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Research article

A fuzzy logic-based tool to assess beef cattle ranching sustainability in complex environmental systems

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ABSTRACT

One of the most relevant issues in discussion worldwide nowadays is the concept of sustainability. However, sustainability assessment is a difficult task due to the complexity of factors involved in the natural world added to the human interference. In order to assess the sustainability of beef ranching in complex and uncertain tropical environment systems this paper describes a decision support system based on fuzzy rule-approach, the Sustainable Pantanal Ranch (SPR). This tool was built by a set of measurements and indicators integrated by fuzzy logic to evaluate the attributes of the three dimensions of sustainability. Indicators and decision rules, as well as scenario evaluations, were obtained from workshops involving multi-disciplinary team of experts. A Fuzzy Rule-Based System (FRBS) was developed to each attribute, dimension and general index. The essential parts of the FRBS are the knowledge database, rules and the inference engine. The FuzzyGen and WebFuzzy tools were developed to support the FRBS and both showed efficiency and low cost for digital applications. The results of each attribute, dimension and index were presented as radar graphs, showing the individual value (0–10) of each indicator. In the validation process using the WebFuzzy, different combinations of indicators were made for each attribute index to show the corresponding output, and which confirm the feasibility and usability of the tool.
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1. Introduction

The issue of sustainability has been intensively debated worldwide over recent decades (Smith and Smithers, 1993; Heitschmidt et al., 1996; Van Passel et al., 2007) not only because environmental and social issues but also to obtain a market competitive advantage (Broom et al., 2013; Sabaghi et al., 2016). Sustainability can be defined as a multidimensional (ecological, economic, sociocultural) and multi-scale (micro, meso and macro) concept (Smith and Smithers, 1993). Although sustainability concept comprehend

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social, environmental and economic dimensions, in many cases its application is limited to the economic aspect.

Several tools have been developed to assess agriculture sustainability (Smith and McDonald, 1998; Rigby et al., 2001; Von Wirén-Lehr, 2001; Singh et al., 2009; Hayati et al., 2010; Lermontov et al., 2009). However, holistic approaches at the ranch level are still limited (Rao et al., 2000; Häni et al., 2007; Paracchini et al., 2015), mainly because they are difficult to implement in practice (Van Passel et al., 2007). Models and indicators will always be incomplete, but the important point is to begin and the task is to reduce uncertainty over time (Meadows, 1998).

The literature offers a number of approaches and tools to measure sustainability, most of them based on indicators (Rigby et al., 2001; Icaga, 2007; Lermontov et al., 2009; Singh et al., 2009; Calheiros et al., 2013), which are considered the most suitable methods (Smith and McDonald, 1998). Sustainability indicators analyze, quantify and simplify a set of data on complex systems, making the information accessible to all users and helping decision-makers gain a better understanding of complex and dynamic systems (Reed et al., 2009; Jia and Wang, 2009; Singh et al., 2009). Despite the availability of a long list of environmental, economic and social indicators, describing a combined list of indicators of each aspect of the system may not be enough. What is necessary are criteria for selection and aggregation, as well as site-specific indicators (Van Passel et al., 2007; Hayati et al., 2010; Lebacq et al., 2013). Additionally, the sustainability of a production system may depend on impacts resulting from the system itself and from factors external to it (Cornforth, 1999; Rigby et al., 2001).

Complex systems are not entirely predictable and their thresholds are difficult to determine. Thus, these systems require adaptive methodologies and continuous monitoring (Nelson et al., 2007). In this process, techniques that allow simple representation are crucial, and should be able to deal with imprecisely determined indicators and participatory approaches (López-Ridaura et al., 2002), as well as intelligent knowledge-based decision support systems (Sikder, 2009). Fuzzy logic offers a suitable method that is easy to implement and provides knowledge about complex environmental systems to decision makers (Babaei Semiromi et al., 2011; Chevrie and Guely, 1998). This approach was introduced by Zadeh (1965) may be described as an extension of classical set theory, where each object can assume a continuous degree of membership in a set, ranging from 0 (does not belong to the set) to 1 (belongs to the set), instead of a Boolean membership. This flexibility allows the management of complex concepts containing uncertainty or vague information, such as sustainability assessment attempts. Therefore, a reliable and flexible systemic approach that combines multidimensional aspects and assesses uncertainly would be ideal (Phillis and Andriantiatsaholiniaina, 2001).

