Aquatic Birds at the Taiamã Ecological Station: Seasonal Variation of Community Structure and the Importance of Protected Areas in the Pantanal

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Recebido em 30/03/2020 – Aceito em 20/06/2020

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ABSTRACT – As the largest floodplain in the world, the Pantanal plays an important role in maintaining biological diversity. Taiamã Ecological Station (TES) is a protected area located in the north Pantanal; it is considered a relevant area for bird conservation. The species composition of these areas must be studied and known for the development of specific management plans. Besides, waterfowl are important in assessing quality and are highly sensitive to environmental changes. Thus, we investigated the aquatic bird composition at the TES and surrounding area and evaluated the richness and abundance levels among sites and the river level during one year of sampling. We performed a total sample effort of six campaigns, with four sites sampled: two at the TES and two in the surroundings. We identified a total of 45 aquatic bird species, divided into nine orders, 20 families and 36 genera. The large number of individuals observed in February 2012 can be related to a natural phenomenon that occurs in Pantanal, called 'dequada', which is associated with the processes of decomposition of submerged plant biomass at the beginning of the flood. By analysing the most common species in this study, we found that *Nannopterum brasilianus, Ardea alba* and *Butorides striata* abundances also increased during this period. We observed the highest abundance and the largest number of species in the sites located within the TES, so the existence of this protected area for conservation is an important factor for the maintenance of bird communities in the region. Thus, we highlight the importance of protected areas for bird conservation in the Pantanal. Currently, a very small portion (5.37%) of the biome is protected, so increasing this proportion should help to maintain existing habitat. Subsequent research may be conducted to corroborate or refute the seasonal trends observed in this study.

Keywords: Waterfowl; floodplain; Paraguay River; protected area.

Aves Aquáticas da Estação Ecológica de Taiamã: Variação Sazonal da Estrutura da Comunidade e a Importância das Áreas Protegidas no Pantanal

RESUMO – Maior planície de inundação do mundo, o Pantanal desempenha um papel importante na manutenção da diversidade biológica. A Estação Ecológica de Taiamã (EET) é uma unidade de conservação localizada no norte do Pantanal e é considerada uma área relevante para a conservação de aves. A composição de espécies dessa área deve ser estudada e conhecida para a elaboração de planos de manejo específicos. Além disso, as aves aquáticas são importantes na avaliação da qualidade ambiental e com alta sensibilidade a possíveis alterações. Assim, investigamos a composição das aves aquáticas da EET e entorno e avaliamos os níveis de riqueza e abundância entre os locais e o nível do rio durante um ano de amostragem. Foi realizado um esforço amostral total de seis campanhas, com quatro locais amostrados: dois na EET e dois nos arredores. Identificamos um total de 45 espécies de aves aquáticas, divididas em nove ordens, 20 famílias e 36 gêneros. O grande número de indivíduos observado em fevereiro de 2012 pode estar relacionado a um fenômeno natural que ocorre no Pantanal, chamado dequada, o qual está associado aos processos de decomposição da biomassa submersa das plantas no início da cheia anual do bioma. Ao analisar as espécies mais comuns neste estudo, foi verificado que as abundâncias de *Nannopterum brasilianus, Ardea alba*

DOI: 10.37002/biobrasil.v10i3.1513

e *Butorides striata* aumentaram durante esse período. A maior abundância e o maior número de espécies foram observados no local de amostragem dentro da EET, de forma que a existência dessa área protegida para conservação é um fator significativo para a manutenção das comunidades de aves da região. Desta forma, fica evidenciada a importância de áreas protegidas para a conservação de aves no Pantanal. Atualmente, uma parcela muito pequena (5,37%) do bioma está protegida; portanto, aumentar essa proporção deve ajudar na manutenção dos *habitat* existentes. Pesquisas subsequentes devem ser conduzidas para corroborar ou refutar as tendências sazonais observadas neste estudo.

Palavras-chave: Área alagada; rio Paraguai; unidade de conservação.

Aves Acuáticas de la Estación Ecológica Taiamã: Variación Estacional de la Estructura Comunitaria y la Importancia de las Áreas Protegidas en el Pantanal

RESUMEN – Como la llanura de inundación más grande del mundo, el Pantanal tiene un papel importante en el mantenimiento de la diversidad biológica. La Estación Ecológica Taiamã (EET) es un área protegida ubicada en el norte del Pantanal y se considera un área relevante para la conservación de las aves. La composición de especies de estas áreas debe estudiarse y conocerse para el desarrollo de planes de manejo específicos. Además, las aves acuáticas son importantes para evaluar la calidad y son muy sensibles a los cambios ambientales. Por lo tanto, investigamos la composición de las aves acuáticas en el EET y el área circundante y evaluamos los niveles de riqueza y abundancia entre los sitios y el nivel del río durante un año de muestreo. Realizamos un esfuerzo de muestra total de seis campañas, con cuatro sitios muestreados: dos en el EET y dos en los alrededores. Identificamos un total de 45 especies de aves acuáticas, divididas en nueve órdenes, 20 familias y 36 géneros. La gran cantidad de individuos observados en febrero de 2012 puede estar relacionada con un fenómeno natural que ocurre en Pantanal, llamado "dequada", que está asociado con los procesos de descomposición de la biomasa vegetal sumergida al comienzo de la inundación. Al analizar las especies más comunes en este estudio, encontramos que las abundancias de *Nannopterum brasilianus, Ardea alba* y *Butorides striata* también aumentaron durante este período. Observamos la mayor abundancia y el mayor número de especies en los sitios ubicados dentro del EET, por lo que la existencia de esta área protegida para la conservación es un factor relevante para el mantenimiento de las comunidades de aves en la región. Por lo tanto, destacamos la importancia de las áreas protegidas para la conservación de aves en el Pantanal. Actualmente, una porción muy pequeña (5.37%) del bioma está protegida, por lo que aumentar esta proporción debería ayudar a mantener los hábitats existentes. Se pueden realizar investigaciones posteriores para corroborar o refutar las tendencias estacionales observadas en este estudio.

Palabras clave: Llanura de inundación; río Paraguay; área protegida.

Introduction

The Pantanal biome, which is the largest floodplain in the world, occupies approximately 140,000 km^2 (Alho & Silva 2012) and plays an important role in maintaining biological diversity due to its natural habitat variety (Alho 2008). The environment is highly complex, comprising forest formation mosaics and a constant transition between aquatic and terrestrial ecosystems. Further, seasonal fluctuations in water levels regulate the existing ecological processes (Cunha *et al*. 2007). A total of 582 bird species have been reported in the Brazilian Pantanal (Nunes 2011), of which 104 depend directly on wetlands (Junk et al. 2006).

