



SMALL WETLANDS IN THE BRAZILIAN SAVANNA (CERRADO): AN UNDERESTIMATED FRESHWATER RESOURCE

PEQUENAS ÁREAS ÚMIDAS NO CERRADO BRASILEIRO: UM RECURSO DE ÁGUA DOCE SUBESTIMADO

Stela Rosa Amaral Gonçalves¹

Cátia Nunes da Cunha²

Wolfgang Johannes Junk³

Abstract

In Brazil, in scientific research and public policy have largely ignored small wetlands, they are not specifically covered by current environmental laws and reference standards. Furthermore, the lack of information about, small wetlands has made their protection and management difficult. Large-scale land use changes that modify the hydrology of low-order streams often lead to the accelerated degradation and loss of small wetlands. The aim of this study conducted in Brazilian Cerrado Biome area, was to map the type, size, and distribution of small wetlands in ancachment area). Areas represented in 12 high-resolution multispectral images were individually classified in a geographic object-based image analysis (GEOBIA), resulting in a sensitivity or recall 0.872 (~87%). The 7,132 mapped wetlands had a total area of 163km², corresponding to a density of 4.27wetlands km⁻², with smallest wetlands smaller than 4.0 hectares (90.5%). The following descriptors were applied to map small wetlands: feature: asymmetry, rectangular fit, mean nir band, compactness, density, and length. Seven types of natural wetlands and four types of man-made wetlands were accordingly identified in the study area. Their classification within a system that follows the hierarchy of the Brazilian wetland classification system is proposed. Recommendations for the future study and protection of wetlands was are also provided.

Keywords: wetland classification, macrohabitat, brazilian savanna.

¹ Postgraduate Program in Education, Institute Federal of Mato Grosso/IFMT, goncalvessra@gmail.com.

² Federal University of Mato Grosso/UFMT, National Institute of Science and Technology in Wetlands/INAU, 2367 Fernando Corrêa da Costa Av, Cuiabá, MT, 78060-900, Brazil.

³ Federal University of Mato Grosso/UFMT, National Institute of Science and Technology in Wetlands/INAU, 2367 Fernando Corrêa da Costa Av, Cuiabá, MT, 78060-900, Brazil.

Resumo

No Brasil, a pesquisa científica e as políticas públicas têm ignorado amplamente as pequenas áreas úmidas, que não são especificamente amparadas pelas leis ambientais e padrões de referência atuais. Além disso, a falta de informação sobre as pequenas áreas úmidas dificultou a sua proteção e gestão. Mudanças em grande escala no uso da terra, que modificam a hidrologia dos cursos de água de baixa ordem contribuem frequentemente para a degradação acelerada e à perda de pequenas áreas úmidas. O objetivo deste estudo, realizado na área do Bioma Cerrado brasileiro, foi mapear o tipo, tamanho e distribuição de pequenas áreas úmidas em uma área de manancial. As áreas representadas em 12 imagens multiespectrais de alta resolução, foram classificadas individualmente em uma análise de imagem baseada em objetos geográficos (GEOBIA) resultando em uma sensibilidade ou recall de 0,872 (~87%). As 7.132 áreas úmidas mapeadas tinham uma área total de 163 km², correspondendo a uma densidade de 4,27 áreas úmidas/km⁻², sendo a maioria delas com dimensões inferiores a 4,0 hectares (90,5%). Os seguintes descritores foram aplicados para mapear as pequenas áreas úmidas: a assimetria, o ajuste retangular, a banda do infravermelho próximo (NIR), a média, a compacidade, a densidade e o comprimento. Sete tipos de áreas úmidas naturais e quatro de áreas úmidas artificiais foram identificados na área de estudo. Foi proposta uma classificação dentro de um sistema que segue a hierarquia do sistema brasileiro de classificação de áreas úmidas. São também fornecidas recomendações para o futuro estudo e proteção dessas áreas.

Palavras-chave: classificação de áreas úmidas, macrohabitat, savana brasileira.

1. INTRODUCTION

Wetlands are one of the most anthropogenically threatened ecosystems in the world despite the many services they provide to humans. In addition, they are colonized by plant and animal communities adapted to their specific environmental conditions (JUNK and WANTZEN, 2004; JUNK *et al.*, 1989) and offer food and resting places for visiting animal population. The many different hydrological processes that characterize wetlands account for their diversity throughout the world. In Brazil, with its large territorial extension, these processes together with the country's rainfall and temperature regimes give rise to a wide variety of large and small wetlands (ALVARES *et al.*, 2013; JUNK *et al.*, 2015).

Small wetlands are extremely valuable in retaining water in the landscape and serve as habitats for wetland organisms. However, they are also very sensitive to changes in climate and human land use (EULISS and MUSHET, 1996; CONLY and VAN DER KAMP, 2001; ZHANG *et al.*, 2011; SULLIVAN *et al.*, 2019; SALIMI *et al.*, 2021). The loss of small wetlands leads to the fragmentation of biodiversity among ecosystems and to population disruption, as described in amphibian species (SEMLITSCH *et al.*, 1996; BOZELLI *et al.*, 2018). Therefore, governmental and non-governmental organizations are becoming increasingly interested in the protection of these areas and, in turn their ecological services (COSTANZA *et al.*, 1997; SEMMLITSCH and BODIE, 1998; ACHARYA, 2000; KANDUS *et al.*, 2008; BOZELLI *et al.*, 2018).

Few studies have examined the geographic distribution of small wetlands and their interactions with other landscape units, but the inventory, assessment, and monitoring of wetlands are essential to support decision-making in their conservation and management. Detailed maps on the types, sizes and distribution of small wetlands are required, but the necessary data are not available.

The utility of remote-sensing techniques and Geographic Information Systems (GISs) in the elaboration of wetland inventories has been demonstrated in several publications, by the Ramsar Convention (DAVIDSON and FINLAYSON, 2007). Mapping has also been facilitated by images obtained from satellites and remotely piloted aircraft systems (DRONOVA, 2015; NUNES, 2017). The advantage of remote-sensing techniques in landscape studies is that they overcome both the difficulty of access and the risk of disturbing vulnerable habitats and species while capturing the high surface complexity arising from small-scale variations in topography, hydrology, and vegetation as well as landscape-level conditions at different scales (NUNES, 2017; PARANHOS-FILHO, *et al.*, 2016; PONZONI *et al.*, 2015; REBELO *et al.*, 2009).

In the detection of small wetlands, remote-sensing techniques must take into account: (1) the small size of these areas, which determines the scale and type of sensor, the resolution required for their mapping, and therefore the need for high spatial resolution images, aerial photographs or unmanned aerial vehicle images (GONÇALVES, *et al.*, 2019; NUNES, 2017; SECRETARÍA DE LA CONVENCION DE RAMSAR, 2010), and (2) the spectral confusion inherent in their composition (OZESMI and BAUER, 2002), given that, depending on the season (rainy or dry), the amount of water, the degree of soil saturation, and the vegetation will vary. Integration of Geographic Object-Based Image Analysis (GEOBIA) with high-resolution imaging allows mapping at different scales, discrimination of the color, geometry, position, and texture of landscape units, and a reduction of the noise level, thus improving the accuracy of the landscape characterization (BLASCHKE, 2010; KIM *et al.*, 2011; DRONOVA 2015). In fact, GEOBIA has been used successfully in the last 30 years to map wetlands (KUCHARCZYK *et al.*, 2020).

In GEOBIA, objects are created by a segmentation process and represent “primitive” elements (BLASCHKE *et al.*, 2014; DRONOVA, 2015). Over the years, improvements have been made in segmentation and merging, feature extraction, feature space reduction, image-object classification, and accuracy assessment. The advantages of GEOBIA include the application of its attributes to discriminate the color, geometry, position, texture, and context of targets on the Earth's surface, the ability to integrate remote sensing data from multiple sources or remote sensing and GIS data, the reduction of “salt and pepper noise” and an improved classification accuracy (KIM *et al.*, 2011; DRONOVA, 2015; GUO *et al.*, 2017).

The aim of the present study was to: (1) determine the spatialization and distribution of small wetlands, (2) describe and classify their types according to the Brazilian classification system and (3) formulate recommendations for the sustainable management and protection of small wetlands.

