RESEARCH ARTICLE

Effects of ecological and anthropogenic factors on waterbird abundance at a Ramsar Site in the Yangtze River Floodplain

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Abstract Continuing declines in abundance of many waterbird species on wetland ecosystems require explanations to support effective management interventions. We used 6 year survey data from Shengjin Lake National Nature Reserve in the Yangtze River Floodplain, China, to study the effects of ecological and anthropogenic variables as determinants of waterbird species abundance. Our results showed that effects were guild-dependent, although distance to nearest human settlements had the largest adverse effects on bird abundance across all guilds. These results suggested that although the abundance of waterbird species could be affected by habitat conditions and buffalo grazing activities, Yangtze River Wetlands would most likely benefit most from reduced pressure from the proximity to the surrounding human population. We suggest that screening and/or restricting public access at some key sites may be the most cost-efficient way to restrict or reduce human activity in these wetlands, to improve the conservation status and wintering conditions for these waterbirds.

Keywords Conservation · Feeding guilds · Waterbirds · Wetland management · Yangtze Wetlands

INTRODUCTION

Wetlands provide a range of important ecosystem services, e.g., flood control and water quality moderation, as well as providing habitats that support a rich biodiversity (Keddy 2010). However, wetlands are currently among the most

threatened of all habitats; over 50% of wetlands have been lost and the rate of wetland loss has also increased steeply over the last century, adversely affecting the ecosystem services that they provide (Davidson 2014). Conservation actions, therefore, are urgently required, both to maintain these ecological services and to sustain the species reliant on wetland habitats.

Many waterbird species rely on wetlands for all or part of their life cycle. The distribution and abundance of these species can be affected by various ecological and anthropogenic factors. Understanding how ecological and human factors interact to affect their relative distribution and abundance is complicated by the fact that species of different feeding guilds exploit different facets of a wetland ecosystem. Foraging habitat patch size is one of the most important factors influencing avian habitat selection and thereby the abundance and density of a species (Riffell et al. 2001; Davis 2004). Hence, we expect that land area is one of the most important factors positively correlated with the abundance of many waterbird guilds that forage on these areas. For dabbling duck and diving birds, as they forage on water, the size of water area is expected to be a good estimator. Optimal foraging theory predicts that animals should select patches offering the highest forage intake (Werner and Hall 1974), and forage biomass has been found to play an important role in determining patch selection of organisms (Froneman et al. 2001; Chudzińska et al. 2015). Grazing waterbirds, such as geese, often selected patches offering the highest nitrogen intake (Zhang et al. 2016), and nitrogen content generally decreases with increasing sward height (Prop and Vulink 1992). A global study also showed that seasonal variation in vegetation biomass is one of the most important predictors of waterfowl species richness (Dalby et al. 2014). For wading birds, for which the foraging success depends

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on invertebrate prey availability, vegetation biomass may be negatively correlated with avian abundance as habitats with higher vegetation biomass reduce prey detection and adversely affect foraging success, with the result that waders select areas with lowest vegetation biomass (Lantz et al. 2011).

More importantly, an expanding human population and the unsustainable use of wetland resources mean that anthropogenic factors play an increasing role in determining bird abundance (Lepczyk et al. 2008). Human activities directly or indirectly influence waterbird habitat selection and abundance in wetlands (Madsen and Fox 1995; de Boer et al. 2011; Fox and Madsen 2017). Quan et al. (2002) showed that waterbird abundance was strongly negatively correlated with frequency of disturbance attributable to humans, but not with habitat quality. Activities associated with aquaculture, especially as a result of associated boat traffic, also tend to reduce waterbird abundance in open water areas (Bajer et al. 2009; Fox et al. 2011). Hence, the human-induced disturbance factors, such as the number of boats on the lake and the human settlements surrounding the waterbird habitats, are predicted to reduce waterbird abundance across all feeding guilds.

Human disturbance reduces avian foraging time through increased time spent vigilant or flying from disturbance loci, and thereby reduce profitability of patches, resulting in lower bird densities (Martin et al. 2015). However, waterbirds may also benefit from human activities, such as livestock grazing (by, e.g., buffalo or sheep), which may create and maintain shorter swards of favoured grass species, thereby facilitating grazing by herbivorous birds (Zhang et al. 2015a) and creating attractive habitats for wader species (Sabatier et al. 2010). Moreover, bird species foraging together with larger livestock species may also share vigilance, and benefit from improved predator detection (Fitzgibbon 1990).

