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ARTICLE

A floodplain with artificially reversed flood pulse is important for migratory and rare bird species

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ABSTRACT: Wetlands are increasingly scarce and the construction of water-flow regulation structures is predicted to increase in the coming years. The correct management of these impacted areas may play an important role in the conservation of wetland bird species. In a floodplain whose natural flood pulse was reversed in relation to local rainfall seasonality by the construction of a dam (the Tanquã floodplain), we investigated how the composition and abundance of the waterbird community varied with the water depth to understand how artificially maintained flooded areas could sustain different bird functional groups, preventing future biodiversity losses. We recorded 72 waterbird species, 17 reproducing in the area. Seventeen species are short-distance migrants in Brazil, while eight are long-distance migrants. As overall bird abundances are negatively correlated with the water depth, any further modification in the flood-pulse may cause the area to lose its ability to support its biodiversity. Future dam construction projects should take actions to transform or maintain their areas of influence as important habitats for the threatened waterbird community, thus contributing to their conservation.

KEY-WORDS: bird functional groups, dam impacts, waterbirds, wetland management, wetlands.

INTRODUCTION

As energy demand grows and governments seek for cleaner forms of energy production, the focus has been set on hydropower plants, which are responsible for approximately 16% of the global electricity consumption and is a rapidly growing industry (IHA 2015). The re-accelerating construction of hydropower dams will globally lead to the fragmentation of 25 of the 120 large river systems currently classified as free-flowing, primarily in South America (Zarfl *et al.* 2015).

Dams usually alter the river hydrology, with consequences for the associated biota, including species associated with wetlands, one of the most fragile and threatened ecosystems in the world, recognized as priority for biodiversity conservation (Amezaga *et al.* 2002). At least 64% of wetlands were lost globally during the past century (Gardner *et al.* 2015). As these areas are drained or altered, their ability to sustain viable populations of wetland-dependent organisms decreases. Waterbirds, for instance, are increasingly threatened to extinction and the successes of conservation measures are being outweighed by their negative response to habitat loss (Paszkowski & Tonn 2000, Gardner *et al.* 2015). In order to compensate for habitat loss, birds often occupy artificial wetlands, whose correct management can contribute to conservation (Ma *et al.* 2004, Acosta *et al.* 2010, Sebastián-González & Green 2016).

The region known as "Tanquã" is a floodplain located upstream from the estuary formed by the confluence of the Piracicaba and Tietê Rivers in southeast Brazil (Fig. 1). It encompasses five shallow lakes seasonally connected to the Piracicaba River and secondary channels. In 1963, the construction of Barra Bonita dam downstream from the floodplain led to the elevation of the water level and increased the magnitude of the floods, creating a more dynamic habitat. Furthermore, the dam water retention period is longer during the drier months, as its water discharge is responsible for maintaining the level of the Tietê-Parana waterway, in addition to producing electricity (Petesse *et al.* 2007). As a result, the seasonal fluctuation of the water depth was altered in Tanquã: in the wettest months Tanquã faces a drought period, with the water depth at its minimum while the dam is at its maximum discharge, but in the driest months the area is flooded because of the longer water retention period in the reservoir.

Preliminary observations indicate that this artificial hydrological cycle imposed by the dam apparently benefited several waterbird species, including rare and migratory ones, an example of what Rosenzweig (2003) called "happy accident", a human action that ends up having an unexpected positive effect on wildlife. Notwithstanding, a project to construct a new dam to expand the Tietê-Paraná waterway is planned, providing the necessary depths to new sections of the river that would cause a further rise and stabilization of the water level.

Because water depth and flood-pulses are the most important features determining the quality and quantity of habitat for waterbirds (Ntiamoa-Baidu *et al.* 1998, Lantz *et al.* 2011, Baschuk *et al.* 2012, Tavares *et al.* 2015), in this study we investigated how the composition and abundance of the waterbird community varied with the river depth seasonality, to understand how Tanquã may be impacted by the construction of new water retention structures, and how artificially maintained flooded areas could sustain different bird functional groups, preventing future biodiversity losses. In a scenario where wetlands are becoming increasingly scarce and the construction of many new water-flow regulation structures is predicted, it is essential to find solutions that take into consideration the preservation of the biodiversity of wetlands while meeting human needs. For this, properly managed artificial areas may play an important role in the conservation of waterbird species.

METHODS

Study site

The study was conducted 30 km upstream the estuary formed by the confluence of the Piracicaba and Tietê Rivers in southeast Brazil (22°39'S; 48°01'W, 452 m a.s.l.). The floodplain of 2.4 ha encompasses five shallow lakes that are seasonally connected to the Piracicaba River, forming a complex locally known as Tanquã (Fig. 1). The climate is highly seasonal, with two well-defined seasons, a warmer and humid season from October to April, with the remainder of the year being cooler and drier.

Tanquã is surrounded by pastures and sugarcane plantations, with only two small fragments remaining from the original riparian forest. The vegetation in the floodplain is composed by herbs and bushes in the dryer margins and islands, while floating and emergent macrophytes dominate the flooded areas.