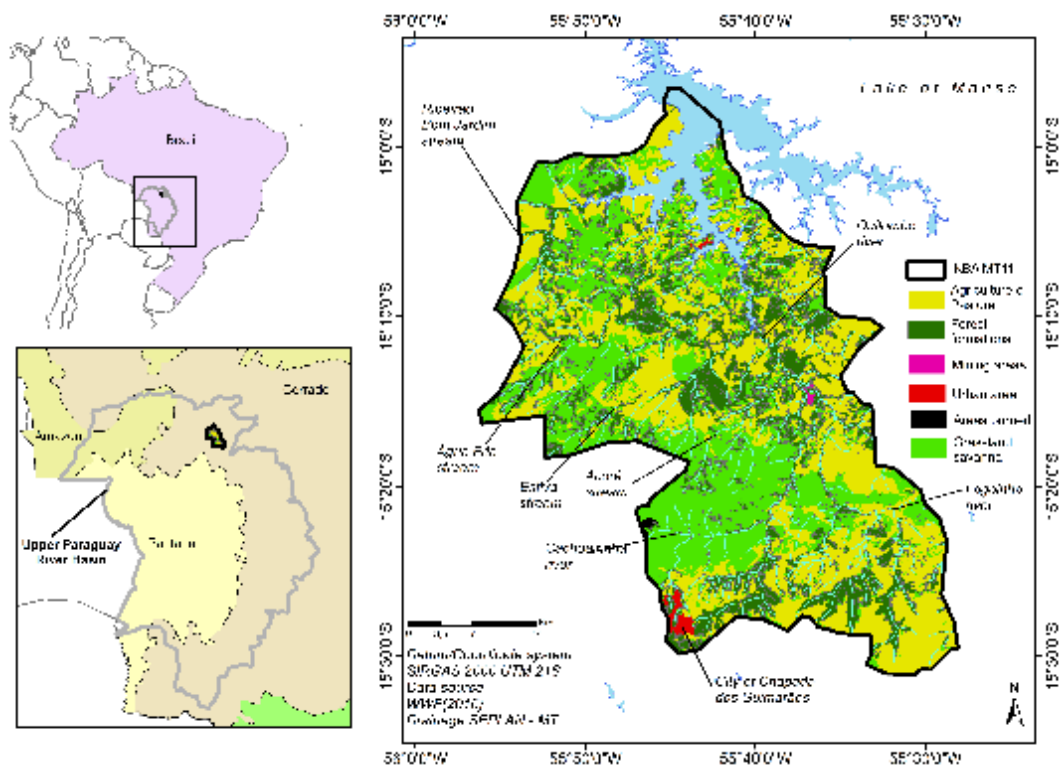
2. DATA ACQUISITION AND METHODOLOGY

Wetlands were identified and classified in two steps: (1) mapping using high-resolution satellite images and GEOBIA and (2) description of the different wetland types according to the field data.

2.1 Study Area

The study was conducted in the catchment of the Quilombo River, and specifically in Key Biodiversity Areas (KBA) MT11 (Fig. 1), as defined in the Biodiversity Hotspot Ecosystem Profile of the Cerrado (SAWYER *et al.*, 2017). at the border of the Upper Paraguay River Basin and the Pantanal, one of the largest freshwater wetlands of the world (DA SILVA and DE MOURA ABDON, 1998). According to the World Wildlife Fund's map of land use and vegetation for KBA MT11 (2016), 36% of the study area is used for agriculture and cattle ranching, 34% is covered by savanna grasslands, and 25% consists of different forest formations.

Fig.1 - Study site MT11, located within Key Biodiversity Areas of southern Mato Grosso, Brazil (adapted from WWF 2016)



The Quilombo River, one of its major tributaries, crosses the KBA from north to south and receives water from a dense network of tributaries (Fig. 1). The Cuiabá River, a major tributary of the Pantanal wetland, drains the The Manso Hydroelectric Reservoir. According to the Köppen classification, the climate of region is type Aw, with mostly dry winters and rainy summers (SILVA *et al.*, 2008). The mean annual rainfall, determined during the last 60 years, is 1,384.4 mm, with a high of 2,131.5 mm, recorded in 2018, and a low of 579.3 mm, in 1993.

The geomorphologic features of the region include small waterfalls, caves, and small lakes embedded in the typical cerrado biome. Sandy soils of arenitic origin cover > 50% of the area., areas of organic soils and areas covered by hydrophilic tropical forest are found (soil map SEPLAN, MT, scale 1:250, 000). Headwaters are considered first-order streams. Two first-order streams build a second order stream, two second order streams a third order stream, etc. Stream density is an important indicator of water availability in the catchment area, because low-order streams are major sources of water and their riparian wetlands provide habitats for many wetland plants and animals.

The density of the stream network ranges from regions with elevated precipitation (>2,000 mm yr⁻¹), The mean annual precipitation in the catchment area reaches 1,384 mm. It contains 180 first-order, 39 second-order, 13 third-order, and 4 fourth-order streams. The Quilombo River is a fifth-order river.

2.2 Dataset

2.2.1 Remote Sensing Satellite Imagery and Preprocessing

Twelve orthorectified images, obtained between the 22nd and 23rd of April 2018, by the Education and Research Program, were used in this study. The images had a spatial resolution of 3.125 m, spectral resolution bands at 455–515 nm (blue), 500–590 nm (green), 590–670 nm (red), and 780–860 nm (near infrared), and a radiometric resolution of 12 bits (Planet 2016). In this study, wetlands were defined according to the lowest level of spatial resolution of the sensor, which is 9.16 m².

The image dates were selected according to the parameters for the delineation of the extension of Brazilian wetlands (JUNK *et al.*, 2015), which define wetland extent based on the period of the greatest accumulation of precipitation or the limit of influence of the maximum mean floods specific to the site. Accordingly, the best available images, i.e., those with the least cloud cover, were selected.

In the preprocessing step, atmospheric correction of each image was performed individually using the ENVI program (Environment for Visualizing Images) and the QUAC (Quick Atmospheric Correction) module (BERNSTEIN *et al.*, 2005). This procedure was indispensable, even in the absence of a temporal analysis (PAHLEVAN, 2015), as it removed atmospheric attenuation effects that directly interfered with the spectral parameters in the segmentation process, which otherwise would have caused variability in the targets of the same class from scene-to-scene.

2.2.2 Segmentation and GEOBIA Classification

In the application of the GEOBIA classification, the following steps were used: H-resolution image acquisition; image and ancillary data pre-processing; classification design; segmentation and merging; feature extraction and feature space reduction; image-object classification; and accuracy assessment (KUCHARCZYK *et al.*, 2020). Segmentation was performed using the multi-resolution segmentation algorithm, developed by (Baatz, Martin; Benz, Ursula ; Dehghani, Seyed ; Heynen, Markus; Höltje, Astrid; Hofmann, Peter; Lingenfelder, Iris; Mimler, Matthias; Sohlbach, Malte; Weber, Michaela; Willhauck, 2004) and implemented using the e Cognition Developer to increase classification accuracy and success (BAATZ *et al.* 2008). In this step the image is separated into regions or objects (BAATZ *et al.*, 2004).

In the segmentations, for each of the 12 images the same three parameters (scale, shape, and compactness) were used, to control for the size, geometry, and color of objects in the images (PINHO, 2006; MUI *et al.*, 2015). The shape parameter was considered more important than the spectral one, due to the large number of irregularly shaped targets in the surveyed area, which besides wetlands included rocky outcrops, areas of native vegetation, and watercourses. Thus, in all segmentations, a value of 0.9 was assigned to the shape parameter, and a value of 0.1 to the color parameter (PINHO, 2006; FRANCISCO and ALMEIDA, 2012). The value of the compactness parameter was set at 0.5, considered a median value. This parameter was less influential in segmentation based on the observed landscape, which, in general, had very compact targets (roads, watercourses, etc.).

After several trials, a scaling factor of 30 was chosen, as it allowed objects of different sizes to be distinguished. This is especially important in observations of a single wetland, whose correct delineation requires the identification of many small objects. To improve wetlands delineation according to spectral parameters, a spectral difference algorithm was applied. The algorithm uses the spectral difference of the objects to generate a new segmentation, that is, fusion of the objects formed from the multi-resolution segmentation based on the spectral difference. This required the definition of a spectral difference threshold, which in this work was set at 50. Topology was applied to the export results using dissolve tools.

Sixteen potential features were tested for the classification of small wetlands. These included nine statistical parameters: the sensor's multispectral layers (Blue, Green, Red and Near-infrared), the contrast (Brightness), the maximum difference in spectral values (Maximum Difference), and the conversion components of the hue color system (Hue, Saturation, and Intensity); six functions of geometric descriptors: Area, Length, Asymmetry, Compactness, Density, and Rectangular Fit; and a

texture resource to determine the distribution of the gray tones of the targets in space, calculated using the gray level co-occurrence matrix (GLCM) (HARALICK *et al.*, 1973).

All 16 potential features were entered into the Feature Space Optimization tool to aid in the separation of thematic classes. This tool allows the selection of the best combination of features for a scene (BAATZ *et al.*, 2004). Based on the training samples and their selected statistics (in this case the statistics generated with the 16 functions), a curve was obtained that could be used to distinguish wetland features, and the relationship of those features to the proposed classes. The features descriptors obtained with the tool were analyzed according to the Nearest Neighbor classifier for image classification.

