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Soil management in the Atlantic Forest's rural properties: the Águas Claras Reserve case

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Abstract

The environmental benefits arising from the interaction between matter and energy flows of permacultural systems accelerate the recovery processes of degraded areas, which can be potentiated by the increase of plant biomass associated with the green manure technique, proposed in this work for the study territory: the surroundings of two Conservation Units (UC), of the Private Reserve of Natural Heritage (RPPN) type, the RPPN Águas Claras I and II. The RPPN Águas Claras I and II are located in the Macabu River basin, a microbasin of the Carukango River. The objective of this study was to analyze areas submitted to reforestation and agroforestry system (SAF) projects, through estimates of local biomass obtained with the aid of secondary data from the UCs' forest inventory. As a result, it was possible to list *Ficus sp* and *Sparattosperma leucanthum* as priority native species for forest restoration. It was concluded that it is necessary to consort the two species with the planting of species considered green manures, in order to increase forest biomass and stimulate the improvement of soil conditions in the degraded portion of the reserve. This strategy can accelerate the regeneration process, as indicated by secondary soil analysis data using scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS), performed in the area of implementation of the SAF.

Keywords: Green manure. Reforestation. Agroforestry systems. Permaculture.

Introduction

Ecosystem services are fundamental benefits for all human activity and can be classified as services of provision, support, regulation, maintenance and culture (FINISDORE et al., 2020). Among support services, nutrient cycling involves the interaction of the carbon and water biogeochemical cycles and is of fundamental importance for the maintenance of planetary balance, given that carbon is a basic constructive element of organic compounds and water is essential for all life forms (ODUM, 2001). Forest restoration is a nature-based solution (NbS) for carbon sequestration and storage. The term NsB is an umbrella concept for other approaches related to ecosystem services (FERREIRA, GOMES NÉTO, 2020).

Forests are renewable natural resources that effectively contribute to the reduction of the greenhouse effect, as they are the largest accumulators of biomass on the planet (SANQUETTA et al., 2002) and are identified as carbon sinks (RIBEIRO, 2007; MIRANDA, 2008).

Given this situation, the conservation of forests, through the protection of natural remnants and the reforestation of native species in degraded areas, contribute positively to the mitigation of processes associated with climate change and to the increase of biodiversity in ecosystems. Forests store carbon in both the biomass located above and below the ground, as they cover about 30% of the Earth's surface and fix around 85% of organic carbon (HOUGHTON, GOODALE, 2004). Biomass can be defined as matter of biological origin, living or dead, animal or vegetable. The term forest biomass means all biomass existing in forests or just in its trees (SANQUETTA et al., 2002).

Through the knowledge of the native species and forest cover of an area, it is possible to evaluate its carbon stock.

Considering carbon fixation in forests in reforestation processes, the objective of this study was to estimate which species can contribute to the gain of aerial biomass, employing indirect methods based on diameter at chest height (DCH), from the forest survey of the RPPN Management Plan secondary data. The study also aimed to present the benefits of performing the recovery of these areas using permacultural techniques of agroforestry management compared to conventional reforestation techniques, starting from the comparison of soil analysis results of the study area already published (BRITTO FILHO et al., 2023).

Material and methods

In the present work, the defined *locus* of study were the Private Reserves of Natural Heritage (RPPN) Águas Claras I and II, located in the municipalities of Conceição de Macabu and Trajano de Moraes, respectively, because they have conserved areas as well as areas to be reforested, both with the potential to mitigate CO_2 emissions. This article presents the results of documentary and bibliographic research guided by this case study. Participant observation (BOGDAN, 1973) was also used, through monitoring and supporting the technical team responsible for the implementation of agroforestry centers in the surroundings of the Águas Claras I RPPN, and for the participation in the workshops and field activities held in 2022, which subsidized the elaboration of the management plan of the UCs, in the final phase of publication. The results the mapping of the UCs, as well as the material referring to the data of the management plan, were kindly provided by the RPPN's management team, co-authored in this work.