In South America, the Pantanal is probably the most important wetland to birds associated with aquatic environments and muddy substrates (Scott & Carbonell 1986). However, despite the remarkable significance of this region for the conservation of resident and migratory birds, the spatiotemporal patterns of distribution, habitat use, structure of bird communities and the status of aquatic bird populations are poorly understood in the Pantanal (Tubelis & Tomas 2003, Figueira *et al*. 2006, Junk *et al*. 2006, Oliveira 2006). According to Morrison *et al*. (2008), the seasonality in the Pantanal plays a major role in bird distribution, but the patterns of distribution related to seasonality are still poorly understood. Besides, this biome is an important biological refuge for several endangered or even extinct species in other regions of Brazil. As the environment with the largest number of waterfowl on the continent, this biome still resists forest fragmentation and covers preserved areas (Tubelis & Tomas 2003, Donatelli *et al*. 2014).

The Taiamã Ecological Station (TES) is a federal protected area located in the north Pantanal; it is considered an important area for bird conservation (Frota *et al*. 2017). This protected area is characterised by its importance for the maintenance of local fish stocks, the abundance of waterfowls and seasonal flooding of the biome (ICMBio 2017). The species composition of this area and factors that threaten them need to be studied and known for the development of specific management plans (Efe *et al*. 2007). Waterfowl are important in assessing environmental quality. Indeed, they are key players in determining conservation hot spots. In addition, this diverse group occupies different habitat types and trophic levels and are highly sensitive to environmental changes (Valadão 2012).

Taking the above information into consideration, we investigated the community structure (richness, abundance and composition) of waterfowl over one year of sampling at the TES and surrounding areas. We subsequently evaluated the changes between sites and the river level.

Material and Methods

Study area

The Pantanal is divided into 11 subregions that have received local names based on the flood regimen and vegetation cover type (Silva & Abdon 1998). The north Pantanal comprises the sub-regions of the Mato Grosso State, formed by the sub-regions: *Poconé, Pantanal, Barão de Melgaço* and *Cáceres* (Adámoli 1982), and TES is inserted in this region.

The TES is a federal conservation unit, with full protection established by Decree n. 86061 of 02 June 1981 (ICMBio 2020), situated on the banks of the Paraguay River. It has an area of 11,555 ha, located on a river island in the city of Cáceres, Mato Grosso, Brazil (Figure 1). The area is bordered by the Paraguay and Bracinho rivers; it is mainly composed of floodplains, and its interior contains a great variety of aquatic environments, such as permanent, temporary lagoons, meander lagoons and ‘corixos’ (natural connections between rivers and lagoons that have great importance to water bodies in the Pantanal; Carvalho 1984). The TES has high levels of biodiversity, high rates of fishing productivity and the occurrence of populations of vulnerable or endangered species. One-hundred-thirty-one fish species have been identified in the rivers that border the TES and its surroundings

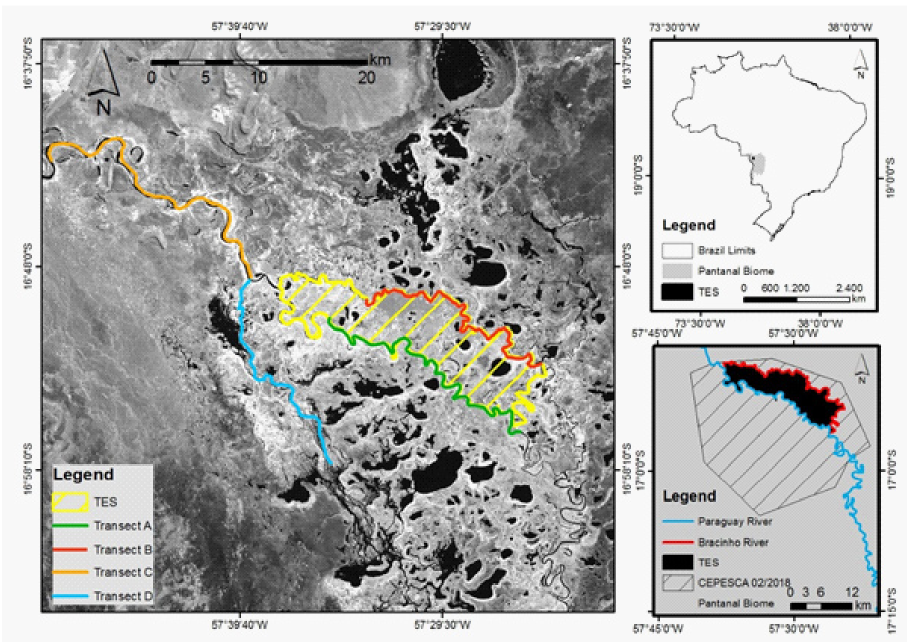

Figure 1 – Map of sites sampled at the Taiamã Ecological Station and surroundings, in Mato Grosso, Brazil.

(ICMBio 2017); this amount represents 48.33% of the total species of the Pantanal biome (Britski *et al*. 2007). The TES is also characterised by its great abundance of birds: 278 species have been identified (Frota *et al*. 2020), or 47.76% of the total birds already described for the Pantanal biome (Nunes 2011). Among these, 34 are migrants (Frota *et al*. 2020). Every week, hundreds of amateur (from several states of Brazil) and professional fishermen sail to the TES vicinity to fish (Neves *et al*. 2012). This phenomenon indicates that the area has considerable population sizes for these species and plays an important role in maintaining the regional fishery stocks. In view of these, the Station was declared a Ramsar site in 2018. Within the TES and adjacent areas, fishing is prohibited by law (Federal Decree n. 86.061/81 and Resolution 02/2018 of the Fisheries Council of the State of Mato Grosso [CEPESCA/MT] Brazil, respectively). The TES and its surroundings are considered optimal for some fish species because there is food (Furlan *et al*. 2017) and favourable environmental conditions (Muniz *et al*. 2016). Some species of economically important migratory fish that occur in the Pantanal wetland are observed at the TES. These fish are crucial to the regional economy due to fishing tourism (Wantzen *et al*. 2011). Fish are a significant food resource for aquatic birds in the Pantanal (Figueira *et al*. 2006); thus, the TES region is important for the conservation of waterfowl.

The TES is inserted in a region that plays important roles in flood control and sediment depositional processes of the north Pantanal. This region is characterised by the overflow of waters in the Paraguay River; it is flooded during most of the year (Assine & Silva 2009).

Sampling

In this study, we performed a total sample effort for six campaigns. We collected data every two months, from June 2011 to April 2012, corresponding to the periods of low rainfall and early dry season, the dry season (reproductive period of most bird species and no rainfall) and the rainy season.

We performed a bird census by means of displacement by water courses on board an aluminum boat with a 40-hp motor, with a constant average speed of 10 km/h (adapted from Alava 2005). We observed, counted and identified aquatic bird species at a specific level, according to the Brazilian Ornithological Records Committee (Piacentini *et al*. 2015), using binoculars (10 x 50 and 8 x 40). We photographed unidentified species in the campaigns (with a 300-mm lens) and compared the images with field guides. The migratory species were identified according to Somenzari *et al*. (2018).

