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GIS-fuzzy logic approach for building indices: regional feasibility and natural potential of ranching in tropical wetland

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A B S T R A C T

The regional feasibility of ranching (RFR) index was obtained in order to evaluate the productive potential of farms in the Pantanal. Five indicators were selected by expert and employed for the developing of the index. One of the five indicators corresponded to the natural potential for livestock ranching (NPLR) index which was generated by GIS-fuzzy logic. Fuzzy inference process, involving definitions of membership functions, fuzzy set operations and inference rules was implemented and validated with the participation of primary stakeholders. Different scenarios were simulated in a batch, next validated and adjusted with the participation of stakeholders. Both procedures were performed by the use of the Webfuzzy software. The NPLR and RFR index values, calculated for the pilot ranch, corresponded to the expectations of both expert and stakeholders. Fuzzy logic combined with landscape metric seems to be suitable for the definition of the productive natural potential of ranches to produce livestock in the Pantanal. The indices can assess the regional feasibility of ranching, contributing to decision-making of stakeholders.

1. Introduction

The Pantanal is a complex and dynamic tropical wetland. It is a seasonally flooded plain whose principal vegetation formations are arboreal, woody grass (savannas), open grasslands and aquatics, distributed in mosaic in the different landscape units (physiognomies) of the region such as forest, forested and arboreal savanna, open grasslands, dirty grasslands, permanent and temporary ponds, temporary canals and lowlands. Extensive livestock was established over 200 years ago in the Pantanal due to presence of abundant natural pasture areas (Santos et al., 2011).

Regardless to the characteristics of the individual regions, livestock is developed in almost all Pantanal (about 95%) whose traditional management (low effort practices and low inputs) contributed to the natural resources conservation. However, in recent decades, this activity is becoming less sustainable, mainly in areas with environmental and infrastructure restrictions. Not all regions have appropriate areas to livestock due to natural limitations such as intense flooding and low availability of permanent water bodies, and the situation may be aggravated by critical regional public infrastructure

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such as roads, electrical network, communication system, educational and health services. Depending on location, each farm comprise a unique set of ecological and infrastructure conditions which allows to develop a raising, breeding and/or fattening system (Abreu et al., 2010).

A sustainable farm in the Pantanal needs to attend environmental, economic and social domains, equilibrium among these domains and their interactions. Thus, the development of a tool to assess sustainability is necessary. In the literature, there is a number of sustainability assessment methods and tools based on indicators (Rigby et al., 2001; Icaga, 2007; Lermontov et al. 2009; Calheiros et al., 2013), being considered the most suitable methods (Smith and McDonald, 1998). Due to the complexity of the system, it is necessary to develop tools to evaluate and monitor the sustainability of different ecosystems of the region in a holistic manner (Santos et al., 2011). Like this, a combination of quantitative and qualitative indicators with GIS techniques and fuzzy logic which takes into account expertise (Chevrie and Guely, 1998) was built in this paper.

2. Materials and Methods

Several expert meetings were realized to identify the main aspects related to regional feasibility of ranching (RFR) in the Pantanal. The index for natural potential for livestock ranching (NPLR) was also built in advance using the same procedure. Four landscape indicators related to livestock production were selected by an expertise group (Table 1): forest cover proportion (FC), landscape productive value (LPV), diversity of types of water bodies (DAH) and flooding degree (FD). A core set of five indicators/indices were selected to evaluate the productive potential of farms in the Pantanal (Table 2): access to education (AE), energy and communication networks (ECN), access to ranch (AR), NPLR and access to health services housing (AHSH).

