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Landscape dynamics of floodplain rangelands under different management units on a ranch in the Pantanal, Brazil

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Abstract. This paper provides a spatio-temporal analysis of landscapes types changes over a 24-years period (1988-2011) and examines how landscape metrics differ among management units on a livestock ranch of the Pantanal. For this study, three functionally independent management units (MU) with different management histories were selected: Unit A – Reserve area without grazing + occasional wildfires; Unit B- Grazing + fluvial flooding influence; Unit C- Continuous grazing. Landsat images, preferably from the late dry season were categorized into five landscapes classes over the period 1988–2011: (1) forested savanna (Sf); (2) arboreal savanna (Sa); (3) grassland savanna (Sg); (4) wetland (We) and (5) water bodies (Wb). Landscape metrics were analyzed using the software Fragstats. The change point detection for habitat proportions over time was fitted, and the log values for water bodies (Wb) showed a better fit, indicating a change in the proportion of water bodies around 2002, from 1988 to 2011. The years were classified as wetter (W) and drier (D), and variance analysis was performed to evaluate the effects of year (D and W), management unit (A, B, and C), and their interaction. The 15°year (2002) showed a notable change in the proportion of water bodies from 1988 to 2010. The years were classified in wet (W) and dry (D) and variance analysis was conducted to assess the effect of year (D and W), management unit (A, B and C) and interaction. There were differences between wetter and drier years, management units and their interaction for Wb, We, Sa and CS. All other metrics were influenced by the year and, to a large extent by the management unit. Therefore, decision-making for landscape management can be done adaptively based on climatic conditions.

Key-words: landscape ecology, spatio-temporal analysis, landscape change threshold

Resumo. Este artigo apresenta uma análise espaço-temporal das mudanças nos tipos de paisagem durante o período de 24 anos (1988-2011), utilizando métricas da paisagem em diferentes unidades de manejo em uma fazenda de gado de corte no Pantanal. Para este estudo foram selecionadas três unidades funcionalmente independentes com diferentes históricos de manejo: Unidade A – Reserva sem pastejo, com incêndios acidentais ocasionais; Unidade B - pastejo com influência de inundação fluvial; e Unidade C - pastejo contínuo. Imagens de Landsat obtidas preferencialmente no final da época seca foram classificadas em cinco classes de paisagem: (1) savana florestada (Sf); (2) savana arbórea (Sa); (3) campo limpo (Sg); (4) áreas úmidas (We) e (5) corpos d'água (Wb). As métricas de paisagem foram analisadas por meio do software Fragstat. Para avaliar a ocorrência de mudança abrupta entre as paisagens durante os anos detectou-se o ponto de mudança e o melhor ajuste foi obervado para Wb. O 15º ano (2002) mostrou uma mudança marcante em relação ao período de 1988 a 2011. Esses anos foram classificados como mais chuvosos (W) e mais secos (D), e uma análise de variância foi conduzida para avaliar o efeito de ano (W e D), unidade de manejo (A, B e C) e das interações. Observou-se diferença significativa entre anos, unidade de manejo e interações para Wb, We, As e CS. As demais métricas também foram influenciadas pelo ano, mas principalmente pela unidade de manejo. Portanto, as tomadas de decisão para manejo das paisagens podem ser feitas de maneira adaptativa, com base nas condições climáticas.

Palavras-chave: ecologia da paisagem, análise espaço-temporal, limiar de mudança da paisagem.

1. Introduction

The flood pulse (frequency and duration) that can occur by the rise of connected rivers and lakes or by rainwater Junk et al. (1989) drives floodplain rangelands of the Pantanal. These drives create topographic hydrological gradients across the floodplain, leading successional vegetation communities with plants species and other organisms adapted to the flooding transition zone Junk (1989); Capon, (2003). Colonization by some native shrub species naturally occurs along these gradients, with their dominance often considered encroachment by most managers. However, this dynamic can be natural, as the flood pulse, itself is not a disturbance Bayley, (1995). When associated with disturbances such as fire and grazing, these species can become invasive on open grassland (native pasture). Thus, natural floodplain ecosystems exhibit cyclic dynamic involving a shifting mosaic of vegetation types, explained by the "shifting mosaic" theory Bormann and Likens, (1979). This theory results from the long and short-term interactions of climate, floods, fire, grazing, and plant succession Fuhlendorf and Engle (2004); Whited, (2007).