Information on elevation was derived using the TOPODATA digital elevation model (MDE), which is based on Shuttle Radar Topographic Mission data (available at: <http://www.dsr.inpe.br/topodata/index.php>). For the other processing steps in GEOBIA, eCognition software was used.

The most important features used in post-processing were the Edge Ratio, the Size Ratio, and small manual edits performed to correct details. The most frequently used feature was the Relation Border, to resolve wetlands in cases in which shadows were confused with wetlands adjacent to roads. Polygons with an area smaller than the spatial resolution of the image were not considered. Finally, from data collected during the field campaigns, wetlands that were actually adjacent to roads were corrected.

2.2.3 Accuracy assessment of the small wetlands map

Accuracy was assessed by constructing an error matrix (or confusion matrix), an efficient and well-accepted method to evaluate accuracy in thematic classification maps (Foody 2002; Goutte and Gaussier 2005; Congalton and Green 2019). The matrix contained the reference samples and the samples to be classified, arranged in columns and rows, respectively. F-score approach was used together with the concepts of precision and recall based on the values to determine true positive (TP), true negative (TN), false positive (FP) and false negative (FN) results (GOUTTE and GAUSSIÉ 2005).

The training samples were not the same as the validation samples. After the sample size was set, the most rigid scenario from which the reference data were obtained was chosen. For validation, a total of 585 data points were used: 513 random data points distributed throughout the area between the two final mapping classes (wetlands and no wetlands) and 72 data points

acquired during field campaigns. Accuracy measures consisted of sensitivity, specificity, precision, negative predictive value, FP Rate, false discovery rate, FN rate, accuracy and F-Score.

2.2.4 Field Survey Data

The reference data collected in the field survey were divided into (a) fieldwork carried out September 24–26, 2019; (b) other data collected during the dry season, on August 18–21, 2020, and on (c) October 15, 2020, and (d) data from high-resolution Google Earth images. To obtain wetland description information, 72 field points were acquired from the different types of mapped wetlands.

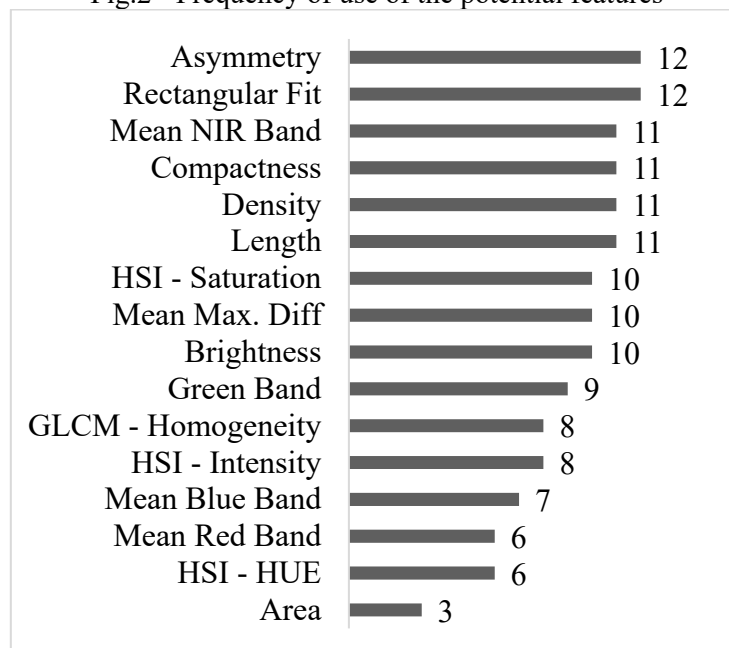
The Brazilian wetland classification system distinguishes between (i) wetlands with a relatively stable water level and (ii) wetlands with a fluctuating water level.

3. RESULTS

3.1 Frequency of features and parameters

The frequencies of the analyzed features are shown in descending order in Figure 2. The most frequently used features were Asymmetry, Rectangular Fit, Mean NIR Band and Compactness, Density, and Length. The least frequently used feature was Area.

Fig.2 - Frequency of use of the potential features

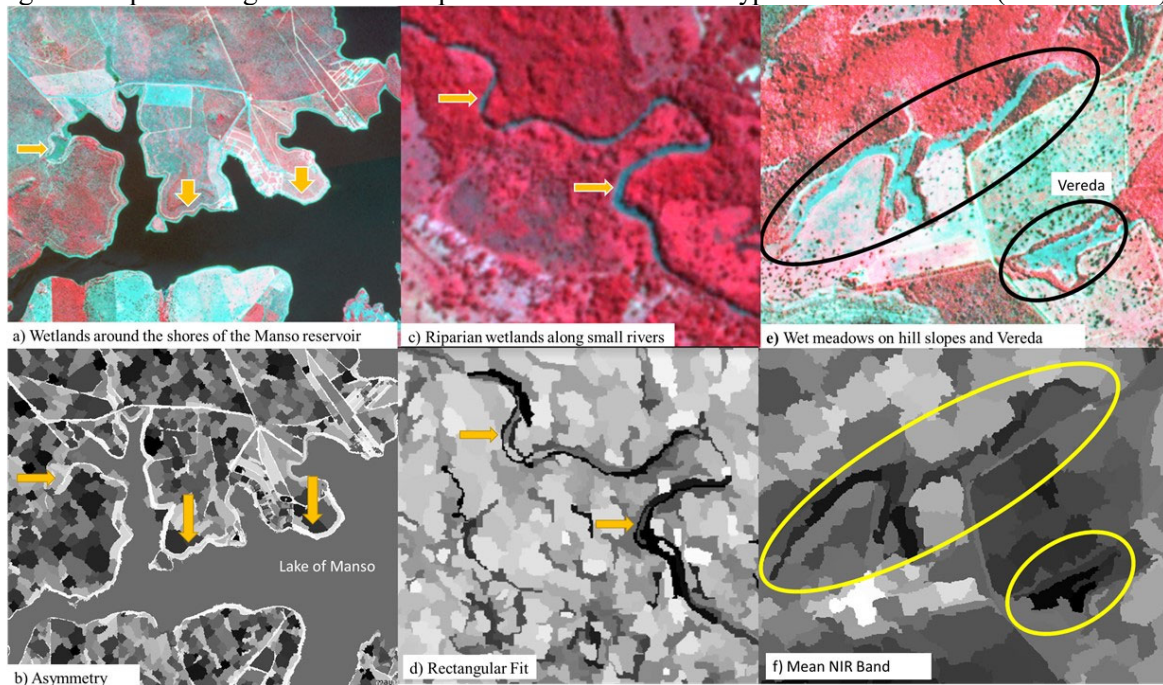


Data source: the authors

The six most successfully used features in the 12 classifications were grouped as small wetlands descriptors: Asymmetry, Rectangular Fit, Mean NIR Band, Compactness, Density, and Length. The first three had the highest frequencies and robustness among the descriptors enabling separation.

The composite images (RGB-432, false color) for different types of macrohabitats (wetlands around the shores of the Manso Reservoir, riparian wetlands along small rivers, wet meadows on hill slopes, and paths) and the descriptors features that highlighted them (Asymmetry, Rectangular Fit, and Mean NIR Band) are shown in Figure 3.

Fig.3 - Composite images and the descriptors features for different types of small wetlands (macrohabitats)



Data source: the authors

3.2 Number and extent of wetlands and their distribution in the landscape

The 7,132 wetlands identified in the study area corresponded to a density of 4,27wetlands km⁻². They ranged in size from 9.2 m² (lower detection limit) to 3.56km², and as high as 72.66 km² in the Manso Reservoir. To facilitate comparisons with wetland studies conducted in other regions of the world (e.g.Gibbs 1993), the wetlands in our study were separated into two groups: wetlands < 4.0 hectares (n = 6,451wetlands, 90.5%) and wetlands > 4 hectares (n = 681, 9.5 %). Table 1 provides quantitative data on the wetlands in the study area as determined using GEOBIA.

