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Sustainability of the Agroecosystem: A Case Study in an Agroextractive Settlement of the Brazilian Amazon

Sustentabilidade do Agroecossistema: Um Estudo de Caso em um Assentamento Agroextrativista da Amazônia Brasileira

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Abstract:

The evaluating sustainability indicators can demonstrate the diversity of agroecosystems and point out strategies that can lead to better sustainability rates. The aim of this study was to analyze a set of environmental, social, and economic indicators used to characterize the sustainability of agroecosystems of Praialta Piranheira Agroextractive Settlement Project, located in Eastern Amazon. The study was developed in six sectors of the settlement (Vila Belém, Maçaranduba, Maçaranduba II, Cupú, Praialta, and Tracoá), with each sector representing a different occupation time (< 9, between 10 and 19, and > 20 years of occupation). In each sector, three agroecosystems were studied. Based on the MESMIS tool (Natural Resources Management System Evaluation Framework Incorporating Sustainability Indicators) a structured questionnaire, was applied to each agroecosystem. In addition to the occupation time, another 32 qualitative indicators were considered from the environmental, social, and economic dimension. All indicators were divided into three categories that represent the degree of sustainability: highest, medium, and lowest. A multiple correspondence analysis was performed, and indicators were tested independently through the Monte-Carlo test. At least two basic types of agroecosystems are opposed: those with a longer occupation time, which demonstrate low sustainability, and those with a shorter or intermediate occupation time, which still show the potential of following more sustainable paths. The diversification of production systems and activities within a system indicates a contradiction between the public policies available—specifically, the lines of credit that do not encourage diversification and the willingness to diversify from the agroextractive workers.

Keywords: MESMIS; Multiple correspondence analysis; Public policy; Rural development; Indicators.

Resumo:

A avaliação de indicadores de sustentabilidade pode demonstrar a diversidade de agroecossistemas e apontar estratégias que podem levar a melhores índices de sustentabilidade. O objetivo deste estudo foi analisar um conjunto de indicadores ambientais, sociais e econômicos utilizados para caracterizar a sustentabilidade dos agroecossistemas do Assentamento Agroextrativista Praialta Piranheira, localizado na Amazônia Oriental. O estudo foi desenvolvido em seis setores do assentamento (Vila Belém, Maçaranduba, Maçaranduba II, Cupú, Praialta e Tracoá), sendo que cada setor representa um tempo de ocupação diferente (< 9, entre 10 e 19 e > 20 anos de ocupação). Em cada setor foram estudados três agroecossistemas. Com base na ferramenta MESMIS (Estrutura de Avaliação do Sistema de Gestão de Recursos Naturais Incorporando Indicadores de Sustentabilidade) foi aplicado um questionário estruturado a cada agroecossistema. Além do tempo de ocupação, foram considerados outros 32 indicadores qualitativos da dimensão ambiental, social e econômica. Todos os indicadores foram divididos em três categorias que representam o grau de sustentabilidade: alto, médio e baixo. Foi realizada análise de correspondência múltipla e os indicadores foram testados de forma independente por meio do teste de Monte-Carlo. Pelo menos dois tipos básicos de agroecossistemas se opõem: aqueles com maior tempo de ocupação, que demonstram baixa sustentabilidade, e aqueles com tempo de ocupação menor ou intermediário, que ainda apresentam potencial para seguir caminhos mais sustentáveis. A diversificação dos sistemas de produção e das atividades dentro de um sistema indica uma contradição entre as políticas públicas disponíveis – especificamente, as linhas de crédito que não incentivam a diversificação e a vontade de diversificar dos trabalhadores agroextrativistas.

Palavras-chave: MESMIS; Análise de correspondência múltipla; Políticas públicas; Desenvolvimento rural; Indicadores.

1. Introduction

The application of sustainability indicators to rural settlements in the Amazon region can be challenging, as these settlements present an array of diverse and complex environments. Such rural communities exhibit differences in lifestyle, reproduction strategies, and occupation times and are influenced by alternative management strategies and macro factors, such as environmental and social policies (Bjørn et al., 2020). They are comprised of family units or small farms, which can be understood as agroecosystems consisting of a mosaic of different land uses.

The existence of settlement projects in the Amazon is historically linked to the official occupation period of the Amazon region, which occurred in the last century (Hecht & Rajão, 2020; Brondizio et al., 2021) and was commanded by the federal government. This process involved human migration through the implementation of major infrastructure projects (the construction of federal highways, hydroelectric dams, and opening of areas for mineral exploration). The strategies proposed for the use of natural resources by national development projects often conflicted with the local communities' perspectives.

This resulted in the consequential acquisition of the territory through the gradual privatization of the land and subsoil, intensification of forestry extraction, and formation of different social, economic, and political groups (Brondizio et al., 2021). As of the 1990s, social pressure has led to increased accountability from the federal government regarding land usage and promote land regularization. These actions are currently reflected throughout the Amazon region, where almost

74% of rural establishments are destined for settlement projects, representing one third of the useful land in Brazil (Le Tourneau & Bursztyn, 2010; Brondizio et al., 2021).

Various types of settlements exist in the region, such as Managed Settlement, Rapid Settlement, and Extractive or Agroextractive Settlement Projects (Le Tourneau & Bursztyn, 2010); the latter are intended for the sustainable exploitation of wood and non-wood products, fishing, and hunting. Hence, Agroextractive Settlement Projects are agroecosystems with complex environmental-social-economic dimensions, making them difficult to understand and evaluate (Brondizio et al., 2021). However, due to its enormous importance for the conservation of biological diversity and the social and economic development of the area's populations, it is necessary to identify sustainable development solutions.