Anthropic and natural disturbances can affect the floodplain ecosystem pattern and ecological processes Turner et al. (1993), creating landscape heterogeneity Dongjie et al. (2008), Hohensinner et al. (2010) as well as declines in biodiversity. Thus, the knowledge how landscape responded to different disturbances and the physical and biological constraints over time and space is crucial for managing the structure and function of ecosystem Fuhlendorf and Engle (2004) and for defining restoration strategies Suding et al., (2004). These changes in ecosystem can be gradual and continual or abrupt and catastrophic, commonly defined as bistability Rietkerk et al., (2004), Kéfi et al. (2007). Despite, disturbance could be managed to promote benefitial changes in landscapes for optimizing pasture productivity, recovering and conserving natural ecosystems Villagra et al., (2009); Mori, (2011), as well as to promote biodiversity and carbon sequestration Magnano et al., (2023).

2. Objective

To examine the composition and configuration of floodplain habitats (landscapes types) in different management units over time, in relation to disturbances and climatic conditions.

3. Material and Methods

Study area

This study was conducted on Nhumirim Ranch, located in the Nhecolândia sub-region, Pantanal, MS (lat. 19°04'S, long. 56 36'E; elevation 98m). The ranch features landscapes representative of the sub-region, characterized mainly by a rain-floodplain system with small areas affected by fluvial flooding, and a mosaic of physiognomic groups: wetlands, open grasslands, savanna shrublands, savanna woodlands, and semi-deciduous forests. The ranch was divided into management units ranging from 133 to 681 ha, with extensive livestock production under continuous stocking. For this study, three functionally independent management units (MU) with different management histories were selected: A unit - No grazing + occasional wildfires (681 ha); B unit- Grazing + fluvial flooding influence (133ha); C unit- Grazing (262 ha). The A unit is a Private Natural Heritage Reserve (RPPN), a private conservation area established in 1988, which has not had cattle presence since then. However, during this period, the RPPN experienced two major accidental fires (September 2002 and August 2005), while the B unit was affected by fluvial flooding during the 2005 and 2011.

Climatical data and standardized precipitation index (SPI)

Rainfall is unpredictable in both timing and amount in the Pantanal. Monthly precipitation data sets were available from the Nhumirim Ranch agrometeorological station from January 1977 through to December 2011. The standardized precipitation index (SPI), developed by McKee et al. (1993), based on the cumulative probability of a given rainfall event occurring at a station, was used. For each value, precipitation was transformed into the standard normal random variable Z, with a mean of zero and a variance of one, resulting in the SPI value. This index was used to estimate both dry and wet periods Seiler et al. (2002). SPI were calculated on scales of 9 months (rain, flood and ebb) from October to March for each month of the year (**Figure 1**) using the SPI package in R (version 2.9.2, R Development Core Team 2009).

Image set and processing

Landsat 5-Thematic Mapper satellite images from 1988 to 2011, acquired from the INPE, the Brazilian National Institute for Space Research, were processed. Images were chosen preferentially from the late dry season to avoid clouds and to obtain better visualization. Data preparation and image processing were carried out utilizing 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. Landsat images were separated into 50 initial classes, and five classes (floodplain vegetation types) were quantified for each the nine sets of images over the period 1988–2011: (1) forested savanna (Sf): areas dominated by woody vegetation, usually not flooded; (2) arboreal savanna (Sa): areas with varying proportions of herbaceous and woody vegetation; (3) grassland savanna (Sg): areas dominated by herbaceous vegetation, mainly grasses; (4) wetland (We): areas with vegetation that present a high humidity level; and (5) water bodies (Wb): all water bodies, including ponds, lowlands and channels. The accuracy assessment showed that the overall accuracy of the classified maps was approximately 94%, 93%, 91%, 91%, 94%, 88%, 86%, 90% and 90% for the 1988, 1991, 1994, 1997, 2000, 2003, 2006, 2009, 2011 images, respectively.