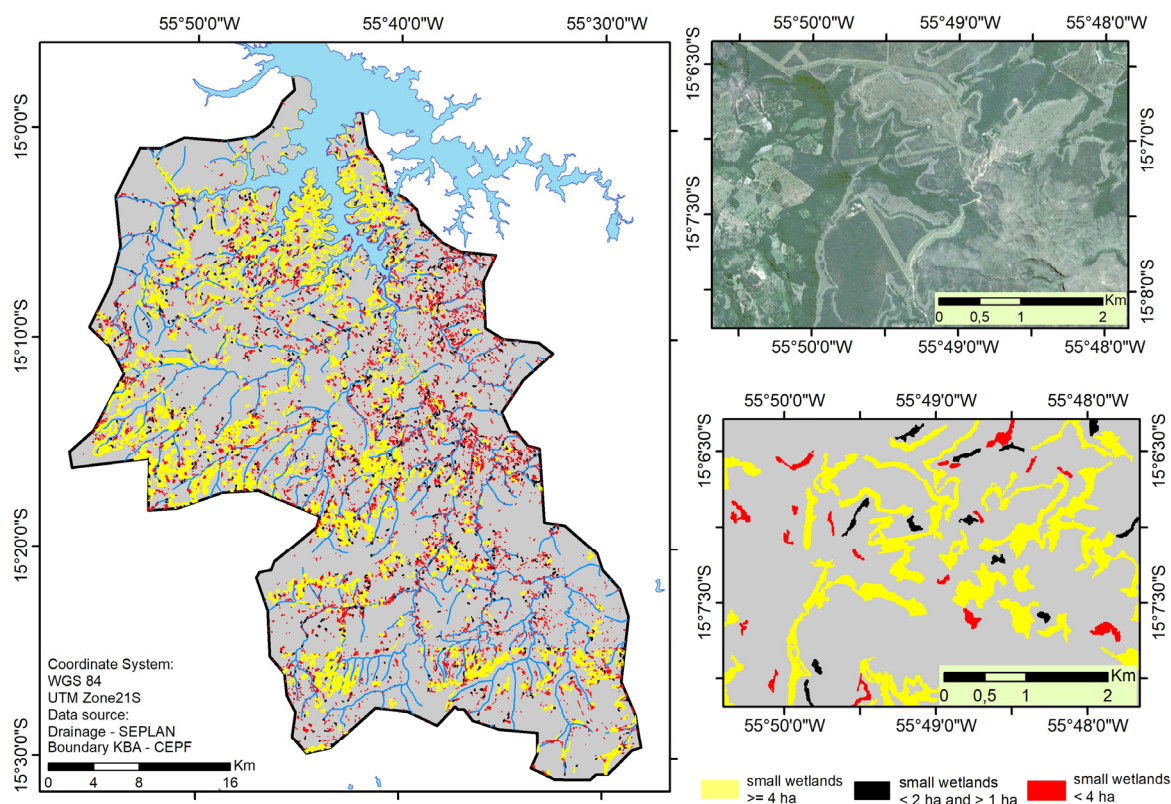
Table 1 - Extent of wetlands in the study area during the wet season as determined using Geographic Object-Based Image Analysis (GEOBIA)

	km ²	%
Study area (KBA MT11)	1669	100
Area of no wetland classes	1433	85.8
Area of the Manso Reservoir	73	4.4
Area of wetlands < 4.0 ha (6451 wetlands)	43	2.6
Area of wetlands > 4.0 ha (681 wetlands)	120	7.2
Total area of wetlands (7132)	163	9.8

Data source: the authors

The final map showing all small wetlands and their distribution across the three size classes defined for this study is shown in Figs. 4 and 5. The Sensitivity or recall was 87.2 % and the F-Score 93 %.

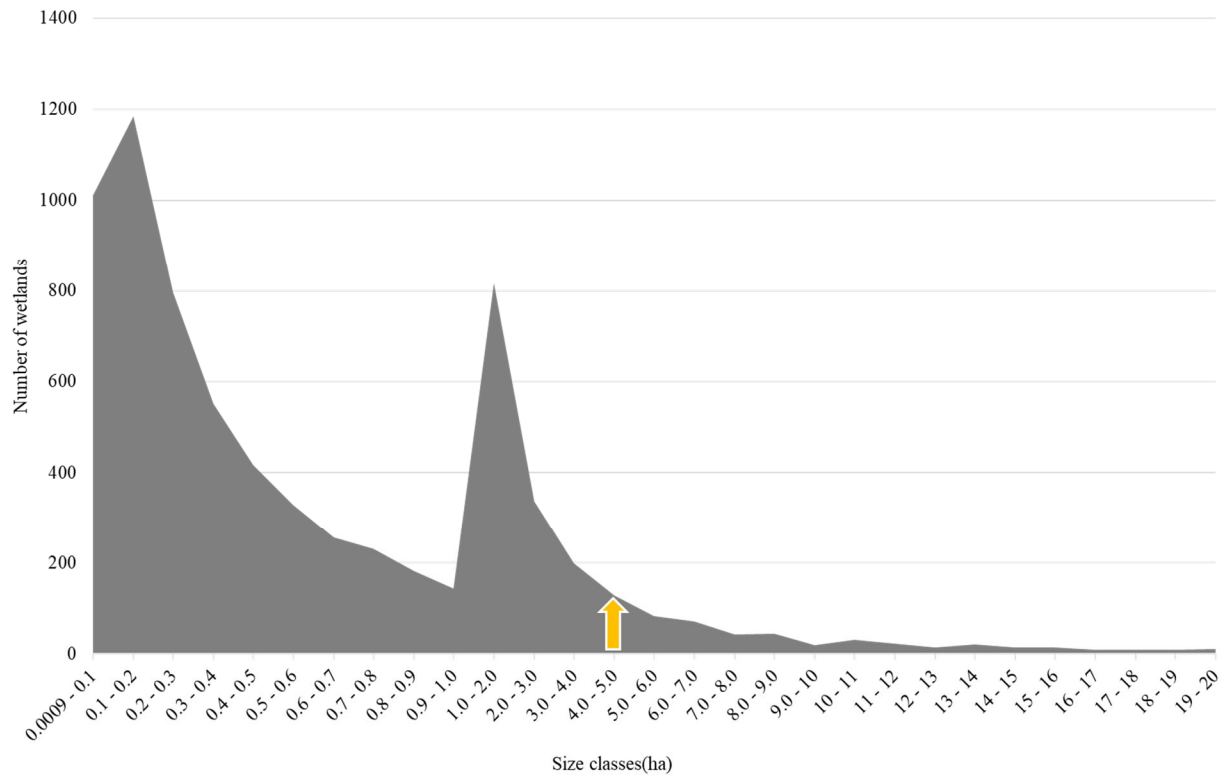
Fig. 4 - Map of the of wetlands according to size class



Data source: the authors

Mapping of the small wetlands in our study revealed two peaks in abundance, one in the range of the detection limit up to 0.3 hectares, and the other in the range of 1-2 hectares. For wetlands > 4 hectares in size, the number of wetlands declined drastically.

Fig. 5 - Distribution of small wetland sizes (n = 7,132) from the catchment of the Quilombo River



Data source: the authors

3.3 Classification of the different wetland types according to the Brazilian classification system

The Brazilian wetland classification system is hierarchical, with its higher-level categories based on hydrological parameters and its lower-level categories on higher vegetation (JUNK *et al.* 2013). This system was used to establish the classification presented in Table 2. As recommended by Junk *et al.* (2013), additional macrohabitats can be included in the original classification, if necessary. Some have already been described in the classification of large Brazilian wetlands, such as the Pantanal of Mato Grosso (NUNES DA CUNHA and JUNK, 2014).

Table 2 - Classification of the wetlands in study area KBA MT 11 (municipality of Chapada dos Guimarães, Mato Grosso)

System 2: Inland wetlands
Subsystem 2.1: Wetlands with a relatively stable water level Subclass: Forested swampy wetlands Macrohabitat: Palm forest of <i>Mauritia flexuosa</i> (buritizais) Subclass: Swamps with multi-species herbaceous vegetation Macrohabitat: Vereda Macrohabitat: Wet meadows on hill slopes (campo brejoso de surgência) Macrohabitat: Termite mound savanna (campo de murunduns) Macrohabitat: Humid meadows of <i>Axonopus purpusii</i> (campo úmido de <i>Axonopus purpusii</i>) Subsystem: 2.2: Wetlands with fluctuating water level Order: 2.2.2: Polymodal, unpredictable pulses of short duration Macrohabitat: Riparian wetlands along small rivers (florestas de galleria) Macrohabitat: Rainwater-fed wetlands in small depressions (áreas úmidas em pequenas depressões)
System 3: Artificial wetlands
Macrohabitat: Water reservoirs (açudes) Macrohabitat: Water-filled depressions arising from mining activities (cavas de mineração) Macrohabitat: Flooded areas on streams resulting from road construction (represamentos de riachos pela construção de estradas) Macrohabitat: Wetlands around the shores of the Manso Reservoir (áreas úmidas na beira da represa do Manso)

3.4 Accuracy assessment

The Table 3 summarizes the accuracy measure of the confusion matrix for classifying small wetlands.

