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Collaborative creation of a monitoring framework for agroforestry systems

Criação colaborativa de um protocolo de monitoramento de sistemas agroflorestais

Creación colaborativa de un protocolo de monitoreo de sistemas agroforestales

Audrey Barta de Santana[1], João Vitor Mariano Ribeiro[2], Carolina Cassiano Ferreira[3], Klécia Gili Massi[4]

[1] Student in the Departamento de Engenharia Ambiental at the Universidade Estadual Paulista (Unesp), Instituto de Ciência e Tecnologia, São José dos Campos, Brazil. E-mail: audrey.barta@unesp.br

[2] Graduate student at Pós-graduação em Desastres Naturais - Unesp/Cemaden, São José dos Campos, Brazil. E-mail: joao.mariano@unesp.br

[3] Environmental analyst at Associação Corredor Ecológico do Vale do Paraíba, São José dos Campos, Brazil. E-mail: carolina@corredordovale.org.br

[4] Professor in the Departamento de Engenharia Ambiental at the Universidade Estadual Paulista (Unesp), Instituto de Ciência e Tecnologia, Doctorate in Ecology at Universidade de Brasília. São José dos Campos, Brazil. Orcid: 0000-0003-1823-7965. E-mail: klecia.massi@unesp.br

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Abstract

Agroforestry Systems (AFS) are an alternative technique for recovering degraded ecosystems that, in addition to promoting ecological recovery in itself, also bring a social component by generally involving family farming. Currently, one of the obstacles to the dissemination of AFS in environmental recovery is the lack of a monitoring protocol for these systems that is easy to apply and can cover the wide diversity of existing models. Therefore, our objective was to collaboratively create a framework with these characteristics. Four workshops were held in different municipalities in the Vale do Paraíba region, Brazil, and one online workshop where small AFS producers were invited to contribute their opinions on the best indicators to monitor them. In the end, we created a framework with 21 simple indicators (seven socioeconomic ones). The framework was also tested to verify its applicability in three AFS models.

Keywords: Agroforestry, participatory, protocol, restoration.

Resumo

Os Sistemas Agroflorestais (SAFs) são uma alternativa de técnica de recuperação de ecossistemas degradados que além de promover a recuperação ecológica em si, também trazem o componente social ao geralmente envolver a agricultura familiar. Atualmente, um dos entraves para a difusão dos SAFs na recuperação ambiental é a falta de um protocolo de monitoramento desses sistemas que seja de fácil aplicação e que consiga abranger a grande diversidade de modelos existentes. Assim, nosso objetivo foi criar de forma colaborativa um protocolo com essas características. Foram realizadas quatro oficinas presenciais em diferentes municípios da região do Vale do Paraíba, Brasil, e uma online onde pequenos produtores de SAFs foram convidados a contribuir com suas opiniões acerca de quais os melhores indicadores para monitorá-los. Ao final chegamos em um protocolo com 21 indicadores simples (sete socioeconômicos). O protocolo também foi testado para verificar a sua aplicabilidade em três modelos de SAF.

Palavras-chave: Agrofloresta, participativo, protocolo, restauração.

Resumen

Los Sistemas Agroforestales (SAFs) son una técnica alternativa para la recuperación de ecosistemas degradados que, además de promover en sí misma la recuperación ecológica, también trae un componente social al involucrar generalmente a la agricultura familiar. Actualmente, uno de los obstáculos para la difusión de los SAF en recuperación ambiental es la falta de un protocolo de seguimiento de estos sistemas que sea de fácil aplicación y que pueda abarcar la amplia diversidad de modelos existentes. Por tanto, nuestro objetivo fue crear colaborativamente un protocolo con estas características. Se realizaron cuatro talleres presenciales en diferentes ciudades de la región de Vale do Paraíba, Brasil, y uno online donde se invitó a pequeños productores de SAF a aportar sus opiniones sobre los mejores indicadores para monitorearlos. Al final llegamos a un protocolo con 21 indicadores simples (siete socioeconómicos). El protocolo también fue probado para verificar su aplicabilidad en tres modelos SAF.