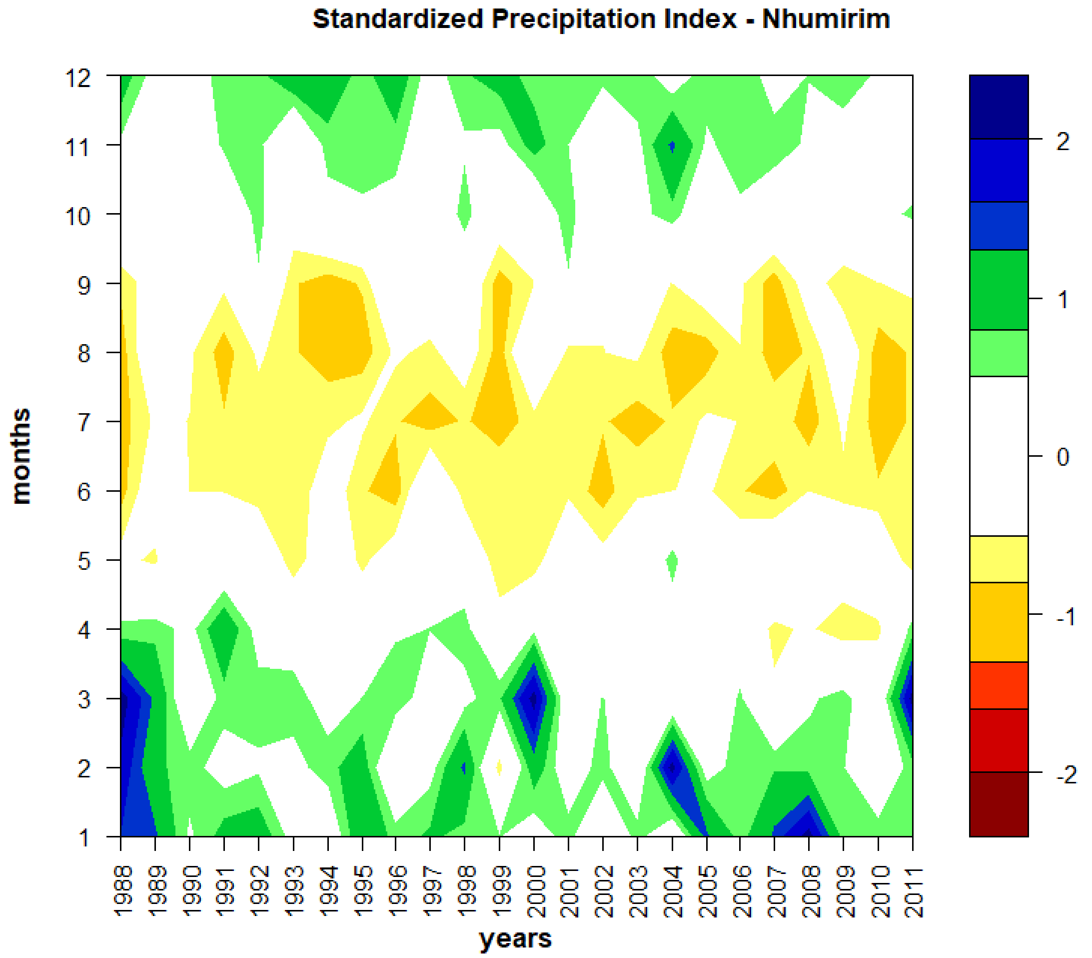

Figure 1. SPI (standardized precipitation index) values for Nhumirim ranch calculated from the 1977–2011 series for periods of 12 months. Legend: (+2 – extremely wet; 1.5 to 1.99 – moderately wet; 1.0 to 1.49 – moderately wet; -0.99 to .99 – near normal; -1.0 to -1.49 – moderately dry; -1.5 to -1.99 – severely dry; -2.0 and less – extremely dry.