Sustainability indicators are useful tools to carrying out an integrated analysis of the environmental, social and economic dimensions, in addition to providing elements for the formulation of public policies and uses of new agricultural technologies; good sustainability indicators must be able to: incorporate progress towards the long-term goal, monitor natural resource use, address the state of ecosystem services, be easy to understand and employ; and, finally, an indicator can highlight the existence of risks and the potentialities and trends in the development of a territory, aiding community cooperation and engagement to ensure decisions are rationally made (Da Silva et al., 2020).

Thus, evaluating sustainability indicators can demonstrate the diversity of agroecosystems and point out strategies that can lead to better sustainability rates. Mainly the Indicators associated with occupation time that are elements of the agroecosystem that affects the family lifecycles, vegetation cover, land use dynamics, and environmental biodiversity (Silva, 2016). The MESMIS tool (Natural Resources Management System Evaluation Framework Incorporating Sustainability Indicators) can help in the evaluation of the three main dimensions of sustainability: environmental, social, and economic (Loureiro et al., 2020); since this tool allows adaptations of multidimensional evaluation indicators according to the situation that one wishes to evaluate or monitor (Valdez-Vazquez, 2017).

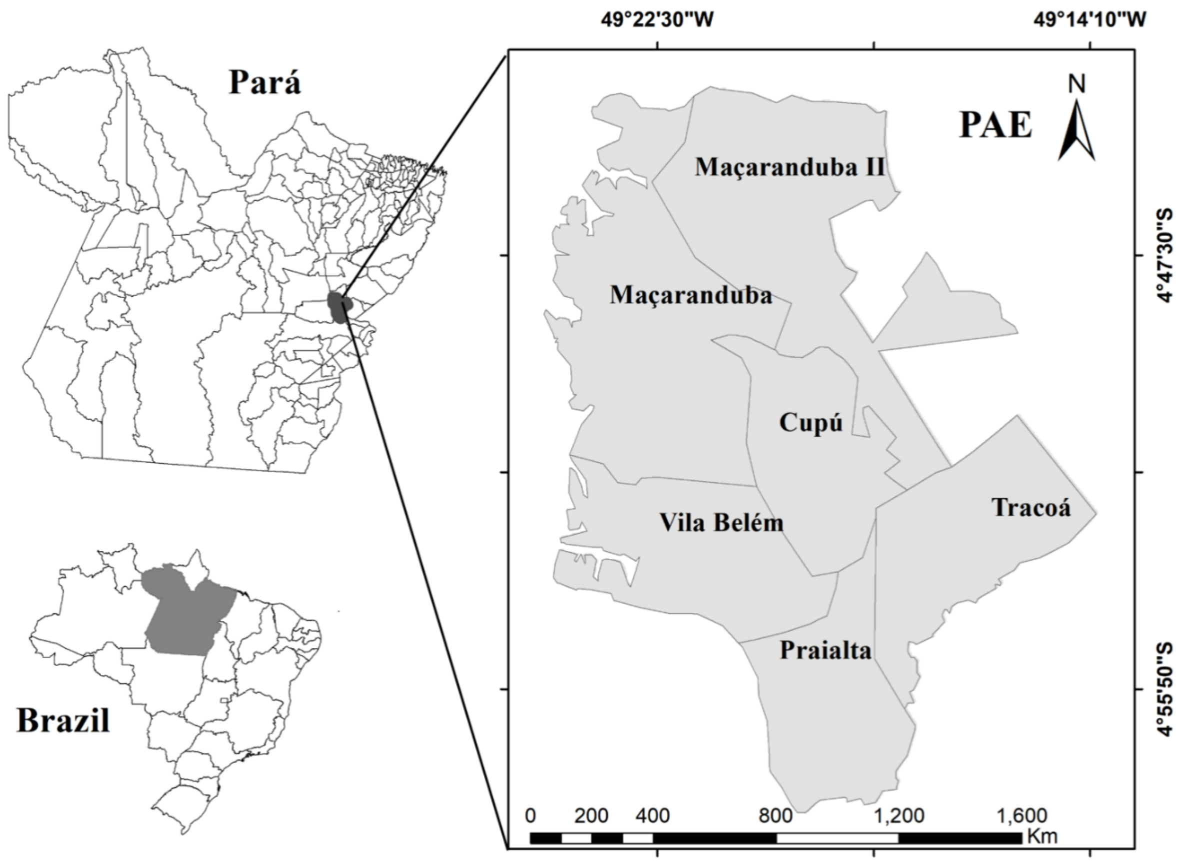
The aim of this study was to analyze a set of environmental, social, and economic indicators used to characterize the sustainability of agroecosystems of Agroextractive Settlement Projects in Eastern Amazon, to answer the following questions: 1) Is there a sustainability gradient related to time of occupation of the agroecosystem? 2) What are the best indicators for characterizing the sustainability of agroecosystems?