Table 1. Indicators and Fuzzy set defined to classify the natural potential of livestock ranches (NPLR) of the Pantanal wetland

Indicators	Thresholds
Forest cover proportion (FC)	Ideal - <0,3 Moderate – 0,3-0,6 Critical – 0,61-0,80 Poor – > 0,8
Landscape productive value (LPV)	Ideal – 0,41-0,70 Moderate – 0,2-0,4 Critical – 0,1-0,21 Poor - <0,10
Diversity of types of Aquatic habitats(DAH)	High – 3 Moderate - 2 Low - 1
Flooding degree/flooding extension (FD)	High -3 (>75%) Moderate – 2 (25-75%) Low -1 (<25%)

The application of this approach was illustrated through a pilot farm located in the Nhecolândia sub-region, Pantanal. Remote Sensing (RS) and Geographic Information System (GIS) technologies were used for mapping the farm's vegetation types and water bodies (landscapes types) of this farm. Images from Landsat 5-Thematic Mapper satellite from 2010 and 2011 were acquired from the INPE, the Brazilian Space Agency. Image from 2010 was chosen preferentially from the late dry season to avoid clouds and to obtain better visualization to estimate the three first indicators while image 011 was taken from late wet season to estimate the fourth indicator.

Table 2. Indicators and Fuzzy membership functions defined to classify regional feasibility of ranching in the Pantanal

Indicators/Index	Scores/thresholds	Description
Access to education (AE)	Good - 3	Possibility of daily displacement using appropriate ways of transport.
	Regular -2	Boarding regime (weekly or fortnightly) or concentrated in certain months.
	Poor – 1	The other criteria are not acceptable or regular presence of student is hampered by access.
Energy and communications networks (ECN)	Good - 3	Existence of a high-tension electrical wire and communication provided full time
	Regular -2	Electrical energy provided by generator distributed unevenly and communication provided full time
	Poor – 1	Problems with distribution and maintenance of energy and communication or absence in relation to a specific period or inexistence.
Access to ranch (AR)	Easy- 3	Continuous terrestrial access and well-maintained airstrip during all year.
	Reasonable – 2	Terrestrial and air access with certain difficulties, especially during the rainy season.
	Poor – 1	Terrestrial and air access interrupted during the rainy season or terrestrial access precarious.
Natural potential for livestock ranching (NPLR)	High - >9 Moderate – 5-9 Low- <5	
Access to health services Housing (AHSH)	Good- 3	Emergency service in less than 3 hours
	Regular -2	Emergency service between 3 and 6 hours
	Poor -1	Emergency service in more than 6 hours

Data analyses and image processing were carried out using the ERDAS software package. All images were rectified to UTM zone 21, WGS 84. Unsupervised classification was then used to map the vegetation units in ERDAS. 2010 Landsat image was separated in five classes (floodplain vegetation types): (1) forested savanna -FS; (2) arboreal savanna - AS; (3) grassland savanna - GS; (4) wetland – Wl, and (5) water bodies – Wb. Similar procedure was made with 2011 image but separated into two landscape classes: (1) dry areas, and (2) water areas (Santos et al., 2011). Classified images were then exported to ARCGIS version 9.0 (ESRI, Redlands, USA) and then metric composition of vegetation types were made and generated the following indicators: forest cover proportion (FC) that refers to proportion of forested savanna (%); landscape productive value (LPV) that refers to the ration between grazing preferred vegetation classes (Wetland +grassland savanna)/grazing less preferred vegetation class (arboreal savanna); diversity of types of Water bodies (DWB) were estimated by permanent water bodies number and distribution over the farm. The 2011 thematic map was used to estimate flooding extension that contributes to determine the indicator flooding degree (FD).

Fuzzy inference process

Fuzz logic represents intrinsically vague or linguistic knowledge (Zadeh, 1965) and offers a suitable method that is easy to implement and enables transfer knowledge of an environment complex for decision makers and general public (Chevrie and Guely, 1998; Babaei Semiromi et al., 2011). The process involved three steps: membership functions, fuzzy set operations and inference rules. Membership functions and thresholds for the different indicators are shown in the Table 1 for NPLR index and Table 2 for the RFR index. The trapezoidal functions at the interval ends, and triangular functions at intermediate portions of intervals were used as membership functions of these fuzzy sets. These linguistic terms and thresholds were validated in a participatory manner. An example of the NPLR and RFR indices and their respective fuzzy sets can be seen in the Figures 1 and 2, respectively. Two fuzzy models were developed, one to define the NPLR index with four indicators and another to define the RFR index with five indicators. For the selected set of four indicators from NPLR and five indicators from RFR, 144 and 243 inference rules were generated, respectively, in the Webfuzzy software (Lima et al., 2012). These rules base were evaluated and validated to reflect the knowledge of experts on the subject. Examples of rules for the NPLR index are as following: “If FD is high and DAH is high and LPV is ideal and FC is ideal, then index is moderate”; and for the RFR index: “IF AE is good and ECN is regular, and AR is poor and, NPLR is poor and AHSH is poor, then the index is poor. The RFR index was classified into three categories: high, moderated and low productive potential while the RFR final index was classified into three categories: good, regular and critical.