Study area

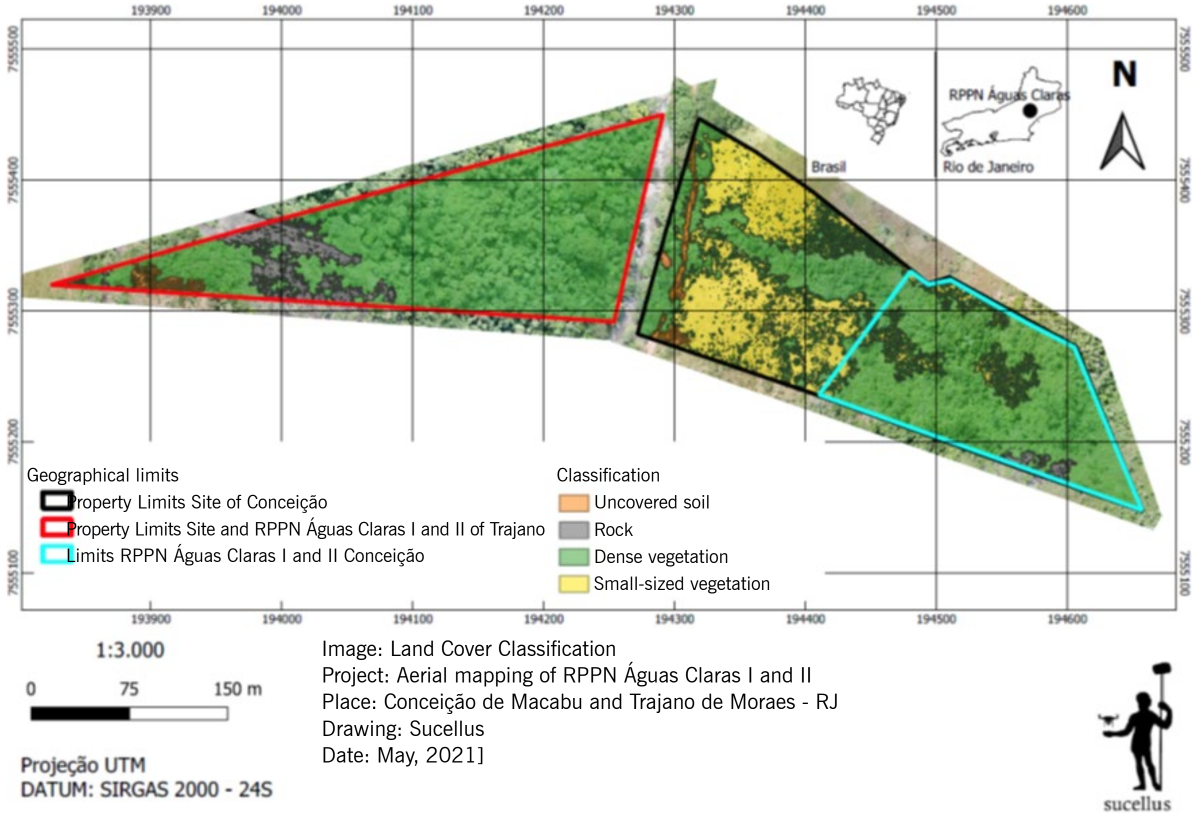
The Águas Claras I and II RPPNs are located within the Águas Claras Site, which has 8.5 ha, as shown in Figure 1. On one side, the municipality of Trajano de Moraes is located, bordering the RPPN Águas Claras II, with 3.6 ha of fully conserved Atlantic Forest area; the property is crossed by the Carukango River, which separates the 4.9 ha ,located in the municipality of Conceição de Macabu, part of the Águas Claras Site (2.8 ha) and the 2.1 ha composing the territory of the RPPN Águas Claras I.

The total area of the Águas Claras Site (RPPN and its surroundings) was transformed into a permaculture station associated with the Pindorama Institute, the Águas Claras Seed Station, to serve as a model to disseminate permacultural practices among the residents of the surrounding area and neighboring municipalities, bringing them knowledge about nature conservation and associating it to agroforestry systems (SAF).

Part of the area of the Águas Claras Site has been recurrently affected by fire coming from surrounding properties, thus constituting an area of environmental frailty, as can be seen in Figure 2. In September 2022, the last fire destroyed all the forest cover of Macabu's portion of the property. The fires are common practices of vegetation management in the region of the Macabu River basin, which is characterized by several altitude levels, formed by mountainous massifs and asymmetric profiles oriented in the southeast-northeast direction (PRADO et al, 2004)

The predominant soil in the region is the red-yellow latosol (PRADO et al., 2004), present in the hills and mountains. The vegetal formation of the region is the submontane open ombrophilous

Figure 1. Chart-image of the use and occupation of the Águas Claras site lands, in the state of Rio de Janeiro, showing the forest cover, the limits of the Águas Claras I and II RPPNs and the Carukango River.