We sampled four sites (30-km transects) twice per campaign, in the morning (after dawn) and afternoon (starting at 14:00 h), for a total of four days. We did not sample the same site twice on one day. The total effort of the study comprised 144 h of sampling.

We made observations for each site only in a margin of the rivers present (see details in Figure 1): A, we considered only the animals visualised in the left bank of the Paraguay River; B, we considered only the animals on the right bank of the Bracinho River; C, we considered only the individuals observed on the left bank of the Paraguay River; and D, we counted only the animals of the left bank of the Bracinho River. We adopted this strategy because the width of the rivers does not allow one to visualise both sides at the same time. During these observations, we also counted any animals in the middle of the river. The details of the sites are:

SITE A, TES – Paraguay River: the water and land transition area with terrestrial predominance can be subdivided into (1) polyspecific forest and (2) clean and natural field. These field areas have different characteristics according to the seasonality, so that there is predominance of aquatic plants such as water hyacinth (*Eichhornia* sp., Kunth 1843). The forest is composed of species such as *Bactris* sp. Jacq. ex Scop., *Triplaris americana* L., *Sapium obovatum* Klotzsch ex Mull, *Spondias mombin* L. and *Inga vera* Willd., common in the Paraguay River islands (Ikeda-Castrillon *et al*. 2011). Another type of area on this transect is (3) floating marshes, formed by layers of floating organic matter (remnants of aquatic vegetation, roots and rhizomes), which accompany the fluctuation of the water level (Pott & Pott 2000). The epiphyte plinths predominate in these areas; the most numerous families are Cyperaceae and Poaceae (Pivari *et al*. 2008).

DOI: 10.37002/biobrasil.v10i3.1513

SITE B, TES – Bracinho River: the water and land transition area with terrestrial predominance can be subdivided into (1) monospecific forest, characterised by the presence of the species *Erythrina fusca* Lour, which condenses into 'islands' called '*Abobrais*', (2) polyspecific forest and (3) floating marshes. Monospecific forests are predominant in this transect.

SITE C, upstream of the TES – Paraguay River: composed of sites of (1) polyspecific forest, (2) pasture planted for cattle farming and (3) clean and natural field. This region has a greater flow of vessels because, unlike other sampling sites, fishing is legally permitted in this area.

SITE D, flooded: located in a complex network of water channels (channels that intersect more than once with each other or other channels), without hierarchical order, leaving sandbanks among them. There are also many bays associated with this network of channels. This site is located outside the TES but is a legally protected area in which fishing is prohibited. Vegetation mainly comprises (1) clean and natural field and (2) floating marshes.

Statistical analysis

We performed analysis of variance (ANOVA) to evaluate potential differences in richness (S) and abundance among the sites sampled (Jolliffe 1986). To compare pairs of sites, we performed a t-test for independent samples with Welch correction in Instat version 3.05 software.

We used Whittaker diagrams to evaluate the equability of the sites, ordering the species from the most common to the rarest (x axis) and the abundance value (y axis). Equability is interpreted by the curves' inclination – more inclined curves have low equability (Smith & Wilson 1996) – and to estimate the equability index (Pielou 1975), where for values close to 1 the sample is more equitable than values close to 0. Magurran (2004) indicated that an advantage of this diagram type is the large volume of information it presents succinctly.

We performed a crown analysis of total abundance; in the graph, crowns (circles) that are plotted more in the centre represent a larger scale in the value of abundance. The graph separates species by families. We performed all analyses using R version 3.4.1 (R Development Core Team 2017). We acquired the Paraguay River water level during the sampling periods from the National Water Agency (ANA). We plotted the total richness and abundance of the five most sampled species with the level of the Paraguay River during the various samplings. We prepared these charts in Microsoft Excel. We performed linear regression analysis between the Paraguay River level and observed richness using Instat version 3.05. The regression considered all sampling periods, as well as without the December sample.

Results

We identified a total of 45 aquatic bird species, divided into nine orders, 20 families and 36 genera, with a total of 18,698 sightings over a 144-h sampling effort. Site A presented the highest richness (S) of 40, followed by C, B and D (with S of 35, 34 and 33 species, respectively; see Table 1). Orders Pelecaniformes and Charadriiformes represented the largest species numbers (S = 15 and 8, respectively), and the orders with the lowest species number (n) was represented by Suliformes and Ciconiiformes (S = 1 and 2, respectively; Table 1).

The families with the highest richness were Ardeidae (S = 10), followed by Alcedinidae (S = 5) and Threskiornithidae (S = 5). The families with the lowest richness were Anhimidae, Rynchopidae, Phalacrocoracidae, Anhingidae, Pandionidae, Aramidae, Heliornithidae, Recurvirostridae and Jacanidae (S = 1 for each; see details in Figure 2 and Table 1)

At the end of the sampling, we identified 45 bird species. The cumulative curve of species tended to stability. The estimated first order jackknife richness was 47.83 species, and the observed bird richness represents 94.08% of this estimator (Figure 3).

There were significant differences in the richness variations among the sites (F = 3.80, P = 0.02; Figure 4), but no significant differences in abundance among the sites (F = 2.71, P = 0.07; Figure 4). When we compared richness and abundance between sampling sites in pairs, there was a significant richness difference only between sites A and B and A and D. There were significant abundance differences only between sites C and B and C and D. The accumulated richness at site A was always higher compared the other sampled sections (Figure 5).

DOI: 10.37002/biobrasil.v10i3.1513

Table 1 – Aquatic bird composition present at the Taiamã Ecological Station and surroundings. * = migratory species