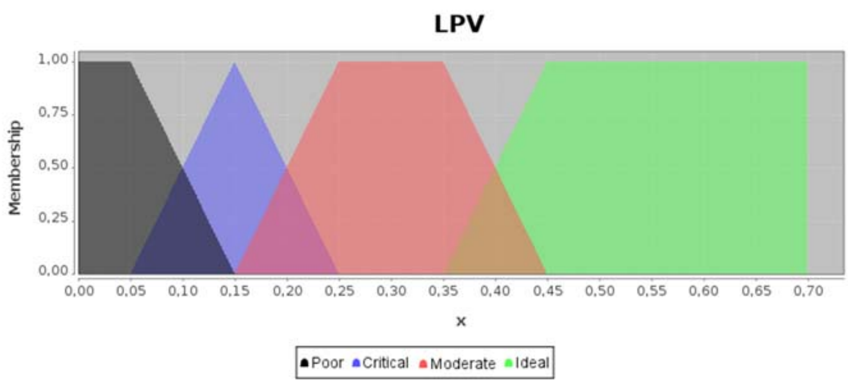

Figure 1. An example of the indicator LPV (Landscape productive value) and their respective fuzzy sets

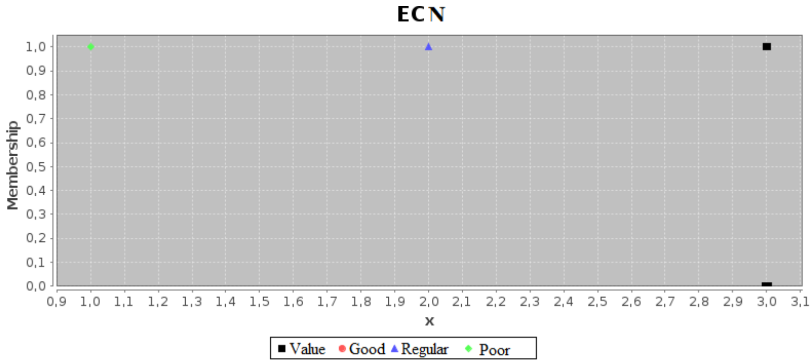

Figure 2. An example of the indicator ECN (Energy and communications networks) and their respective fuzzy sets

At the end of inference, the output fuzzy set is determined and defuzzified by center of gravity method (Chevrie and Guely, 1998). To perform the inferences and subsequent analysis, the software Webfuzzy were used (Lima et al., 2012). A simulation process in batch using the same software was accomplished, testing the output of model to several scenarios. For the social validation, criteria for assessing the indicators were defined and organized in 3 topics: conceptual coherence, operational coherence and utility indicator, where the responses of the stakeholders according to Cloquell-Ballester et al. (2006) were presented using Likert type scales (1 a 5) to assess the concordance degree. An importance ranking of each indicator was also evaluated.

Pilot Tests and simulations in batch were conducted using the Webfuzzy software and adjusts were made on fuzzy rules with the users. The calculated NPLR and RFR indices obtained with the Fuzzy model from simulation in batch were compared with the class of each indicator by Pearson correlation.

3. Results and Discussion

Figures 3 and 4 show the fuzzy output, named deffuzification using the center of gravity method to NPLR and RFR indices, respectively. The output of the NPLR model refers to Nhumirim farm that presented values of 0.3, 0.63, 2 and 1 to FC, LPV, DWB and FD input variables, respectively, using 144 rules. The output of the RFR model presented values 3; 3; 2; 9.06 and 1 to FC, LPV, DWB and AHSH, respectively, using 243 rules.