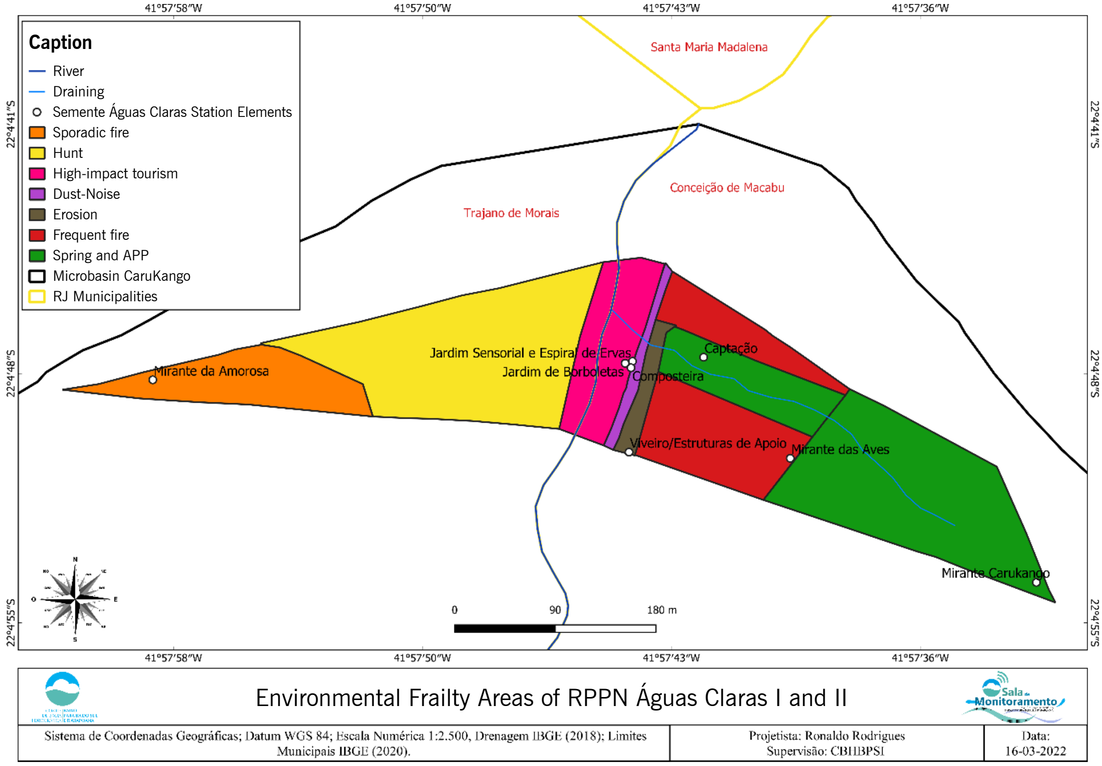
Source: Sucellus, 2021.

forest, according to the Technical Manual of Brazilian Vegetation (IBGE, 2012). The climate is tropical according to the Köppen classification. The average temperature is 24º C, with total annual precipitation around 1.528 mm (PRADO et al., 2004).

Since 2021, when this research was initiated, the studies' focus were extremely dry, with their vegetation cover partially taken over by sapé grass (*Imperata brasiliensis*) and brachiaria (*brachiaria decumbens*), indicatives of acidic soil. The acidity was confirmed by soil analysis, carried out in 2020, which revealed pH 5 and high aluminum (Al) content. For the correction of soil acidity in the early stages of the SAF nuclei, liming was applied, and for the increase of the organic matter content, weeding of the grasses was done, and their biomass was applied around the nuclei.