Palabras-clave: Agroforestal, participativo, protocolo, restauración.

INTRODUCTION

Ecological restoration is "the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed" (SER, 2004). Active and passive restoration are two important strategies to aid the recovery of large areas of deforested and degraded tropical lands (Morrison; Lindell, 2011). Agroforestry systems (AFS) can be considered an active restoration technique, based on linking crop production and tree planting (Paludo; Costabeber, 2012), applied to degraded land recovery and also as an alternative for conventional agriculture (Abdo; Valeri; Martins, 2008). Agroforestry systems encompass a wide variety of production systems using, at least, one woody component: (i) some are very simple in structure, with only two or three components and by that, demanding higher technological levels and more inputs to maintenance of productivity levels; (ii) others are very complex systems, like the multi-strata successional systems, which mimic natural succession and resembles to a forest structure (EMBRAPA, 2025).

The assessment and monitoring of restored ecosystems are essential for correcting and improving restoration techniques, especially in tropical ecosystems (Brancalion *et al.*, 2015). Monitoring is possibly the most important step in a restoration project, since it allows researchers to evaluate, through indicators, the responses of a degraded area to treatments. Studies that have evaluated agroforestry systems in a tropical environment (Noumi *et al.*, 2018; Paulo; Massi, 2022) highlight the importance of monitoring for restoration and the difficulty in performing it. In addition, the lack of consensus in scientific literature on the most appropriate indicators for assessing the success of agroforestry systems and, consequently, the associated environmental gains and high costs of implementation is an important obstacle for monitoring these agroecosystems.

Several studies and norms have suggested best indicators for monitoring protocols of agroforestry (Navas; Silva, 2016; Oliveira, 2016). In São Paulo state, southeast Brazil, the two main legal monitoring protocols (Resolução SMA 32/2014, see Massi *et al.*, 2022 for the effectiveness of it, and Resolução Conjunta SAA/SIMA 03, 2020) do not comprise agroforestry. The only legal monitoring protocol in the same Brazilian state that enables monitoring of agroforestry systems is restricted to using native species in mandatory restoration areas in legal reserves (Lei 12651/2012 (Brasil, 2012) and

Resolução SMA 189/2018 (São Paulo, 2018)). All these protocols have in common some indicators (especially regarding cover and richness of native species and soil quality), but they do not cover the multitude of different agroforestry systems, which are affected by system age, system model arrangement (with trees or smaller plants, open or closed) and several yields (fruits, wood, horticulture, beans). In addition, these protocols are usually built by scientists, public managers, and environmental analysts without talking to small and local farmers, who have an empirical background on this issue. Thus, an easy and ready to go protocol for monitoring agroforestry systems built in a participative manner is not available.

In addition, several international agreements (such as the Bonn Challenge or 20x20 Initiative) are demanding effective restoration, and thus, a monitoring framework will be even more important and needed if we are going to scale ecological restoration and stewardship. However, the gap between institutional proposals of protocols and the real situation of agroforestry systems in the field invites us to think about how welcome, in rural daily life, the guidelines and standards developed by state agents, public managers and who guide work processes, are. If these norms are not enough, what is necessary? With this study, we argue that a participative and collaborative construction of a monitoring framework, based on coupling research and action methodology in a process in which stakeholders (such as small and local farmers) and researchers interactively come to elucidate the reality in which they are inserted (Thiollent, 1997), might be a possible solution. From this perspective, a stakeholder is anyone who is able for conscious collective action in a delimited social context. Thus, this research aimed to collaboratively create a monitoring framework for agroforestry systems that can be implemented in different models, ages, yields, and by any farmer. We also aimed to test this framework in various agroforestry models within the Southeast Atlantic Forest, Brazil, to assess its functionality.