Table 3 - Accuracy assessment values

Classified sample	Reference sample			Total classified
		Wetlands	No Wetlands	
	Wetlands	361	1	362
	No Wetlands	53	170	223
	Total collected	414	171	585
	Measure			%
	Sensitivity or recall			0.8720
	Specificity			0.9942
	Precision			0.9972
	Negative Predictive Value			0.7623
	False Positive Rate			0.0058
	False Discovery Rate			0.0028
	False Negative Rate			0.1280
	Accuracy			0.9077
	F Score			0.9304

4. DISCUSSION AND CONCLUSIONS

Wetlands cover ~20% of Brazil's territory, but coverage varies between regions. In the wet Amazon basin, wetlands account for 30% whereas in dryer regions the percentage is smaller. The lack of studies in these dryer regions do not allow a precise determination (Junk et al. 2014) and detailed studies are lacking (JUNK *et al.*, 2014). Most of the studies of Brazil's wetlands have focused on the wetlands found along the large Amazonian rivers (várzeas and igapós) as well as those in the Pantanal of Mato Grosso and along the Parana, Araguaia, and Guaporé Rivers. By contrast, small wetlands have been largely ignored, although their combined area may be as large or even larger than that of large wetlands (JUNK *et al.*, 2013).

Small wetlands are essential for the conservation and management of biodiversity (Bozelli et al. 2018) but can be omitted in surveys based on medium and high-resolution satellite images because of their size, their seasonal variability, and their difficult detection (e.g., linear-fringing wetlands) (GUO *et al.* 2017). The present study provides the first detailed analysis of the distribution and extent of the different wetland types in an entire river catchment area. The use of GEOBIA and the inclusion of parameters describing the scale, shape, compactness, and maximum spectral difference threshold enabled the mapping of small wetlands in the study area with a sensitivity or recall measure of 87.2 %.

The use of an image-based approach for wetland identification is adaptable for many other contexts in other geographic areas as well, although differences in the landscape and in the wetland types will likely require methodological adaptations. GEOBIA provides more information than, e.g. pixel by pixel based classification techniques, which are limited mainly with respect to their spectral information (FISHER, 1997; BLASCHKE and STROBL, 2001; BURNETT and BLASCHKE, 2003). Nonetheless, despite the potentially very high accuracy of remote sensing, Tiner (2016) emphasized the importance of fieldwork to verify the results and to identify wetlands that may have been missed during imaging.

Many GEOBIA-based studies used multiple levels of classification (PINHO 2006; MUI *et al.*, 2015; SERRAN and CREED 2016), but this complex hierarchical approach is only successful when there is variability in the target sizes (BAATZ, 2000). This was not the case in our study area, since the largest object in the images was the Hydroelectric Reservoir, such that the hierarchical approach could not be applied. The parameters describing the smoothness/compactness weight can be the same for images with different spatial resolutions and they will have less influence on segmentation than the scale parameter in the segmentation result (MOFFETT and GORELICK, 2013), however, no such configuration was satisfactory for mapping the small wetlands in the Brazilian Cerrado Biome.

The scale parameter (30) was close to that used in (GILMORE *et al.*, 2008). In the latter, 20 was the scale factor used in the QuickBird images. The spatial resolution was 2.4 m, similar to the spatial resolution of the Planet images (3 m) used in this study. In addition, resource selection methods are the simplest and reduce the complexity of the classification (MA *et al.* 2017).

The most frequently used features in the classification processes were Asymmetry, Rectangular Fit, Mean NIR Band, Compactness, and Density, with only the Mean NIR Band presenting a spectral feature. In the literature, most authors employed only a few descriptors and/or only cite those that were actually used (YU *et al.* 2006; MALLINIS *et al.* 2008; VIEIRA

et al. 2011; MUI *et al.* 2015). However, standardization of the method as suggested by Kucharczyk *et al.* (2020) will only be possible when authors also describe the individual contributions of the feature in the classification result.

Among the 16 features included in this study, the Mean NIR Band highlighted the Manso Reservoir and especially surface-water regions. In the latter case this was due to the chemical characteristics of water, which result in the absorption of radiation in the red and infrared ranges (CURCIO and PETTY, 1951; JENSEN *et al.*, 1984; JENSEN, 2015; BARBOSA *et al.*, 2019). The Mean NIR Band was between 780 and 860 nm and in the images used in this range the reflectance was very low. In addition, the Mean NIR Band also aided in identifying riparian wetlands along small rivers, vereda, wet meadows on hill slopes, termite mound savanna, humid meadows of *A. purpusii* and rainwater-fed wetlands in small depressions (GONÇALVES, 2021). It also separated regions with higher and lower degrees of waterlogging, again due to the absorbance range of water in the red and infrared ranges (NOVO, 2008; JENSEN, 2015). Consequently, places with larger amounts of water or humidity appeared in darker tones in the images.

The Rectangular Fit attribute has been used to discriminate agricultural areas (VOGELS *et al.* 2017). based on its ability to identify quadratic forms (BAATZ *et al.*, 2004). In this study it was used due to its ability to identify the macrohabitats riparian wetlands, palm forest of *M. flexuosa*, and wet meadows on hill slopes.

Although the scale factor (factor 30) was satisfactory in establishing the boundaries between classes, the true limits of the evaluated wetlands were not defined, due to the presence of many small objects within the small wetlands class. A better definition was obtained after application of the spectral difference segmentation algorithm and post-processing to merge adjacent objects. Over-segmentation requiring the application of a fusion process or the generation of other objects was also reported in (HOSSAIN and CHEN, 2019), in which non-satisfactory results in the image segmentation process were likewise noted.

Although the Mean Red Band correlated perfectly with the Intensity in the Pearson correlation, we suggest using the Mean Red Band, instead of the Intensity as the data are derived from the image itself, which minimizes the machine effort and processing time (SCHOWENGERDT, 2007).

For wetland studies, classification accuracies of 81%, 84.46%, and 90% are considered acceptable; higher percentages indicate that the attribute selection approach is robust (MUI *et al.* 2015; MA *et al.*, 2017; SALINAS *et al.*, 2020). A recent study (SALINAS *et al.*, 2020) reported an unsatisfactory classification for small wetlands in Southeastern Brazil when an

unsupervised classification using the K-media classifier was applied (52.55%) to a mixture of wetlands with classes 'covered by terrestrial vegetation'. This supports the use of classifications with GEOBIA (DRONOVA, 2015; KUCHARCZYK *et al.*, 2020).

There are very few studies that describe the hydrological systems of major catchment areas according to the stream order of the tributaries. In the our study area, 236 first- to fourth-order streams were detected; the Quilombo River was the only fifth-order water body. In another study of the Cerrado region of Mato Grosso, near the city of Jaciara, Wantzen (2006) analyzed streams of the catchment area of the fifth order Tenente Amaral River. The catchment covers 875.36 km² and contains 585 streams up to the 4 fourth order. Despite a similar annual precipitation of about 1.400 mm, stream density in the Tenente Amaral River catchment is more than twice as high as that in the Quilombo River catchment. Geomorphological peculiarities likely account for these differences, for example greater slop and hilly regions. As the Tenente Amaral River catchment region includes plateaus, it has a high permeability of rainwater such that the streams are shorter, resulting in lower drainage densities than in to other regions (AB'SÁBER, 2003)

International and national wetland definitions do not refer to wetland size, and there are only few studies that use size to differentiate wetlands. In a study of wetlands in the Atlantic coastal plain, Semlitsch and Bodie (1998) found 371 wetlands smaller than 10 hectares. Serran and Creed (2016) described wetlands of 0.1 to 1.0 hectares in the Prairie Pothole region of Central Alberta. Gibbs (1993) in a study of small wetlands in Maine, defined 4.05 hectares as separating small and large wetlands.

The 7,132 identified wetlands described in our study covered an area of 163 km², which corresponds to 9.8 % of the study area and a density of 4.27 wetlands km⁻². Wetlands size distribution was characterized by two peaks in abundance, one in the range of the detection limit up to 0.3 hectares and the other in the range of 1-2 hectares. For wetlands >4 hectares in size, the number declined drastically (Fig. 5). These results are in agreement with the studies of Semlitsch *et al.* (1996), Semlitsch and Bodie (1998), Serran and Creed (2016) and Gibbs (1993).

For a savanna biome covered with xerophytic vegetation and thus adapted to frequent wildfires, the number of small wetlands was unexpectedly high. The density of small wetlands in Maine as determined by Gibbs (1993) was 0.59 km⁻² whereas in Semlitsch and Bodie's (1998), study of the southeastern Atlantic coastal plain, the density was 0.476 wetlands km⁻², with 62% and 87.3% of the wetlands, respectively, being <4.0 hectares. In the above-mentioned study of the Prairie Pothole region of Central Alberta, the density of small wetlands was 117 km⁻² (SERRAN and CREED, 2016).

Wetlands in the study area differed with respect to their hydrological dynamics and vegetation cover (JUNK *et al.*, 2015; NUNES *et al.*, 2015; NUNES DA CUNHA *et al.*, 2017). Application of the Brazilian wetland classification system, which recognizes distinct wetland macrohabitats, is an essential step in the formulation of management and protection measures. d. The natural macrohabitats could be grouped according to their hydrological parameters and vegetation cover but among the previously identified vegetation units of the cerrado, only veredas were detected (OLIVEIRA and MARQUIS 2002; RIBEIRO and WALTER 2008). Descriptions of the other small-wetland macrohabitats in the study area will require additions to the classification system.