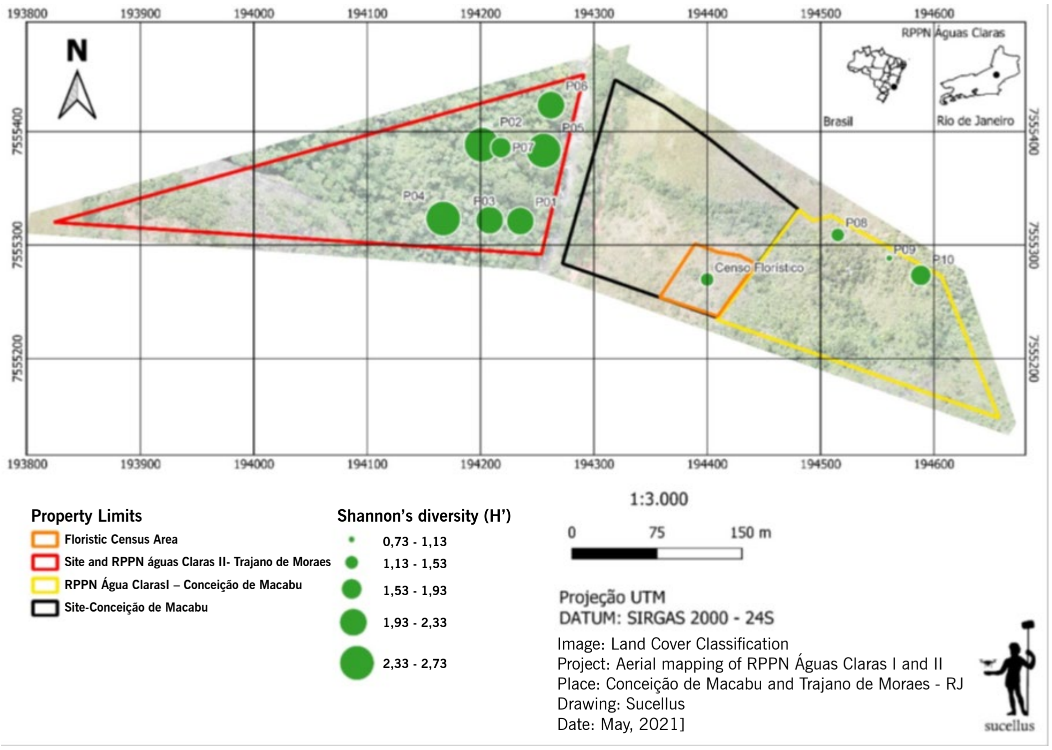
The characterization of the soil was later detailed by spectrometric methods (BRITTO FILHO et al., 2023). Until September 2022, the area destined for the implementation of the SAF had the presence of shrub species such as canela de velho (*Miconia albicans*) and cambará (*Moquiniastrum polymorphum*), and arboreal species such as monjoleiro (*Parapiptadenia rigida* (Benth.) Brenan) and jacarandá-da-Bahia (*Dalbergia nigra*). The agroforestry nuclei were located in the area subject to a floristic census (Figure 3). Separated from the SAF by a small stream's riparian forest (tributary of the Carukango River), there was an area of experimental conventional reforestation, also with about 0.3ha, located downstream of Parcel 08 (Figure 3), also affected by fire.

Figure 2. Areas of environmental fragility in the RPPN Águas Claras I and II and in its immediate surroundings, displaying the places of sporadic and frequent occurrence of fires in the property named by the Committee of Basins of the Lower Paraíba do Sul and Itabapoana (CBH BPSI) as RPPN Semente Águas Claras.



Source: CBH-BPSI, 2022.

Figure 3. Parcels of the RPPN Águas Claras I and II forest inventory's Management Plan.



Source: Sucellus, 2021.

Field data collection and analysis

The RPPN's forest inventory and the floristic census, elaborated in September 2021 for the management plan of the UCs (in the final phase of publication), were used as the basis for the quantification of biomass (Figure 3). Ten plots of 10 m x 10 m were inventoried in the RPPN and the census was carried out in an area of 0.3 ha, in order to subsidize the planning for the APS' implementation (Figure 3). These data formed the basis for quantifying the biomass present at the site. Quantification can be performed by a direct method (determination) or an indirect method (estimation). In the direct method, parameters of the individual trees raised in the plots are used (SILVEIRA et al., 2008).