2. Material and Methods

The study was carried out at the Praialta Piranheira Agroextractive Settlement Project, located in the municipality of Nova Ipixuna, southeast of the state of Pará (04º 56' 16" S and 49º 04' 37" W), Brazil (Figure 1). The original vegetation of this area is tropical rain forest, or 'terra firme' forest; the climate is hot and humid, characterized by two well-defined seasons, the rainy season (November to April) and the dry season (May to October). This settlement was formally created in 1997 in the "castanhais polygon" which is well-known for its high concentration of tree Bertholletia excelsa H.B.K. that produces the much-valued Brazil nuts. This settlement occupies an area of 22,000 ha and housed 330 families in 2017; it was subdivided into six sectors which differ mainly in terms of (1) access, which was initially via the river before the roads opened; and (2) occupation time.

Figure 1. Location map of the Praialta Piranheira Agroextractive Settlement Project, which is divided into six sectors: Praialta, Vila Belém, Tracoá, Cupú, Maçaranduba, and Maçaranduba II. Municipality of Nova Ipixuna, State of Pará, Brazil.

Figura 1. Mapa de localização do Projeto de Assentamento Agroextrativista Praialta Piranheira, que é dividido em seis setores: Praialta, Vila Belém, Tracoá, Cupú, Maçaranduba, and Maçaranduba II. Município de Nova Ipixuna, Estado do Pará, Brasil.



This study was carried out in three sectors of the settlement: Cupú, Maçaranduba II, and Vila Belém. Each of these sectors has well-defined characteristics, described in Table 1. In each sector, three agroecosystems were studied, totaling nine agroecosystems; each one with 71 hectares on average, characterized by presence of pastures, secondary forests at different stages of development as well as fragments of native forests. An agroecosystem was considered as a small family property, constituted by a mosaic of different land uses, which presents interconnected environmental, social and economic characteristics.

Table 1. Characteristics of the agroecosystems of the three sectors studied in the Agroextractive Settlement Project Praialta Piranheira, Municipality of Nova Ipixuna, State of Pará, municipality of Nova Ipixuna, State of Pará, Brazil.

Tabela 1. Características dos agroecossistemas dos três setores estudados no Projeto de Assentamento Agroextrativista, município de Nova Ipixuna, Estado do Pará, Brasil.

Characteristics	Cupú	Maçaranduba II	Vila Belém
Occupation time (years)	< 9 years	between 10 and 19	> 20 years
Access for locomotion	by road	by road	by road or Tocantins River
Forest area	> 60%	> 50%	< de 40%
Pasture area	< 40%	> 50%	> de 60%
Importance of vegetal and animal extractivism	High	Low	Very low
Frequency of annual crops	Annually	Annually	Sporadically

A structured questionnaire was applied to each of the nine agroecosystems using both a qualitative and quantitative research approach, based on the MESMIS tool. The questionnaires were answered by the owners of the agroecosystems; the questions sought to obtain information on 33 indicators (Table 2). The indicators used were previously defined for this region, assuming the same perceptions of the diversity of agroecosystems as stated by Silva (2016). In addition to the occupation time, another 32 qualitative indicators were considered: 8 from the environmental dimension, 12 from the social dimension, and 12 from the economic dimension. All indicators were divided into three categories that represent the degree of sustainability: highest (A), medium (B), and lowest (C) (Table 2).

Initially, the indicators were described through the percentage of agroecosystems that were found in each of the three categories. Then, a multiple correspondence analysis (MCA) was performed, with a matrix formed between the nine agroecosystems and the 29 remaining indicators. MCA is an ordination technique applied in situations where all variables are qualitative. This ordination summarizes information about the simultaneous presence of categories in the same agroecosystem through the variance explained between the groups, presented in percentage terms; this method is comparable to the principal component analysis (PCA), which is used for quantitative data (Renisio & Sinthon, 2014). In the MCA analysis, 29 indicators were used, since four indicators were removed (water scarcity, education services, rest and leisure, and diversity of credit lines available) because they did not contribute to explaining the differences between agroecosystems. The 29 indicators were tested independently through the Monte-Carlo test at a significance probability level of 5%. All analyses were performed on the R 3.4.2 platform (R Foundation for Statistical Computing, Vienna, AT, 2017), through the ade4, Factoextra, and FactoMineR packages.

Table 2. Description of sustainability indicators in the environmental, social, and economic dimensions applied to agroecosystems of the Praialta Piranheira Agroextractive Settlement Project, municipality of Nova Ipixuna, State of Pará, Brazil.

Tabela 2. Descrição dos indicadores de sustentabilidade nas dimensões Ambiental, social e econômica aplicados nos agroecossistemas do Projeto de Assentamento Agroextrativista, município de Nova Ipixuna, Estado do Pará, Brasil.

Sustainability Indicators	Categories (or sustainability degree)
Environment Dimension	
1 - Deforestation of natural vegetation (Deforestation)	A - 20% deforested or maintenance of fallow; B - 21 a 50%; C - > 50%.
2 - With pastures in deforested areas (Pasture)	A - < 10% of deforested areas; B -11 a 50%; C - > 50%.
3 - Species richness in agricultural crops (Richness)	A - > 2 species; B - up to 2 species; C - monocultures.
4 - Productive activities diversity (Prod. activities)	A - Cattle-raising + Raise small livestock (e.g. pigs and chicken) + Annual crops + Perennial crops + others B - Cattle-raising + Raise small livestock (e.g. pigs and chicken) + Annual crops C - Cattle-raising + Raise small livestock
5 – Frequency of use of chemical inputs (Chem. inputs)	A - Does not use chemical inputs B - Sporadic use of chemical inputs C - Frequent use of chemical inputs
6 - Frequency of use of organic inputs (Org. inputs)	A - Frequent use of organic inputs B - Sporadic use of organic inputs C - Does not use organic inputs
7 - Existence of visible erosion at farm (Erosion)	A - No sign of visible erosion B - Few signs of visible erosion C - Many signs of visible erosion
8 – Existence of water scarcity (Water scar)	A - No water scarcity B - Rare water scarcity