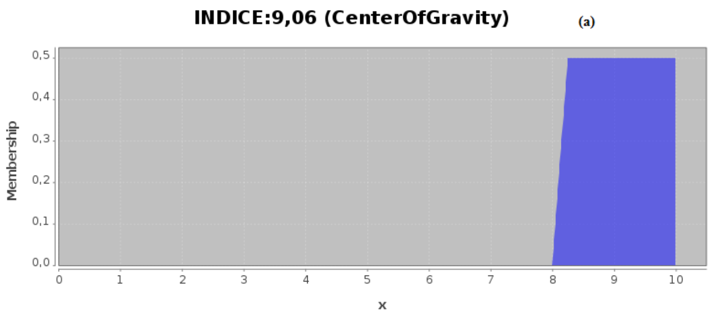

Figure 3. Center of gravity position of the output fuzzy set evaluate the NPLR (natural potential of livestock ranches) index to Nhumirim farm with values of 0.3, 0.63, 2 and 2 to AE, ECN, AR, NPLR and FD, respectively.

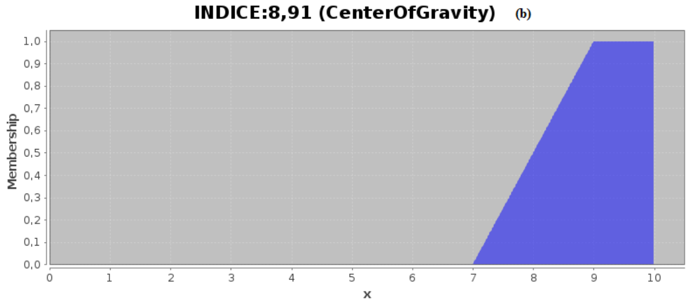

Figure 4. Center of gravity position of the output fuzzy set evaluate the RFR (regional feasibility of ranching) index to Nhumirim farm with values of 3; 3; 2; 9,06 and 1 to FC, LPV, DWB and AHSH, respectively.

For the NPLR index, correlation coefficients were high to forest cover (-0.76) and productive value (0.68) but low to diversity of types of aquatic habitats (0.20) and flooding degree (-0.28). Results from social validation presented mean score of concordance over 4, i.e., the end users agreed almost entirely with the NPLR's indicators. The most important indicator identified by the experts was productive value, followed by flooding degree, types of aquatic habitats and forest cover. With regard to RFL index, simulations in batch resulted in correlation coefficients higher for natural potential for livestock ranching (0.55) and access to ranch (0.51) whereas for others indicators, the values were lower: energy and communications networks (0.30), access to education (0.19) and access to health services housing (0.10). Social validation of the indicators that compound the RFR index also produced mean score of concordance over 4. Ranking of importance of the indicators in descendent order was: NPLR, AR, AE, ECN and AHSH.

The final results obtained on the pilot farm were presented in radar graph to NPLR index (Figure 5) and RFR index (Figure 6).