However, small wetlands in the study are at high risk of destruction, as the majority (90.5%) are very small (< 4 hectares) and the total area that they occupy is only 43 km² (2.6% of the catchment area).

One of the multiple functions of the stream network and the connected wetlands in the catchment area of the Pantanal of Mato Grosso is to supply water to this emblematic large wetland of national and international importance. An ecological risk assessment conducted by the World Wildlife Fund (2012) that took into account hydrological parameters, biotic interactions, habitat structures, and the evaluation of stressors called attention to the importance of the connectivity of the headwaters and associated small wetlands in the cerrado region with those in the Pantanal (PETRY *et al.*, 2012).

Between 1995 and 2021, agrobusiness transformed 36% of the study area into agricultural land for the production of soybean, corn, and beef (Fig. 1). Thus, small wetlands in the affected areas have become even smaller or disappeared, with the structure of riparian wetlands further modified by the damming of low-order streams, thus increasing the sediment load from erosion gullies. The application of toxic agrochemicals has polluted the water (DAVIS and FROEND, 1999; PUTHUR *et al.*, 2021). Between 1933 and 1960, intensive mineral extraction (Fig. 1) was practiced (ZOLINGER, 2000) and, although subsequently banned, it continues in some areas illegally. All these activities have reduced both the supply of clean water to the local population and the diversity of wetland plants and animals (WANTZEN *et al.*, 2006). Moreover, the Manso Reservoir has changed the natural hydrological regime and interrupted the migration routes of many fish species (IRIGARAY *et al.*, 2020; MEDINAS DE CAMPOS *et al.*, 2020).

Thus, to facilitate future studies and for management purposes the following measures are recommended: (1) the establishment of a size limit for the inventory of small wetlands, for example 0.2 or 4 hectares, to produce standardized maps for management and protection

planning; (2) the formulation of laws for the protection of small wetlands that consider both the multiple functions of these landscapes as well as the different stakeholder groups; and (3) the inclusion of small wetlands in the national wetland inventory.

4. ACKNOWLEDGMENTS

This paper is based on a chapter of the PhD thesis of Stela R. A. Gonçalves. The research described herein was supervised by her advisor, Professor Cátia Nunes da Cunha and Professor Geison Jader Mello. The survey of small and medium-sized wetlands was conducted as a subproject of The National Institute of Science and Technology on Wetlands (INCT-INAU) and Critical Ecosystem Partnership Fund (CEPF) - Cerrado Hotspot. S.R.A.G thanks the National Institute of Science and Technology in Wetlands (Instituto Nacional de Ciência e Tecnologia em Áreas Úmidas/INAU) and The Programa de Pós-graduação em Ensino - PPGEN/IFMT for enabling the fieldwork, and The Coordination for the Improvement of Higher Education Personnel of Brazil (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior/CAPES), Finance Code 001, for the doctorate post-doctorate (EDITAL 13/2020/CAPES - AMAZÔNIA LEGAL).

5. REFERENCES

AB’SÁBER, A. N. Os domínios de natureza no Brasil: potencialidades paisagísticas. **Vol I ed. [s.l.]: Ateliê editorial., 2003.**

ACHARYA, G. **Approaches to valuing the hidden hydrological services of wetland ecosystems.** *Ecological Economics*, [s.l.], v. 35, nº 1, p. 63–74, 2000. ISSN: 09218009, DOI: 10.1016/S0921-8009(00)00168-3.

ALVARES, C. A. et al. **Köppen’s climate classification map for Brazil.** *Meteorologische Zeitschrift*, [s.l.], v. 22, nº 6, p. 711–728, 2013. ISSN: 16101227, DOI: 10.1127/0941-2948/2013/0507.

BAATZ, M.; HOFFMANN, C.; WILLHAUCK, G. **Progressing from object-based to object-oriented image analysis.** *Lecture Notes in Geoinformation and Cartography*. [s.l.]: [s.n.], 2008. p. 29–42. ISSN: 18632351, DOI: 10.1007/978-3-540-77058-9_2.

BARBOSA, C. C. F.; NOVO, E. M. L. M.; MARTINS, V. S. **Introdução ao Sensoriamento Remoto de sistemas aquáticos.** In: BARBOSA, C. C. F.; NOVO, E. M. L. M.; MARTINS, V. S. (Orgs.). 1 ed. São José dos Campos: Instituto Nacional de Pesquisas Espaciais - INPE, 2019. ISBN: 9788517000959.

BERNSTEIN, L. S. et al. **A new method for atmospheric correction and aerosol optical property retrieval for VIS-SWIR multi- and hyperspectral imaging sensors: QUAC (Quick Atmospheric Correction).** *International Geoscience and Remote Sensing Symposium (IGARSS)*, [s.l.], v. 5, p. 3549–3552, 2005. ISBN: 0780390504, DOI: 10.1109/IGARSS.2005.1526613.

BLASCHKE, T; STROBL, J. **What's wrong with pixels? Some recent developments interfacing remote sensing and GIS.** *Zeitschrift für Geoinformationssysteme*, [s.l.], p. 12–17, 2001.

BLASCHKE, T. **Object based image analysis for remote sensing.** *ISPRS Journal of Photogrammetry and Remote Sensing*, [s.l.], v. 65, nº 1, p. 2–16, 2010. ISSN: 09242716, DOI: 10.1016/j.isprsjprs.2009.06.004.

BLASCHKE, Thomas et al. **Geographic Object-Based Image Analysis - Towards a new paradigm.** *ISPRS Journal of Photogrammetry and Remote Sensing*, [s.l.], v. 87, p. 180–191, 2014. ISSN: 09242716, DOI: 10.1016/j.isprsjprs.2013.09.014.

BOZELLI, R. L. et al. **Pequenas Áreas Úmidas: Importância Para Conservação E Gestão Da Biodiversidade Brasileira.** *Diversidade e Gestão*, [s.l.], v. 2, nº 2, p. 122–138, 2018. ISSN: 2527-0044.

BURNETT, C.; BLASCHKE, T. **A multi-scale segmentation/object relationship modelling methodology for landscape analysis.** *Ecological Modelling*, [s.l.], v. 168, nº 3, p. 233–249, 2003. ISSN: 03043800, DOI: 10.1016/S0304-3800(03)00139-X.

CONGALTON, R. G.; GREEN, K. **Assessing the Accuracy of Remotely Sensed Data.** In: CONGALTON, R. G.; GREEN, K. (Orgs.). *Assessing the Accuracy of Remotely Sensed Data*. 3rd ed. Boca Raton: CRC press, 2019. ISBN: 9781498776660, DOI: 10.1201/9780429052729.

CONLY, F. M.; KAMP, G. VAN DER. **Monitoring the hydrology of Canadian prairie wetlands to detect the effects of climate change and land use changes.** *Environmental Monitoring and Assessment*, [s.l.], v. 67, nº 1–2, p. 195–215, 2001. ISSN: 01676369, DOI: 10.1023/A:1006486607040.

COSTANZA, R. et al. **The value of the world's ecosystem services and natural capital.** *Nature*, [s.l.], v. 387, nº 6630, p. 253–260, 1997. ISSN: 0028-0836.

CUNHA, C. N. Da; PIEDADE, M. T. F.; JUNK, W. J. **Classificação e Delineamento das Áreas Úmidas Brasileiras e de seus Macrohabitats . Parte I : Definição e Classificação das Áreas Úmidas (AUs) Brasileiras : Base Científica para uma N ...** [s.l.]: EdUFMT, 2015. ISBN: 9788532705570.

CURCIO, J. A.; PETTY, C. C. **The Near Infrared Absorption Spectrum of Liquid Water.** *Journal of the Optical Society of America*, [s.l.], v. 41, nº 5, p. 302, 1951. ISSN: 0030-3941, DOI: 10.1364/josa.41.000302.

DAVIDSON, N. C.; FINLAYSON, C. M. **Earth Observation for wetland inventory , assessment and monitoring.** *Aquatic Conserv: Mar. Freshw. Ecosyst.*, [s.l.], v. 17, p. 219–228, 2007. DOI: 10.1002/aqc.