In the indirect method, estimates can be made in two ways: firstly, by the volume data of trees or plots found in the field, multiplied by appropriate factors for the determination of biomass; and secondly, by the biomass estimate, which, with the application of an equation, calculates the estimated biomass (EB)in function of the Dch, together with other measurement data for the sample plots' trees. Thus, it can be stated that, in most studies of forest biomass, estimates are generated instead of determinations (SANQUETTA et al., 2002; SOMOGYI et al., 2007).

In this article, we worked with the indirect method, through the forest inventory made for the UCs, in which 166 species were cataloged. The sampling universe was limited to the plots in which the species were included, as shown in Figure 3. In order to obtain an integrated reading of the environment, the phytosociological parameters (FARIA, MELLO, BOTELHO, 2012) relative dominance (Rdo%), relative frequency (Rf%) and importance value (IV) were extracted from the data collected in the forest inventory. It is noteworthy that the methodology used to define the location and the sampling method of the plots, as well as the sampling effort to carry out the surveys presented here, were defined by the team of specialists hired to elaborate the management plan of the UCs.

The formula developed for real biomass by the author Watzlawick (2003) was applied, adapted for the calculation of the estimated biomass (EB) as described in Equation 1.

$$\mathbf{EB = d \cdot e^{d} \cdot ln(d \cdot DCH^{2} \cdot h)}, \quad (1)$$

in which:
EB = estimated biomass (m³)
d = CCH – circumference at chest height (cm)
DCH = diameter at chest height (cm)
h = height (m)
e= number of individuals of the same species
ln= Neperian logarithm

Results and discussion

Regarding the studies on biomass, the quantification of carbon in tropical ecosystems has received attention (BOLFE, BATISTELLA, FERREIRA; 2011; MEIRA et al., 2020), because the knowledge of the carbon fixed in natural ecosystems is of great relevance, since forests contribute to environmental stability. Somogyi et al. (2007) report that, during the last decades, the amount of carbon stored in biomass has been highlighted, as a result of the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, an agreement after which countries began to report their CO_2 emissions and deforestation rates.

In the surroundings of the Águas Claras I RPPN, both the area object of conventional reforestation and the area destined to the implantation of the SAF suffered with the past fire and the suppression of vegetation, subsequently being taken over by grasses. In one of these areas, near the Estrada da Amorosa, where there was increased erosion, the beginning of gully formation was observed. There are several setbacks encountered during an environmental recovery process, especially in the case of degraded areas. The conservation of recovered areas, choice of native species of the region for planting and high costs of reforestation are challenges to overcome (JESUS, 1992; FERREIRA et al., 2007; ANDRADE, SANCHEZ, ALMEIDA, 2014).

In the literature, there are reports of areas in advanced environmental recovery processes that use green manure as a way to reestablish the soils' lost physical properties. The adequate vegetation cover in these areas leads to the reduction of erosive processes and feeds the water table by the tree species' roots (JESUS, 1992). For the recovery of areas covered by small vegetation, reforestation associated with the use of green manures helps in the speed of soil recovery. For Kiehl (1979), the main function of green manure is to produce biomass to enrich the soil.

The agricultural technique called green manure is carried out with the objective of fertilizing and enriching the soil, promoting the recycling of nutrients in degraded areas. This enrichment covers the physical, chemical and biological parts of the soil. The fertilization occurs through the planting of species, mainly legumes (MATRANGOLO, 2016), since these produce biomass with high nitrogen value, because they capture nitrogen directly from the air by symbiosis. In addition, they sharpen the growth of mycorrhizal fungi, which, in turn, accelerate the absorption of nutrients and water by plant roots, improving soil characteristics (ESPINDOLA et al., 2005).