Order / Family / Species	**Common Name(s)**	**Abundance A**	**B**	**C**	**D**	**Total**
Anseriformes (Wagler 1831)						
Anhimidae (Stejneger 1885)						
Chauna torquata (Oken 1816)	Southern Screamer	115	68	77	182	442
Anatidae (Leach 1820)						
Dendrocygna viduata (Linnaeus 1766)	White-faced Duck				14	14
Dendrocygna autumnalis (Linnaeus 1758)	Black-bellied Whistling-duck	49	122	11	52	234
Cairina moschata (Linnaeus 1758)	Muscovy Duck	89	59	8	6	162
Ciconiiformes (Bonaparte 1854)						
Ciconiidae (Gray 1840)						
Jabiru mycteria (Lichtenstein 1819)	Jabiru	13	17	25	9	64
Mycteria americana (Linnaeus 1758)	Wood Stork	92	42	20	7	161
Suliformes (Sharpe 1891)						
Phalacrocoracidae (Reichenbach 1849)						
Nannopterum brasilianus (Gmelin 1789)	Neotropical Cormorant	115	68	77	182	4883
Anhingidae (Reichenbach 1849)						
Anhinga anhinga (Linnaeus 1766)	Anhinga	896	805	516	313	2530
Pelecaniformes (Sharpe, 1981)						
Ardeidae (Leach 1820)						
Tigrisoma lineatum (Boddaert 1783)	Rufescent Tiger-heron				14	508
Cochlearius cochlearius (Linnaeus 1766)	Boat-billed Heron	49	122	11	52	201
Nycticorax nycticorax (Linnaeus 1758)	Black-crowned Night-heron	89	59	8	6	158
Butorides striata (Linnaeus 1758)	Green-backed Heron	1359	811	480	562	3212
Bubulcus ibis (Linnaeus 1758)	Cattle Egret	275	7	9	37	328
Ardea cocoi (Linnaeus 1766)	Cocoi Heron	411	333	281	436	1461
Ardea alba (Linnaeus 1758)	Great White Egret	763	324	41	560	1688
Pilherodius pileatus (Boddaert 1783)	Capped Heron	4	2	20		26
Egretta thula (Molina 1782)	Snowy Egret	141	31	8	22	202
Egretta caerulea (Linnaeus 1758)	Little Blue Heron	5				5
Threskiornithidae (Richmond 1917)						
Mesembrinibis cayennensis (Gmelin 1789)	Green Ibis	16	2			18
Phimosus infuscatus (Lichtenstein 1823)	Bare-faced Ibis		4	2		6
Theristicus caerulescens (Vieillot 1817)	Plumbeous Ibis	5			11	16
Theristicus caudatus (Boddaert 1783)	Buff-necked Ibis			3		3
Platalea ajaja (Linnaeus 1758)*	Roseate Spoonbill		2	3		5
Eurypygiformes (Furbringer, 1888)						
Eurypygidae (Selby, 1840)						
Eurypyga helias (Pallas, 1781)	Sunbittern	1				1

Order Family Species	Common Name(s)	Abundance				
		A	B	C	D	Total
Gruiformes (Bonaparte 1854)						
Aramidae (Bonaparte 1849)						
Aramus guarauna (Linnaeus 1766)	Limpkin	94	1	21	23	139
Rallidae (Rafinesque 1815)						
Aramides cajanea (Statius Muller 1776)	Grey-necked Wood-rail	14	2	5	3	24
Gallinula galeata (Lichtenstein 1818)	Common Gallinule	2			2	4
Heliornithidae (Gray 1840)						
Heliornis fulica (Boddaert 1783)	Sungrebe	8	14	2	2	26
Charadriiformes (Huxley 1867)						
Charadriidae (Leach 1820)						
Vanellus cayanus (Latham 1790)	Pied Lapwing	2	10	7	1	20
Vanellus chilensis (Molina 1782)	Southern Lapwing	5		7		12
Charadrius collaris (Vieillot 1818)	Collared Plover				1	1
Recurvirostridae (Bonaparte 1854)						
Himantopus melanurus (Linnaeus, 1758)	Black-winged Stilt	6				6
Jacanidae (Chenu and Des Murs 1854)						
Jacana jacana (Linnaeus 1766)	Wattled Jacana	226	4	35	221	486
Sternidae (Bonaparte 1838)						
Sternula superciliaris (Vieillot 1819)	Yellow-billed Tern	342	5	54	43	444
Phaetusa simplex (Gmelin 1789)	Large-billed Tern	76	75	184	172	507
Rynchops niger (Linnaeus 1758)*	Black Skimmer	1		6	6	13
Coraciiformes (Forbes 1884)						
Alcedinidae (Rafinesque 1815)						
Megaceryle torquata (Linnaeus 1766)	Ringed Kingfisher	104	121	85	5	315
Chloroceryle amazona (Latham 1790)	Amazon Kingfisher	36	26	119	6	187
Chloroceryle aenea (Pallas 1764)	American Pygmy-kingfisher	4				4
Chloroceryle americana (Gmelin 1788)	Green Kingfisher	16	17	20	4	57
Chloroceryle inda (Linnaeus 1766)	Green-and-rufous Kingfisher	2	1			3
Accipitriformes (Vieillot 1816)						
Pandionidae (Sclater and Salvin 1873)						
Pandion haliaetus (Linnaeus 1758)*	Balbuzard pêcheur	2	1	22	7	32
Accipitridae (Vieillot 1816)						
Busarellus nigricollis (Latham 1790)	Black-collared Hawk	17	16	19	6	58
Rostrhamus sociabilis (Vieillot 1817)*	Snail Kite	40	31	36	63	170
Urubitinga urubitinga (Gmelin 1788)	Great Black Hawk	14	28	13	7	62

DOI: 10.37002/biobrasil.v10i3.1513

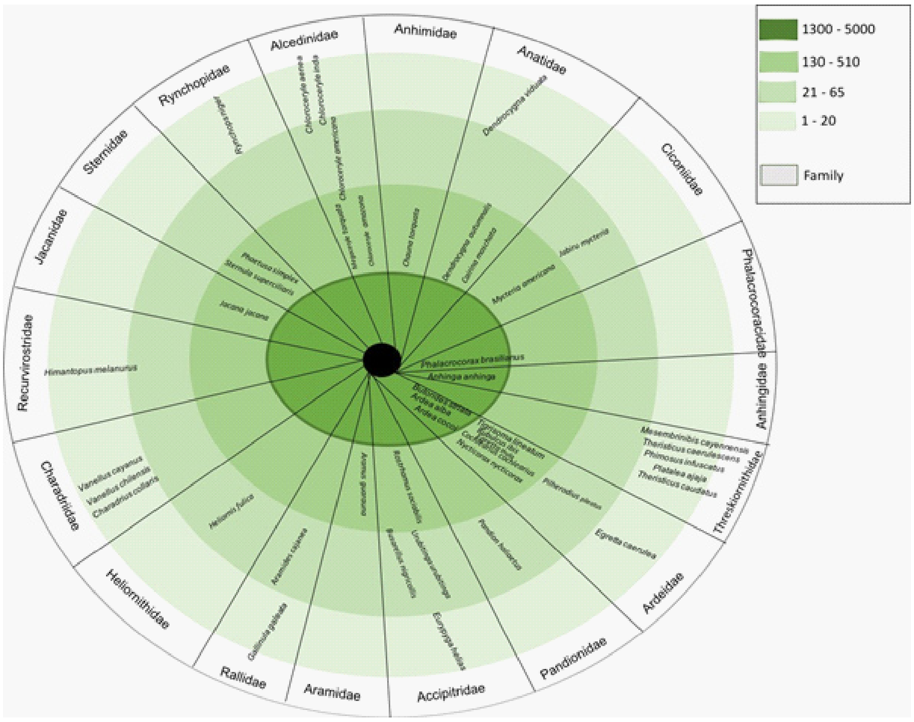

Figure 2 – The abundance crown of aquatic bird species separated by family at the Taiamã Ecological Station, Pantanal wetlands and surrounding area. Smaller circles with darker colours in the centre represent species with higher abundance, while the larger circles with lighter colours represent lower abundance values. Richness is seen on the lines separated by families.