METHODS

Our study was performed in Paraíba do Sul River Valley of São Paulo state, southeastern Brazil. The region was largely deforested in the late 19th and early 20th centuries for establishing sugar cane and coffee plantations (Devide *et al.* 2014). As market conditions shifted, these areas were later replaced by planted pastures for cattle ranching, and more recently, industrial *Eucalyptus* plantations, especially to supply pulp and paper industries (Silva *et al*., 2016, 2017). The region landscape is now a mosaic of pasture, industrial Eucalyptus secondary and old-growth native forests, restoration plantations, and other native vegetation remnants. The study area has become a focus for the regeneration of the Atlantic Forest biome due to environmental policies adopted, i.e., over the past 60 years, forest cover in the basin increased from 200,000 to 450,000 ha, equating to 30% of the territory, primarily through natural regeneration processes (Sapucci *et al*,. 2021). Consequently, the forest cover in the Paraíba do Sul River Valley is now a complex blend of different forest types, reflecting the dynamic history of land use and conservation in the region, making it a good case study and environment for this study. Mostly, rural land is small (less than 50 ha), and cultivated by small and local farmers (IBGE, 2019), where agroforestry systems occur (Paulo; Massi, 2022)

ERC Foundation, ecosystem restoration community Desperto - Regenerative Cultures Centre - in Brazil, the NGO Corredor Ecologico, which works on ecological restoration, and Rede Agroflorestal do Vale do Paraíba, a local network of small farmers, helped us to run five workshops from August 2023 to March 2024 (four in different municipalities of Paraíba do Sul River Valley and one online). These workshops joined people working in agroforestry and had discussions about appropriate proxies, indicators and methods to be included in the agroforestry monitoring protocol. Based on the outputs of these workshops, a common framework was drafted. Additionally, a field day occurred in June 2024, when the framework was shared and tested at ERC Desperto agroforestry sites. ERC supports restoration activities that are part of the global ecosystem restoration communities movement, which includes connecting volunteers with restoration communities and providing technical, educational and financial support to these initiatives (ERC, 2025).

Workshops were publicized through announcement cards sent to several social media networks in Paraíba do Sul River Valley. People were invited to register themselves using a Google forms link, with a small survey (name, email, phone number, occupation, transportation need, background, and work with agroforest and monitoring).

The first workshop happened in August 2023 in Tremembé, the second was in September 2023 in Guararema, the third was in October 2023 in São José dos Campos, the fourth was in November 2023 in Cruzeiro, and the last one occurred online, in March 2024, using the Google Meet platform and had three attendees. Finally, in June 2024 a field day occurred in ERC Desperto agroforestry sites in Caçapava, when the framework was shared and tested. The first two workshops had more people; in general, most attendees were small farmers, who had previously worked with agroforestry systems for various periods of time, and a minority of them had a background in monitoring agroforests (**Table 1**). Each workshop occurred from 2 to 5 pm (3 hours long), when most small farmers used to not work in the field due to the hot weather conditions.

Table 1. Characteristics of four different workshops regarding transportation need, occupational background, and work with agroforestry and monitoring for the collaborative creation of a monitoring framework for agroforestry systems.

Workshops	Transportation need (%)	Small farmer (%)	Work with agroforestry (%)	Time of working (years)	Background with monitoring agroforests (%)	Time of monitoring (years)
1) 18 attendees	39	61	78	1-14	44	1-7
2) 14 attendees	7	36	50	2-7	29	1-4
3) 3 attendees	0	67	67	4-10	0	0
4) 6 attendees	17	83	67	2-22	17	10

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Before the first workshop, a literature search was performed looking for monitoring indicators used in frameworks (Navas; Silva, 2016; Oliveira, 2016; São Paulo, 2018). Thus, we selected the most common indicators to prepare the first version of the framework, which were species diversity or number of species, plant density, percentage of soil with living and/or dead cover, water infiltration into the soil or water retention, presence of diseases and insects, erosion, income or economic viability of agroforests and effective participation of young people and women in AFS activities. It is noteworthy that the most common indicators were physical and biological ones, with only one economic and one social indicator, which will influence the design and creation of our framework.