Thus, different waterbird species respond differently to these ecological and anthropogenic factors, depending on habitat preference, diet, and body size (Tavares et al. 2015). Hence, policymakers and managers often face dilemmas regarding the timing and type of measures taken to maximize conservation benefits. To date, conservation measures aimed to safeguard waterbirds species often tend to target the protection of single species. Analysing the effects of ecological and anthropogenic factors on avian feeding guilds may represent a first step in developing effective conservation actions for waterbirds (Canterbury et al. 2000). Currently, conservation measures include actions such as habitat restoration, local community education, financial compensation for crop damage, or food provisioning. Waterbirds may also benefit from habitat creation as a result of anthropogenic activities (e.g., wetland creation after mineral extraction; Fox and Salmon

1989). However, while such actions may be helpful, they may not always halt declining trends in population sizes (Zhang et al. 2015b). More research efforts are urgently needed to guide conservation actions and improve their effectiveness.

Wetlands in the Yangtze Floodplain are globally unique for their extensive ephemeral lakes, recharged with water, sediments, and nutrients by spring and summer monsoonal rains. Because of the spring/summer recharge, autumn drawdown, and large annual variation in water levels, these Yangtze Wetlands are exceptional in their ability to produce a large pulse of plant and animal biomass as food for a range of waterbird species. The floodplain supported in excess of 1 million waterbirds in 2004 and 2005, including the entire populations of several globally threatened species (Cao et al. 2010). Although the distributions and abundance of birds may have changed recently, it is still, by far, the most important wintering region in China for migratory waterbirds. In addition, the Yangtze Watershed supports 29% of China's human population and generates 40% of the national GDP (Wang et al. 2017). China's current economic growth has accelerated wetland destruction and habitat loss, and triggered declines in waterbird species diversity and population size (Ma et al. 2009; de Boer et al. 2011). For this reason, the potential conflicts between economic activities and wetlands conservation need urgent attention.

In this paper, we studied the effects of ecological and anthropogenic factors on the abundance of several guilds of waterbird species in the Shengjin Lake National Nature Reserve by testing whether a set of human and ecological factors were positively or negatively correlated with guild abundance (Table 1).

MATERIALS AND METHODS

Study area

This study was conducted in Shengjin Lake National Nature Reserve (30°16'–30°25' N, 116°59'–117°12' E), designated as a Ramsar Site in 2015, located on the southern bank of the Yangtze River, China. In the wet season (summer), the maximum lake area is about 14 000 ha. However, the lake area decreases to about 3400 ha in the dry season (winter) when the water recedes. The lake is connected to the Yangtze River via the Huangpen Sluice, built in 1965 to regulate water level for supporting agricultural and aquacultural activities and to control flooding (Fig. 1).

The Shengjin Lake National Nature Reserve is one of the most important wetlands in the Yangtze Floodplain because of the high diversity of wintering migrating

Table 1 Independent variables and their predicted relationships with bird abundance for each of the bird guilds. Water area (WA), land area (LA), normalized difference vegetation index (NDVI), distance to the nearest settlement (DH), number of boats at anchor (BA), number of domestic geese (GOOSE), and number of buffalos (BUFF)

Species	LA (km ²)	WA (km ²)	NDVI	DH (m)	BA	GOOSE	BUFF
Dabbling duck	+			+	–	–	
Diving birds		+		+	–	–	
Grazing birds	+		+	+	–	–	+
Tuber-feeding birds	+		+	+	–	–	
Larger wading birds	+		–	+	–	–	+
Smaller wading birds	+		–	+	–	–	+

+, Predicted positive effect; –, predicted negative effect; blank, predicted no effect

waterbirds, including some endangered and vulnerable species (IUCN 2015), yet around 20 000 people currently live within its boundaries.

Wintering waterbird surveys and definitions of bird guilds

Waterbird point counts were carried out during winter (October–April) for the winters between 2008/2009 and 2013/2014. To support a statistical analysis drawing on factors derived from satellite images, surveys were only conducted on days when satellite images were taken, and the survey methods followed Cao et al. (2011) and Zhang et al. (2015a). In brief, the counts were carried out as follows: Shengjin Lake was divided into 59 survey areas, defined by natural boundaries and features, covered from 56 counting points established to ensure that the birds could be seen and species identified across each of the survey areas, and that the entire lake was completely sur-

Fig. 1 Location of Shengjin Lake in China. The circles indicate survey counting points (56 in total) and the triangle indicates the location of the Huangpen Sluice

veyed (Fig. 1). A survey was conducted by two teams of two persons on 2 days, recording species richness and abundance of all waterbird species per survey area. In total, 22 waterbird surveys for Shengjin Lake were carried out.