Sustainability Indicators	Categories (or sustainability degree)
	C - Frequent water scarcity
Social Dimension	
9 - Existence of Health Services (Health serv.)	A - There is a health program with visits by a medical team B - There is a health program with visits by health agents C - There is no health program or the health agent is not very active
10 - Basic sanitation services (San. serv.)	A – All services (Tap and treated water + lavatory + sewage system) B – There were only aseptic fossa and the use of hypochlorite in water for consumption C – No services
11 - Education services (Educ. serv.)	A - In the community there is a medium education school offer B - In the community there is a basic education school offer C - There are no basic schools in the community
12 - Family health condition (Fam. health)	A – Good: almost never gets sick (years without problems) or sick sometimes (mild illnesses 1 or 2 times a year) B – Reasonable: sick frequently (several times a year) C – Bad: has limitations and/or weaknesses (discomfort, with constant or permanent problems) or is unable
13 - Family educational situation (Fam. educ)	A – There is at least one person with a higher education level B – There is at least one person with medium education level C - Everyone has an incomplete basic level of education
14 - Participation in social organizations, such as unions, associations or other organized groups (Part. Org)	A - Active: Registered in at least one social organization and participates in meetings. B - Passive: Registered in at least one social organization but does not participate in meetings. C - None: No registration in a social organization.
15 - Active participation in social groups in order to make collective decisions (Coll. dec)	A - Always participates B - Rarely participates C - Never participates
16 - Frequency of effective dialogue with ATER - Technical Assistance and Rural Extension team (Dial.ATER)	A - Constant dialogue B - Sporadic dialogue C – No dialogue
17 - Frequency of hiring labor (in addition to family members) (Hire.lab)	A – Never hires labor B – Rarely hires labor C – Always hires labor
18 - Frequency of selling labor to other agroecosystems (Sell.lab)	A – Never sells labor B – Rarely sells labor C – Always sells labor
19 – Family members enjoy rest and leisure (Rest leis)	A - On vacation and weekends B - Only on weekends C - Never enjoys rest and leisure
20 - Ability to cover domestic demand (Domest dem)	A – High B - Medium C – Low
Economic Dimension	
21- Per capita family income (Inc. perCap)	A - > 0.75 Minimum wage monthly B – 0.75-0.5 Minimum wage monthly C - < 0.5 Minimum wage monthly
22 - Importance of productive activities, in the farmer's view (Imp.prod.act)	A - > 80% B - between 75 and 50% C - < 50%
23 - Importance of the sale of labor, in the farmer's view (Imp.sale lab)	A - Not important B - between 10 and 50% C - > 50%

Sustainability Indicators	Categories (or sustainability degree)
24 - Greatness of family property (Great.fam prop)	A - Farm that contains the required infrastructure (fences + corral), and with a production system that generates profit. B - Farm with intermediate infrastructure (fences + corral + production system), however, it needs maintenance or expansion. C - Farm without infrastructure and production system.
25 - Debt existence (Debt)	A - No debt B - Debt with PRONAF (National Program for Strengthening of Family Farming, a federal government program) C - Other debts beyond PRONAF
26 - Gain on family assets. If there was an improvement in the farm's infrastructure, such as: fence construction, construction of cattle corral, pasture cleaning, bought new cattle (Gain.assets)	A – High B - Medium C – Low
27 – Loss on family assets. If there was a loss of farm infrastructure, such as: broken fence, fire, disease (Loss.assets)	A - None B - Low C – High
28 - Expansion possibilities. There is infrastructure, hand labor, expertise, technology, and financial resources to expand activities (Exp.possib)	A - Yes, Possibilities for > 3 activities B - Yes, Possibilities for 2-3 activities C - No possibility of expansion
29 - Dependence on external inputs (Dep.ext.inp)	A - None B - Partial C –Total
30 - Diversity of available credit lines (Avail. credit)	A – High (> 2 available credit lines) B – Low (1 available credit line) C – No available credit line
31 - Current diversification of the production system (Diver.Syst.Prod)	A - > 3 activities B - 2 or 3 activities C - 1 activity
32 - Desire to diversify production (Des.Div.Prod)	A - Thinks and acts on it B - Just thinks about it C - Does not think about it

3. Results and Discussion

All agroecosystems were classified in the same category for four of the indicators: the absence of water scarcity, the ability to enjoy rest and leisure on weekends, the availability of a basic education offer, and the low diversity of available credit lines (Figure 2).