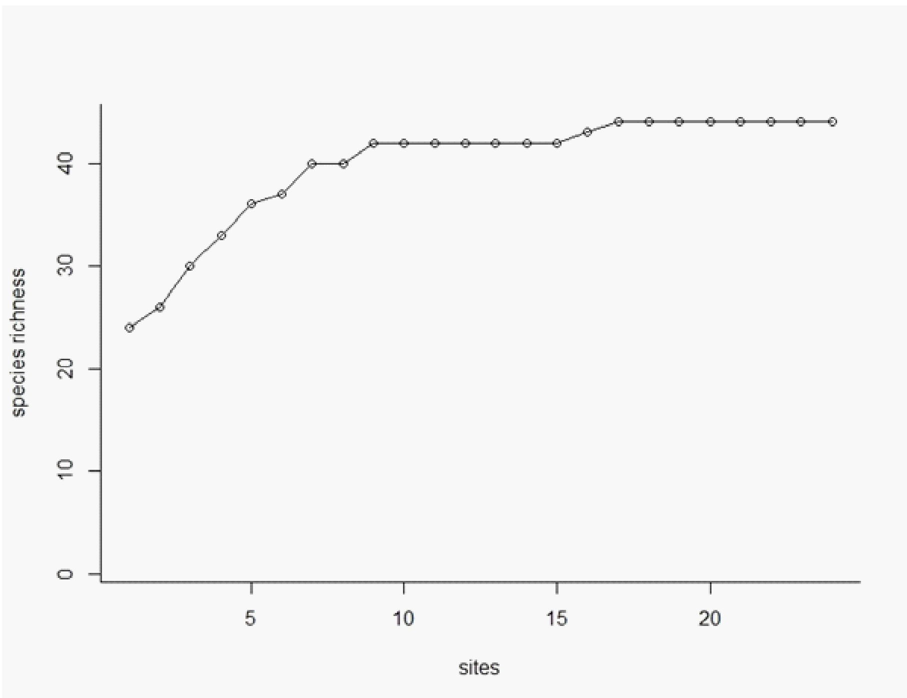

Figure 3 – Cumulative number of species obtained from the samplings at the Taiamã Ecological Station, Pantanal wetlands and the surroundings.

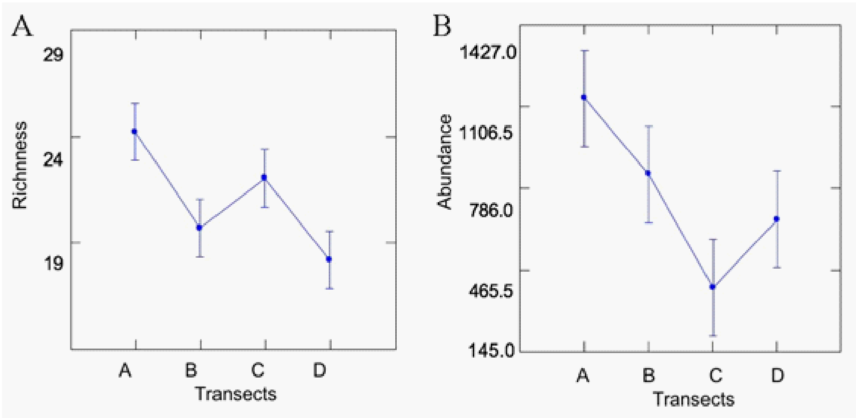

Figure 4 – Mean differences in the aquatic birds' richness (A) and abundance (B) among the sites sampled at Taiamã Ecological Station and surrounding area in the Pantanal wetlands.

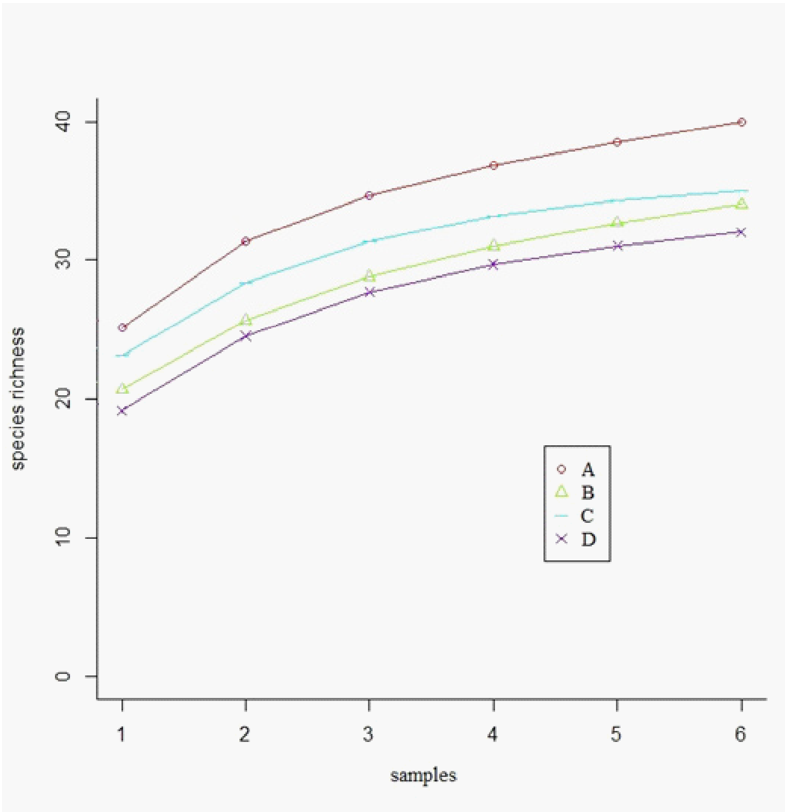

Figure 5 – Accumulated richness values for sites throughout the samples.

DOI: 10.37002/biobrasil.v10i3.1513

Sites C and A presented higher values of J (equability), with lines less inclined in the Whittaker diagram (C: J = 0.72; A: J = 0.70). Sites B and D has more inclined lines (B: J = 0.58; D: J = 0.65; Figure 6).

The total abundance of sampled individuals varied during the sampling periods. In February 2012, we observed the largest number of individuals (Figure 7A); this time was also the beginning of the flood in the Paraguay River.

