

Assessment of socio-environmental sustainability and resilience in a rural settlement in Southeast Pará, Amazon

Avaliação da sustentabilidade e resiliência socioambiental em um assentamento rural no sudeste do Pará, Amazônia

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ABSTRACT

The study conducted at the Castanhal Araras Settlement Project in São João do Araguaia, Pará, Brazil, assessed socio-environmental sustainability using a mixed methods approach. The research was grounded in diagnostic analysis of agrarian systems and the Framework for the Assessment of Natural Resource Management Systems Incorporating Sustainability Indicators (Mesmis). Data collection involved field notes, interviews, photographic records and participant observation. The results indicated a 'compromised' level of sustainability in both the social (score: 37) and environmental (score: 39) dimensions. On the social front, strengths included the use of family labour and a generally satisfactory quality of life. However, there were notable challenges regarding access to water, social inclusion, and community participation. Environmentally, while positive practices like diversified livelihoods and partial conservation efforts were present, they were offset by issues like pesticide use, soil compaction, the use of fire and extensive cattle ranching. Resilience was observed through the adoption of agroforestry systems and resourcefulness in agricultural practices. To address these challenges, it is essential to strengthen environmental education, enhance community engagement, and promote sustainable land management practices.

Keywords: Socio-environmental resilience. Mesmis. Sustainability indicators. Settlement.

RESUMO

O estudo realizado no Projeto de Assentamento Castanhal Araras, em São João do Araguaia (PA), avaliou a sustentabilidade socioambiental usando métodos quali-quantitativos com base na Análise Diagnóstico de Sistemas Agrários (DAS) e no Marco para Avaliação de Sistemas de Manejo de Recursos Naturais Incorporando Indicadores de Sustentabilidade (Mesmis). A coleta de dados incluiu entrevistas,

observação participante, registros fotográficos e diário de campo. Os resultados indicaram um quadro de sustentabilidade “alterado” nas dimensões social (37) e ambiental (39). Socialmente, destaca-se a presença de mão de obra familiar e qualidade de vida satisfatória, mas há desafios no acesso à água, inserção social e participação comunitária. Ambientalmente, práticas como pluriatividade e preservação parcial coexistem com problemas, como pecuária extensiva, uso de defensivos, compactação do solo e queimadas. A resiliência é refletida em práticas como sistemas agroflorestais e bricolagem. Para superar os desafios, é essencial fortalecer a educação ambiental, ampliar a participação social e incentivar práticas sustentáveis.

Palavras-chave: Resiliência socioambiental. Mesmis. Indicadores de sustentabilidade. Assentamento.

1 INTRODUCTION

In recent decades, the theme of sustainable development has gained increasing relevance, particularly after the 1987 Brundtland Report, also known as *Our Common Future*, by the World Commission on Environment and Development (WCED, 1987). The Brundtland Report introduced the concept of sustainable development as the ability to meet present needs without compromising the ability of future generations to meet their own needs (Japiassú; Guerra, 2017).

Since then, numerous definitions and concepts of sustainable development have been proposed, highlighting the growing global concern for harmony between human progress and environmental preservation. The multiplicity of definitions reflects the understanding that different contexts require distinct approaches to achieving sustainability. The diversity of specific challenges faced by different regions and communities highlights the need for adaptation and flexibility in sustainable development strategies. Issues like climate change, soil degradation, biodiversity loss, and natural resource scarcity pose complex challenges that demand innovative and collaborative solutions.

The integrated approach to the Sustainable Development Goals proposed by the UN in 2015, through the 2030 Agenda, highlights the need to address contemporary global challenges. Among these challenges, food security, poverty eradication, and environmental management emerge as decisive concerns, outlining a path toward building a more sustainable future (Oliveira *et al.*, 2021).

In this context, the concept of resilience gains centrality in debates on sustainability, especially in agricultural systems. The term, which originated in physics—coined by Thomas Young in 1807 to describe the ability of materials to return to their original shape after undergoing deformation (Silva; Cardoso, 2020)—was subsequently adopted by various fields of knowledge. In contemporary literature, it is widely understood as the ability of a system to absorb disturbances and reorganise itself, maintaining its essential functions in the face of change or adversity.

The resilience and sustainability of agricultural systems have been discussed both from the perspective of sustainable development—emphasising the integration of agricultural production and environmental conservation—and from the perspective of alternative food systems and social movements (Lamine, 2015). Within this context, agroecological strategies have established themselves as promising paths for strengthening socio-ecological resilience by promoting practices that include increased agrobiodiversity, sustainable management of natural resources (soil, water, and forests), and the mitigation of socio-environmental risks (Altieri; Nicholls, 2013).

At the heart of these strategies, family farming emerges as a key agent in promoting food security and achieving the Sustainable Development Goals. A seminal study conducted by Graeub *et al.* (2016) revealed that family farming activities play an extraordinary role, contributing over 53% of global food production. With over 500 million small family farms spread across the world, family farming is a vital element in the food security equation.

Within the broad panorama of agricultural establishments in Brazil, the significant presence of family farming stands out, with 3,897,408 units. Interestingly, this category of producers is concentrated primarily in the Northeast Region, accounting for 76.8% of this contingent, followed by the North Region, with a significant share of 14.5%. The dynamics of family farming are not limited to its significant territorial presence; they also play a decisive role in job creation in the sector. In 2017, this type of agriculture employed 66.3% of workers involved in agricultural activities (IBGE, 2018).