In all workshops a paper sheet was given to each attendee containing a brief descriptive introduction in Portuguese, translated below, followed by a table with indicators (the final version of the framework is in the Supplementary Material):

> There are some AFSs in Vale do Paraíba. There are biodiverse AFSs, and there are those with just two species. We have AFSs with horticulture, aromatics, native fruits, wood, bananas, with and without green manure. All this diversity of possibilities is wonderful, but it also poses a challenge, which is monitoring them, knowing when to manage them and what to do. Monitoring is a fundamental step, as it allows you to continuously analyze the area and assess how it is reacting. That is why we are here, to collaboratively create a protocol that allows monitoring these areas. Below are some suggested indicators. Let's think about them! Do you think they are important? If yes, mark an x (indicators are in the next section).

A semi-structured approach to the workshops was adopted, with the aim to elicit and maximize directed discussion. The format of the workshops was the same across the four sites (and also online). There were two main stages to the workshop, namely: i) reading and presentation of the given sheet to attendees and ii) open discussion and questions to the participants. Discussions were mediated by authors of this study and were transcribed. As time was short, sometimes it was necessary to interrupt when the topic was not being addressed. In each workshop many indicators were suggested, but we kept in the framework only the ones that were easy, practical and mostly agreed by participants, because the framework criteria were thought to include indicators that could be assessed by any farmer and stakeholder and at any conditions.

In the discussion, participants were invited to ask whether suggested indicators were useful or not, discard them, indicate totally different and new ones; they were asked to improve the way the indicator was presented to clarify it, or to change the sequence of indicators, or the method to collect that indicator, and they could change the parameter (instead of richness, diversity, for example) and so on. In summary, after the end of a workshop, we could have a completely different and new framework, in comparison when the workshop began. In addition, discussions were cumulative, thus, in the second workshop the presented version of the framework was the one that ended the first workshop, in the third workshop the presented version of the framework was the one that ended the second workshop and so on, until the last workshop with the final version. Results will be presented as the changes in indicators along the five workshops (and its final version in supplementary material) and the discussions about the main topics and indicators, respecting the privacy of all participants (unpersonally).

Lastly, in June 2024 we collected data using the framework final version in ERC Desperto agroforestry sites in Caçapava. Desperto – Regenerative Cultures Centre is situated on top of a mountain, most of the land has been used for grazing over the past 15 years which has led to very compacted soil and inhibiting growth of the original rainforest and the entire area surrounding the restoration community is highly degraded, with pastures or monoculture eucalyptus plantations. Desperto has planted three areas of regenerative agroforestry, one with almost 70 banana trees and other species, the other with native trees and the other with aromatic plants, indicating a high diversity of systems.

RESULTS AND DISCUSSION

In total, 28 indicators were part of the framework along the five workshops (**Table 2**). We started the first workshop with 10 indicators, then 14, in the second, 16 in the third, 19 in the fourth, 19 in the fifth and ended with 21 indicators in the final version (more than twice the initial number). Six indicators were the same in all five workshops: plant species richness, litter height, number of layers in the agroforest, age of the system, family members in the management of agroforests and happiness/satisfaction with the AFS, indicating that these six may be the fundamental indicators for monitoring frameworks

The number of indicators increased across all workshops. Specifically, the indicators that were maintained in workshops increased from six to 18, and there were excluded and added indicators in almost all workshops (**Figure 1**). The increase in the indicators that were maintained along workshops shows that these five events were responsible for consolidating a reasonable number and quality of indicators.

Table 2. List of indicators that were suggested in the first version of the monitoring framework and that were maintained, added, or excluded during the five workshops. AFS is an agroforestry system, PPA is a permanent preservation area, LR is a legal reserve, and CU is a consolidated use.