All bird species were assigned to different guilds according to their foraging habitat, diet, and morphology (O’Connell et al. 2000; Tavares et al. 2015). Species that were infrequently recorded (counted on < 3 occasions) were excluded from the analysis. We classified all waterbird species into six different guilds: diving birds, dabbling ducks, grazing birds, tuber-feeding birds, larger waders, and smaller waders (Table S1).

Ecological variables

We used NDVI as an indicator of plant biomass (Tucker 1979) to test for the effects of forage availability on waterbird abundance, as a good NDVI–vegetation relationship was found in the study area previously (Zhang et al. 2015a). Note that all count areas within the study area comprise semi-natural (not agricultural) vegetation for which NDVI measures were derived, because unlike in Europe and North America, Chinese geese are largely restricted to foraging on the grassland within the wetland areas (Yu et al. 2017). Similarly, areas of floating (e.g., *Trapa* spp.) and emergent (e.g., *Zizania* spp.) vegetation were also excluded from NDVI measures by implementation of the criteria applied to delineate water areas (see “Methods”). The previous positive relationships between vegetation biomass and waterfowl abundance have been demonstrated (Marklund et al. 2002), and we predicted that the abundance of grazing birds would be positively correlated with NDVI because of their reliance on such habitats. However, we predict no such relationship for dabbling ducks (which tend to forage along water edges and in shallow water) or diving birds (selecting for open water), which we predict would avoid areas of highest vegetation biomass. For wading birds of all sizes, high vegetation biomass renders invertebrates inaccessible (Fuller 2012). Hence, we predicted a negative relationship between NDVI and the abundance of waders (Table 1).

Bird abundance generally increases with increasing patch size (Connor et al. 2000). We, therefore, also related the abundance of birds per guild to their prime habitat type, i.e., either water or land surface areas, with the expectation that the abundance of dabbling duck, grazing bird, tuber-feeding birds, and large and small waders will be positively correlated with the land area, whereas diving birds are more likely to be positively correlated with water area.

NDVI data for land area were calculated using Multispectral HJ-1A, Landsat Thematic Mapper (TM), and Enhanced Thematic Mapper+ (ETM+) images (with a consistent spatial resolution of 30 m), captured around our

survey dates with less than 10% cloud cover. A gap-filling method based on local linear histogram matching (Scaramuzza et al. 2004) was used to fill the missing data on the edges of the ETM+ image (about 5% of our study area) due to the sensor failure of Landsat 7 in 2003. Image calibration, atmospheric correction, and geometric correction were then conducted, and pseudo-invariant features were used to normalize all images to allow for comparison between data sets.

A support vector machine method was employed to discriminate between water and land within each study area over the whole study period. Furthermore, we applied an NDVI threshold (with a value of 0.18) to distinguish between bare soil and meadows. For full details of these methods, see Zhang et al. (2015a).

Anthropogenic variables

Potential anthropogenic factors, including the number of domestic geese, domestic buffalos, and boats at anchor (as a measure of point-specific disturbance as well as general fishing activity in the immediate area), were recorded for each survey area during each survey. As normal practice within the protected area, farmers fed domestic geese (in flocks of up to several thousand released to feed in the nature reserve by day but gathered and penned at night) and domestic buffalos grazed on the grasslands used by wild birds within the study area. The number of domestic geese present was considered to represent a measure of the potential for interspecific competition and we predicted an adverse effect of their abundance. Domestic buffalos can remove tall vegetation by grazing (Fuller 2012), and, therefore, create grasslands of reduced biomass and more open structure that grazing birds and waders select as they benefit from the higher food accessibility. We, therefore, predicted that the number of buffalos would be positively correlated with the abundance of geese species and waders. The number of boats at anchor, a potential source of human disturbance, was predicted to have a negatively effect on bird abundance for all species, because they introduced a source of water-borne activity to all areas of the wetlands within each survey area.

