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Aggregate index of social–environmental sustainability to evaluate the social–environmental quality in a watershed in the Southern Amazon

Delmonte Roboredo[a,*], Sonia Maria Pessoa P. Bergamasco[b], Monica Elisa Bleich[a,1]

[a] Universidade do Estado de Mato Grosso, Brazil
[b] Universidade Estadual de Campinas, Brazil

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ABSTRACT

The purpose of this study was to build an aggregate index of social–environmental sustainability derived from incorporation of indicators of the quality of soil, water, and vegetation, and social organization and socioeconomic variables, in order to assess the overall social–environmental quality in a micro watershed in the Southern Amazon. From a population of 105 family production units 56 were randomly selected for evaluation of indicators of the quality of soil and water as well as for conducting interviews to evaluate the farmers' perception of soil, water, and vegetation quality and also of socioeconomic aspects of agroecosystems. The aggregate index built from social–environmental sustainability indicators shows that the selected indicators were adequate for describing social–environmental quality and confirms the hypothesis that the studied micro-watershed in the southern edge of the Amazon is in a state of collapse, and is socially and environmentally degraded.

1. Introduction

On the periphery of the Amazon Basin there are high deforestation rates (Trancoso et al., 2009; Rosa et al., 2013). The Tapajós Basin, in particular, has the highest percentage of total area loss in the Amazon (Trancoso et al., 2009). In the North of Mato Grosso, in the micro watershed of Taxidermista I River, in Alta Floresta-MT, the landscape was dominated by livestock, the area is dominated by small forest fragments disconnected from the riparian zone (Bleich and Silva, 2013).

Alta Floresta is an occupation front in the Southern Amazon, through the directed colonization project, conducted by Colonizadora Indeco S.A., initiated in 1978 on land acquired from the State of Mato Grosso (Rosa et al., 2013). The first farmers arrived in 1978 in response to the Colonizadora Indeco marketing campaign, which was extremely promising, because it urged the settlers from the central-west regions to pursue the construction of a dream (Guimarães Neto, 2002), and a new way of life, where families could achieve better quality of life, with government support through subsidized projects, getting a good economic return through the cultivation of perennial crops (cocoa, coffee and guarana) (Roboredo, 2014).

At first, the farmers obtained a good economic return because of the high prices paid for agricultural production, as well as the favorable edaphoclimatic conditions that contributed to the achievement of good yields. However, over the years agricultural activities have become economically unviable because of the decline in productivity caused by the gradual loss of natural soil fertility, soil compaction and the low price paid for agricultural products (Roboredo, 2014).

In an attempt to understand and monitor the process of degradation of natural resources, since 1990, the scientific community has discussed the physical and chemical properties of agroecosystems in an integrated manner to better understand them. Understanding agroecosystems is necessary for the maintenance of agricultural productivity and to minimize environmental problems caused by production processes derived from the green revolution (Casalinho et al., 2007; Vezzani and Mielniczuk, 2009). An alternative to facilitate the understanding of agroecosystems is the use of an index that incorporates the multidimensionality of the researched space, involving quantitative and/or qualitative variables, which are standardized and synthesized into a number which indicates the sustainability level of the territory studied (Sepúlveda, 2008; Astier et al., 2008). This index consists of sustainability indicators,

* Corresponding author. Tel.: +55 6635216904; fax: +55 6684032480.
E-mail addresses: roboredo@gmail.com (D. Roboredo), soniaberga@yahoo.com (S.M.P.P. Bergamasco), mebleich@yahoo.com.br (M.E. Bleich).
[1] Deceased author.

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which are essential tools in identifying problems and finding their solution, through the participation and perceptions of the people who live in the area researched (Guimarães and Feichas, 2009), and also by using indicators that are analyzed in laboratories (Karlen and Stott, 1994; Camargo and Alleoni, 1997; Iori et al., 2012).

The indicators show the state of health of the agroecosystem, meaning they reflect the *status quo* of the level of sustainability (or lack thereof) of the system. According to Doran and Parkin (1994), indicators used for monitoring production units must be sensitive to management methods and also be compatible with a timescale that is conducive to verification. In this respect, for evaluation of indicators of soil physical quality, Brandão (2006), recommend analysis of density, macro- and total porosity, and Camargo and Alleoni (1997), and Iori et al. (2012) suggest the addition of soil mechanical resistance to penetration (SMRP) as an important parameter for the measurement of compaction.

Evaluation of sustainability indicators for social, economic, and environmental aspects of agroecosystems have been used in case studies in diverse regions of the world (Astier et al., 2008; Speelman et al., 2007; Garcia et al., 2012; Humberto et al., 2012; Moldan et al., 2012; Yao et al., 2013). On the other hand, biological monitoring based on multimetric evaluation indexes of biological integrity is a powerful tool used to diagnose, prevent or reduce human-induced environmental impacts (Karr and Chu, 2000). A multimetric approach accounts for several aspects of ecosystem structure and function, making it robust and better suited than exclusively biological indexes (Barbour et al., 1996).