indicator	**first version**	**workshop**				
		1	**2**	**3**	**4**	**5**
species richness	x	maintain	maintain	maintain	maintain	maintain
native species richness	x	exclude	-	-	-	-
individual density	x	exclude	-	-	-	-
% of soil cover	x	exclude	-	-	-	-
litter height	x	maintain	maintain	maintain	maintain	maintain
number of layers	x	maintain	maintain	maintain	maintain	maintain
main yield	x	exclude	-	-	-	-
age of AFS	x	maintain	maintain	maintain	maintain	maintain
family member in the AFS	x	maintain	maintain	maintain	maintain	maintain
happiness with AFS	x	maintain	maintain	maintain	maintain	maintain
plant average spacing	-	add	maintain	exclude	-	-
more fauna with the AFS	-	add	maintain	maintain	maintain	maintain
ants presence	-	add	exclude	-	-	-
women in the AFS	-	add	maintain	maintain	maintain	maintain
different yields	-	add	maintain	maintain	maintain	maintain
AFS is for income or self-consumption	-	add	maintain	maintain	maintain	maintain
AFS in PPA, LR, or CU	-	add	maintain	maintain	maintain	maintain
historical land use of site	-	add	maintain	maintain	maintain	maintain
aim of AFS	-	-	add	maintain	maintain	maintain
degradation signs	-	-	add	maintain	maintain	maintain
plant leaf damage	-	-	add	maintain	maintain	maintain
size of AFS	-	-	-	add	maintain	maintain
AFS products sell	-	-	-	add	maintain	maintain
canopy cover	-	-	-	add	maintain	maintain
canopy height	-	-	-	add	exclude	-
initial management action	-	-	-	-	add	maintain
AFS as the main activity	-	-	-	-	-	add
joint effort and partners	-	-	-	-	-	add

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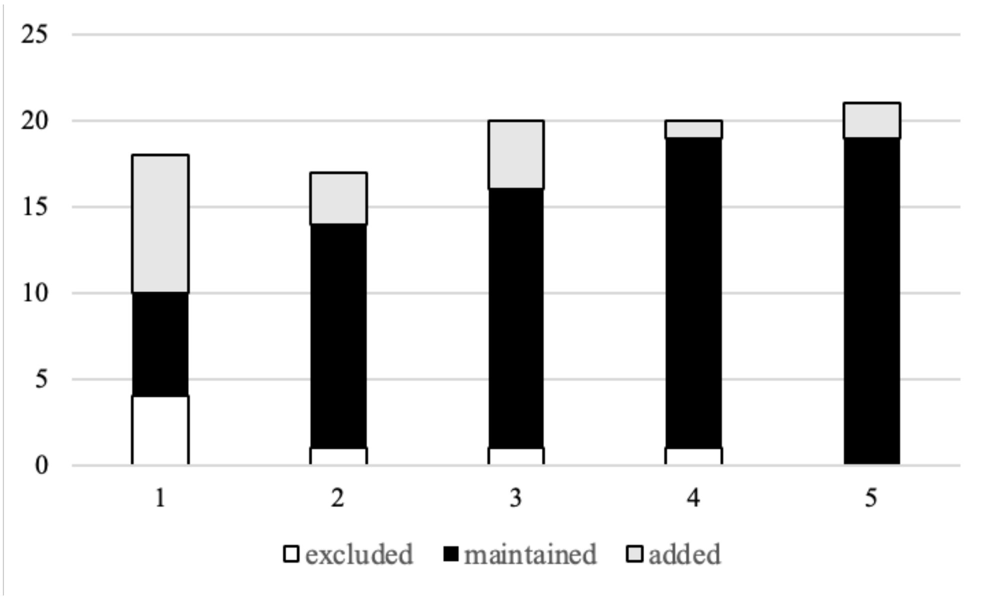

Figure 1. Number of indicators that were maintained, added or excluded along the five workshops to create a monitoring framework for agroforestry systems.
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We found that the majority of indicators suggested along the five workshops were biological (10) and economic (five) and qualitative (16) (**Figure 2**). The first version of the framework had mostly biophysical indicators, and we noticed that the participants agreed for these to be important indicators. But they also included several indicators related to the socio-economic performance of the AFS, demonstrating that the framework has also to show whether an AFS is paying itself and generating income, which is an important result. We also verified that qualitative indicators predominated (family member, happiness, more fauna, women presence, different yields, income or self-consumption, agroforest in permanent preservation area, legal reserve and/or consolidated use, historical land use of site, aim of the agroforest, degradation signs, plant leaf damage, size, products sell, initial management action, agroforest as the main activity and joint effort and partners for the agroforest), implying that a subjective analysis is more important for monitoring AFS than only quantifiable indicators. That poses a challenge, since qualitative information cannot be easily compared among other AFS sites, however it might mean that smallholders need to observe, collect and compare that information for themselves and need to understand and manage their own systems. We might stress that qualitative indicators, including those collected with a participatory approach, could be applied to monitor production systems such as AFS, direct planting systems and to ecological restoration projects, especially as references to show the possibility of analysing this information.