This paper reports the development of the Sustainable Pantanal Ranch (SPR) to evaluate the sustainability of beef cattle ranching in a large, complex and dynamic tropical wetland ecosystem. It describes the hierarchical structure of the SPR framework with the definition of principles, criteria, indicators and reference values according to environmental, economic and social dimensions, and presents the fuzzy logic approach and its application to design and develop a decision support system, which may be applicable to other similar ecosystems.

2. Material and methods

2.1. Site description

The decision support system (SPR) was developed for the Pantanal wetland, located in western Brazil, from which 80% (140,000 km^2) is in Brazil and the remaining area is shared by Bolivia and Paraguay. The Pantanal is a large Neotropical floodplain located in the upper Paraguay River basin; most of it is seasonally inundated by local rainfall and river overflow. The temporal and spatial variability of its inundated areas generates an extensive aquatic-terrestrial transition zone whose biodiversity is controlled by the flood pulse (Junk et al., 1989; Neiff, 2000). The region is a complex, dynamic tropical rangeland with a variety of vegetation types composing an intricate mosaic landscape containing forests, open savanna woodlands, arboreal-grassy savannas, open non-floodable grasslands, floodable grasslands, permanent and seasonal ponds, draining canals, and swampy lowlands. The region is well known due to its rich biodiversity and abundant wildlife, holding vigorous populations of several endangered species (e.g., Mourão et al., 2000; Tubelis and Tomas, 2003; Harris et al., 2005; Tomás et al., 2010; Nunes, 2011; Cavalcanti et al., 2012; Tomas et al., 2015). Extensive cattle ranching was established in the Pantanal more than 200 years ago owing to the presence of abundant natural pastureland, and it became the most important economic activity in the region. Presently, there is a trend towards the intensification of the ranching practices, including the replacement of native vegetation by cultivated, African grass species. This interference in the natural landscape often includes deforestation, which may jeopardize the biodiversity and ecosystem functioning in the region (Harris et al., 2005; Santos et al., 2011).

2.2. Definition of principles, attributes, indicators and reference values

The following assumptions and principles were considered in the SPR development:

- Ranch design and its sustainable management in the Pantanal wetland is complex, thus requiring a multidisciplinary and holistic approach.
- Ranch evaluations require the use of a combination of quantitative indicators and qualitative assessments.
- A reduced set of indicators should represent the overall aspects implicated on sustainability assessment, considering that it is virtually impossible to understand, incorporate and evaluate all aspects relevant to ecological processes, biodiversity maintenance, social issues, and economic and cultural dimensions, to cite a few.
- The set of indicators should avoid the need of scientific personnel in the field, and adopt measurements that are both low-cost and easy to apply by non-scientific auditors while maintaining its conformity with the aspects under evaluation (for example, biodiversity or ecological processes).
- Evaluation can increase the contact of decision-makers with scientific information, thereby improving the quality of policy making in the context of conservation of the Pantanal wetland.
- This tool must be dynamic, and its development process must be interactive and continuous, as advances in scientific knowledge may require the development of new indicators or improvement of the existing ones.

An interdisciplinary team constructed a hierarchical set of principles, attributes and indicators (Fig. 1). Delphi technique was adopted with a panel expert using questions with iterative feedback in order to assess a list of pre-defined indicators surveyed from literature and research results (Santos et al., 2008; Bélange et al., 2012). This methodology involved online consultations and several meetings among experts, considering the inputs of authors such as Rigby et al. (2001) and Van Cauwenbergh et al. (2007). Relevant and specific attributes pertaining to sustainable beef cattle ranching practices and economics in the Pantanal were taken into

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