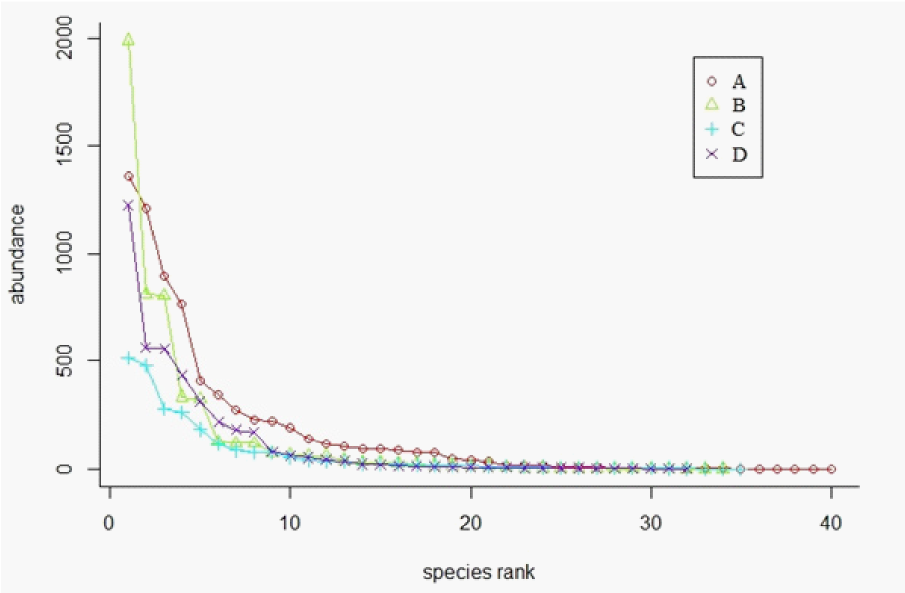

Figure 6 – Whittaker diagram for four aquatic bird communities at the and surroundings area in the Pantanal wetlands.

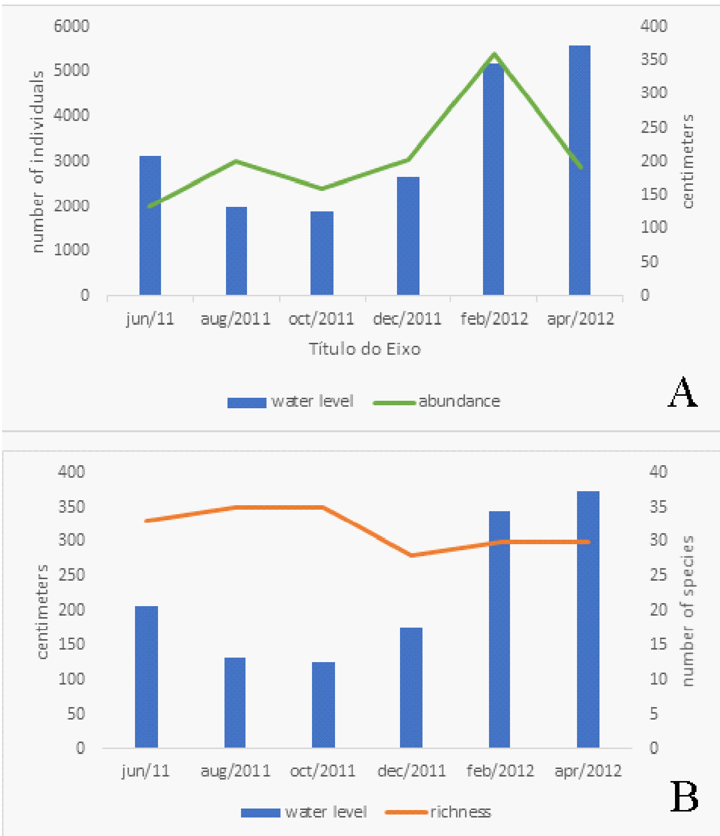

Figure 7 – Variation of (A) abundance and (B) richness of waterfowl species of the Taiamã Ecological Station and surrounding area in relation to the Paraguay River water level.

DOI: 10.37002/biobrasil.v10i3.1513

We noted the greatest richness during the period with the lowest river level (August and October 2011; Figure 7B). The linear regression between the level of the Paraguay River and the observed species richness was not statistically significant (p = 0.212). However, when removing the December sample, the regression was significant (p = 0.0004) (Figure 8).

We divided total abundance into four large scales separated by number of aquatic bird individuals (*see* details in Figure 2). The first scale (1,300–5,000 individuals) included five species: the neotropical cormorant (*Nannopterum brasilianus*: 4.883n, family Phalacrocoracidae), the green-backed heron (*Butorides striata*: 3.212n, family Ardeidae), the anhinga (*Anhinga anhinga*: 2.530n, family Anhingidae), the great white egret and the *Cocoi heron* (*Ardea alba*: 1.688n and *Ardea cocoi* 1461n, family: Ardeidae). The lower abundance scale (1–20 individuals) comprised 16 species; the sunbittern (*Eurypyga helias*, family Accipitridae) and collared plover (*Charadrius collaris*, family Charadriidae) were the rarest, with only one individual (abundance scale details can be seen in Figure 2 and Table 1).