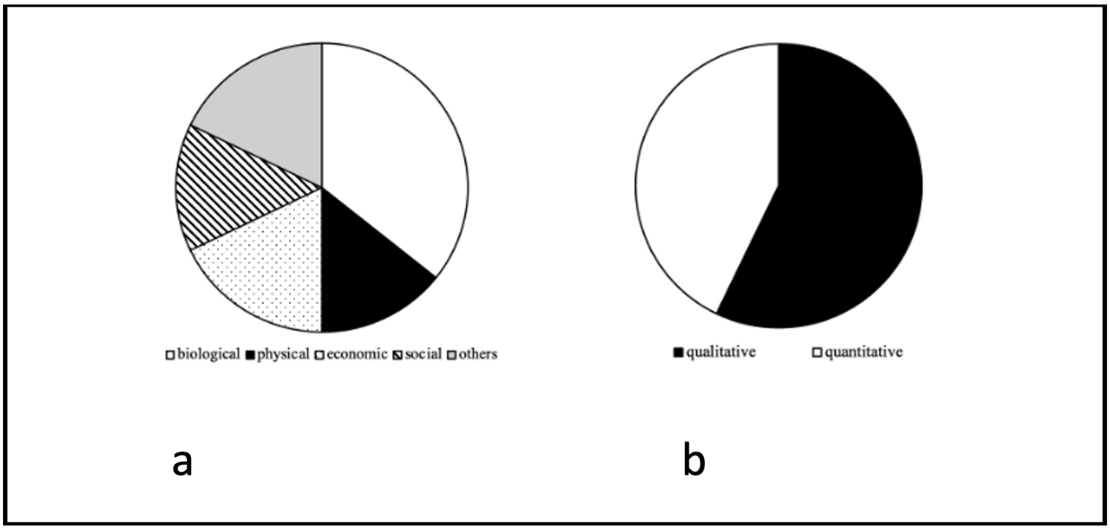

Figure 2. Proportion of indicators classified as biological, physical, economic, social and others (a) and between qualitative and quantitative (b) along the five workshops to create a monitoring framework for agroforestry systems.
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Park and Higgins (2018), employed a qualitative content analysis of 61 literature resources and semi-structured interviews with 16 experts in the fields of food forestry and ecological restoration in Galiano Island, British Columbia in Canada and developed a monitoring framework for food forestry that comprised plant diversity, trophic structure, ecological processes (e.g., carbon sequestration, succession, and nutrient cycling), soil organic matter, soil biological conditions and social indicators based on local food security and economy, cultural revitalization, education, and active research collaboration. Some of the indicators of their study overlap with this study.

Regarding discussions in workshops, participants discussed generally how "difficult is for measuring an AFS productivity, and thus, how important is having a protocol that helps management and having concrete values that make day-to-day life easier". Attendees discussed existent indicators in the framework, methods to collect them and new indicators. Following are the main topics discussed in the five workshops.