Bird survey

We surveyed birds once a month from October 2014 to September 2015 (66 h of sampling effort) in seven sampling points separated by at least 500 m from each other, which were accessed by boat and permitted an unobstructed view of the birds. Points were sampled by two researchers from 07:00 h to 11:30 h for 20 min each, period in which the boat engine was turned off. The sampling order of the points was randomized for each month. All individuals resting, foraging or engaging in reproductive activities within 250 m from sampling points were recorded with the aid of Nikon Prostaff 10 × 42 binoculars. Data on the total number of individuals of each species, number of females, males, young and offspring were recorded to investigate the occurrence of reproductive activities. In addition to the quantitative survey, we made 60 h of *ad libitum* observations during the afternoons, from 15:00 h to 18:00 h to complement the bird species list. Birds were recorded with a Canon EOS 7D camera and Canon 70–300 mm lens. Some of the images were deposited in digital bases such as WikiAves and IBC (Internet Bird

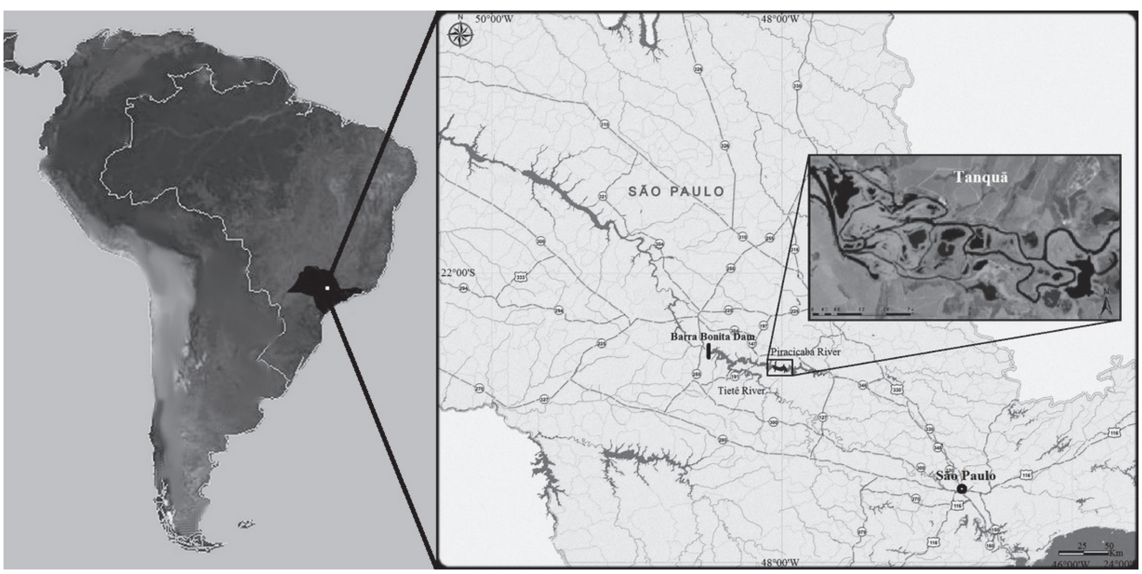

Figure 1. Location of Tanquã floodplains and Barra Bonita dam in the state of São Paulo, southeast Brazil.

Collection). Species were identified based on field guides (Novelli 1997, Sigrist 2009). Species from Scolopacidae and Charadriidae families were always photographed. The nomenclature and taxonomic arrangement follow the annotated checklist of the birds of Brazil by the Brazilian Ornithological Records Committee (Piacentini *et al.* 2015). Species conservation status in São Paulo state follows Decree 60133, from 07 February 2014 (São Paulo 2014). Migratory status follow Piacentini *et al.* (2015), while short-distance migrants were identified according to Antas (1994), Sick & Barruel (1997), and Sigrist (2009). The height of the water column of the Piracicaba River was visually monitored before the start of each bird sampling with limnimetric rulers graded every 2 cm.

To compile a species list as complete as possible, we also considered species recorded by us outside the censuses, records published in the EIA (Environmental Impacts Study) of the proposed dam ("Aproveitamento Múltiplo Santa Maria da Serra") and reliable and verified records published on WikiAves, IBC and EBird websites. To do so, records in which the photographer or researcher was known were used; when this was not possible (*e.g. Anas platalea* and *Anas georgica*) the photographer or his guide were contacted to confirm the exact location of the photo.

Data analyses

For all the analyses, only waterbird species were considered, such as typically water dependent families (Podicipedidae, Phalacrocoracidae, Anhingidae, Ardeidae, Threskiornithidae, Ciconiidae, Anatidae, Aramidae, Rallidae, Pandionidae, Jacanidae, Charadriidae, Scolopacidae, Recurvirostridae, Sternidae, Rynchopidae, Alcedinidae and Donacobiidae) and also species from families that are not typically associated to water (Anhimidae, Accipitridae, Furnaridae, Tyrannidae, Hirundinidae, and Icteridae), but depend on waterbodies for foraging or reproduction. Species that inhabited the area, but were not dependent on water bodies for foraging or reproducing, were excluded from the analyses. We estimated bird species richness using estimators Jacknife 1 and Chao 2 with the software Past (version 1.81; Hammer *et al.* 2001).

To investigate how bird traits affect their response to fluctuations in the water depth, we classified birds in functional groups using a cluster analysis carried out in FDiversity software (Casanoves *et al.* 2011). Ward's method and Gower distance were used since they are suitable for qualitative functional traits as used in this study (Schleuter *et al.* 2010). The following bird traits were used for clustering: (1) body mass (Dunning-Jr. 1992); (2) diet (fish, other vertebrates, insects or other invertebrates, benthic macroinvertebrates, macrophytes); (3) foraging substrate (water column, shores, mudflats, water surface, floating macrophytes, emerged macrophytes, water margins); and (4) migratory status (Piacentini *et al.* 2015). For the qualitative traits above, a number from one to five representing the affinity of the species with the particular trait was assigned to each species based on field observations and the literature (Sick & Barruel 1997, Sigrist 2009). A correlation analysis performed in FDiversity software was used to certify that none of the functional traits were correlated to each other.