Family farming maintains an intrinsic connection with agrarian reform. Several variables, including the issue of agrarian reform, condition the number of established family farmers. For a long time, agrarian reform was considered taboo in Brazil for a series of complex reasons associated with economic interests, specific political ideologies, such as socialism or communism, conflicts of interest, and uncertainty about its outcomes, such that combinations of these reasons have occasionally led to its repression (Fernandes, 2000, p. 89).

Examining the historical trajectory of this public policy, it is clear that the Brazilian state has alternated between inaction and isolated interventions. In general, government initiatives have been limited both in the creation of new settlements and in the continued allocation of resources to combat land inequality. The implementation of basic infrastructure, the provision of public services, and technical and productive support to settlers have historically been insufficient, revealing the absence of an enduring, structured model to support settlement development (Navarro, 2001).

The agrarian issue in Brazil, therefore, is marked by historical disputes surrounding land structure, state action, and the power of rural social movements. Beginning in the 1980s, with the strengthening of the *Movimento dos Trabalhadores Rurais Sem Terra* (MST), the Landless Workers' Movement, and the creation of the *Programa Nacional de Reforma Agrária* (PNRA) [National Agrarian Reform Programme], these tensions became even more evident. Authors like Martins (1994) and Oliveira (1995) argue that agrarian reform should be understood not merely as a land redistribution policy, but rather as a strategic field of dispute between distinct models of rural development.

In the Amazon, this complexity is intensified by the disorderly expansion of the agricultural frontier, the recurrence of land conflicts, and the socio-cultural heterogeneity of settlers, who range from peasants expelled from other regions to urban migrants and traditional communities (Almeida, 2010; Schneider *et al.*, 2010). Therefore, rural settlements cannot be seen as homogeneous structures, but rather as socio-technical territories in constant transformation (Pacheco, 2009).

According to the *Instituto Nacional de Colonização e Reforma Agrária* (Incra) [National Institute of Colonisation and Agrarian Reform], there are currently 9,427 settlement projects in Brazil, distributed across all states, numbering over 965,000 settled families. The Legal Amazon accounts for 40% of the country's agrarian reform projects, and Pará is the state with the largest number, with 1,137 projects. Among these, almost 50% are in Southeast Pará (Incra, 2018; Incra, 2021).

Despite their significant historical contribution to agrarian reform, rural settlements have resulted in substantial environmental liabilities that compromise the sustainability of these territories as productive environments. The situation is particularly alarming in the Legal Amazon, where, by 2021, 47% of the forest cover in settlements had been deforested. Deforestation is most pronounced (81%) in the southern and eastern Amazon, notably in the states of Maranhão, Mato Grosso, Rondônia, Pará, and Acre, in areas of conventional settlements where the main proposal is land redistribution and colonisation. At the same time, sustainable development remains a secondary concern (Maeda *et al.*, 2021). Furthermore, of the 9,374 registered rural settlements, including those located in sustainable use conservation units, 1,559 (16.6%) have at least one registered deforestation alert (Azevedo *et al.*, 2022).

Socially, the challenges experienced in Amazonian settlements clearly demonstrate precarious living conditions, where settlers face limited access to essential services and development opportunities (De Souza; Silva, 2023). Furthermore, the lack of adequate infrastructure and investment in education and technical support contributes to the perpetuation of precarious conditions, hindering the full development of communities, making it essential to implement effective measures to improve the settlers' way of life significantly.

In this context, the words of De Souza *et al.* (2020) echo the pressing need to promote sustainability in Amazonian settlements, highlighting the importance of an approach that restructures the way these settlements are conceived and implemented. This entails conducting an integrated analysis of the historical context of the occupation of these areas, understanding the socioeconomic reality of the settler groups, assessing the forest cover rate, and considering market accessibility (Amazônia 2030, 2022).

When we refer to the concept of sustainability, we draw on the pioneering contributions of Masera *et al.* (2000), who provided a comprehensive and holistic framework for addressing the complex challenges facing humanity regarding natural resource use and socio-economic development. This perspective recognises that sustainable development requires a delicate balance between human needs and the limits of natural resources. Thus, promoting sustainability involves adopting practices and policies that seek to maximise human well-being while ensuring ecosystem conservation and social equity.

The purpose of this article is to investigate the conditions of sustainability and socio-environmental resilience in the Projeto de Assentamento Castanhal Araras in São João do Araguaia, Pará, focusing on analyses of agricultural and environmental practices adopted by the settled families.

2 METHODOLOGICAL PROCEDURES

The study was conducted in São João do Araguaia, in south-eastern Pará, approximately 40 km from Marabá. With an area of 1,279.89 km² and an estimated population of 14,105, the municipality received its name from its proximity to the confluence of the Araguaia River. The research scope comprised the Projeto de Assentamento (PA) Castanhal Araras, a settlement project that has a unique history and explains the true reasons that enabled the settlement of the first farmers who benefited from agrarian reform in the State of Pará. This project was designed with the mission of implementing innovative and sustainable practices, aimed not only at providing land and housing, but also promoting socio-economic development and environmental conservation, reducing land inequalities and improving the quality of life of rural communities.

2.1 DATA COLLECTION

The research began with an exploratory review of the literature to familiarise ourselves with the phenomenon under investigation. This approach provided a solid foundation for planning activities, seeking to significantly contribute to a more holistic understanding of the complex reality of rural areas, as highlighted by Silva *et al.* (2019).