The distance to the nearest settlement, determined as the shortest distance from the centre of each survey area to the nearest inhabited building (Longoni et al. 2011), was also included in the analyses as a proxy for the effects of general human activities that are likely to impact local bird abundance. We predicted that with increasing distance to the nearest settlement, waterbird abundance will also increase. The distance to the nearest settlement was measured by Google Earth with a DigitalGlobe high-resolution image taken on 22 December 2013.

Statistical analyses

The waterbird count data included many zero counts, and to deal with data over-dispersion and the problem of pseudo-replication, we fitted a zero-inflated negative binomial generalized linear mixed model (GLMM) for each guild separately, followed by model averaging. Month, year, and site were included as random effects. Before fitting the GLMMs, we also assessed multicollinearity by examining the variance inflation factors (VIFs) of the candidate variables. All VIF values were less than 2, indicating that there was a little collinearity among variables (O'Brien 2007). All possible subset models were ranked according to Akaike's information criterion for small sample size (AIC_c), and Akaike weights (ω_i) were calculated to estimate the likelihood of each model (Burnham and Anderson 2002). Model averaging was subsequently applied to obtain parameter estimates for these variables. The model averaging calculation was done on the most parsimonious models using a cut-off $\Delta AIC_c \leq 2$ (Burnham and Anderson 2002). We thereafter estimated the relative importance of the variables by summing the Akaike weights across all models where a certain variable was included (Burnham and Anderson 2002). A generalized additive model (GAMM) was further used to test for the effect of the most important variables determining the abundance of birds in each of the guilds. Month, year, and site were included as random variables in the GAMM. We calculated Moran's I indices for each guild and found a little evidence for spatial autocorrelation (all $|Moran's I| < 0.04$), suggesting that spatial autocorrelation was not a point of concern in our analysis. All statistical analyses were conducted in R 3.1.2 with the package glmmADMB, MuMIn, mgcv, and ape.

RESULTS

In total, 584 684 grazing birds (76.1%), 75 185 dabbling ducks (9.8%), 44 457 smaller waders (5.8%), 41 754 larger waders (5.4%), 15 805 tuber-feeding birds (2.1%), and 6300 diving birds (0.8%) were counted in 22 surveys (Table S1). The assemblage of Shengjin Lake was characterized by a relatively high abundance of Anatidae species (> 86% of waterbirds counted).

All potential predictor variables were frequently included in the best fitting statistical models ($\Delta AIC_c < 2$), correlated with the abundance of each guild (Table 2). The results of the model averaging showed that the effects of the variables were diverse and depended on guild type, except that distance to the nearest settlement was always positively correlated with the bird abundance in each guild (Table 3). Water surface area had a positive effect on the

abundance of diving birds, but land area had no significant effect on the bird abundance in the other guilds. NDVI was negatively correlated with the bird abundance for large and small waders (as predicted), but positively correlated with diving birds and dabbling ducks, which did not conform to our predictions of no relationship. The number of boats at anchor had no effect on the bird abundance in each of the guilds, except for grazing birds. The number of buffalos was positively correlated with the number of larger and smaller waders as predicted, but had no effect on other guilds (Table 3).

The most important factor determining bird habitat selection and abundance was distance to the nearest settlement, followed by NDVI (Fig. 2). The effects of other factors such as water or land surface area, number of boats at anchor, domestic geese, and buffalos were relatively weak. For waders, the effects of distance to the nearest settlement, NDVI, and the number of buffalos were always significant (Fig. 2; Table 3).

According to the results of the GAMM, bird abundance in each of the guilds increased linearly with increasing distance from the nearest human settlement except for diving and dabbling birds, where the increasing trends levelled off at a distance of ca. 1 km (Fig. 3).

DISCUSSION

We demonstrated that both ecological and anthropogenic variables affected waterbird abundance in Shengjin Lake National Nature Reserve. The effects of most variables were diverse, depending on guild type. Distance to the nearest settlement, however, was the most important variable, with consistent decreasing bird abundance closer to human settlements across all guild types.

We found that diving duck abundance was positively correlated with water surface area, confirming results of the previous studies (Froneman et al. 2001; Sebastian-Gonzalez et al. 2010). This suggests that a larger surface area of water offers a greater amount and potentially greater diversity of feeding resources for diving ducks and reduces interference competition (van Dijk et al. 2012). We failed to detect a significant positive effect of land area on other guilds, presumably, because habitat complexity compounded simple density relationships.