The relationship between bird abundances (total and separated by functional groups) and water depth were tested with GLM (Generalized Linear Model) in the software R, estimating a Poisson regression model with a dispersion parameter (or quasi-Poisson), as the count data presented overdispersion. This method allows the linear model to be related to the response variable by allowing the magnitude of the variance of each measurement to be a function of its predicted value. An analysis of deviance was carried out to test all models against null models (Zuur *et al.* 2009). All eight migratory non-reproductive species whose presence in the area was not dependent on the water depth, and all 12 passerines whose counts were not always precise (see Table 1 for a list of these species), were excluded from the GLM analyses.

Ardea alba and *Nannopterum brasilianus* were recorded in aggregations too discrepant in relation to the other species in their functional groups (660 and 385, respectively), and were excluded from the functional group models as outliers. Both species are habitat generalists found in great aggregations in a variety of water bodies.

RESULTS

We recorded 72 water-depending bird species, 12 of which were recorded only during *ad libitum* observations. Species were distributed in 24 families, being Anatidae (11 species), Ardeidae (10) and Rallidae (9) the most speciose families. *Nannopterum brasilianus* was the most abundant species, followed by *Gallinula galeata*, *Ardea alba* and *Dendrocygna bicolor*. The species whose abundance varied the most were *N. brasilianus* and *G. galeata*, followed by *Himantopus melanurus* and *A. alba*. We found signs of reproduction for 17 species, and the presence of five species locally threatened by extinction, two "Near Threatened" and one listed as "Data Deficient" (Table 1). Richness estimated with Jacknife 1 was 76.42 ± 3.94 species, and with Chao 2 73.21 ± 3.40 species, figures similar to the species richness actually recorded.

The census data plus the compilation of literature and online data resulted in 94 species. Of the 22 species that were not recorded in the censuses, eight are migratory

Table 1. Monthly abundances (number of birds counted) of wetland-dependent bird species recorded from October 2014 to September 2015 in Tanquã floodplains. "x" denotes the presence of a species recoded only in *ad libitum* observations. Bird nomenclature is based on Piacentini *et al.* (2015).

Species	O	N	D	J	F	M	A	M	J	J	A	S	Group*
Anhimidae													
Anhima cornuta[1,6]												x	WS
Anatidae													
Dendrocygna bicolor[5,6]	50	44	71	24	5	12	x	x	4	100	337	9	WS
Dendrocygna viduata[5]	85	148	12	6	x	x	x		x		x	x	WS
Dendrocygna autumnalis[6]	43	47	26	21	2	5	x	x	9	x	18	5	WS
Cairina moschata				x	1								WS
Sarkidiornis sylvicola[1]						x	x	x	x	x			WS
Amazonetta brasiliensis	20	1	30	17	6	14	4	10	17	31	10	16	WS
Anas bahamensis	20	x	1	10	1		x				2	x	WS
Anas versicolor[5]	25	11	2	9	9	x	x	2	2	5	2	x	WS
Netta erythrophthalma	20			1	4	x	x	5		1		x	WS
Netta peposaca[4,5,6]	16	8	10	35	10	x	x	1	52	9	103	4	WS
Nomonix dominicus[2]						x	x				x		WS
Podicipedidae													
Tachybaptus dominicus	1			2									DP
Podilymbus podiceps[6]	3	3	3	3	2	4	7	14	6	6	3		DP
Ciconiidae													
Jabiru mycteria[1,5]		12	19	8	x	x					x	x	LP
Mycteria americana[2]	26	130	129	99	15	x	x					1	LP
Phalacrocoracidae													
Nannopterum brasilianus[5]	662	119	9	2	25	42	106	71	59	86	130	103	DP
Anhingidae													
Anhinga anhinga	x	2	x	4	3	3		1	1	1	x	1	DP
Ardeidae													
Tigrisoma lineatum	x	x	x	x	x	1	x	x	x	x		2	LP
Ixobrychus involucris									x				EM
Nycticorax nycticorax[6]	x	4	23	4	15	5	8	2	5	3	3	14	LP
Butorides striata[6]	x	x	x	4	2	25	1	4	3	1	4	5	LP
Bubulcus ibis	2	15	4		x		x				x		LP
Ardea cocoi	11	35	12	17	22	30	19	14	29	37	11	28	LP
Ardea alba	83	79	49	27	11	122	92	42	136	409	16	79	LP
Syrigma sibilatrix	x										1		LP
Egretta thula	207	110	11	9	6	48	60	19	12	12	2	58	LP
Egretta caerulea	x	x				x		x					LP
Threskiornithidae													
Plegadis chihi[5]	28	x					x						PW
Mesembrinibis cayennensis		x		x	2	x			x		x		PW
Phimosus infuscatus[5]		x	x	2	x		x	2	x	x	1	4	PW