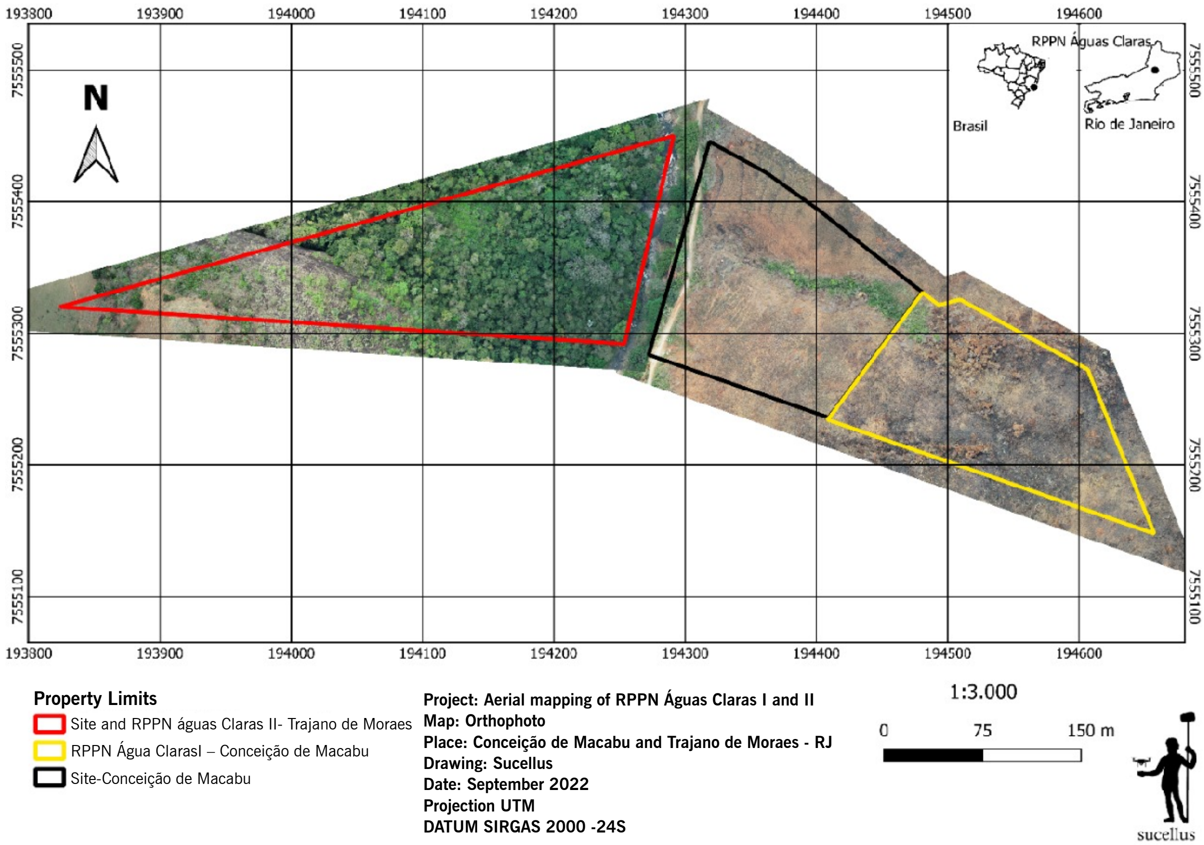
Green manure can be used in planting alternately with native species and/or with those that interest economic cultivation, interspersed. This practice is called intercropping (ESPINDOLA et al., 2005). There are annual and long-living plants, which form the ground cover for many years. To choose the species for reforestation and green manure, the forest and/or phytosociological survey is essential. In this survey, the objective is to identify plant communities, as well as their floristic and structural parts, their activities, interrelations, classifications and distributions. It is essential to carry out such studies to make the compositions of the sites' vegetation known in the project (FELFILI, REZENDE, 2003; SANQUETTA et al., 2002).

In September 2022, a large fire reached about 50 ha of the Environmental Protection Area (APA) of the Procura, destroying practically all the forest cover of the Águas Claras I RPPN and its surroundings (Figure 4). With this new episode, it became necessary to reconsider the area as a whole, because its soil was even more punished, requiring more nutrients.

For forest restoration, especially in degraded areas or with nutrient-poor soil (a condition evidenced by the soil analysis of the deforested area around the Águas Claras I RPPN), the use of green manure is an excellent option. Improvements in soil are numerous, among them: increase in organic matter and biological activity; recycling of percolated nutrients, control of phytoparasitic nematodes; wetter and cooler land; improved water infiltration, increasing water storage in the soil; more porous earth for circulation of more oxygen; structuring, aeration, and, in soil that often suffers the use of plow at 20 cm depth, the decompaction of soil layers, making it softer for penetration of plants' roots; reduction in prolonged temperature variation, nitrogen increase, protection against erosion and solar radiation, control of pests, weeds and pathogenic microorganisms; promotion of biomass production and soil cover, as well as the production of phytomass, generating mulch (ALCÂNTARA et al., 2000; LIMA et al., 2003).