Firstly, the plant species richness indicator was one that rendered much of the discussion. Some suggested that small farmers already know what they have in the system, some argued that spontaneous plants cannot be easily identified and should not be accounted, some suggested that spontaneous plants should be inventoried during the wet season, when they are more abundant, some suggested that it would be useful to differentiate among several classes of plants such as stratum (trees, shrubs herbs), successional stage (pioneer, secondary and climax), function (green manure), and others attested that successional stage is important to understand if the system is moving forward. Another important discussion topic was about species dominance. For example if there are many individuals of a single species and only one individual of other species, thus, the species number alone does not reflect much of the diversity, because equity was not considered. Also, depending on what are the main cultures of the AFS, richness could be great or low. It has also been reported that the decrease in species over time does not necessarily indicate something bad, as it depends on the purpose of AFS is. According to Raneri *et al*. (2021), monitoring biodiversity with few required resources is a relevant outcome, which can help defining efficient biodiversity-friendly farming practices. Richness and diversity were also important indicators inventoried by Paulo and Massi (2022) in agroforests in the southeast Atlantic Forest. Another study in the southeast Atlantic Forest showed that richness (in that case of regenerants) were associated with a more qualified indicator (a functioning indicator) and can be considered a good proxy of ecological parameters to monitor and attest restoration success of tropical rainforest (Massi *et al*., 2021).

Another indicator that was much debated was the involvement of family members in the management, because not only family but also the surrounding community should be evaluated, or because participation of family members would not necessarily be in management, but in any activities, such as cooking, searching for supplies, logistics and sales, which are related to the AFS. The permanence of family members participation can indicate the ASF success and importance, once it possibly is the main source of family income. In addition, in the indicator about satisfaction or happiness with AFS, many attendees declared that knowing the former experience of the smallholder with AFS would balance expectations, also that there are several daily frustrations in managing AFS, which is very difficult and subject to several mistakes, disappointments, and challenges, such as the lack of specialized field technicians. In this case, when the happiness with AFS is not reached it is important to separate the AFS itself from the ability to manage it and we believe the framework might help farmers to identify the causes of this and change, social indicators are extremely important as Mulyoutami *et al.* (2023) found that agroforests are an intersection of instrumental and relational values of nature: gendered, culture-dependent perspectives.

Secondly, regarding the methodology to collect data on indicators, one question was if each framework should be applied in each module of AFS or in the whole area. Also, attendees discussed if indicators should be collected by walking in the AFS or by installing plots and they concluded it depends on AFS size. In a large site (a 1 ha-AFS), three 10 x 10 m plots should be used, while in smaller sites walking and observing would be fine. However, we highlight that plots could be use in small areas, depending on the aims of AFS and other things, like species diversity. Participants also argued that AFS are very heterogeneous in space and time, and thus, monitoring has to capture that, spatially, by walking or allocating plots along the whole system, and temporally, by carrying out monitoring twice a year (dry and rainy season). Restoration protocols of the Atlantic Forest Restoration Pact deal with limitations of heterogeneity in restored sites (Viani *et al.*, 2017) and Resolution SAA/SIMA 03/2020 (São Paulo, 2021) presents two methodologies (plots and walking) according to the size of a restoration area, which were the background for discussions in the workshops. Another interesting discussion topic in workshops was that some indicators should be taken in the planting line or between lines (such as litter height, average plant spacing, and plant density), because they will present different measures (again, related to the spatial heterogeneity of agroforests). In this regard, the percentage of soil cover was excluded from the framework by participants (Table 2) because constant management in AFS implies a constant variation of this indicator.

Thirdly, several indicators were suggested but not included in the final version of the framework in light of the main objective of creating a protocol applicable by any farmer. They included, for example, quantifying plants that were in the site before starting the AFS, records of spontaneous plant species (as already presented) and soil analyses. Regarding value chains, a small farmer stated that he sells his products in the region and ends up emitting less carbon and, thus, we should implement AFS not only as a way of compensating carbon emitted, but as stopping emissions. In relation to soil, participants discussed that restoration projects and AFS help soil conservation and, therefore, an indicator related to soil analysis would be necessary. This is in line with a study conducted in Brazil that has shown the enhancement of soil fertility and physical indicators after the establishment of agroforestry systems over areas previously occupied with extensive pasturelands (Matos *et al.*, 2022). However, attendees also agreed that soil analyses are not easy and cheap for smallholders. Even a practical guide, such as Comin *et al.* (2024), impose several technical challenges for farmers that are not used to the terminology.