Species	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**Group***
Theristicus caudatus	2								x	x			PW
Platalea ajaja[5]	40	22	10	x	x						x	1	PW
Pandionidae													
Pandion haliaetus[4]			1	1					1				LP
Accipitridae													
Circus buffoni[1,6]					x	1	1	x		2	1		PW
Rostrhamus sociabilis[5,6]					x	1	x		1	x	x	x	PW
Aramidae													
Aramus guarauna[6]	1		1	x	x	x	x	1	x	1		x	PW
Rallidae													
Aramides cajaneus	x	x											EM
Laterallus melanophaius[5]	4	x	1	4	1	3	2	6	6	16	1	1	EM
Laterallus exilis[3]		1	1	1	x		x		x			x	EM
Porzana flaviventer[5]			3					1		x	x	1	EM
Mustelirallus albicollis			x	x	x	x		x	x	x	x	x	EM
Pardirallus maculatus[5]			x					x		x			EM
Pardirallus nigricans[5]			x	x	x	x		x	x	x	x	x	EM
Pardirallus sanguinolentus		x	x	x	x	x	x	x	1	x	x	x	EM
Gallinula galeata[6]	468	237	117	45	60	53	21	42	36	35	89	58	WS
Porphyrio martinicus[5,6]	3	2	7	1	10	4	5	2	4	x	2	5	WS
Charadriidae													
Charadrius semipalmatus[4]				x									SW
Recurvirostridae													
Himantopus melanurus[6]	393	53	3	x	x	x	x	x	x	x	x	x	PW
Scolopacidae													
Gallinago paraguaiae									x				PW
Tringa flavipes[4]	13			x	x								SW
Tringa melanoleuca[4]	86			1									SW
Tringa solitaria[4]	5	x	x										SW
Calidris melanotos[4]				2									SW
Calidris fuscicollis[4]				x									SW
Jacanidae													
Jacana jacana[6]	40	48	26	48	43	46	31	42	51	50	111	68	WS
Sternidae													
Phaetusa simplex[1]		2			x	x	x		x	3		x	DP
Rynchopidae													
Rynchops niger		1		x	x		1	x		x	x	x	DP
Alcedinidae													
Megaceryle torquata		x	x	x	2	x	1	1	1	1	2	x	DP
Chloroceryle amazona	x	x	2	x		x	x	x	1	x		x	DP

Species	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**Group***
Furnaridae													
Certhiaxis cinnamomeus[6]	x	x	x	x	x	x	x	x	x	x	x	x	-
Cranioleuca vulpina							x	x					-
Tyrannidae													
Pseudocolopteryx sclateri					1				1	x	1	x	-
Fluvicola albiventer	x	x	x	1	x	x	x	x	x	x	x	x	-
Fluvicola nengeta	x		x	x		2	x	x	x	x	x	x	-
Arundinicola leucocephala		x	x	1	x		x	x	x			x	-
Gubernetes yetapa				x									-
Hirundinidae													
Tachycineta albiventer[5]			1	x	x	x		2	x		1		-
Donacobiidae													
Donacobius atricapilla[6]			1	x	x	1	x	1	x	1			-
Icteridae													
Agelasticus cyanopus	x	x	x	x			x		x	x			-
Chrysomus ruficapillus	x	x	x	x	x	x	x	x	x	x	x	x	-
Pseudoleistes guirahuro					x	x	x						-

[1] – Threatened to extinction (São Paulo 2014)
[2] – Near Threatened (São Paulo 2014)
[3] – Data Deficient (São Paulo 2014)
[4] – Migratory species (Piacentini *et al.* 2015)
[5] – Short-distance migrant species (Antas 1994, Sick & Barruel 1997, Sigrist 2009)
[6] – Species with evidences of reproduction
* – Functional groups generated in the cluster analyses (PW = Probing waders, SW = Small waders; LP = Large piscivores, DP = Diving piscivores, EM = Emerged macrophytes, and WS = Water surface).

that nest in the Northern Hemisphere and spend only a few days in Tanquã, and four species make seasonal movements throughout the country (Appendix I).

Twenty-one species (29.5%) were recorded in more than 90% of the sampling months, being considered residents, while 67.8% of the species were recorded in at least half of the samplings, thus considered common in the area. Eighteen species are short-distance migrants in Brazil, and eight are classified as non-reproductive long-distance migrants, although we found more than one nest and several juveniles of one of these species (*Netta peposaca*). Except from *N. peposaca*, which was present all year round, the other migratory species visited the area from October to February (Table 1).

The cluster analysis generated six functional groups with a cophenetic correlation coefficient from the distance matrix of 0.73. These groups where classified as (1) *Probing waders*: species that forage mainly on the shores and exposed mudflats, feeding primarily on macroinvertebrates in the mud, (2) *Small waders*: mainly sandpipes and plovers, this group comprises small migratory species (up to 60 cm) that eat small invertebrates picked out of the mud or soil, (3) *Large piscivores*: species that mostly capture fish and other prey while foraging in shallow areas near the shore, without diving, (4) *Diving piscivores*: birds that dive for fishes and other prey, (5) birds that forage on *Emerged macrophytes*: small and inconspicuous species (mainly rails) found in the dense vegetation that surround the water, and (6) birds that feed on the *Water surface*: a group congregating species that forage by filtering organisms in the water surface, or spend most of the time floating in the river surface while searching for food (Table 1). Large piscivores and birds that feed on the Water surface were the most abundant groups, accounting for 87.3% of the total abundance.