The number of boats at anchor was also frequently included in the best models, although results showed that there was a positive relationship between the number of boats at anchor and the abundance of all waterbird guilds, contrary to our predictions. Waterbirds might aggregate in areas with more biological productivity and hence greater fish abundance, and such as co-vary with the number of fishing boats. Moreover, fishing activities are seasonal

Table 2 Regression coefficients of each parameter featured in best models for each guild in order of increasing AIC_c (Akaike information criterion for small sample size), Δ AIC_c, and ω_i (Akaike weights) based on the generalized linear mixed model (GLMM) with a negative binomial distribution. Land area (LA), water area (WA), normalized difference vegetation index (NDVI), number of boat at anchor (BA), number of domestic geese (GOOSE), number of buffalos (BUFF), and distance to the nearest settlement (DH). df = degrees of freedom, logLik = log likelihood

Guilds	Models	LA	WA	NDVI	BA	GOOSE	BUFF	DH	df	logLik	AIC _c	Δ AIC _c	ω_i
Dabbling duck	1			− 3.108	0.055		0.005	0.003	10	− 3063.90	6147.8	0.00	0.266
	2			− 3.255			0.005	0.003	10	− 3064.30	6148.6	0.80	0.179
	3	0.059		− 3.200	0.045		0.005	0.003	11	− 3063.79	6149.6	1.78	0.109
Diving birds	1		0.246	3.433	0.030			0.001	10	− 2016.18	4052.4	0.00	0.145
	2		0.241	3.531	0.030		− 0.003	0.001	11	− 2015.86	4053.7	1.36	0.074
	3		0.252	3.387		− 0.0006		0.001	10	− 2016.86	4053.7	1.36	0.074
	4		0.241	3.474			− 0.003	0.001	10	− 2016.92	4053.8	1.48	0.069
	5		0.251	3.725					8	− 2018.93	4053.9	1.50	0.069
	6		0.251	3.430	0.028	− 0.0005		0.001	11	− 2015.93	4053.9	1.50	0.069
Grazing birds	1	0.040		− 2.151	0.093			0.003	10	− 4201.04	8422.1	0.00	0.306
	2			− 2.273	0.094	− 0.0004	0.002	0.003	11	− 4200.30	8422.6	0.52	0.236
	3	0.044		− 2.228	0.094	− 0.0004		0.003	11	− 4200.53	8423.1	0.98	0.187
	4	0.028		− 2.140	0.093		0.002	0.003	11	− 4200.84	8423.7	1.60	0.137
Tuber-feeding birds	1						0.007	0.002	8	− 1983.38	3982.8	0.00	0.088
	2					0.002		0.002	8	− 1983.53	3983.1	0.30	0.075
	3					0.001	0.006	0.002	9	− 1982.54	3983.1	0.32	0.075
	4			1.936			0.007	0.002	9	− 1982.82	3983.6	0.88	0.056
	5			2.116		0.002		0.002	9	− 1982.86	3983.7	0.96	0.054
	6			2.080		0.001	0.005	0.002	10	− 1981.89	3983.8	1.02	0.053
	7							0.002	7	− 1984.96	3983.9	1.16	0.049
	8	0.114					0.007	0.002	9	− 1982.98	3984.0	1.20	0.048
	9	0.113				0.001	0.006	0.002	10	− 1982.14	3984.3	1.52	0.041
	10	0.106				0.002		0.002	9	− 1983.18	3984.4	1.60	0.039
	11				− 0.001		0.007	0.002	9	− 1983.38	3984.8	2.00	0.032
	12			2.002				0.002	8	− 1983.38	3984.8	2.00	0.032
Larger wading birds	1			− 1.917			0.004	0.001	9	− 4411.92	8841.8	0.00	0.151
	2			− 1.955	0.012		0.004	0.001	10	− 4411.50	8843.0	1.16	0.085
	3			− 1.732			0.004		8	− 4413.74	8843.5	1.64	0.067
	4			− 1.917		0.000	0.004	0.001	10	− 4411.92	8843.8	2.00	0.056
	5	0.001		− 1.918			0.004	0.001	10	− 4411.92	8843.8	2.00	0.056
Smaller wading birds	1			− 4.920			0.010	0.002	9	− 2551.27	5120.5	0.00	0.239
	2			− 4.976	0.049		0.010	0.002	10	− 2550.33	5120.7	0.12	0.225
	3	− 0.142		− 4.829	0.064		0.010	0.002	11	− 2549.86	5121.7	1.18	0.132
	4	− 0.048		− 4.872			0.010	0.002	10	− 2551.21	5122.4	1.88	0.093
	5			− 4.911		0.000	0.010	0.002	10	− 2551.26	5122.5	1.98	0.089

events and there are less fishermen within the boats in winter, so that disturbance pressure is relatively low. Further studies are still needed to fully understand the underlying mechanisms behind this correlation.