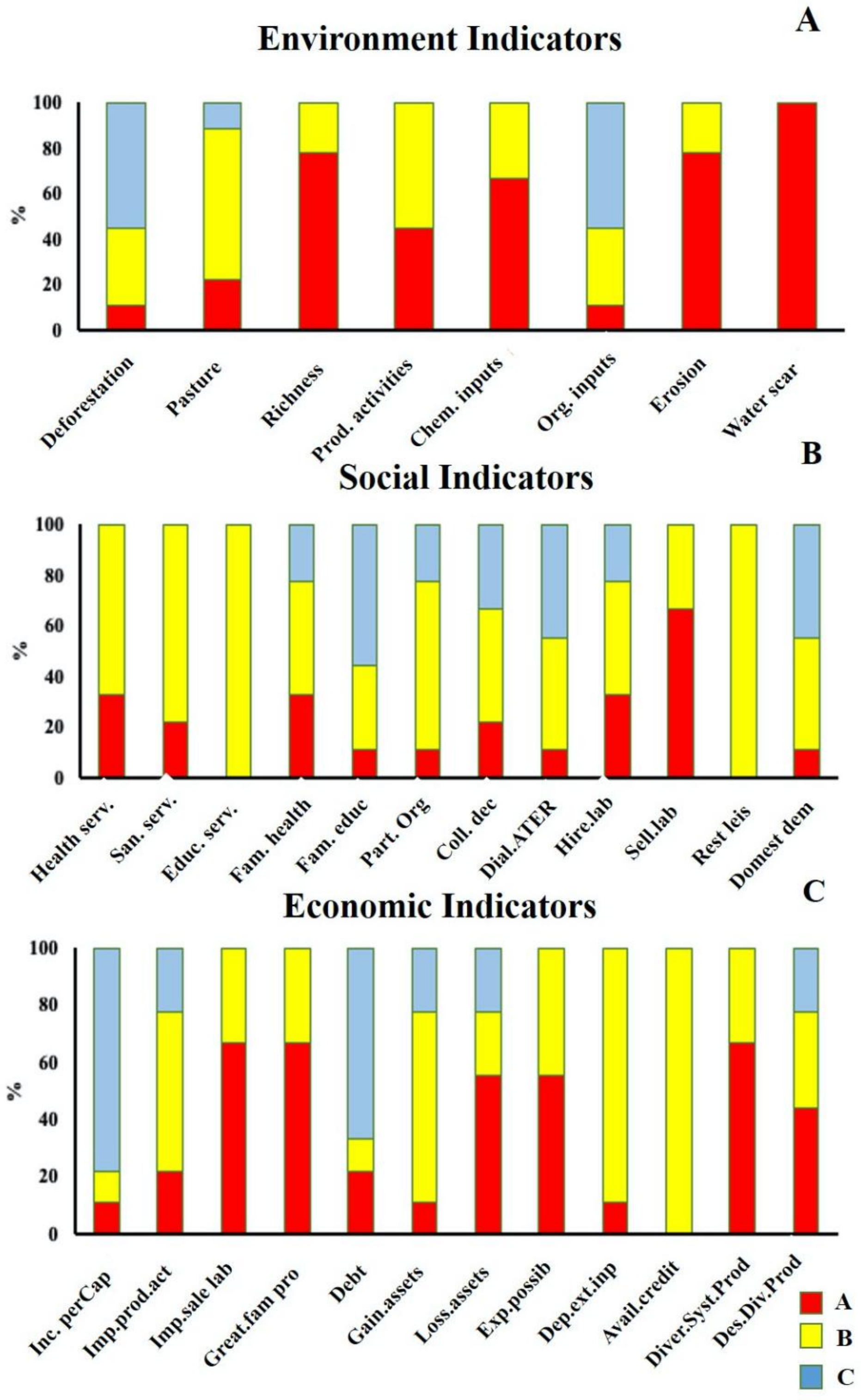
Most agroecosystems were characterized by more than 50% of deforested area; 11–50% of these deforested areas had been replaced by pasture. However, in most of the agroecosystems, the species richness in agricultural crops was greater than 2; the diversity of productive activities was median; there were no signs of visible erosion; and they did not use chemical or organic inputs (Figure 2A).

With regards to the social dimension of sustainability, in most agroecosystems, there is a health program with routine visits by health agents; sanitation consisted only of the aseptic fossa and the use of hypochlorite in water for consumption; everyone had incomplete basic education; residents were registered in at least one social organization but did not participate in the meetings; and labor is never sold to other agroecosystems. The other indicators of the social dimension were very heterogeneous among the three sustainability categories (Figure 2B).

With regards to the economic dimension, more than 50% of agroecosystems showed a per capita family income of < 0.5 of the monthly minimum wage; the farmer's viewed the importance of productive activities as median values, between 50 and 75%, and the importance of the sale of labor was viewed as null; most of the agroecosystems had complete infrastructure and production systems generating a profit; finally, there was no loss on family assets and the gain on family assets was medium; however, debts were high. Most of the agroecosystems also showed partial dependence on external inputs and high current diversification of the production system (Figure 2C).

Figure 2. Percentage of agroecosystems in each dimension: environmental (Figure A), social (Figure B) and economic indicators (Figure C). Dates from the structured questionnaire applied in nine agroecosystems in the Praialta Piranheira Agroextractive Settlement Project, municipality of Nova Ipixuna, State of Pará, Brazil. The indicators are divided into three categories that represent the degree of sustainability: highest (A, red), medium (B, green), and lowest (C, blue).