The water depth varied monthly from 5.3 m to 9.6 m, while monthly bird abundance ranged from 294 to 2411 individuals, and species richness varied from 24 to 35. Richness was not correlated to water depth ($R^2 = 0.016$, $P = 0.4$), but total bird abundance was negatively correlated to it (pseudo $R^2 = 0.36$ $P = 0.041$) (Fig. 2, Table 2). The functional groups responded differently to fluctuations in water depth. The abundances of Water surface, Large piscivores and Probing waders were negatively correlated to water depth, while models for Emerged macrophytes and Diving piscivores groups were non-significant (Fig. 3, Table 2).

Table 2. Analysis of deviance table for the GLM testing the relationship between the total bird abundance and abundances of functional groups with the water depth.

	Residual *df*	Residual Deviance	*df*	Deviance	*F*	*P(>F)*
Null	11	3964.50				
Total abundance	1	1463.80	10	2500.70	5.48	0.041
Null	11	696.76				
Large piscivores	1	557.95	10	138.81	44.45	<0.01
Null	11	2019.55				
Probing waders	1	803.11	10	1216.40	13.77	<0.01
Null	11	24.49				
Diving piscivores	1	2.53	10	21.97	1.29	0.283
Null	11	36.18				
Emerged macrophytes	1	7.08	10	29.11	2.39	0.153
Null	11	1893.00				
Water surface	1	677.89	10	1215.10	4.68	0.055

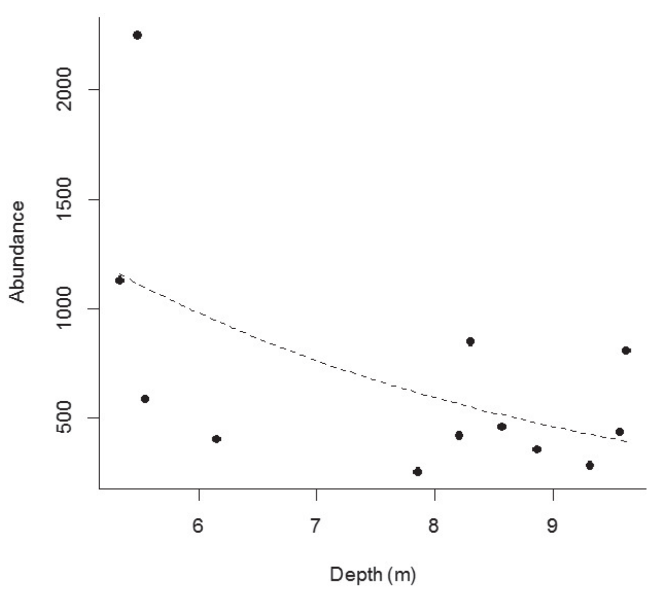

Figure 2. Quasi-Poisson regression model showing the response of total bird abundance to variation in the water depth.

DISCUSSION

The importance of Tanquã for birds

Compared to other wetlands in southeast Brazil, Tanquã have the highest number of water-dependent bird species, representing 53.3% (or 69.6% if we add the species reported in the literature and online data) of all 135 wetland species found in the Atlantic Forest Biome (Moreira-Lima 2013). In a natural coastal lagoon in Rio de Janeiro state, 46 water-dependent bird species were recorded (Tavares & Siciliano 2014), 37 (Faria *et al.* 2006) and 27 species (Rodrigues & Michelin 2005) were recorded in Minas Gerais state, while in São Paulo state, 51 (Crozariol 2010), 49 (Schunck *et al.* 2016), and 39 (Schunck & Rodrigues 2016) water-dependent species were found.

Apart from the high bird species richness, Tanquã is important for rare, migratory and locally threatened species. Eight threatened (*Anhima cornuta*, *Sarkidiornis sylvicola*, *Ciconia maguari*, *Jabiru mycteria*, *Busarellus nigricollis*, *Circus buffoni*, *Phaetusa simplex* and *Sternula superciliaris*) and five "Near Threatened" species (*Nomonyx dominicus*, *Mycteria americana*, *Tryngites subruficollis*, *Pluvialis dominica* and *Gallinago undulata*) (São Paulo 2014) occur at the area (Table 2). Other noteworthy bird records are (1) *N. peposaca*, a migratory species that nests west of Brazil or in the south of the country (Antas 1994), but was found all year around and reproducing in Tanquã, the first place outside of the south region of Brazil where reproductive activities were recorded. (2) *M. americana* was recorded in 50% of surveys and in flocks of up to 150 individuals. This species also migrates through the Paraná River Valley, staying in the Pantanal from November to April where it breeds and then migrates to feeding areas in Rio Grande do Sul, south Brazil (Antas 1994). This is the same period when the species was found in Tanquã, but we could not find any signs of reproduction. Many of the birds we recorded were juveniles that could be using the area only for foraging. (3) *Pseudocolopteryx sclateri*, a bird discovered in the state of São Paulo only in 2009, with pairs engaging in mating activities at Tanquã. (4) *Porzana flaviventer*, a bird common in Tanquã, but rarely seen in other parts of Brazil whose biology and regional movements are not yet understood in the country.