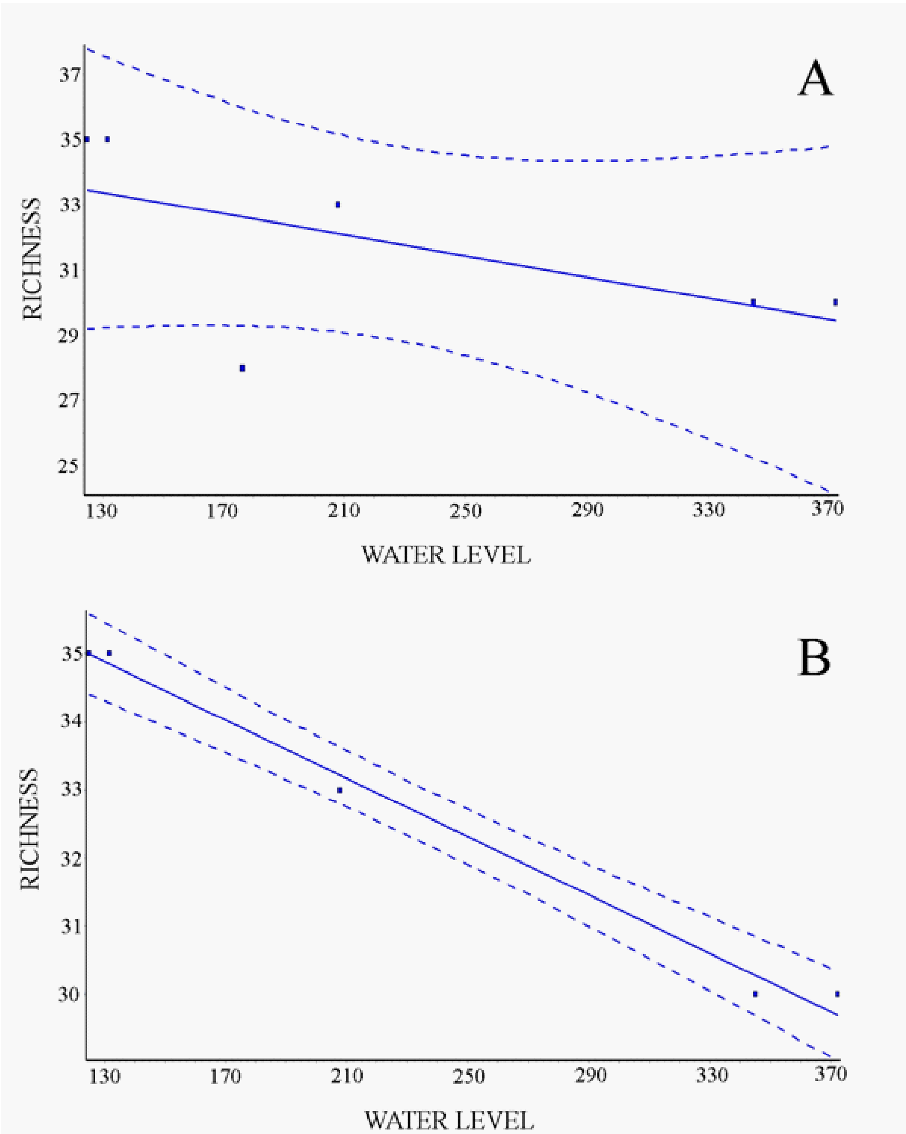

Figure 8 – Scatter plot, regression (blue lines) and 95% confidence intervals (blue dashed lines) between the richness and water level: (A) all samples, r = -0.5962 and P = 0.2117 and (B) all samples without December, r = - 0.9953 and P = 0.0004.

The abundance of the most observed species varied over time (Figure 9). There was an increase in the number of observed individuals of *N. brasilianus, A. anhinga* and *A. Alba*, and the most pronounced increase occurred with *N. brasilianus*. The abundance values in *A. cocoi* and *A. anhinga* remained relatively stable throughout the sample period.

Discussion

In Brazil, the Ardeidae family has 23 species (Piacentini *et al*. 2015), of which we recorded 10 in the TES. Another study conducted in the southern Pantanal (Donatelli *et al*. 2014) also detected several species of this family. In addition, among the five most abundant species of this study, three are from this family (Figure 2). Among the many bird species found in South American wetlands, species from Ardeidae are very representative in abundance and frequency of occurrence and widely distributed in Brazil (Sick 1997, Cintra 2012). One of the factors that may be influencing the occurrence of this family in Brazil is the great occurrence of water bodies in the country, which has about 12% of the world's fresh water (ANA & PNUMA 2007). Further, Ardeid birds seem to prefer the aquatic macrophyte micro*habitat* (Hancock & Kushlan 1984, Gimenes & Anjos 2006, Pimenta *et al*. 2007, Kushlan 2011).

The tendency for stability observed in the species cumulative curve indicates that the studied areas have the potential to house a few more species than the 45 we observed. Studies in the Pantanal biome have identified up to 135 water bird species (Donatelli *et al*. 2014). This difference can be explained by variations among sampling sites: those studies with a large number of aquatic species were carried out in more diverse environments. In addition, our study area has a relatively monotonous landscape and we performed samplings in very close places. In any case, the 45 species identified represent 33.33% of the total found in the biome. For such a small studied area, these values are significant. The high abundance and richness of aquatic birds in the Pantanal *habitat* can be explained by the great abundance and richness of fish. In fact, the Pantanal features some of the highest fish diversity biome on the planet (Conceição & Paula 1986).

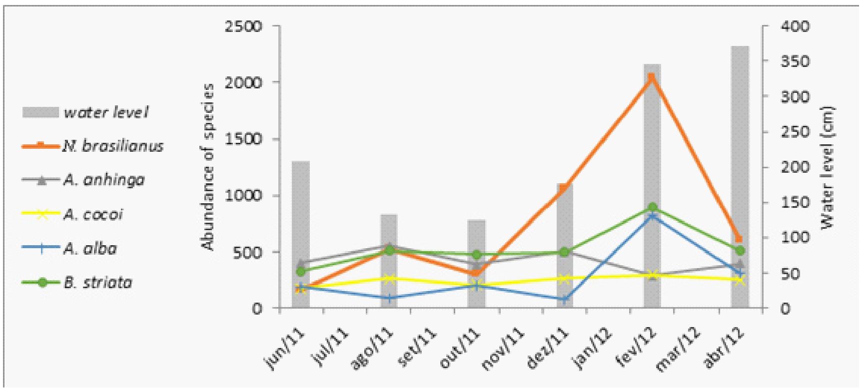

Figure 9 – Abundance variation over the sampling period of the five most abundant species of this study.

The large number of individuals (5,389) observed in February 2012 can be related to a natural phenomenon that occurs in Pantanal, namely 'dequada'. This phenomenon is associated with the processes of decomposition of submerged plant biomass at the beginning of a flood. Therefore, anoxic environments with high levels of carbon dioxide (reaching values higher than 100 mg/L of free CO_2), which is lethal to practically all fish species, are generated. According to this magnitude, it can cause natural fish mortality of the order of thousands of tons. This occurrence, without comparison with other wetlands of the planet, by its magnitude and extent, can be considered a natural regulating factor of the structure and dynamics of diverse

DOI: 10.37002/biobrasil.v10i3.1513

biotic communities (Calheiros & Ferreira 1997; Hamilton *et al*. 1997). This phenomenon occurs annually in this region of the TES (Macedo *et al*. 2015) and offers great resources for piscivorous birds (Oliveira *et al*. 2013). After this period of flooding, dissolved oxygen levels increase; hence, the fish supply to the birds is reduced, as well as the abundance of water birds (Figure 7A).

In the region of Nhecolândia/MS, in the south of the biome, the highest abundance of waterfowl occurred in the dry period (Donatelli *et al*. 2014). Likewise, in a study carried out in Poconé/MT, the increase in the abundance of waterfowl also begins with the decrease in water levels (Oliveira 2006). Unlike TES, in these two locations there is no intense 'dequada' (Macedo *et al*. 2015), which may be related to the seasonal differences in the abundance peaks between our study and these two mentioned above.

The 'dequada' occurs with greater amplitude in sites A, B and D (Macedo *et al*. 2015), since in site C the water from the river channel does not flood wide plains. Thus, due to the importance of fish as a food resource for waterfowl, and considering that 'dequada' makes this food resource more available, the abundance values for the sampled sites are also influenced by this phenomenon, and as predicted, the value obtained for site C is the smallest (Figure 4).