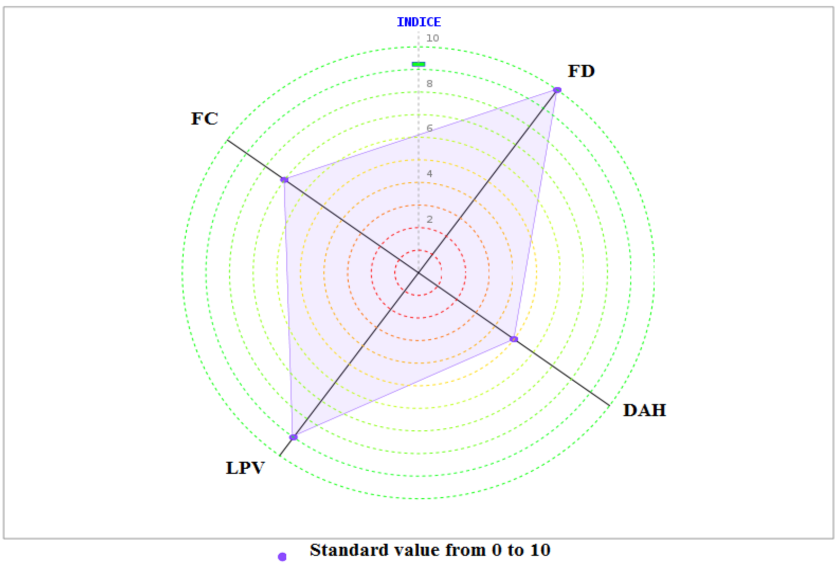

Figure 5. Livestock natural productive capacity indicators displayed in radar by the Webfuzzy software

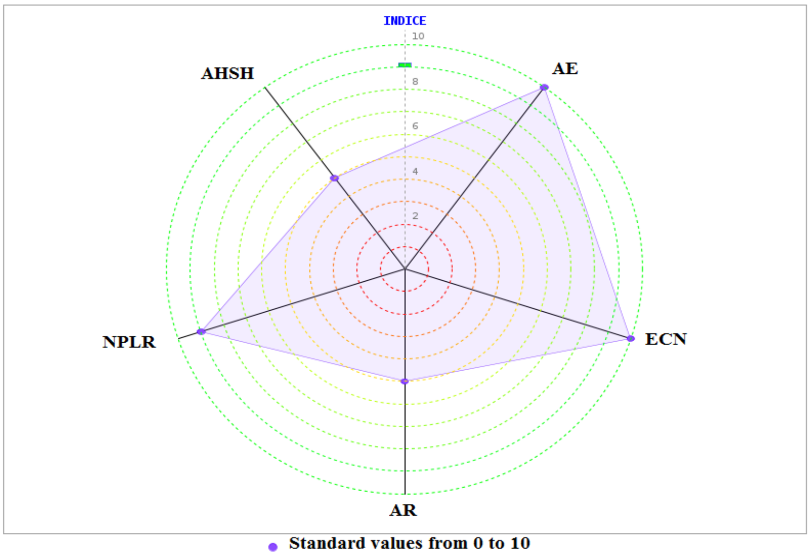

Figure 6. Regional feasibility of ranching indicators displayed in radar by the Webfuzzy software

There is a lack of available quantitative tools on the impact of structural policies in agriculture at a world level (Josling & Valdés, 2004). According to Santos et al. (2011), several factors have caused damage to economic situation of the ranchers and threaten the production systems and sustainability of the Pantanal. Among them, the lack of infrastructure and road, making the logistic and commercialization of beef cattle more expensive. The purpose of the indicators and indices built in this paper was to provide subsidies for policy analyses and decision makers to identify where the distortions are great and where the most important priority actions are needed to promote the sustainable regional development of livestock ranching in the Pantanal.

This study showed that the regional livestock suitability depend mainly on the access to ranch as well as natural potential for livestock ranching, a composite index was also built in a participatory way. Stakeholder involvement was very important in the choice and validation of relevant indicators and decision rules. However, goals and practices of the stakeholders should be consistent with the principles of sustainable development in an adaptive learning process that integrates bottom–up and top–down approaches (Reed et al., 2006). In this paper, the simulation in batch allowed the evaluation of different scenarios by expert opinion as well as enabled the establishment of targets and baselines avoiding conflicts of interest.

4. Conclusion

According to the results from the present study, remote sensing and GIS combined with fuzzy logic appear to be useful to assess both NPLR (natural potential of livestock ranches) and RFR (regional feasibility of ranching) indices. NPLR index is adequate to describe the beef cattle natural productive capacity in farm level, consisting in a diagnostic index for decision making. When used together with other indicators, it also contributes to build the RFR index in regional level. The RFR index can be used by local governments to plan policies and actions to address health, education and general infrastructure to promote the sustainable regional development. Participative processes in the development of rules are efficient and flexible because sustainability is a continuous process of learning that can be updated dynamically.

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