Only 29.5% of the species recorded were residents,

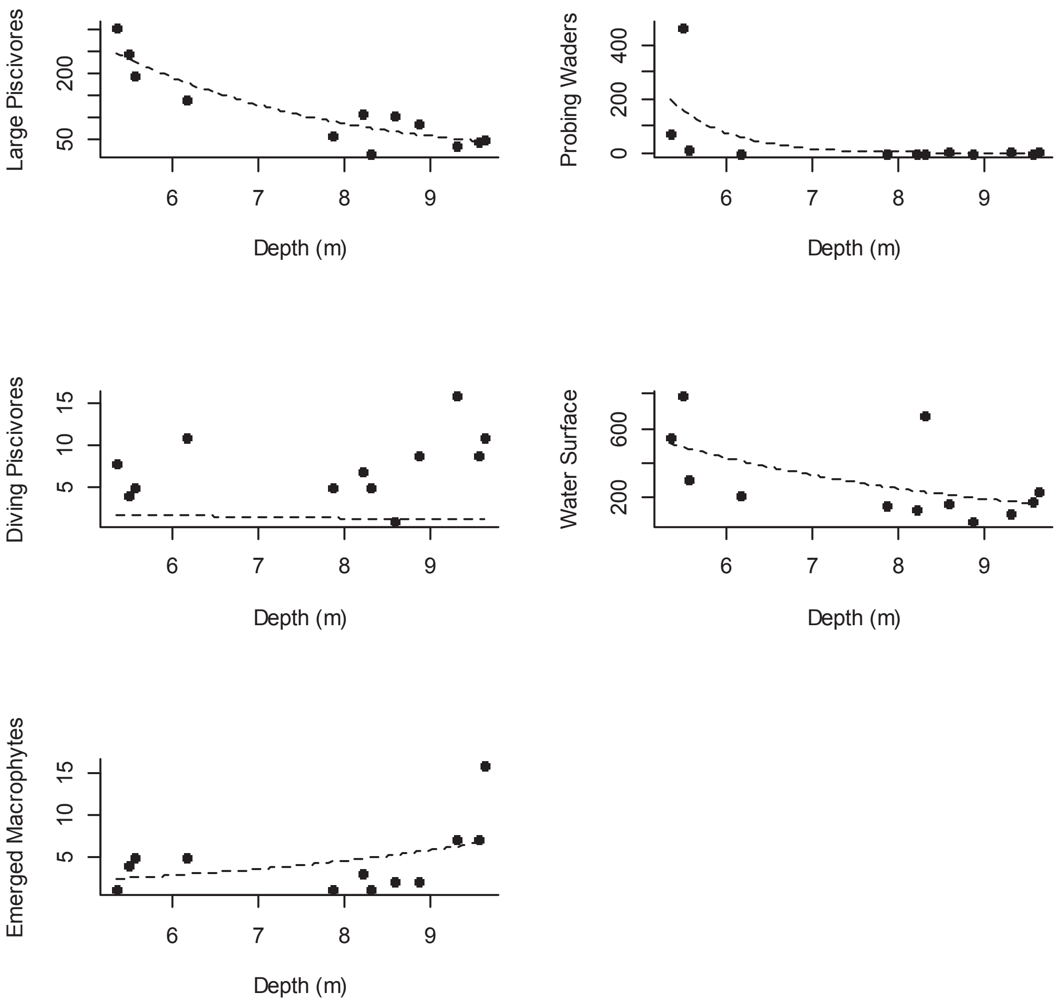

Figure 3. Quasi-Poisson regression model showing the response of the abundances of different bird functional groups to variation in the water depth.

while several species make seasonal movements within the Brazilian territory, migrating through the Paraná River Valley, from south Brazil to the Pantanal region (*e.g.*, *J. mycteria*; Antas 1994). Valente *et al.* (2011) produced the first catalogue of important areas for Nearctic migratory birds in Brazil, highlighting six sites in southeastern Brazil. The number of species classified as non-reproductive long-distance migrants (according to Piacentini *et al.* 2015) recorded in our censuses (8 species) is similar to the average species richness recorded at these areas (8.14 ± 3.02 species), but our literature review raises this number to 16 species, thus corroborating the importance of Tanquã for Nearctic birds in Brazil.

Mehlman *et al.* (2005) analyzed the importance of migratory passerine stopover sites in the Northern Hemisphere and generated a useful scale for their categorization. Although designed for terrestrial birds, Kirby *et al.* (2008) considered this typology adaptable to other groups of migratory birds. Type 1 sites ("fire-escape"), usually small, isolated habitats surrounded by unsuitable habitat that are rarely used but vital in emergencies. Type 2 sites ("convenience store") are structurally heterogeneous sites with freshwater and a variety of food resources where birds can rest briefly (two days or less) and easily replenish body reserves. Type 3 sites ("full service hotel") are extensive areas suitable for migratory birds, where all the necessary resources are relatively abundant and available. Type 3 sites can sustain many individuals of many species that can remain there for weeks allowing them to achieve the physiological conditions necessary to continue their migration to the next stop or final destination. We believe that Tanquã can be classified as a type 2 or 3 stopover site, because large agglomerations of species from the families Scolopacidae and Charadriidae were found during their wintering periods in Brazil. These families comprise several migratory species that require newly exposed mud to forage (Sick & Barruel 1997). The energy accumulated in sites like Tanquã is likely important for these species to return to the Northern Hemisphere, as food obtained in stopovers sites provides energy to migration (Davison & Evens 1988), and the increase in nutritional reserves is essential to further reproductive success (Hvenegaard & Barbieri 2010).