- DAVIS, J. A.; FROEND, R. **Loss and degradation of wetlands in southwestern Australia: Underlying causes, consequences and solutions.** *Wetlands Ecology and Management*, [s.l.], v. 7, nº 1–2, p. 13–23, 1999. ISSN: 09234861, DOI: 10.1023/A:1008400404021.
- DRONOVA, I. **Object-based image analysis in wetland research: A review.** *Remote Sensing*, [s.l.], v. 7, nº 5, p. 6380–6413, 2015. ISSN: 20724292, DOI: 10.3390/rs70506380.
- EULISS, N. H.; MUSHET, D. M. **Water-level fluctuation in wetlands as a function of landscape condition in the prairie pothole region.** *Wetlands*, [s.l.], v. 16, nº 4, p. 587–593, 1996. ISSN: 02775212, DOI: 10.1007/BF03161350.
- FISHER, P. **The pixel: A snare and a delusion.** *International Journal of Remote Sensing*, [s.l.], v. 18, nº 3, p. 679–685, 1997. ISSN: 13665901, DOI: 10.1080/014311697219015.
- FOODY, G. M. **Status of land cover classification accuracy assessment.** *Remote Sensing of Environment*, [s.l.], v. 80, nº 1, p. 185–201, 2002. ISSN: 00344257, DOI: 10.1016/S0034-4257(01)00295-4.
- FRANCISCO, C. N.; ALMEIDA, C. M. De. **Interpretação de imagens orbitais por meio de sistema especialista para o mapeamento de cobertura da terra em região montanhosa.** *Sociedade & Natureza*, [s.l.], v. 24, nº 2, p. 283–302, 2012. ISSN: 0103-1570, DOI: 10.1590/s1982-45132012000200009.
- GIBBS, J. P. **Importance of small wetlands for the persistence of local populations of wetland-associated animals.** *Wetlands*, [s.l.], v. 13, nº 1, p. 25–31, 1993. ISSN: 02775212, DOI: 10.1007/BF03160862.
- GILMORE, M. S. et al. **Integrating multi-temporal spectral and structural information to map wetland vegetation in a lower Connecticut River tidal marsh.** *Remote Sensing of Environment*, [s.l.], v. 112, nº 11, p. 4048–4060, 2008. ISSN: 00344257, DOI: 10.1016/j.rse.2008.05.020.
- GONÇALVES, S. R. A. **Inventário e Classificação de Pequenas Áreas Úmidas para a Gestão e Manejo Sustentável com uso de Sensoriamento Remoto.** 105p p. - Universidade Federal de Mato Grosso, 2021.
- GONÇALVES, S. R. A.; NUNES DA CUNHA, C.; JUNK, W. J. **Etapas Prioritárias para uso de Dados Remotos e Sistemas de Informações Geográficas em Planejamento de Inventário , Avaliação e Monitoramento de Áreas Úmidas.** *Biodiversidade Brasileira - BioBrasil*, [s.l.], v. 2, nº 2, p. 86–96, 2019. DOI: <https://doi.org/10.37002/biobrasil.v9i2.766>.
- GOUTTE, C.; GAUSSIER, E. **A Probabilistic Interpretation of Precision , Recall and F - Score , with Implication for Evaluation.** In: LOSADA, D. E.; FERNANDEZ-LUNA, J. M. (Orgs.). *Lecture Notes in Computer Science*. Berlin Heidelberg: Springer-Verlag, 2005. v. 3408, p. 345–359.
- GUO, M. et al. **A Review of Wetland Remote Sensing.** *Sensors*, [s.l.], v. 17, nº 4, p. 777, 2017. ISSN: 1424-8220, DOI: 10.3390/s17040777.

HARALICK, R. M.; SHANMUGAM, K.; DINSTEIN, I. **Textural features for image classification.** *IEEE*, [s.l.], v. 34, p. 610–621, 1973. ISSN: 19494645, DOI: 10.1190/segam2015-5927230.1.

HOSSAIN, M. D.; CHEN, D. **Segmentation for Object-Based Image Analysis (OBIA): A review of algorithms and challenges from remote sensing perspective.** *ISPRS Journal of Photogrammetry and Remote Sensing*, [s.l.], v. 150, n° February, p. 115–134, 2019. ISSN: 09242716, DOI: 10.1016/j.isprsjprs.2019.02.009.

IRIGARAY, C. T. J. H.; NUNES, C.; JUNK, W. J. **Pantanal à Margem da Lei: panorama das ameaças e perspectivas para a conservação.** Cuiabá - MT: [s.n.], 2020. 134 p. ISBN: 978-85-69786-09-2 1.

JENSEN, J. R. **Introductory digital image processing : a remote sensing perspective.** 4 ed. South Carolina: [s.n.], 2015. 659 p. ISBN: 9780134058160.

JENSEN, J. R.; CHRISTENSEN, E. J.; SHARITZ, R. **Nontidal wetland mapping in South Carolina using airborne multispectral scanner data.** *Remote Sensing of Environment*, [s.l.], v. 16, n° 1, p. 1–12, 1984. ISSN: 00344257, DOI: 10.1016/0034-4257(84)90023-3.

JUNK, W. J., & WANTZEN, K. M. **The flood pulse concept: new aspects approaches and applications An update.** *Proceedings of the second International Symposium on the Management of Large Rivers for Fisheries*. [s.l.]: [s.n.], 2004. p. 117–149.

JUNK, W. J. et al. **Brazilian wetlands: Their definition, delineation, and classification for research, sustainable management, and protection.** *Aquatic Conservation: Marine and Freshwater Ecosystems*, [s.l.], v. 24, n° 1, p. 5–22, 2014. ISSN: 10527613, DOI: 10.1002/aqc.2386.

JUNK, W. J.; BAYLEY, P. B.; SPARKS, R. E. **The Flood Pulse Concept in River - Floodplain System.** *Fish. Aquat Proceeding*, [s.l.], v. 106, p. 110–127, 1989.

JUNK, W.J. et al. **Parte I: Definição e Classificação das Áreas Úmidas (AUs) Brasileiras: Base Científica para uma Nova Política de Proteção e Manejo Sustentável.** *Classificação e Delineamento das Áreas Úmidas Brasileiras e de seus Macrohabitats*. EdUFMT ed. Cuiabá - MT: [s.n.], 2015. p. 165. ISBN: 978-85-327-0557-0.

JUNK, W J et al. **Brazilian wetlands : their definition , delineation, and classification for research , sustainable management, and protection.** *AQUATIC CONSERVATION: MARINE AND FRESHWATER ECOSYSTEMS*, [s.l.], 2013. DOI: 10.1002/aqc.2386.

JUNK, Wolfgang J. et al. **A classification of the major habitats of Amazonian black-water river floodplains and a comparison with their white-water counterparts.** *Wetlands Ecology and Management*, [s.l.], v. 23, n° 4, p. 677–693, 2015. ISBN: 1127301594, ISSN: 15729834, DOI: 10.1007/s11273-015-9412-8.

KANDUS, P.; MINOTTI, P.; MALVÁREZ, A. I. **Distribution of wetlands in Argentina estimated from soil charts.** *Acta Sci. Biol. Sci.*, [s.l.], v. 30, n° 4, p. 403–409, 2008. DOI: 10.4025/actascibiolsci.v30i4.5870.

- KIM, M. et al. **Multi-scale GEOBIA with very high spatial resolution digital aerial imagery: Scale, texture and image objects.** *International Journal of Remote Sensing*, [s.l.], v. 32, n° 10, p. 2825–2850, 2011. ISSN: 13665901, DOI: 10.1080/01431161003745608.
- KUCHARCZYK, M. et al. **Geographic object-based image analysis: A primer and future directions.** *Remote Sensing*, [s.l.], v. 12, n° 12, p. 1–33, 2020. ISSN: 20724292, DOI: 10.3390/rs12122012.
- MA, L. et al. **A review of supervised object-based land-cover image classification.** *ISPRS Journal of Photogrammetry and Remote Sensing*, [s.l.], v. 130, p. 277–293, 2017. ISSN: 09242716, DOI: 10.1016/j.isprsjprs.2017.06.001.
- MEDINAS DE CAMPOS, M. et al. **Predicted impacts of proposed hydroelectric facilities on fish migration routes upstream from the Pantanal wetland (Brazil).** *River Research and Applications*, [s.l.], v. 36, n° 3, p. 452–464, 2020. ISSN: 15351467, DOI: 10.1002/rra.3588.
- MOFFETT, K. B.; GORELICK, S. M. **Distinguishing wetland vegetation and channel features with object-based image segmentation.** *International Journal of Remote Sensing*, [s.l.], v. 34, n° 4, p. 1332–1354, 2013. ISSN: 13665901, DOI: 10.1080/01431161.2012.718463.
- MUI, A.; HE, Y.; WENG, Q. **An object-based approach to delineate wetlands across landscapes of varied disturbance with high spatial resolution satellite imagery.** *ISPRS Journal of Photogrammetry and Remote Sensing*, [s.l.], v. 109, p. 30–46, 2015. ISSN: 09242716, DOI: 10.1016/j.isprsjprs.2015.08.005.
- NOVO, E. M. L. de M. **Sensoriamento remoto: princípios e aplicações.** 3 ed. [s.l.]: Blucher, 2008. 363 p. ISBN: 978-85-212-0441-1.
- NUNES DA CUNHA, C; JUNK, W. J. **Part II: A Classificação dos Macrohabitats do Pantanal Matogrossense.** *Classificação e Delineamento das Áreas Úmidas Brasileiras e de seus Macrohabitats*. Cuiabá - MT: [s.n.], 2014. p. 77–112.
- NUNES DA CUNHA, Catia; ARRUDA, E. C. De; JUNK, W. J. **Marcos referenciais para a Lei Federal do Pantanal e gestão de outras áreas úmidas.** Cuiabá - MT: Carlini & Caniato Editorial, EdUFMT, 2017. 156 p. ISBN: 978-85-8009-177-9.
- NUNES, G. M. **Marco metodológico para delimitação e mapeamento de áreas úmidas.** *Marcos Referenciais para a Lei Federal do Pantanal e gestão de outras áreas úmidas*. Cuiabá - MT: Carlini & Caniato Editorial, EdUFMT, 2017. p. 45–53.
- OLIVEIRA, P. S.; MARQUIS, R. J. **The Cerrados of Brazil Ecology and Natural History of a Neotropical Savanna.** [s.l.]: Columbia University Press, 2002.
- OZESMI, S. L.; BAUER, M. E. **Satellite remote sensing of wetlands.** *Wetlands Ecology and Management*, [s.l.], v. 10, n° 5, p. 381–402, 2002. ISSN: 09234861, DOI: 10.1023/A:1020908432489.
- PARANHOS FILHO, A. C.; MIOTO, C. L.; MARCATO JUNIOR, J. **Geotecnologias em**