The second stage consisted of defining objective criteria for selecting family farmers to be interviewed. The main criteria adopted were: residence and active production in the PA Castanhal Araras; direct involvement in the agricultural and environmental practices of the production unit; and the willingness to consent to voluntary participation in the research. The selection process aimed to ensure the representation of different production profiles and management experiences in the settlement. Following this stage, direct observation of the production units was performed, allowing for in situ knowledge of the cultivation systems and management practices. The interviews covered both technical

(agricultural practices, input use, and marketing) and subjective aspects (perception of quality of life, social relationships, and interaction with the environment).

Fieldwork took place between July 2023 and February 2024. The data collection instruments used were semi-structured interviews using a questionnaire. This choice was based on the advantages highlighted by Marconi and Lakatos (2003, p. 198), including the lack of reading and writing skills required by interviewees, flexibility in clarifying questions and adapting to changing circumstances, and the ability to capture nuances, including body language, tone of voice, and emphasis in responses.

The fieldwork procedures were guided by the steps of the diagnostic analysis of agrarian systems and the *Marco para la Evaluación de Sistemas de Manejo de recursos naturales incorporando Indicadores de Sustentabilidad* (Mesmis) [Framework for the Assessment of Natural Resource Management Systems Incorporating Sustainability Indicators]. These methodologies are widely recognised in family or peasant farming contexts, as demonstrated by Deponti *et al.* (2002) and López-Ridaura *et al.* (2002). Furthermore, meetings were held with local leaders to understand the needs and concerns of those affected by the study topic, community members, management members, and public bodies, to obtain relevant technical and statistical information, enriching the research perspective and ensuring a comprehensive approach.

The methodology employed included participant observation, audio recording, photographic records, and the preparation of field diary reports, as recommended by Albuquerque *et al.* (2008). Guided tours supported the interview process, enabling us to accompany the farmers in their production areas and listen to them as deep experts of the environment.

The interviews were conducted through the application of a form that characterised the production unit and another to assess the capacity to promote resilience and sustainability, developed and adapted based on the recommendations of Masera *et al.* (2000). This adaptation was necessary to incorporate local land use and management practices, the role of family pluriactivity, and the importance of ecosystem services provided by the settlement's native forest areas. Furthermore, some social and environmental assessment criteria were updated, including indicators on co-operative action, technical assistance, and the use of native seeds. These indicators were not included in the original proposal but are crucial for assessing sustainability in Amazonian contexts. This method provided families with the opportunity to introduce relevant topics while maintaining a focus on socio-environmental issues, capturing significant nuances during data collection.

2.2 DATA ANALYSIS AND SUSTAINABILITY INDICATORS

Initially, sustainability indicators were selected, and the criteria were defined. Next, an analysis of family agro-ecosystems was conducted, identifying management systems, together with their social and environmental characteristics. Subsequently, the indicators were evaluated and scored. Local hotspots were also identified, highlighting areas requiring special attention.

The strategically aligned set of indicators focused on the fundamental attributes of equity, resilience, stability, reliability, adaptability, productivity, and self-management, as defined in the Mesmis method. This set encompasses 40 indicators that consider aspects ranging from social issues, the preservation of forest areas and natural resources, to specific agricultural practices, such as the use of green compost and chemical pesticides.

The quantification of information was performed using scores ranging from 1 to 3, where each score corresponded to a specific condition: 1 indicating an undesirable condition (bad), 2 representing a regular condition (average) and 3 denoting a desirable condition (good) (Table 1).

Table 1 – Socio-environmental indicators used to assess family units

Dimension	Indicators	Parameters		
		1	2	3
Environmental	Permanent preservation area (PPA)	< 50% protected	< 100 ≥ 50%	100% protected
	Animal access in PPA	Full access	Isolated areas	No
	Legal reserve	< 20% of the area	20% of the area	> 20% of the area
	Use of natural resources	No	Yes, but not managed	Yes, managed
	Use of wooded areas	No	Yes, with no environmental education	Yes, with environmental education
	Indicator plants	None	Pollution and quality	Environmental quality
	Bird life	None	Some	Significant numbers
	Wild animals	None	Non-threatened animals	Threatened with extinction
	Pluriactivity	Monoculture	Animal or vegetable	Animal & vegetable
	Fertiliser	< 50% organic	< 90 ≥ 50% organic	≥ 90% organic
	Use of green compost	No	In some systems	In all systems
	Crop rotation	No	In some systems	In all systems
	Soil compaction	> 0.5 ha	≥ 0.5 ha	No
	Soil cover	Exposed	During cultivation	Covered all year round
	Use of chemical pesticides	For all crops	For large crops	No, only organic
	Erosive process	Extensive	Partial, easily fixed	None
	Use of local, native or traditional resources & varieties	No	A few	In every system
	Degraded areas	Several	A few	Sempre
	Occurrence of fires	Sometimes	Only once	No
	Deforestation	Yes	Only once	Never