Landscape patterns and metrics

The analysis was performed at the management unit level using the software Fragstats McGarigal et al., (2023), whose chosen variables are described in the **Table 1**. Landscape patterns were analysed on variations in composition (the amount and proportion of a given vegetation type) and configuration (the spatial arrangement of these types). A change point analysis was conducted to fit a piecewise-constant (step-function) relationship, involving two straight lines disconnected at the change point. The jumpoints function from the cumSeg package Muggeo, (2010) in the R program was used to identify the change point along in habitat proportions over time.

4. Results and Discussion

Step-function relationship for habitat proportions along the time was fitted and the log values of Wb (water bodies) had fit better (**Figure 2**), showing the separation among wetter years and drier years from 1988 to 2011.

Table 1. Description of the metrics of landscape.

Landscape metrics	Units	Description
Composition metrics		
Proportion (pi)	Values range between 0 a 100%	It refers to proportion of various vegetation cover types
Shannon-Weaver diversity index (SHDI)	Range between 0 and 1 (normalized)	Variability of the landscape related to the vegetation types and their area proportions.
Shannons's evenness index (SHEI)	Range between 0 and 1	It is the ratio between the actual SHDI and theoretical maximum SHEI
Configuration metrics (spatial arrangement)		
Patch density (PD)	Number/100ha	It expresses number of patches per unit area
Edge Density index (ED)	Meters per hectare	It provides information about the spatial arrangement with respect to special habitats (ecotones)
Area-weighted mean (AM)	hectares	It provides the area-weighted mean patch size of all the patches within each vegetation type
Contagion index (Co)	Values range between 0 a 100%	It specifies the degree of aggregation of the existing patches in the image
Lacunarity index (LI)	Values greater than zero -	It express retention of resources

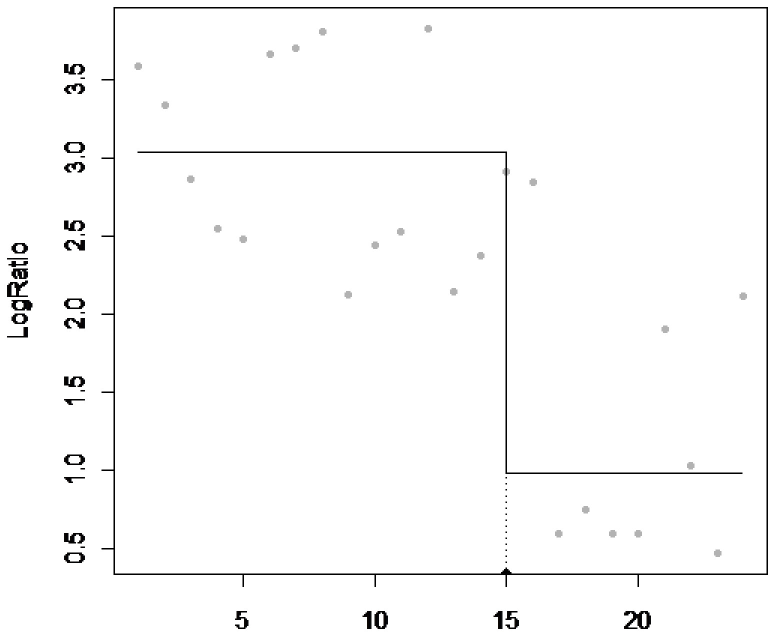

Figure 2. Point junction function showing the change in the 15°year (2002) in relation to water bodies proportion, from 1988 to 2011.

The years were classified as wetter (W) and driest (D) period according to **Figure 2**. To evaluate whether there were differences among the years, an analysis of variance was used to examine metric parameters, with Year (W and D periods) and Unit (management unit) as fixed factors and their interaction. **Table 2** presents a summary of the variance analysis, and in the **Figure 3** shows the means of landscape types proportion metrics in drier and wetter years for the three evaluated management units.

Table 2. F values for analysis of variance for types of vegetation proportion and landscape metrics.