Lastly, participants suggested that this study should provide training for small farmers who have and work in AFS as they would learn about the framework, indicators and would apply the protocol in their own agroforests. Another suggestion was the creation of a simple phone app to insert framework data, such as Agrotag from EMBRAPA (EMBRAPA, 2017), shared among smallholders, and used to compare information. Reference values for indicators were always a topic of discussion in all workshops, but at the end participants agreed that the framework should not have these values, as the protocol was intended to be as general as possible and to be applied to different AFS models (thus, reference values could not cover this variety). Instead, participants suggested the regular application of the protocol to monitor the AFS evolution, but they did not consider comparing AFS values to conventional agricultural sites, neither to conserved forested sites or to reference ecosystems. Also, many participants pointed out that transforming landscapes into healthier places by using agroforests brings several other benefits than ecological and economic ones and that applying only quantitative indicators might not identify these benefits. We believe both kinds of indicators could point important directions of these benefits, as qualitative indicators are collected in a non-measurable way and are based on visual observation and on the observer judgment (such as historical land use of AFS site), while quantitative indicators are obtained in a measurable way, which reduces the evaluator participation and judgment, providing greater security, transparency and replicability (such as species richness). Thus, we need a holistic monitoring that could also include cultural parameters, such as quality of life of small farmers and AFS sentimental value for the family. A last interesting topic was that several indicators depended on each other and should not be separately analyzed, as for example the combination of age of AFS, aim of AFS and plant species richness. If one system is 15 years old and aims to produce timber, but has two species there is nothing wrong with it, because it probably is being managed for this intent.

Lastly, results of field monitoring showed that the framework was able to give a good picture of the three different systems in the same area (**Table 3**). Social and qualitative indicators presented no variation, once they were applied to the same farm and in just one moment, requiring more than one application in a certain period of time for comparison. However, canopy cover reflected the aim of each AFS, once in AFS 1 and 2 was expected higher trees with great canopy while AFS 3 was dominated by shrubs Species richness was high in AFS 1 and reduced in the AFS 3, related to the aim of AFS, conservation purpose and medicinal plants cultivation, respectively. On the other side, litter height was greater in AFS 3, which might be associated to a lower and more open system, where pruning is more frequent.

We argue that our indicators are complementary and together they were able to easily show the differences among three sites, which agree with the objective of framework creation. In addition, they were easy, practical, fast and could be performed by anyone. In the beginning of this study, we mention some monitoring protocols (Navas; Silva, 2016; Oliveira, 2016; São Paulo, 2018), which we used as models to build a first version of this framework, with ten indicators, mostly biophysical. At the end, only six of those indicators were maintained in the last version of this framework, with 15 new indicators, mostly socio-economic, which shows how the proposed model differs and/or is innovative.

Table 3. List of collected indicators in the final version of the monitoring framework in the field survey. AFS is agroforestry system, PPA is permanent preservation area, LR is legal reserve and CU is consolidated use.

Indicator	AFS 1	AFS 2	AFS 3
Aim of AFS	Fruits, conservation, restoration	Cocoa, biodiversity	Medicinal plants, wood
Age of AFS	4 years	6 years	2 and half years
Size of AFS	0.2 ha	0.04 ha	0.1 ha
AFS in PPA, LR, or CU	LR	CU	CU
Historical land use of site	natural regeneration, fire	pasture	pasture
AFS as the main activity	No	No	No
Different yields	None	Fruits and green leaves	Lavender, lemongrass, citrus
AFS is for income or self-consumption	None	Self-consumption	Both
AFS products sell	None	None	in their house
Initial management action	exotic species control	fertilization	exotic species control and fertilization
Species richness	40	35	30
Canopy cover	90%	90%	10%
Number of layers	3	3	3
Litter height	4 cm	5 cm	10 cm
Degradation signs	No	No	No
More fauna with the AFS	Yes	Yes	Yes
Plant leaf damage	Yes	Yes	No
Family member in the AFS	6	6	6
Women in the AFS	1	1	1
Joint effort and partners	Yes	Yes	Yes
Happiness with AFS	Yes	Yes	Yes

Font: Authors, 2024.

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