The initial project of SAF in the area affected by the fires aimed to reconstitute the forest already degraded by pasture, introducing green manure seeds such as pidgeon pea and jack bean. Green manure is particularly important in organic production systems, and expands the biodiversity of agricultural ecosystems (FERREIRA, SOUZA, CHAVES, 2012; ESPINDOLA et al., 2005).

Figure 4. Image chart of the RPPN Águas Claras I and II and their immediate surroundings after September 2022's fire



Source: Sucellus, 2022.

It is reported in the literature that when grasses cover soil, their decomposition increases its level of nutrients (SIMIDU et al., 2010). After the fire, soil composition was determined by scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) (BRITTO Filho et al., 2023). The spectrometric analysis of the soil sample that had been prepared for the implantation of the agroforestry nuclei revealed such soils' absence of germanium (Ge) when compared to the soil sample of a nearby area, maintained under conditions of natural regeneration. This fact is attributed to the faster growth of grasses and the higher rate of shrub species' regrowth observed during post-fire field incursions in the area of the SAF's agroforestry nuclei. This observation can be correlated with the process of phytoremoval of germanium from the soil (TAVARES et al., 2022).

Once all the organic matter that would provide the quantification of forest biomass was consumed by the fire, such an evaluation became impossible. Quantification would involve assessing all forest components, including the living mass above and below ground of trees, shrubs, palms, seedlings, understory components, vines, epiphytes, etc., and the mass of dead plants, such as thin litter and wood, which have been fully turned to ash.

However, relevant indications could still be obtained using data from the forest inventory conducted in 2021. Table 1 shows the most significant species of each plot, taking into account the highest absolute values of Circumference at Chest Height (CCH), total height (h) and volume (V), as well as the results of the forest species found, associated with the estimated biomass volume as described in the methodology, for each of the 10 plots inventoried. Table 2 shows the results of the biomass estimate for green manure, performed using Equation 1.

Through the analysis of Tables 1 and 2, it is clear that the species ipê verde or caroba branca (*Sparattoperma leucanthum*) is the one with the highest biomass, and that the species *Ficus sp* is dominant and has the highest relative frequency. It is possible to point out the direct relationship between biomass and phytosociological parameters, which can help in the balanced choice to strengthen the reforestation process of the degraded area and optimize the implementation of the SAF. The *Ficus* can be classified as a late secondary species (SILVA et al., 2003), and the *Sparattoperma leucanthum* as a pioneer species (POLATTO, ALVES JUNIOR, 2009).

Pioneer plants, in general, have rapid growth and a shorter life cycle than species that settle later. These pioneers offer more favorable conditions for those who will settle later, who will offer conditions for others who settle even later and so on. The species present have evolutionary relationships formed by historical interactions with biotic and abiotic conditions that shape contemporary interactions under the current condition (MEINERS et al., 2015). For forest restoration, it is indicated to plant the largest number of this species on the property. In ecological succession, *Ficus sp* should be planted after *Sparattoperma leucanthum*.

The SAF are recognized for their advantages over monocultures, thus responding to the demand for multifunctional agriculture, provision of environmental services and important aesthetic values, employing green manure as a strategy, with soil, biodiversity and water quality conservation and carbon capture as the main ecosystem services (BEER et al., 2003; LIMA et al., 2017). In properties that use agroforestry systems or that are still in the process of transition to APS, as is the case with the surroundings of the Águas Claras I RPPN, opting for the use of green manures is advantageous for its nutrient contribution to the soil. Preference should be given to legumes, such as the species: crotalaria (*C. juncea, C. spectabilis, and C. ochroleuca*); guandu beans (*Cajanus cajan*); sorgo volumoso (Sorghum BRS716); fodder radish (IPR 116); gliricidia (*Gliricidia sepium*), among others (BORGES et al., 2018)

Table 1. Biomass volume calculated for the plots of the forest inventory.