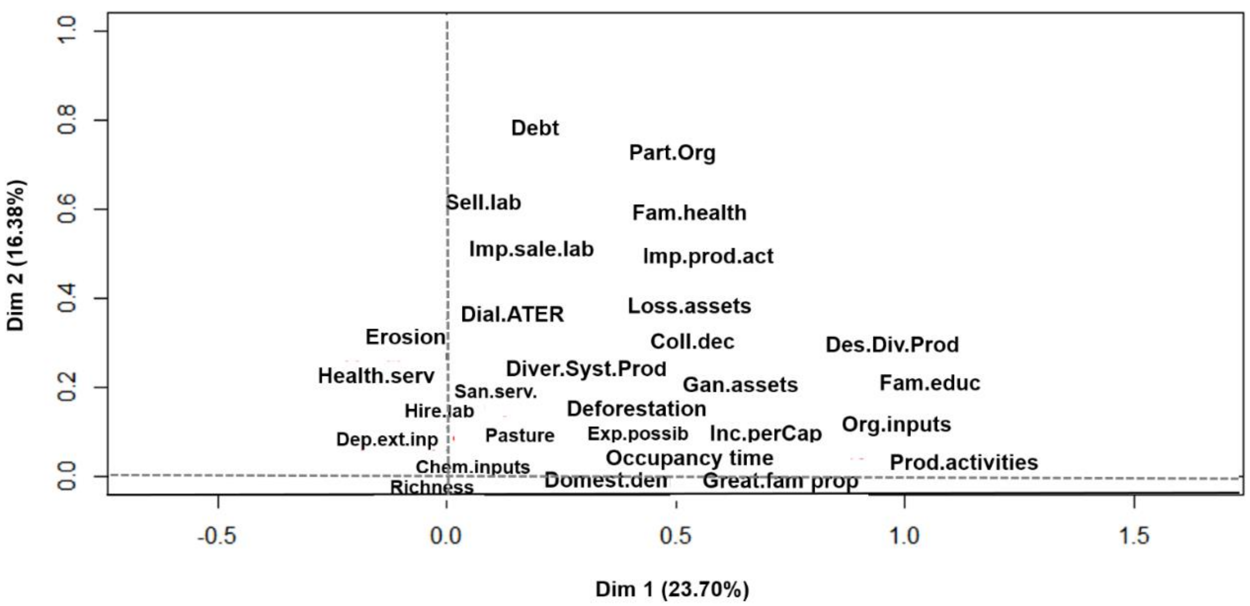
Figura 2. Porcentagem de agroecossistemas em cada dimensão: indicadores ambientais (Figura A), sociais (Figura B) e econômicos (Figura C). Dados originados dos questionários estruturados aplicados em nove agroecossistemas no Projeto de Assentamento Agroextrativista Praialta Piranheira, município de Nova Ipixuna, Estado do Pará, Brasil. Os indicadores foram divididos em três categorias que representam o grau de sustentabilidade: alto (A, vermelho), médio (B, verde) e baixo (C, azul).



The ordination of the indicators shown by the MCA reveals that the first two axes explain 40.1% of the variance in the data (axis 1 = 23.7%; axis 2 = 16.3%). Axis 1 received a high contribution from eight indicators (productive activities diversity, occupation time, per capita family income, frequency of the use of organic inputs, family educational situation, desire to diversify production, active participation in social groups, and loss on family assets); axis 2 received a high contribution from four indicators (frequency and importance of the sale of labor, family health condition, and debts); and both axes received a high contribution from two indicators (participation in social organizations and importance of productive activities) (Figure 3).

Figure 3. MCA ordination using a matrix of 29 sustainability indicators of the nine agroecosystems in the Praialta Piranheira Agroextractive Settlement Project, municipality of Nova Ipixuna, State of Pará, Brazil. Indicator acronyms are presented in Table 2.

Figura 3. Ordenação originária do MCA usando uma matrix de 29 indicadores de sustentabilidade de nove agroecossistemas no Projeto de Assentamento Agroextrativista Praialta Piranheira, município de Nova Ipixuna, Estado do Pará, Brasil. As siglas dos indicadores são apresentadas na Tabela 2.



When testing each indicator by the Monte-Carlo test, seven of them showed significant results (Table 3) comprising of two indicators from the environmental dimension (productive activities diversity and frequency of use of organic inputs), two from the social dimension (family educational situation and participation in social organizations), and three from the economic dimension (debt, importance of productive activities and desire to diversify production).

Table 3. Percentage of the explained variance between groups formed by Multiple Correspondence Analysis from the tested sustainability indicators.

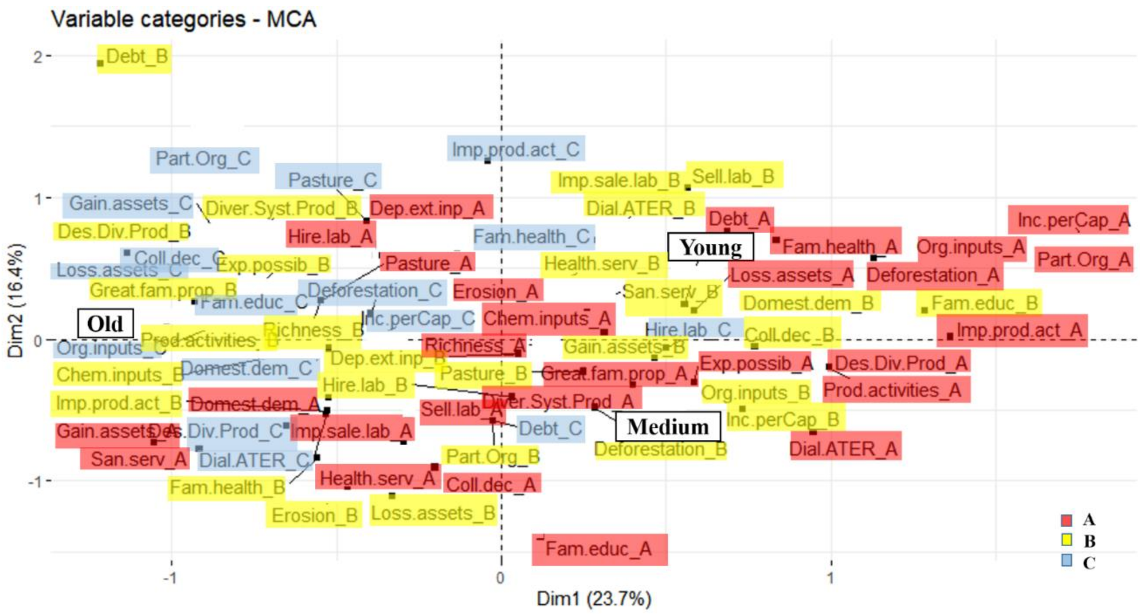
Tabela 3. Porcentagem de variância explicada entre os grupos formados pela Análise de Correspondência Múltipla a partir dos indicadores de sustentabilidade testados.