Dimension	Indicators	Parameters		
		1	2	3
Social	Water for human consumption	Untreated	Filtered	Treated
	Water for agriculture	Untreated	Filtered	Treated
	Sewage	Discharged into the environment	Septic tank	Treated
	Potential for social inclusion	None	Once in a while	Always
	Infrastructure	Inadequate	Needs adjustments	Adequate
	System interdependence	None	Partial	Yes
	Restorative potential	None	Seedling production	Seedlings & nucleation
	Workforce	Outsourced	Outsourced & family	Family
	Participatory action	No	Sometimes	Always
	Degree of dependency and self-financing	None	Sometimes	Yes
	Technical assistance	None	Sometimes	Yes
	Health services	No	Yes, not in PA	Yes, in PA
	Educational services	No	Yes, not in PA	Yes, in PA
	Family health	Poor	Fair	Good
	Co-operative action	None	Is interested	Active
	Financing	None	Has done so	Active
	Advanced training courses	None	Has done some	Active
	Support from public bodies (Seagri, Incra, Emater)	None	Sometimes	Yes
	Work outside the smallholding	Regularly	Sporadically	No
	Quality of life	Poor	Fair	Good

Source: Adapted from Verona (2008), with modifications that consider the specificities of the Amazonian context and integrated application with the Mesmis method.

The values obtained were categorised into three classes, which reflect different levels of viability for sustainable development, as illustrated in Table 2.

Table 2 – Classification of Socio-Environmental Sustainability

Points	Classification	Characteristics
≤ 20	Potentially unsustainable	- Land performs no social role. - Family income is not tied to productive use; it comes exclusively from external activities, retirement benefits and/or social assistance. - Access to basic social services is very low or virtually non-existent. - Water scarcity affects household consumption and productive demand. - Social disarticulation between families is evident. - Immediate land use adjustments are required, as the potential for soil loss is high due to intensive use in areas susceptible to erosion. - Areas of environmental interest may be incorrectly demarcated and subject to inappropriate uses, compromising the performance of their environmental functions.
21 – 50	Compromised	- Land performs a deficient social role. - Dependence on external activities, retirement benefits and/or social assistance, since domestic income does not meet basic needs or generate security. - There may be some form of associationism, but with token participation. - Minor problems with the water supply are admitted. - Access to most basic services is available. - Areas of environmental interest are correctly demarcated, but specific inappropriate uses may occur within them. When they occur, they are minor. - The percentage of land with medium erosion potential is higher than that with low erosion potential.
≥ 51	Potentially sustainable	- Land plays an important social role. - Income composition depends largely on economic activities performed within the smallholdings. - Satisfaction with basic services is high. - There are no problems with water supply. - Associationism is a common practice in the settlement, with high participation and satisfaction among the beneficiaries, since it has generated social, productive, and environmental gains for the settlement. - Overused land is practically non-existent. - Proper use outweighs underuse. - Areas of environmental interest are comprehensively fulfilling their functions of protecting native vegetation.

Source: Adapted from Santos and Castro (2022), with modifications that consider the specificities of the Amazonian context and integrated application with the Mesmis method.

In addition, photographic records were integrated to enrich the interpretation of the landscape, following Costa (2004), who emphasises their value in environmental analysis. The assessment of the indicators considered semi-structured interviews and field observations, ensuring an interdisciplinary and in-depth approach to the environmental and productive dynamics of the settlement.

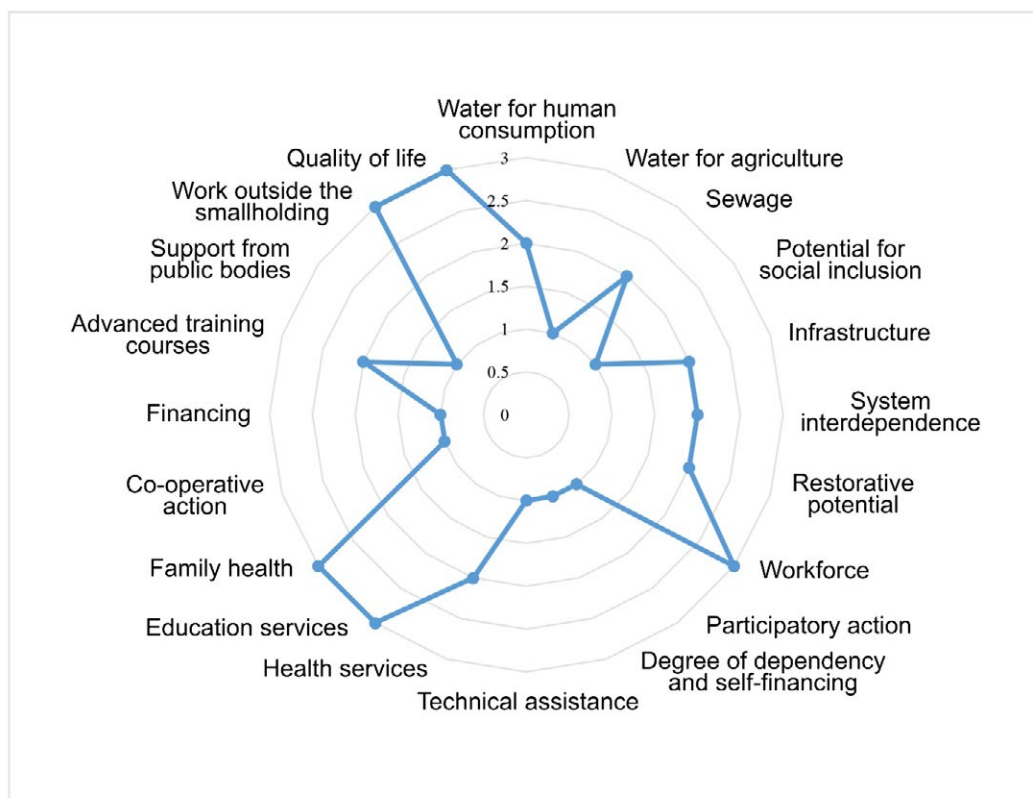
The interview analysis used the lexical technique on the ATLAS.ti platform (ver. 24), exploring the word cloud, where frequency defines the font size, facilitating the identification of the most frequently used terms. To preserve the anonymity of the participants, a coding system was adopted, identifying them as 'E-CA' followed by an ordinal number.