Plot	Tree No	Scientific Name	Common name	CCH (cm)	DBH (cm)	TH (h)	Volume (m3)
01	23	*Plathymenia reticulata*	Vinhático	53	17	13.0	0.185
02	34	*Cecropia glaziovii*	Imbaúba	67	21	16.0	0.351
03	57	*Xylopia sericea*	Pindaíba Vermelha	64	20	17.0	0.349
04	65	*Sparattoperma leucanthum*	Ipê branco	179	57	14.0	1.610
05	89	*Erythroxylum pulchrum*	Arco de Pipa	168	53	15.0	1.566
06	99	*Ficus sp.*	Figueira (fig tree)	179	57	22.0	2.729
07	119	*Parapiptadenia rigida*	Angico Vermelho	119	38	17.0	1.006
08	132	*Moquiniastrum polymorphum*	Cambará	58	18	7.0	0.105
09	141	*Cupania scrobiculata*	Cajuzinho	27	9	6.0	0.024
10	164	*Moquiniastrum polymorphum*	Cafezeiro do Mato	32	10	6.0	0.030

CCH – Circumference at Chest Height; DCH – Diameter at Chest Height; TH - Total Height

Source: Our own elaboration, adapted from data from the management plan of the RPPN under study.

Table 2. Quantification of biomass from the dominant species in each plot, with dominance determined by the comparison of phytosociological parameters.

Species	Common name	Biomass	Rdo%	Rf%	IV
Plathymenia reticulata	Vinhático	1.0972 m^3	0.63%	7.17%	7.15
Cecropia glaziovii	Imbaúba	7.2649m^3	0.39%	11.46%	5.15
Xylopia sericea	Pindaíba Vermelha	1.7305 m^3	0.32%	10.46%	4.38
Sparattoperma leucanthum	Ipê verde	7.9854 m^3	0.40%	81.80%	8.27
Erythroxylum pulchrum	Arco de Pipa	1.0883 m^3	0.63%	72.06%	7.33
Ficus sp.	Figueira (fig tree)	1.2548m^3	0.66%	91.85%	9.30
Parapiptadenia rigida	Angico Vermelho	1.6678m^3	0.51%	41.31%	4.25
Moquiniastrum polymorphum	Cambará	1.1792m^3	0.19%	9.62%	1.11
Cupania scrobiculata	Cajuz	6.9815 m^3	0.04%	2.27%	4.55
Moquiniastrum polymorphum	Cafezeiro do Mato	1.5161 m^3	0.10%	3.10%	5.21

Caption: Rdo% - Relative dominance; Rf% - Relative frequency; IV - Importance Value

Source: Own elaboration.

For greater efficiency in the absorption of water and nutrients by plants, the proper development of the root system is necessary, and legumes have the deep and strong system required. After pruning and covering the soil with the phytomass, the nutrients are removed from the bottom of the soil and brought to the surface, expanding their productive potential and contributing to the ecosystems' biodiversity (MATRANGOLO, 2016). Of the aforementioned species, the guandu bean is well adapted to the regional climate, and because it is also edible, it has good market value in the state of Rio de Janeiro, making it a preferred indication to start the SAF in the areas of small vegetation around the RPPN Águas Claras I, in order to bring to the system the component of economic sustainability necessary to inspire small local owners.

In view of the current accelerated pace of climate change, it is important to carry out reforestation studies related to the formation of biomass in areas where new forest formations are being implemented. The correct management of these forest resources brings additional gains to the processes of implementation of agroforestry systems associated with permacultural practices.

Conclusions

Based on the data collected in the forest inventory of the Águas Claras I and II RPPN management plans' diagnostic stage, it is possible to indicate *Ficus sp* and *Sparattosperma leucanthum* as priority species for the recomposing the degraded territory's forest, and to recommend green manure techniques for the increase of forest biomass and the consequent soil enrichment.

After the extensive additional degradation suffered in the area, as a permacultural practice, green manure is an increasingly indicated technique, as it promotes biological nitrogen fixation, and soil protection and enrichment. At the same time, it reduces carbon gas (CO_2) emissions, requires less use of chemical fertilizers and promotes the increase of carbon stock in the soil, reducing atmospheric GHG levels.

The agroforestry systems and green manure proposed in this work are important for the restoration of degraded areas because they potentiate the rebalance of the impacted ecosystems due to the high diversity of species, the interaction between them and the promotion of soil revitalization, thus leading to the maintenance of the ecosystem functions of rural territories.

Acknowledgments

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