Fine-scale structural vegetation heterogeneity (i.e. variation in vegetation at a scale of tens of metres) is considered to be an important factor that affects animal occurrence and composition (Benton *et al*. 2003, McElhinny *et al*. 2005). For instance, according to the *habitat* heterogeneity hypothesis (MacArthur & MacArthur 1961), resources and niches are augmented with increasing spatial heterogeneity (Pianka 1972, Bazzaz 1975). In this way, the environments sampled in this study also differ in their composition. Even within the TES, sites A and B have different characteristics, a factor that may influence the richness and abundance of water birds. Site A had greater diversity of *habitat* when compared to B, and this difference is probably due to the greater diversity of niches and resources that exist in the former (Frota *et al*. 2017). Most of site B is located in a monospecific forest, while in site A, polyspecific forest dominates. Hence, we can verify that there are significant differences between the waterfowl richness of the sampling sites. However, when richness was compared in pairs, we observed that site A differed significantly only from sites B and D. By contrast, there was no statistical difference in the mean abundance among the sites. The annual variation in water levels clearly changes the environments in the Pantanal. Indeed, throughout the sampling period, there was great variation in richness and abundance in the various sampled environments (Figure 8). This variation increased the standard deviation, making it difficult to detect statistical differences in the richness and abundance averages among the studied sections. Thus, even though we could not detect a statistical difference between the richness of sties A and C, there was a difference between the means. Moreover, in the cumulative richness curve (Figure 5), site A was clearly richer over the entire sampling period. Similarly, there was a clear difference between the abundance averages of A and C. In addition, when looking at Figure 6 (Whittaker diagram), it appears that site A had more identified species and also greater abundance for most species compared to the other sampling sites.

Despite the changes related to anthropic use, site C had greater richness than site B. In site C, due to deforestation on farms, the birds possibly concentrate closer to the banks of the river. In addition, site C is more heterogeneous in relation to *habitat* compared to site B. This result shows that although site C is outside the conservation unit, it is very important for the conservation of Pantanal waterfowl species. In Brazil, marginal strips of the rivers are protected by law. The greater richness of site C when compared to site D is also due to the characteristics of the environment: the latter has less diversity of *habitat* than the former. Site D presented the lowest value of species diversity, a fact that is related to the characteristics of the environment, which has few trees and is located in a region of natural fields and floating marshes and causes greater abundance of the most abundant species when compared to C (see Whittaker diagram), a place with few flooded areas (Figure 1).

We observed the highest abundance and largest number of species in site A. This sample is located within the TES, so the existence of this protected area for conservation is an important factor for the maintenance of bird communities in the region. When the level of the Paraguay River is low, 48% of the TES is composed of marshland (batume), 47% is transitional aquatic and terrestrial areas with a predominance of terrestrial areas (flooded fields) and 5% is permanent aquatic areas. These data indicate that in the flood season almost the entire station and its surroundings are flooded (Frota *et al*. 2017). This flooded feature of the TES is probably what allows the presence of so many water birds. In addition, for greater protection of site A, it would be important that the areas to the right margin of the Paraguay River are also protected in order to conserve the entire river channel.

The highest diversity of aquatic birds observed during the dry season (August 2011 and October 2011) in the study area is due to the scarcity of water, which facilitates concentration of aquatic birds in wet environments like TES during this period. Furthermore, migratory species are observed more frequently in humid areas during dry periods because they use these specific locations at times of food scarcity (Accordi & Hartz 2006). In fact, there are migrations of aquatic birds in response to significant variations in water level and resource availability, such as wood storks, egrets, terns, ducks, sandpipers and swallows (Oliveira 2006). The dry period provides greater quantities of fish, amphibians, mussels, snails, crabs, insect larvae, and other aquatic invertebrates that can easily be captured when water levels fall, as many of these organisms are caught in pools or mud (Antas 1994).

In addition, linear regression also indicates that the lower the river level, the greater the number of species present in the study area. Figure 7A visualises this trend, but the effect was not significant when we analysed all samples together. However, when we removed the December 2011 sample, the linear regression became significant. We withdrew this sample because it was the only point outside the error limits of the line in Figure 4A. In addition, December is the beginning of flooding in the study region, and the phenomenon of dequada alters the environment. The ideal would be to perform 2-3 years of collection in order to verify whether this trend persists.

We observed that the total abundance during the sampling period increased considerably at the beginning of the flood (Figure 6). This fact should be related to the dequada, since the most observed species are piscivores and the fish supply increases dramatically during this period. With regard to the most common species in this study, we found that *N. brasilianus, A. alba* and *B. striata* abundances also increased at the beginning of the flood. In contrast, the abundance values of A. cocoi and A. anhinga remained relatively stable. Neotropical Cormorant (*N. brasilianus*) and Great White Egret (*A. alba*) are capable of migrating (Sick 1997, Antas & Palo Jr. 2004, Barquete et al. 2008), and thus this type of movement can explain the large number of individuals of these two species observed at the beginning of the flood, since there is a large amount of food due to dequada. The data presented here suggest that large concentrations of these two taxa occur in dequada events in the Pantanal of Cáceres. However, it is necessary to confirm this hypothesis by repeating this analysis in consecutive years, and also to verify if this phenomenon occurs at other sites of the Pantanal. According to unpublished data (Kantek & Miyazaki), there was a nesting colony composed of *N. brasilianus, A. alba* and *A. cocoi* located between sites A and D, with reproductive activity in December 2011, April 2012, December 2012 and February 2013, so these birds may have taken advantage of the abundant food available during the dequada to breed. Although a white species (*A. alba*) occurs, this type of grouping is similar to the black Pantanal nests described by Willis (1995), which reported *N. brasilianus* and *A. cocoi* during periods where the river level was higher, a phenomenon that allowed these birds to forage in deep water.

The data generated in this study indicate that site A, located in the TES, had the highest abundance (Figure 4B) and richness, either in average (Figure 4A) or accumulated throughout the samples (Figure 5). Thus, we must highlight the importance of protected areas for bird conservation in the Pantanal. Currently, a very small portion (5.37%) of the biome is protected (Chaves & Silva 2018), so increasing this proportion should help to maintain existing habitat. Even out of the protected area – and therefore more altered due to anthropogenic activities – site C still contained many species of waterfowl. These data demonstrate that maintaining riverbank *habitat* can be efficient in conservation. In Brazil, these regions are protected by law through the permanent preservation areas, so that simple compliance with the law can assist in the persistence of Pantanal waterfowl communities.

Birds are a wildlife resource that is highly valued by many people and that also constitutes a sensitive and readily studied indicator of environmental health. Effective monitoring of bird populations is thus particularly important for the identification of conservation problems and needs. Sometimes, simple direct action, such as the initiation of a protection scheme or the withdrawal of a specific pesticide, may alter bird communities (Baillie 1990). Hence, future studies that utilise a same format and region to this study may be important for monitoring the TES, in order to detect possible environmental changes. In addition, subsequent research may be conducted to confirm or not the seasonal trends observed in this study, as the seasonal patterns values of richness and abundance over river water level. We also hypothesise that the dequada will continue to be a very relevant factor in the variation of the total waterfowl abundance of TES and surroundings.

The analyzes carried out in this study with water birds are foreseen in the actions proposed in the TES management plan, published in 2017. In addition, this document states that aquatic avifauna is one of the conservation targets of this protected area (ICMBio 2017). In this sense, the data obtained can be used directly to assist managers of this area, in order to provide technical support for decision making.

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n. 3, 2020

http://www.icmbio.gov.br/revistaeletronica/index.php/BioBR

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ISSN: 2236-2886