The project was approved by the Research Ethics Committee of * __* under protocol no. CAAE 75482923.0.0000.8607 and report no. 6.581.847. Participants signed a term of free informed consent, under Resolution 466/2012.

3 RESULTS AND DISCUSSION

3.1 NAVIGATING THE CHALLENGES: WHAT DO SOCIAL SUSTAINABILITY INDICATORS SHOW FOR THE PA CASTANHAL ARARAS?

With a final score of 37, the agro-ecosystem falls within the 21-50 range, indicating that it is compromised and presents some critical points in social sustainability. Certain positive aspects stand out, like the availability of family labour and quality of life, both classified as desirable (3). However, significant challenges are identified in indicators that presented lower scores (1), such as water for agriculture, the potential for social inclusion, and participatory action, suggesting critical areas for intervention. Figure 1 presents the mean scores given by family farmers for each category in the quantitative assessment.



Source: Research data.

The analysis of the results highlights a complex dynamic between resilience and social sustainability in the PA Castanhal Araras. Positive aspects like the availability of family labour and a desirable quality of life indicate the community's social resilience. Family cohesion and a satisfactory quality of life suggest that the community has a resilient social base, capable of facing daily challenges and preserving cultural traditions, which are highlighted as a valuable asset.

The contribution of family labour not only strengthens community ties but can also boost agricultural productivity, leveraging traditional knowledge passed down from one generation to the next. Furthermore, a desirable quality of life suggests a favourable environment for human development,

indicating that socio-economic and environmental conditions have the potential to provide a satisfactory life for the settlers.

The analysis also highlights significant challenges represented by indicators that received lower scores. Water scarcity for agriculture is a critical factor, considering the settlement's dependence on agricultural practices. This poses a direct threat to their economic resilience, since agricultural practices are fundamental to the livelihoods of the families. Lack of access to water can also compromise the community's ability to adapt to climate change and ensure the continuity of agricultural activities, affecting both food and economic security.

The low potential for social inclusion in the settlement is an additional challenge that affects social sustainability, given that it is vital for seeking opportunities, accessing resources, and promoting community development. Social resilience does not only concern the ability to withstand challenges, but also the ability to adapt and thrive through collaboration and integration into the broader society.

Furthermore, participatory action, identified as a critical area, highlights the importance of active community engagement in decision-making and the implementation of sustainable practices. A participatory community is fundamental for fostering social resilience, enabling the co-creation of adaptive solutions that consider the needs and perspectives of all members.

The data reveal empirical elements that align with the resilience factors identified by Berkes (2007) and Folke *et al.* (2003). The four groups of factors—diversity, learning capacity, knowledge integration, and self-organisation—are present to varying degrees in the PA Castanhal Araras. A family farmer emphasised the importance of diversifying activities in settler life, stating:

We get by doing a bit of everything. Some work with cattle, others with crops, and some even do both. Some family members find work outside here... some are teachers, others work in offices. In order to live here, it's good to have a plan B, C, and even D. Sometimes, the prices of products go up and down, so if we only have one crop, just milk from the herd, it gets difficult. (E-CA-30)

Over the years, it has been observed that some farmers have played a crucial role in actively promoting diversity, investing time and effort in new productive activities. By expanding the range of species bred and cultivated, they have not only enriched the agricultural supply but also strengthened the resilience of the ecosystem. This approach has not only benefited the farmers themselves but has also had a positive impact on the community at large, promoting a more diverse, dynamic, and ecologically balanced agricultural landscape.

However, in the PA Castanhal Araras, farmers have faced a considerable challenge that goes beyond the technical complexities inherent in agricultural production, because they have experienced a prolonged period of the lack of technical assistance and support from public bodies. For many years, these farmers have been left to their own devices, with few resources to adapt to changing agricultural practices, emerging technologies, and environmental challenges. The lack of adequate technical assistance has resulted in difficulties in effectively implementing the latest scientific discoveries, compromising the efficiency and sustainability of their operations.

In this scenario, farmers face constant challenges in achieving autonomy and self-organisation. A notable example is the adoption of the DIY practice, in which farmers rely heavily on their own resources, whether through the reuse of equipment, materials, and knowledge available on the property, and the use of agroforestry systems, integrating crops, trees, and animals to optimise resources and promote biodiversity. An additional challenge here is the low potential for social inclusion in the settlement, as discussed previously, which has impacted social sustainability.

Fuller *et al.* (2021) emphasise that family farming is widely recognised as a driver of social sustainability, where access to land is perceived as an essential element of social justice. When we turn our attention to the PA Castanhal Araras, it is evident that despite the challenges inherent to public policies in rural areas, this settlement offers a concrete perspective for family farmers to achieve housing autonomy, provide opportunities for their children to study, and work on their own land, actively contributing to food production and family income generation.

