

Finally, the limited number of plots studied in this exploratory work is not sufficient to attest to the sustainability of *coivara* but can suggest indicators. The data suggest that the management undertaken by the community meets a Sustainable Reserve's definition (see Introduction), since local management seems to safeguard major features of Atlantic Forest's soils and vegetation. Also, the management seems to ensure soil conditions for agriculture subsistence when respecting longer fallow periods, and the forest biomass to achieve mature forest levels, which seem to provide enough fertilization through burning for food production. Therefore, sustainability in terms of assurance of near-term agriculture needs seems to be provided through fallows that allow old-growth forest regeneration.

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Declarations

Conflict of Interest The authors have no relevant financial or non-financial interests to disclose.

Informed Consent The authors confirm that all the soil and most of the vegetation data generated or analyzed during this study are included in this published article. The data that support vegetation findings of this study are available from the corresponding author upon request.

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