Sustainability Indicators	Explained variance between groups (%)	Probability value from the Monte Carlo test
Occupancy time	28.876	0.387
Deforestation of natural vegetation	23.044	0.980
With pastures in deforested areas	25.641	0.825
Species richness in agricultural crops	12.829	0.835
Productive activities diversity	21. 381	0.007
Frequency of use of chemical inputs	12.387	0.811
Frequency of use of organic inputs	33.587	0.030
Existence of visible erosion at farm	13.162	0.729
Existence of health services	13.347	0.664
Basic sanitation services	14.669	0.415
Family health condition	29.075	0.337
Family educational situation	35.425	0.025
Participation in social organizations	31.400	0.021
Active participation in social groups	29.690	0.086
Frequency of effective dialogue with technical assistance and rural extension team	26.583	0.653
Frequency of hiring labor	22.709	0.981
Frequency of selling labor	16.292	0.214
Ability to cover domestic demand	25.352	0.377
Per capita family income	28.653	0.462
Importance of productive activities	30.734	0.036
Importance of the sale of labor	16.292	0.067
Greatness of family property	15.788	0.096
Debt existence	29.806	0.043
Gain on family assets	26.851	0.681
Loss on family assets	29.315	0.327
Expansion possibilities	16.903	0.063
Dependence on external inputs	12.756	0.664
Current diversification of the production system	15.305	0.134
Desire to diversify production	32.248	0.014

The ordination of the indicator categories in the MCA shows that category A is evenly dispersed mainly in quadrants 1, 3 and 4; category B is fair in all quadrants; and category C is concentrated in the second quadrant, although it also has some indicators in the fourth quadrant (Figure 4). These categories are correlated with the time of occupation of the agroecosystem (old, medium, and young), where the youngest and medium agroecosystems are related to categories A and B of the first and fourth quadrant; and, finally, the older agroecosystems are related to categories B and C of the second quadrant (Figure 4).

Figure 4. MCA ordination using a matrix of three categories of 29 sustainability indicators of the nine agroecosystems in the Praialta Piranheira Agroextractive Settlement Project, municipality of Nova Ipixuna, State of Pará, Brazil. The categories represent the degree of sustainability: highest (A, red), medium (B, green), and lowest (C, gray). Indicators acronyms are as in Table 2.

Figura 4. Ordenação originária do MCA usando uma matrix de três categorias dos 29 indicadores de sustentabilidade aplicados em nove agroecossistemas no Projeto de Assentamento Agroextrativista Praialta Piranheira, município de Nova Ipixuna, Estado do Pará, Brasil. As categorias representam o grau de sustentabilidade: Alto (A, red), médio (B, green), and baixo (C, gray). As siglas dos indicadores são apresentadas na Tabela 2.



The seven best indicators clearly demonstrated the diversity of agroecosystems existing in the Praialta Piranheira Agroextractive Settlement Project (Table 3). These indicators can be characterized as key sustainability factors (Droulers et al., 2011) at the local level, as they have the potential to guide the implementation of more sustainable actions within the settlement, considering their specificities. Improved primary and high school education and production diversification were also pointed out as key indicators by other agroextractivists in the state of Pará (Folhes et al., 2015). As the indicators were used to evaluate different sustainability degree, it is necessary to conduct an evaluation of them in relation to the proposed objectives (Da Silva et al., 2020; Lopes & Vieira, 2021).

On the one hand, these indicators show the importance of integrating the environmental-social-economic dimensions between them, since all dimensions were similarly important. The integration of these dimensions reduces the linearity of the analysis and presents a more holistic assessment, as recommended by Quintero-Angel & González-Acevedo (2018). On the other hand, these indicators show the importance of national policies that are imposed on the macro scale, since many of these indicators are directly related to some of these policies. For example, the National Program for Strengthening Family Farming (PRONAF), which is the national policy to promote agricultural production, provides credit for specific production systems. Many families of the studied settlement access the financial resources of PRONAF, and consequently acquire debt. The debt itself is an indicator that hinders the sustainability of agroecosystems, however, if it were not for the contradiction of interests by farms between more diversified systems and the use of organic inputs, and by PRONAF with regards to the specific credit lines, it could also be considered as an investment (Silva, 2016). These results indicate how families experience the dichotomy between agrarian policies and the productive systems that interest them. This dichotomy does not offer mechanisms for agroecosystems to advance to higher levels of sustainability.