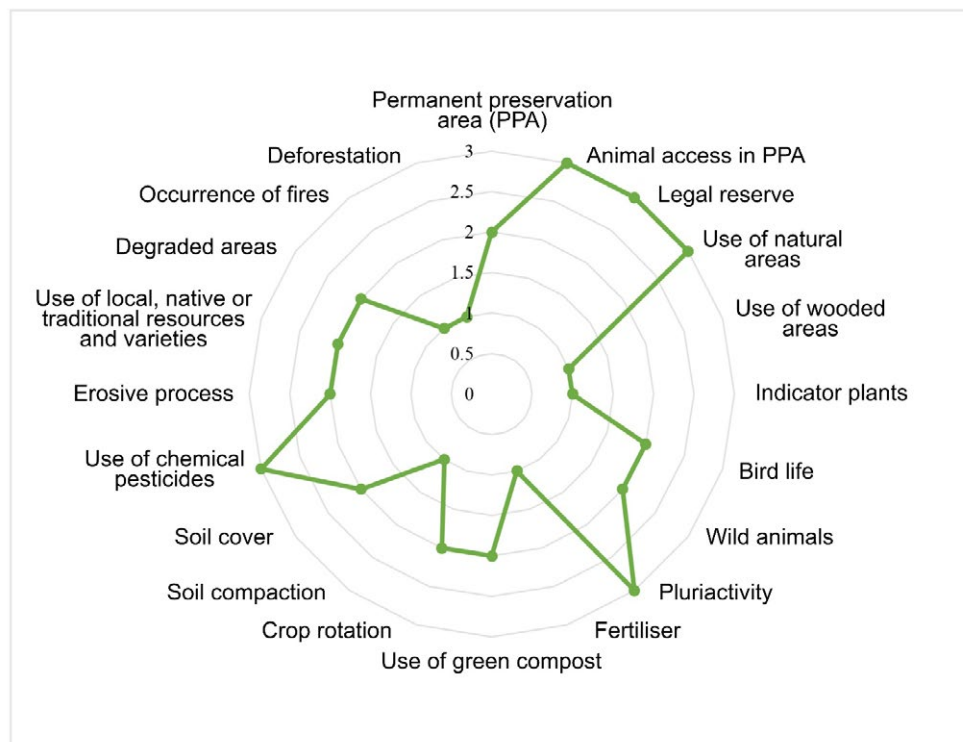
Regardless of the obvious shortcomings, such as the lack of infrastructure and support from public bodies, it is clear that settled families believe their lives will improve after integrating into this context. A careful analysis of farmers' perceptions of their living conditions emerges as a categorical indicator when assessing the potential for local development. This aspect, often underestimated in comparison with objective census data, plays a unique role in offering a perspective closely connected to the local reality, as highlighted by Medina and Novaes (2014).

In the specific context of the PA Castanhal Araras, agrarian reform is consolidated as an essential policy of social inclusion, reaffirming its decisive role in the pursuit of an improved quality of life and the construction of a more just society for the family farmers of this settlement.

3.2 BETWEEN PASTURES AND FORESTS: RESILIENCE AND ENVIRONMENTAL SUSTAINABILITY

The final score for the environmental sustainability assessment was 39, placing the agro-ecosystem in the range of 21 to 50, indicating a 'compromised' state with some critical areas. Detailed analysis revealed that although the agro-ecosystem exhibits good practices in certain aspects, there are critical areas that require immediate attention, such as the use of chemical pesticides and soil compaction (Figure 2).

Figure 2 – Means of environmental dimension indicators



Source: Research data.

The categories that obtained the best scores indicate a certain degree of awareness and sustainable practices. The assessment reveals moderate consideration for the preservation of critical areas, such as permanent preservation areas (PPAs) and legal reserves (LRs). As established by the Brazilian Forest Code, Law no. 12.727/12, enacted on October 18, 2012, PPAs are demarcated along lakes, ponds, riverbanks, reservoirs, waterways, hilltops and steep slopes. These areas, regardless of whether they are covered by native vegetation or not, play a crucial role in preserving water resources, maintaining the landscape, ensuring geological stability, promoting biodiversity, and promoting the gene flow of fauna and flora, in addition to protecting the soil and ensuring the well-being of the human population (Brasil, 2012).

Another relevant point addressed by the Forest Code is the 'legal reserve', an area within rural properties or holdings that must be maintained with its original vegetation cover (Brasil, 2012). This space plays an essential role in conserving biodiversity and preserving local ecosystems, contributing to the maintenance of essential environmental services. However, it is worrying to note that the vast majority of farmers are unaware of both the definition and the importance of PPAs and LR, given the notable discrepancy between the percentage maintained in these areas within family units and those established by the Forest Code.

The high score for pluriactivity suggests a diversified approach to activities. Among the plant species cultivated, farmers identified a variety of crops that play an important role in family nutrition and the local economy. Cassava is considered a key player in this scenario, representing a fundamental food source, as well as a valuable commodity. Besides cassava, other agricultural products stand out among the main commercial crops. The presence of several native species was notable, particularly chestnut and copaiba trees, providing significant natural wealth to the settlement.