Variation	F values (Types of landscape)							
Sources	Wb	We	Sg	Sa	Sf			
Year	46.9**	5.6*	0.8ns	35.1**	2.6ns			
Unit	11.4**	39.2**	119.2**	6.9**	632.0**			
Year x Unit	5.1**	11.9**	1.0ns	5.8**	0.08ns			
Variation	**F values (Landscape metrics)**							
Sources	C/S	PD	ED	Am	Co	SHDI	SHEI	LI
Year	18.5**	27.5**	1.6ns	19.8**	8.9**	37.2**	16.7**	1.98ns
Unit	9.1**	35.8**	41.4**	39.9**	33.8**	6.8**	19.3**	17.9**
Year x Unit	5.6**	3.0ns	5.5**	0.72ns	2.7ns	1.0ns	2.8ns	3.3*

** (P<0.01); * (P<0.05); ns (no significant)

Wb- water bodies; We – wetland; Sg- grassland savanna; Sa – arboreal savanna; Sf – forested savanna; C/S-ratio; PD- patch density; ED- edge density index; Am- area-weighted mean; Co- contagion index; SHDI-Shannon-Weaver diversity index; SHEI - Shannons's evenness index ; LI- Lacunarity index

Only the non-flooded landscapes (vegetation types) as Sg (grassland savanna) and Sa (arboreal savanna) did not vary between periods of wetter and drier years. There was significant variation among management units, particularly in the interaction between periods of years. **Figure 2** show the evaluated metrics concerning the year and management unit. As expected, water bodies were larger in wetter years; however, this increase was more pronounced in areas without cattle (unit A).

In the case of wetlands, they were maintained in units with cattle influenced by rain flooding (unit C), whereas in units with cattle and influenced by casual fluvial flooding (unit B) there was a marked reduction. According to Santos et al. (2020), these wetlands contain higher quality pastures, so in wetter years, theses pasture may not always be available in this type of landscape, despite the increase in open grassland areas, likely due to the clearing of fields by flooding. In unit A (without cattle), this landscape type was low, and there was no difference between wetter and drier years (**Table 2**; **Figure 3**).

The proportion of savanna areas (Sg) was significantly different between years and management units. This landscape is especially dominated by shrub species that invade open grasslands, with a sharp decline between wetter and drier years in the RPPN areas without cattle demonstrating the effect of climatic conditions on this dynamic of shrub encroachment,