Another important macro policy is the National Education Program on Agrarian Reform; this program was responsible for the high and medium level of education in 11 and 33% of agroecosystems, respectively, and its absence influenced the remaining 55% of agroecosystems. Education is strongly linked to the emancipation and empowerment of families as a tool for social transformation (Valladares, 2021), which indicates the importance of maintaining this program within the settlement. In general, rural credit and education policies do not respect regional particularities, which is considered a major problem for regional development (Limonad, 2020). Sustainability indicators must be incorporated into the daily life and planning of people, managers, and organizations (Guimarães & Feichas, 2009), so it is important that they express the distinctiveness of each agroecosystem.

Not all indicators used in this study were effective at assessing the sustainability of agroecosystems, including the 4 indicators that incorporated all the agroecosystems into the same category and the 17 indicators that contributed little to the explanation of the MCA ordination. These indicators do not reflect the diversity of situations in the studied settlement. However, such indicators can be useful if applied as comparative indicators, when considering areas in different social, economic, political, and environmental contexts and under different management regimes, for example, comparing different settlements in the Amazon region. Macro regional contexts influence sustainability and directly affect micro levels (Droulers et al., 2011), as demonstrated by the agroecosystems analyzed here. By recognizing the interdependencies, such as trade-offs and synergies, between the sustainability strategies at various levels of governance, a more coherent strategic design can be proposed (Heitmann et al., 2019). A regional, multi-scale, transdisciplinary framework highlighting horizontal connections across normative orientations, scientific evidence, and solutions for sustainability coupled with iterative feedback across scales that links regional-scale interventions to those at local scale, was highlighted as a solution by Shakya et al. (2020).

The sustainability of the studied agroecosystems was directly related to the occupation time, with the oldest agroecosystems linked to the medium (B) or low sustainability (C) categories and the younger agroecosystems linked to the high sustainability category (A). The occupation time is a natural factor for differentiating agroecosystems, since the basic elements of an agroecosystem, such as family lifecycles, vegetal cover, land use dynamics, and environmental biodiversity all change over time (Silva, 2016). Therefore, it is inseparable from any considered biological, social, or economic process.

The oldest agroecosystems were influenced by the occupation policy of the Amazon region based on the development of great regional projects (Limonad, 2020); the consequence of these projects was a high rate of deforestation of native vegetation to install pastures for livestock (Yanai et al., 2020). The introduction of Brazilian Good Agricultural Practices can be provided economic, social and environmental gains (Mandarino et al., 2019). Sustainable livestock may be possible with a high mean annual investment and on farms with more than 400 hectares of pastureland; in these cases, pastures have the potential to prevent further deforestation in the Amazon, as shown by the study by Garcia et al. (2017) located in São Felix do Xingu, also in the state of Pará (Brazil). Even today, some national programs (e.g., PRONAF and More Food Program) act as a guideline to boost the growth of livestock in the region (Neves & Schmitz, 2018). However, there is still a lack of policies for renewing pastures to mitigate the emission of greenhouse gases (Eri et al., 2020). The absence of a holistic policy aimed at integrating environmental-social-economic sustainability may have influenced the sustainability of the oldest agroecosystems (Maynard, 2020).

The younger agroecosystems are inserted in a new context of socio-environmental discussion and agrarian policies. In 2002, INCRA (National Institute of Colonization and Agrarian Reform, an organ of the federal government responsible for Brazilian agrarian policies) enacted its environmental management plan, and in 2006, it created an area to address the environmental theme in its organizational structure (Dourojeanni, 2019). Also, the law that creates the Agroextractive Settlement Projects has more conservationist ideals, since it encourages the predominance of native forests. However, agroextractive workers live a dichotomy between environmental conservation and a productive model geared towards monoculture (Silva, 2016). This represents a game of apparent contradiction between social and environmental protection (Brondizio et al., 2021), which may explain the spread of category B (medium sustainability) in our data.

The sustainability of younger and medium agroecosystems can follow two paths: either the strategies of the older agroecosystems (low sustainability) or new agricultural production strategies, such as the diversification of production, which is a strategy that promotes sustainability (Brondizio et al., 2021). Strategies for strengthening and empowering family agroecosystems are already being implemented in the Amazon region, for example, home gardens and others agroforestry systems and the use of non-wood forest products. These methods steer communities toward higher levels of sustainability - not only in agroextractive settlements, but in all other settlements in the region.

4. Conclusion

It is possible to identify a sustainability gradient related to the time of occupation of the agroecosystems. At least two basic types of agroecosystems are opposed: those with a longer occupation time, which demonstrate low sustainability, and those with a shorter or intermediate occupation time, which still show the potential of following more sustainable paths.

The most effective indicators were those that clearly showed the diversity of situations in the settlement. Seven indicators deserve to be highlighted: productive activities diversity, frequency of organic input use, family educational situation, participation in social organizations, debt, importance of productive activities, and desire to diversify production. When determining a group of indicators with the greatest potential for correlation with the state of multidimensional sustainability, the methodology used in this study enabled the filtration of the indicators to consider only those that accurately translate the characteristics of sustainability among the studied agroecosystems. Although some indicators were not effective for evaluating agroecosystems at the local level, they have the potential to be used in comparative analysis between sets of agroecosystems with different characteristics, for example, submitted to different management plans or used for different public policies.

In this study, the diversification of production systems and activities within a system indicates a contradiction between the public policies available—specifically, the lines of credit that do not encourage diversification and the willingness to diversify from the agroextractive workers.

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