The indicators used in evaluating a given territory can be converted into an index by aggregating the indicators, summarizing the environmental framework of the area studied (Barrientos, 2006; Sepúlveda, 2008). The aggregate index used to evaluate sustainable development should be monitored in a given timescale to verify if the indicators improve, remain unchanged or worsen (Sepúlveda, 2008; Astier et al., 2008).

Thus, the hypothesis of this study is that micro-watersheds in the Southern Amazon are socially and environmentally degraded. Therefore, our objective was to build an aggregate index of social–environmental sustainability derived from incorporation of indicators of the quality of soil, water, vegetation, and socioeconomic variables, and social organization, in order to assess the overall social–environmental quality in a micro-watershed in Alta Floresta-MT.

2. Materials and methods

The study was conducted on the southern edge of the Southern Amazon basin, in the North of the State of Mato Grosso, in the Micro Watershed Mariana (MBM), located in the peri-urban area of Alta Floresta (latitude 9°52′0″ and 10°0′0″ S and longitude 56°9′0″ and 56°6′0″ W). The municipality has an area of 8976 km^2 and has 49,164 inhabitants, of which 86.9% live in urban areas and 13.1% in rural areas (IBGE, 2010).

The city is at 283 m above sea level, the climate is Köppen type Am, with two distinct seasons, rainy summers and dry winters, annual average temperature around 26 °C, and average annual rainfall is in the range of 2800–3100 mm (Alvares et al., 2014). The vegetation is open ombrophilous forest (IBGE, 2012).

From a population of 105 family production units in the MBM (Fig. 1), 56 were randomly selected for data collection for evaluation of indicators.

To establish the number of farmers surveyed we followed the methodology recommended by Tompkin (1967, p. 55) who states that "[. . .] when only the number of items in the population is important, the variance is not necessary." Thus, when the sample universe is less than 5000 individuals, the author recommended a sample of 50 subjects added 2% of the total population.

In each production unit soil and water samples were collected and semi-structured interviews with open and closed questions were conducted to evaluate the farmers' perception on soil, water, vegetation quality and also on socioeconomic aspects of agroecosystems. Data were collected from August 2011 to January 2012.

The 56 families interviewed, owners of rural properties acquired from Colonizadora Indeco S.A. and/or third parties, come predominantly from the central-west of the country: Bahia (1.8%), Mato Grosso do Sul (10.8%), São Paulo (12.5%), Paraná (60.7%), Minas Gerais (7.1%), and Mato Grosso (7.1%) (Roboredo, 2014).

2.1. Soil quality indicators

In each production unit soil samples were collected in depths of 0–20 cm and 20–40 cm following the method in Embrapa (1997), collected in permanent preservation areas (PPA) and surrounding areas (SRD). PPA sampling points were delimited 50 m from the highest point of the margins of rivers or streams, while SRD points were 100 m from the riverbanks. The soil analysis data used in this study are the product of the average of the two depths, except for organic matter due to its significant decrease with depth (Martins et al., 2006; Camargo et al., 2010).

Physical soil quality was evaluated through density, macroporosity, total porosity and soil mechanical resistance to penetration (SMRP). To determine density, macroporosity and total porosity we used 675 undisturbed samples, collected at 3 sample points in each depth for each production unit. In the macroporosity analysis we used a voltage table at a voltage of 6 kPa. SMRP was evaluated in three different points in the two areas (PPA and SRD), and in each production unit, up to a depth of 40 cm, using an impact penetrometer with a narrow tip with an area of 1.29 cm^2, as in the methodology of Stolf (1991).

We also evaluated the presence or absence of gravel that prevented the collection of undisturbed samples for physical attributes and the texture quality in the existing texture classes in the productive units (Resende et al., 2002).

Soil chemical analysis was done following the protocol in Embrapa (1997), pH, organic matter, potassium, base saturation and CEC at pH 7.0 were evaluated for 222 samples to represent soil fertility (Ronquim, 2010).

2.2. Water quality indicators

For the streams and rivers in each production unit we evaluated dissolved oxygen, pH, ammonia, total phosphate, algal biomass and farmers' perception on water quality of streams and rivers. Both pH and the dissolved oxygen concentration were measured using portable meters, Hanna Instruments, model HI 8424, HI 9147-04, respectively. The concentration of ammonia (NH_3^-) and phosphate (PO_4^-) was determined according to the techniques described in APHA (1998) and the nutrient concentration was measured using a spectrophotometer Quimis model Q798U2M.

The algal biomass (μg/L) was determined by chlorophyll *a* extraction with 90% ethanol heated at 78 °C and concentration reading in a spectrophotometer according to Nush (1980). The analyses were performed at the limnology laboratory of the University of the State of Mato Grosso, in Alta Floresta.

The farmers' perception on water quality of rivers was evaluated through semi-structured interviews with open questions (Richardson et al., 1999).

2.3. Socioeconomic quality indicators

To evaluate the social–environmental quality we adopted the methodology defended by Sepúlveda (2008), which considers