In terms of livestock production, it is clear that the species most frequently raised by family farmers is cattle, with a significant presence in 90% of the family units analysed. By extending their focus to the scenario observed in rural settlements in south-eastern Pará, Arraiz *et al.* (2021) presents a landscape that starkly reveals the effects of the expansion of livestock farming, a profound transformation of the landscape, resulting in a desolate scenario where vast tracts of land have been converted into monoculture pastures in areas that are already intensely degraded.

Data analysis in 2022, provided by MapBiomass, reveals a decreasing trend in forest cover and a significant increase in pasture areas over time in Pará. In 1985, the forest covered 4,959 hectares, falling to 977 hectares in 2022, a loss of 3,982 hectares (80%), converted to pasture. This loss of forest cover is worrying, especially considering the context of the Amazon and the need for sustainability in areas of agrarian reform.

This phenomenon, in turn, is exacerbated by the constant turnover of families on plots of land. A vicious cycle is established when the arrival of a new family in the area triggers new episodes of forest loss. A notable aspect of this scenario is the active participation of wealthy urban stakeholders who invest in the acquisition of farms in the PA Castanhal Araras.

Studies like the one by Yanai *et al.* (2020) highlight how these investors become medium- and large-scale landowners. Their presence in the settlement offers significant advantages, enabling them to benefit from local labour and existing infrastructure, while also facing a certain obscurity in the eyes of law enforcement. The dispersion of their properties into smallholdings, surrounded by family farmers' land, makes it difficult to locate and monitor them, granting them relative impunity, transforming the functionality of rural settlement projects into hubs for forest destruction (Carrero *et al.*, 2020).

It is crucial to recognise that rural settlement projects in Brazil, while often aimed at promoting family farming, are not exclusively geared toward this end. In some cases, these projects include a variety of agricultural and non-agricultural activities, and may even be aimed at large-scale agriculture or

agribusiness (Del Grossi, 2017). This approach, however, raises important questions about equity and the original objectives of agrarian reform. When considering agrarian reform, the expectation is that settlements are tools to support farming families, strengthening family farming and promoting social justice in rural areas.

However, by including large agricultural enterprises in the same programmes, there is a shift in objectives that weakens small farmers. The presence of large producers in the same 'package' intended for small farmers results in unequal competition, compromising resources and attention that should be directed towards the most vulnerable. Therefore, settlement projects must be clearly defined and targeted, ensuring that support for family farming is a priority and that the principles of equity and social justice are respected and maintained.

A moderate score also highlights attention to the conscious use of natural resources. These results indicate a significant commitment to environmental preservation and the promotion of sustainability in various aspects, recognising the importance of these areas for maintaining biodiversity and ecosystems. However, it also highlights the need to improve and strengthen environmental education and preservation practices to ensure a more robust and effective approach.

The categories that received lower scores reveal critical areas and potential problems that require immediate attention and corrective measures. An alarming point is the low score for 'use of forest areas', indicating possible inappropriate use or degradation of these areas vital to biodiversity. From a socio-economic perspective, forest management emerges as a complex development of circumstances shaped by family trajectories, the institutional conditions in which they are settled, and market pressure for timber products, constituting the most immediate avenue for income generation (Bentes; Monteiro; Vieira, 2020).

This panorama exerts a notable influence on the settlers' perceptions, since it is intrinsically linked to the imperative needs of subsistence on their properties. This process does not always unfold from an environmental perspective grounded in conservation and/or preservation, given that family survival often relies on the exploitation of forest resources as a vital source of livelihood.

Another serious concern is the low score for 'fertilisers', suggesting the possibility of inadequate or excessive use of these inputs, with potentially detrimental consequences for soil and water quality. The preference of family farmers for chemical fertilisers over organic fertilisers is influenced by affordability, ease of application, and speed of results. As highlighted by Kamiyama *et al.* (2011), conventional agriculture relies on the use of chemical fertilisers, pesticides, and practices like continuous tillage and lack of soil cover, which diminish ecosystem quality.

Furthermore, the lower scores for 'occurrence of fires' highlight the need for intensified prevention, monitoring, and protection practices. Wildfires pose a persistent threat to ecosystems, exacerbating carbon emissions, endangering biodiversity, and adversely affecting the well-being of local populations. According to data provided by the AQUA EOS satellite, between January 1, 2024, and April 21, 2024, Pará recorded a total of 1,047 fire outbreaks (Inpe, 2024). This number places the state third regarding the incidence of these devastating events.

This reality intensifies the need for preventive and educational measures to ensure that local communities can coexist sustainably with the environment. The situation is exacerbated by the lack of these practices in the settlement, and no preventive or educational measures have ever been implemented in the area. A deeper look at the interaction between fires and agricultural activities in the Amazon reveals that the ongoing risk of fires perpetuates a cycle of low productivity and environmentally degrading agricultural practices. This vicious cycle compromises not only the health of the rainforest but also the livelihoods of the communities that depend on it (Cammelli *et al.*, 2020).

Celis *et al.* (2023) address comprehensive strategies to address the challenges of wildfires and sustainable management in the Amazon region. These strategies include approaches to land cover, fire vulnerability reduction, holistic fire management, harmonisation of community ecological networks, and balanced policies to encourage sustainability. The authors propose the cultivation of moisture-retaining plants to mitigate fire risks, innovative concessions for smallholder farmers aimed at sustainable agroforestry, proactive planning and monitoring measures to reduce fire vulnerabilities, and comprehensive management that includes detection, communication, and ecosystem protection.