Seasonality in the water depth and its effects upon birds

In the rainy season, the water level falls because the power plant is operating and the water is flowing fast out of Tanquã. As a result, the higher abundance of birds observed in this period may be due to the availability of shallow waters, which increase prey concentrations (Macedo-Soares *et al.* 2010, Tavares & Siciliano 2014), and recently exposed mudflats occurring concomitantly with the arrival of migratory species that feed on this microhabitat. Shallow waters and recently exposed mudflats are likely scarce in the region in the rainy season, making Tanquã an important feeding site for birds.

The abundances of birds of the Water surface, Large piscivores, and Probing waders groups were negatively correlated with the water depth. Species from the Water surface group forage by filtering organisms in the water surface; when the water level raises, water surface increases and vegetation become scarce. Baschuk *et al.* (2012) observed that it is easier for dabbling ducks to access submerged aquatic vegetation in shallow waters. Lack of vegetation may also increase the risk of duck predation. Furthermore, shallow lakes were considered preferred habitats for ducks in previous studies (Paszkowski & Tonn 2000, Tavares *et al.* 2015). The Large piscivores group may be influenced by water depth because of their foraging behavior, as they tend to capture fish in shallow areas near the shore. When the water level rises it gets more difficult to capture their prey due to an increase in the dimensional space (Ntiamoa-Baidu *et al.* 1998, Lantz *et al.* 2010). The water depth has also a strong influence in vegetation cover (Padial *et al.* 2009, Ma *et al.* 2010) that may act as a barrier reducing visibility to detect predators. Species in the Probing waders group have a preference for foraging mainly on the shores and exposed mudflats (Tavares *et al.* 2015), a microhabitat that temporarily disappear with the rise of the water level.

Abundance of Emerged macrophytes and Diving piscivores groups were not correlated with water depth. However, the Emerged macrophytes group is composed of several small and inconspicuous species that are recorded mainly by their vocalizations. Because these species sing more frequently during the reproductive period, their abundance may have been underestimated during other seasons. Although the abundance of Diving piscivores was not significantly related to the river depth, previous studies have shown that aerially foraging and diving piscivores could be favored by higher water levels (Paszkowski & Tonn 2000, Paillisson *et al.* 2002, Baschuk *et al.* 2012). Our results show that any rise in the water level can negatively affect bird abundance, especially for species in the Large piscivores, Water surface and Probing waders functional groups. Therefore, the predicted alteration of the current flood cycle by the construction of the planned new dam (called *Aproveitamento Múltiplo Santa Maria da Serra*) carries a real risk of threatening several elements of the local bird community.

In summary, Tanquã is a large floodplain with high environmental heterogeneity offering a mosaic of habitats, ranging from exposed mudflats to open water of variable depth, with remarkable temporal changes in environmental characteristics. The seasonal fluctuation of the water level, heterogeneity of habitats, and the size of the floodplain may be the reasons why so many waterbirds species occurring in high abundances were recorded, as these are among the main factors influencing bird abundance in wetlands (Paracuellos & Tellería 2004). Any further infrastructure project that would maintain Tanquã permanently flooded will lead it to lose its ability to support such a diverse community of waterbirds.

Apparently, the artificial flood regime imposed by the Barra Bonita dam counteracted the damage expected from the construction of the power plant. As such, the Tanquã "happy accident" showed that, by reproducing natural cycles of floodplains during their operation, existing and future power plant projects may take actions to transform or maintain their areas of influence as important habitats for the threatened aquatic bird community. Future studies need to focus on better understanding such actions, which likely includes regulatory provisions foreseeing the establishing of a monomodal flood-pulse when possible. As different bird groups are differently influenced by the water level and its variation, maintaining a monomodal and annual flood pulse contributes to the maintenance of a high species and functional diversity in wetlands. When appropriate flood-pulse regulation is not an option, then the creation of habitat heterogeneity, such as shallow shorelines or island development should be recommended as mitigation and restoration actions in response to dam construction (Desgranges *et al.* 2006). As smaller dams probably offer more manageable options and opportunities, they should be taken into consideration when establishing investment priorities and financing towards new dam projects, either for power generating or any other uses.

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APPENDIX I

A complete list of bird species recorded in Tanquã based on field samplings, bibliographic records, online records published in Wikiaves, IBC and EBird. Bird nomenclature is based on Piacentini *et al.* (2015).

Species	**Censuses Out/14 -Set/15**	**Other field visits**[1]	**EIA *Aproveitamento Múltiplo Santa Maria da Serra*"**	**Internet Collections**	**Status in Brazil**[2]	**Conservation status in São Paulo**[3]
Anhimidae						
Anhima cornuta	x	x		x	R	T
Chauna torquata				x	R	DD
Anatidae						
Dendrocygna bicolor	x	x	x	x	R	
Dendrocygna viduata	x	x	x	x	R	
Dendrocygna autumnalis	x	x	x	x	R	
Coscoroba coscoroba				x	R	
Cairina moschata	x	x	x	x	R	
Sarkidiornis sylvicola	x	x	x	x	R	T
Amazonetta brasiliensis	x	x	x	x	R	
Anas georgica				x	R	
Anas bahamensis	x	x	x	x	R	
Anas versicolor	x	x	x	x	R	
Anas discors		x		x	VN	
Anas platalea				x	VS	
Netta erythrophthalma	x	x		x	R	
Netta peposaca	x	x	x	x	VO	
Nomonyx dominicus	x	x		x	R	NT
Podicipedidae						
Tachybaptus dominicus	x	x	x	x	R	
Podilymbus podiceps	x	x	x		R	
Podicephorus major				x	R	
Ciconiidae						
Ciconia maguari			x		R	T
Jabiru mycteria	x	x		x	R	T