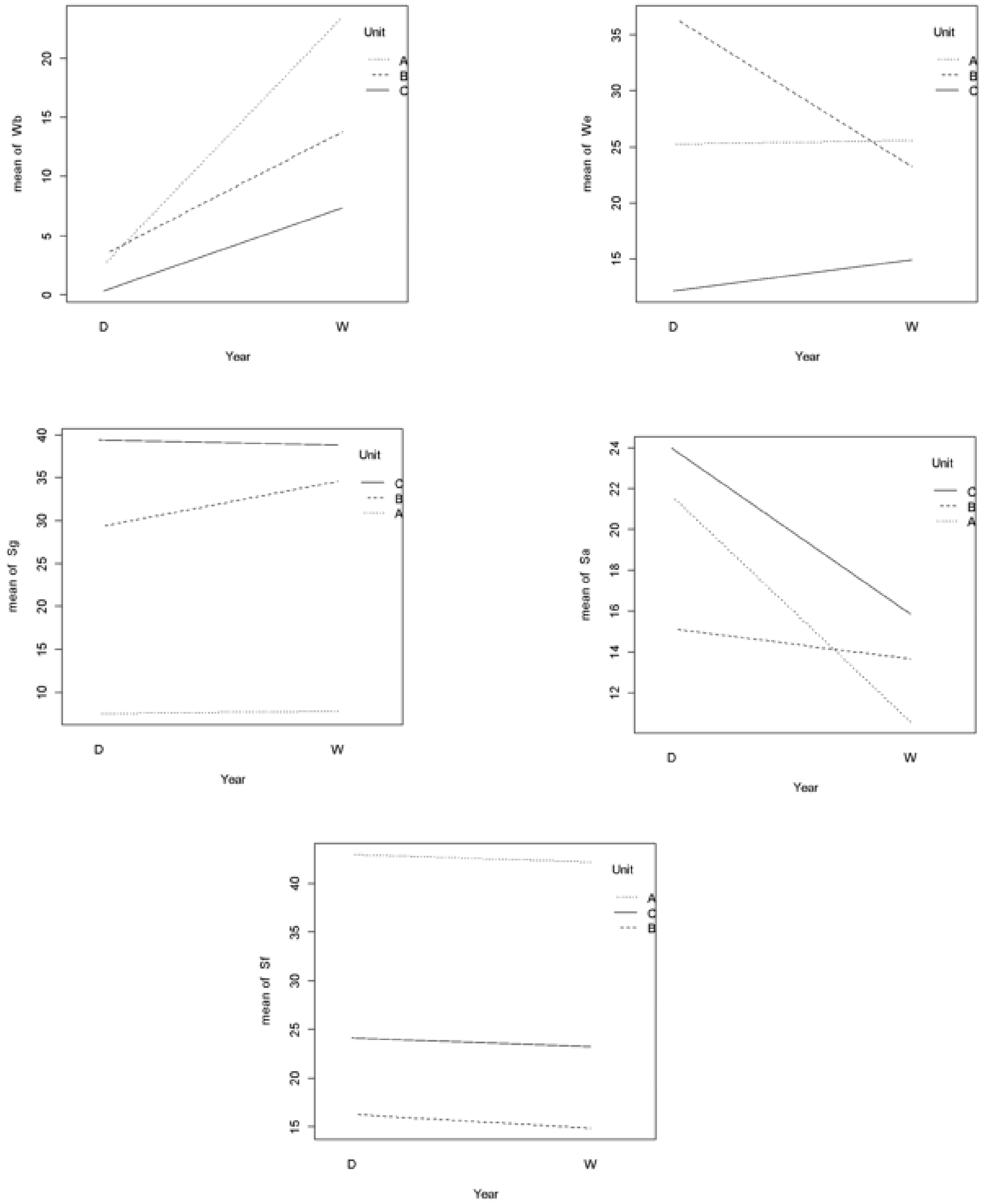

Figure 3. Composition metrics in relation drier (D) and wetter (W) year periods and management units (A unit - No grazing + accidental casual wild; B unit- grazing + fluvial flooding influence; C unit- grazing).

particularly canjiqueira (*Byrsonima orbigyiana*). In contrast, in grazing areas influenced by fluvial flooding (covering a large part the vegetation) in some years (unit B), there may be a lower amount of savanna shrubland (Sa) with minimal variation between years, unlike areas that experience only rainfall-induced flooding (unit C).

The means of the other metrics differed between drier years and wetter years; however, there were interactions in most of the metrics evaluated. The metrics CS ratio, PD, ED, Am, Co, SHDI, SHEI and LI varied significantly among years and units, but interaction between years and units were observed only for CS, ED and LI. The CS ratio means was higher in unit B, which experiences fluvial flooding in both drier and wetter years, while unit A had a lower CS ratio during drier years. PD was lower during drier years across all management units. For diversity, both SHDI and SHEI were slower during drier years; however, unit B showed a slight decline in SHEI. The grazing unit with flooding influence was more diverse.

Due to the complexity of landscapes (influenced by several drives), the responses vary among years, as indicated by significant interactions that need to be understood to define adaptive management. Ecosystem engineering, such as the effects of river flooding, seems to help recover landscapes. Cattle also act as ecosystem engineers, having both positive and negative effects. Grazing cattle reshape the landscape by increasing grazing areas with a dominance of herbaceous plants, such as savanna grasslands and wetlands. Flooding also contributes to this process. Areas without grazing have lower CS ratios during drier years. Grazing units showed more diversity; however, they had lower lacunarity indices, probably due to soil compaction caused by trampling. Cardoso et al. (2011) highlighted that soil compaction in the Pantanal is more associated with the grazing system than with the landscape type. They noted that three years without cattle were not sufficient to promote soil restructuring. The slower impact on unit B can be attributed to periodic fluvial flooding in the mains grazing areas, which contributes to recovery.

5. Conclusions

Management with cattle grazing, combined with flooding levels, influenced landscape proportions, particularly in arboreal savanna habitats and wetlands. Many shrub species in arboreal savannas and open grasslands are controlled by flooding levels, as are many forage species in wetland areas. Therefore, decision-making for landscape management can be done adaptively based on climatic conditions.

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