The category of 'soil compaction' also deserves attention, since it can compromise soil quality and fertility, and negatively impact ecosystem resilience. It directly influences species development and, consequently, the sustainability of crops that depend on it. Although soil compaction occurs naturally due to rainfall and geological processes, large-scale human activities significantly accelerate these phenomena, exacerbating their magnitude. Family farmers have also witnessed significant soil changes over time. By closely observing their land, they have noticed changes that indicate soil compaction. These observations go beyond mere visual appearance, involving an intimate understanding of the nuances of soil that sustains agricultural activities.

Among the signs detected is the texture and consistency of the soil, which appears to have transformed over the years. Many farmers report a more compacted soil, making it difficult for work tools to penetrate, which appears denser and less porous. Water infiltration capacity has also been a growing concern. They observe persistent puddles and surface runoff after rainy periods, indicating a reduced soil capacity to absorb and retain necessary moisture. They note shallower and less vigorous root systems, which affect nutrient uptake and plant health. As a result, crop performance has suffered, with signs of water stress and nutrient deficiencies observed.

A recent study by Rust *et al.* (2023) reported that the origin of this degradation is deeply rooted in political, cultural and socio-economic issues. The results demonstrated that the four elements of social capital—trust, norms, power and connectivity—play a relevant role in farmers' decision-making to modify their soil management practices. Therefore, the implementation of sustainable agricultural practices within farming communities is strongly influenced by social capital, with a special emphasis on trust. The presence of social capital, exemplified by diverse trustworthy networks, facilitates the exchange of knowledge related to sustainable agricultural practices. Furthermore, social norms and connectivity also exert substantial influences on the adoption of these practices, highlighting the importance of social interaction (Rust *et al.*, 2023).

Understanding and addressing these dynamics within farming communities is essential to promote the transition to more sustainable agricultural practices effectively. To contain and mitigate soil damage in the PA Castanhal Araras, the adoption of technically simple conservation practices, such as no-till farming, crop residue maintenance, species diversification, mulching, crop rotation, and green compost planting, can promote soil health and natural resource conservation.

While we recognise and advocate the effectiveness of the model based on small family farms as a more conducive path to sustainability compared with large monoculture farms, we cannot fall into the trap of adopting a static Manichean view, as if there were two closed models, one fully 'sustainable' and the other 'unsustainable' (Clemente, 2015). The complexity of agricultural and environmental issues demands a more nuanced, dynamic approach.

It is undeniable that large monoculture farms have been associated with predatory practices that inflict serious damage on the environment (Faita *et al.*, 2021; Gomes, 2019). In this sense, we consider the monoculture model to be highly unsustainable, given its significant contribution to environmental degradation. However, as we embark on the path of small family farms, and while we envision a greater capacity to promote sustainability, it is imperative to recognise that we are not immune to environmental challenges.

Consequently, to advance our reflection on socio-environmental development in the PA Castanhal Araras, it is essential to understand the relationship between families and the environment in which they live. It is crucial to recognise that production dynamics play a central role in interpreting economic and social reality. Thus, we can infer that one possible improvement strategy would be to promote the unification and expansion of agroforestry farm corridors within the settlement. The data obtained suggest that this approach can offer greater protection and help prevent further environmental damage. We know that environmental restoration can be costly, thus, prevention and protection are always more effective measures.

4 CONCLUSIONS

Sustainability in the PA Castanhal Araras involves several interconnected strategies. The project represents a concrete opportunity to strengthen the autonomy of family farmers and promote their social inclusion, highlighting agrarian reform as an essential policy for building a more just and equitable society.

A broader analysis reveals a complex scenario where historical aspects, social dynamics, and environmental challenges shape the community's trajectory. The transition from perennial crops to livestock farming illustrates the difficulties in implementing agrarian reform and highlights the need for strategic approaches, considering both institutional fragility and the capacity of beneficiaries for sustainable resource management.

Collaboration between different social and institutional actors is essential to ensure effective land redistribution and sustainable agricultural development. However, changes in land use, negative environmental impacts, and the weakening of social cohesion pose additional challenges, requiring the reformulation of public policies aimed at agrarian reform. Strengthening organisational structures and community participation emerge as determining factors for the sustainability of these initiatives.

The socio-environmental assessment of the agro-ecosystem reveals both the potential, such as the availability of family labour and the improvement in living conditions, and significant challenges, including water scarcity and the need for greater social inclusion for and the active participation of beneficiaries. These aspects indicate the urgency of strategic interventions that can mitigate risks and expand opportunities.

Given this scenario, certain essential programmes are recommended: the creation of ongoing technical training courses focused on agro-ecological management and sustainable natural resource management, particularly for young people and women, to ensure generational renewal and social empowerment; incentives for forest restoration and the use of agroforestry systems, to promote sustainable land use and ecological restoration; the valuation of community and associative strategies that foster social participation and the leadership of families in decision-making regarding their territories; and the integration of public institutions, social movements, and universities to develop territorial policies more aligned with local realities.

Although based on a specific case study, the results offer valuable insights into the development of strategies that contribute to the resilience and socio-environmental sustainability of family farming. They reinforce the ongoing need for reflection and research to improve policies and practices aimed at strengthening farming communities and the sustainable management of natural resources.

DECLARATIONS

Conflict of interests: The authors declare that there are no conflicts of interest.

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