Species	Censuses Out/14 -Set/15	Other field visits[1]	EIA *Aproveitamento Múltiplo Santa Maria da Serra*"	Internet Collections	Status in Brazil[2]	Conservation status in São Paulo[3]
Mycteria americana	x	x	x	x	R	NT
Phalacrocoracidae						
Nannopterum brasilianus	x	x	x	x	R	
Anhingidae						
Anhinga anhinga	x	x	x	x	R	
Ardeidae						
Tigrisoma lineatum	x	x		x	R	
Ixobrychus involucris	x	x		x	R	
Nycticorax nycticorax	x	x	x	x	R	
Butorides striata	x	x	x	x	R	
Bubulcus ibis	x	x	x	x	R	
Ardea cocoi	x	x	x	x	R	
Ardea alba	x	x	x	x	R	
Syrigma sibilatrix	x	x	x	x	R	
Egretta thula	x	x	x	x	R	
Egretta caerulea	x	x		x	R	
Threskiornithidae						
Plegadis chihi	x	x	x	x	R	
Mesembrinibis cayennensis	x	x		x	R	
Phimosus infuscatus	x	x		x	R	
Theristicus caudatus	x	x	x	x	R	
Platalea ajaja	x	x	x	x	R	
Pandionidae						
Pandion haliaetus	x	x	x	x	VN	
Accipitridae						
Circus buffoni	x	x		x	R	T
Busarellus nigricollis			x	x	R	T
Rostrhamus sociabilis	x	x	x	x	R	
Aramidae						
Aramus guarauna	x	x	x	x	R	
Rallidae						
Aramides cajaneus	x	x	x	x	R	
Laterallus melanophaius	x	x	x	x	R	
Laterallus exilis	x	x		x	R	DD
Porzana flaviventer	x	x		x	R	
Mustelirallus albicollis	x	x	x	x	R	
Pardirallus maculatus	x	x		x	R	
Pardirallus nigricans	x	x	x	x	R	
Pardirallus sanguinolentus	x	x	x	x	R	
Gallinula galeata	x	x	x	x	R	
Porphyrio martinicus	x	x	x	x	R	

Species	Censuses Out/14 -Set/15	Other field visits[1]	EIA *Aproveitamento Múltiplo Santa Maria da Serra*"	Internet Collections	Status in Brazil[2]	Conservation status in São Paulo[3]
Porphyrio flavirostris				x	R	
Fulica leucoptera		x		x	R	
Charadriidae						
Pluvialis dominica			x	x	VN	NT
Charadrius semipalmatus	x	x		x	VN	
Charadrius collaris		x		x	R	
Recurvirostridae						
Himantopus melanurus	x	x	x	x	R	
Scolopacidae						
Gallinago paraguaiae	x	x	x	x	R	
Gallinago undulata			x		R	NT
Limosa haemastica				x	VN	
Actitis macularius		x	x	x	VN	
Tringa solitaria	x	x	x	x	VN	
Tringa flavipes	x	x	x	x	VN	
Tringa melanoleuca	x	x	x	x	VN	
Calidris fuscicollis	x	x	x	x	VN	
Calidris melanotos	x	x	x	x	VN	
Calidris pugnax				x	VN	
Calidris subruficollis				x	VN	NT
Phalaropus tricolor		x		x	VN	
Jacanidae						
Jacana jacana	x	x	x	x	R	
Rostratulidae						
Nycticryphes semicollaris			x		R	DD
Laridae						
Chroicocephalus maculipennis				x	R	
Sternidae						
Sternula superciliaris				x	R	T
Phaetusa simplex	x	x	x	x	R	T
Rynchopidae						
Rynchops niger	x	x	x	x	R	
Alcedinidae						
Megaceryle torquata	x	x	x	x	R	
Chloroceryle amazona	x	x	x	x	R	
Chloroceryle americana			x	x	R	
Furnariidae						
Certhiaxis cinnamomeus	x	x	x	x	R	
Cranioleuca vulpina	x	x		x	R	
Tyrannidae						
Pseudocolopteryx sclateri	x				R	

Species	Censuses Out/14 -Set/15	Other field visits[1]	EIA *Aproveitamento Múltiplo Santa Maria da Serra*"	Internet Collections	Status in Brazil[2]	Conservation status in São Paulo[3]
Fluvicola albiventer	x	x	x	x	R	
Fluvicola nengeta	x	x		x	R	
Arundinicola leucocephala	x	x	x	x	R	
Gubernetes yetapa	x	x	x	x	R	
Hirundinidae						
Tachycineta albiventer	x	x	x	x	R	
Donacobiidae						
Donacobius atricapilla	x	x	x	x	R	
Icteridae						
Agelasticus cyanopus	x	x		x	R	
Chrysomus ruficapillus	x	x		x	R	
Pseudoleistes guirahuro	x	x		x	R	

[1] Species recorded in field visits performed before or after the censuses conducted between October 2014 and September 2015.
[2] R = resident; VS = Seasonal visitor from the south of the continent; VN = Seasonal visitor from the Northern Hemisphere; VO = Seasonal visitor coming from west of the Brazilian territory (Piacentini *et al.* 2015).[3] T = Threatened by extinction, NT = Near Threatened and DD = Data Deficient (São Paulo 2014).