aplicações ambientais. Campo Grande - MS: Editora UFMS, 2016. 383 p. ISBN: 978-85-7613-522-7.

PETRY, P. et al. **Análise de Risco Ecológico da Bacia do Rio Paraguai: Argentina, Bolívia, Brasil e Paraguai.** [s.l.]: [s.n.], 2012. 54 p. ISBN: 9788560797103.

PINHO, C. M. D. De. **Análise orientada a objetos de imagens de satélites de alta resolução espacial aplicada à classificação de cobertura do solo no espaço intra-urbano: o caso de São José dos Campos - SP.** - Instituto Nacional de Pesquisas Espaciais, 2006.

PLANET. **PLANET IMAGERY PRODUCT SPECIFICATION: PLANETSCOPE & RAPIDEYE.** [s.l.]: [s.n.], 2016.

PONZONI, F. J.; SHIMABUKURO, Y. E.; KUPLICH, T. M. **Sensoriamento remoto da vegetação.** São Paulo: Oficina de Textos, 2015. ISBN: 978-85-79-78-053-3.

PUTHUR, S. et al. **Toxic Effects of Pesticides on Avifauna Inhabiting Wetlands.** In: INAMUDDIN, A. M. I.; E., L. (Orgs.). *Sustainable Agriculture Reviews 47. Sustainable Agriculture.* [s.l.]: Springer, Cham, 2021. p. 335–349. ISBN: 978-3-030-54712-7, DOI: https://doi.org/10.1007/978-3-030-54712-7_10.

REBELO, L. M.; FINLAYSON, C. M.; NAGABHATLA, N. **Remote sensing and GIS for wetland inventory, mapping and change analysis.** *Journal of Environmental Management*, [s.l.], v. 90, nº 7, p. 2144–2153, 2009. ISSN: 03014797, DOI: 10.1016/j.jenvman.2007.06.027.

RIBEIRO, J. F.; WALTER, B. M. T. **As principais fitofisionomias do bioma Cerrado.** *Cerrado: ecologia e flora.* Brasília - DF: Embrapa Informação Tecnológica, 2008. p. 151–212.

SALIMI, S.; ALMUKTAR, S. A. A. A. N.; SCHOLZ, M. **Impact of climate change on wetland ecosystems: A critical review of experimental wetlands.** *Journal of Environmental Management*, [s.l.], v. 286, nº August 2020, p. 112160, 2021. ISSN: 10958630, DOI: 10.1016/j.jenvman.2021.112160.

SALINAS, J. B. G. et al. **Wetland Mapping with Multitemporal Sentinel Radar Remote Sensing in the Southeast Region of Brazil.** *2020 IEEE Latin American GRSS and ISPRS Remote Sensing Conference, LAGIRS 2020 - Proceedings*, [s.l.], p. 669–674, 2020. ISBN: 9781728143507, DOI: 10.1109/LAGIRS48042.2020.9165593.

SAWYER, D. et al. **Perfil do Ecossistema Hotspot de Biodiversidade do Cerrado.** In: *Critical Ecosystem Partnership Fund (CEPF).* [s.l.]: [s.n.], 2017.

SCHOWENGERDT, R. A. **Remote Sensing: Models and Methods for Image Processing.** 3 ed. Tucson, Arizona: Elsevier, 2007. 588 p. ISBN: 9780123694072.

SECRETARÍA DE LA CONVENCION DE RAMSAR, 2010. **Inventario de humedales: Marco de Ramsar para el inventario y la descripción de las características ecológicas de los humedales.** In: *Secretaría de la Convención de Ramsar, Gland (Suiza).* Gland (Suiza): [s.n.], 2010.

SEMLITSCH, R. D. et al. **Structure and dynamics of an amphibian community.** In: CODY, M.; SMALLWOOD, J. (Orgs.). *Long-term studies of vertebrate communities.* [s.l.]: Academic Press, 1996. p. 217–248.

SEMLITSCH, Raymond D.; BODIE, J. R. **Are small, isolated wetlands expendable?** *Conservation Biology*, [s.l.], v. 12, nº 5, p. 1129–1133, 1998. ISSN: 08888892, DOI: 10.1046/j.1523-1739.1998.98166.x.

SERRAN, J. N.; CREED, I. F. **New mapping techniques to estimate the preferential loss of small wetlands on prairie landscapes.** *Hydrological Processes*, [s.l.], v. 30, nº 3, p. 396–409, 2016. ISSN: 10991085, DOI: 10.1002/hyp.10582.

SILVA, F. D.; ASSAD, E. D.; EVANGELISTA, B. A. **Caracterização climática do bioma Cerrado.** *Cerrado: ecologia e flora.* [s.l.]: [s.n.], 2008. p. 69–88.

SILVA, J. D. S. V. DA; MOURA ABDON, M. DE. **Delimitação do Pantanal Brasileiro e suas sub-regiões.** *Pesquisa Agropecuária Brasileira*, [s.l.], v. 33, nº 10 SPEC. ISS., p. 1703–1711, 1998. ISSN: 0100204X.

SULLIVAN, C. A. et al. **Wetland Landscapes and Catchment Management.** *Freshwater Ecology and Conservation: Approaches and Techniques.* Oxford: [s.n.], 2019. p. 404–422.

TINER, R. W. **Wetland indicators: A guide to wetland formation, identification, delineation, classification, and mapping.** [s.l.]: CRC press, 2016.

VIEIRA, M. A.; FORMAGGIO, A. R.; RENNÓ, C. D. **Análise de Imagem Orientada a Objeto e Mineração de Dados aplicadas ao mapeamento da cana-de-açúcar.** In: *Anais XV Simpósio Brasileiro de Sensoriamento Remoto - SBSR.* [s.l.]: [s.n.], 2011.

VOGELS, M. F. A. et al. **Agricultural cropland mapping using black-and-white aerial photography, Object-Based Image Analysis and Random Forests.** *International Journal of Applied Earth Observation and Geoinformation*, [s.l.], v. 54, p. 114–123, 2017. ISSN: 1872826X, DOI: 10.1016/j.jag.2016.09.003.

WANTZEN, K. M. et al. **Stream-valley systems of the Brazilian Cerrado: impact assessment and conservation scheme.** *Aquatic Conservation: Marine and Freshwater Ecosystems*, [s.l.], v. 16, nº October 2006, p. 713–732, 2006. DOI: 10.1002/aqc.

YU, Q. et al. **Objectbased detailed vegetation classification with airborne high spatial resolution remote sensing imagery.** *Photogrammetric Engineering and Remote Sensing*, [s.l.], v. 72, nº 7, p. 799–811, 2006.

ZHANG, H. et al. **Uncertainty assessment of climate change impacts on the hydrology of small prairie wetlands.** *Journal of Hydrology*, [s.l.], v. 396, nº 1–2, p. 94–103, 2011. ISSN: 00221694, DOI: 10.1016/j.jhydrol.2010.10.037.

ZOLINGER, I. T. **Aspectos Minerológicos e Economicos de Diamantes das Regiões de Chapada dos Guimarães, Poxoréu, Diamantino, Paranatinga e Alto Paraguai, Mato Grosso.** 208 p. - Universidadel de São Paulo Instituto de Geociências, 2000.