In agreement with our hypotheses, NDVI was negatively correlated with the abundance of larger and smaller waders and dabbling ducks, likely due to dense vegetation offering no suitable habitat to such species. However, positive correlations with NDVI were found for numbers of diving

birds, contrary to our predictions of no relationships. This may be because diving birds find profitable feeding along the edges of dense beds of emergent vegetation rather than along shallow lake shores and because several species of night feeding diving birds find daytime roosting refuge along the edges of such bodies of dense vegetation.

As predicted, the number of buffalos was positively correlated with the abundance of larger and smaller waders but had no effect on that of other guilds. The buffalo

Table 3 Model averaging results, with parameters (95% CIs) explaining the effect of different variables on the bird abundance for different guild types based on AIC_c model selection. Water area (WA), land area (LA), normalized difference vegetation index (NDVI), number of boat at anchor (BA), number of domestic geese (GOOSE), number of buffalos (BUFF), and distance to the nearest settlement (DH). β = correlation coefficient

Species	Variables	β	Lower 95% CI	Upper 95% CI
Dabbling duck	WA	0.059	− 0.184	0.302
	NDVI	− 3.174	− 5.547	− 0.801
	DH	0.003	0.002	0.004
	BA	0.052	− 0.040	0.144
	GOOSE	0.000	− 0.001	0.001
	BUFF	0.005	− 0.000	0.011
Diving birds	WA	0.247	0.004	0.452
	NDVI	3.486	0.702	6.270
	DH	0.001	0.000	0.002
	BA	0.029	− 0.012	0.071
	GOOSE	− 0.001	− 0.002	0.001
	BUFF	− 0.003	− 0.009	0.004
Grazing birds	LA	0.038	− 0.295	0.372
	NDVI	− 2.199	− 4.512	0.119
	DH	0.003	0.001	0.004
	BA	0.093	0.036	0.151
	GOOSE	− 0.000	− 0.001	0.000
	BUFF	0.002	− 0.003	0.007
Tuber-feeding birds	LA	0.111	− 0.136	0.358
	NDVI	2.036	− 1.558	5.629
	DH	0.002	0.001	0.003
	BA	− 0.001	− 0.059	0.056
	GOOSE	0.001	− 0.001	0.004
	BUFF	0.006	− 0.003	0.016
Larger wading birds	LA	0.001	− 0.136	0.138
	NDVI	− 1.895	− 3.700	− 0.090
	DH	0.001	− 0.000	0.001
	BA	0.012	− 0.015	0.040
	GOOSE	0.000	− 0.001	0.001
	BUFF	0.004	− 0.000	0.009
Smaller wading birds	LA	− 0.103	− 0.395	0.190
	NDVI	− 4.914	− 8.702	− 1.126
	DH	0.002	0.001	0.003
	BA	0.055	− 0.022	0.132
	GOOSE	− 0.000	− 0.001	0.001
	BUFF	0.010	0.003	0.017

represents the main livestock species in the study area, removing tall vegetation by grazing to create short grassland swards with a more open structure selected by waders where they benefit from higher food accessibility (Fuller 2012) and earlier predator detection (Dekker and Ydenberg 2004; Van Den Hout et al. 2008). We failed to detect a

Fig. 2 Relative importance of each variable (calculated by summing the Akaike weights across all models where a certain variable was included) determining the waterbird abundance of each guild. Water area (WA), land area (LA), normalized difference vegetation index (NDVI), number of boat at anchor (BA), number of domestic geese (GOOSE), number of buffalos (BUFF), and distance to the nearest settlement (DH)

facilitative effect of buffalo grazing on grazing bird abundance, despite experimental evidence that larger herbivores facilitate smaller ones (Alberti et al. 2017). However, vegetation availability in Shengjin Lake is closely linked to the hydrological regime over time which may obscure any direct relationship (Zhang et al. 2011). In addition, it may be the case that when temperatures were cold and vegetation growth rate was low, intraspecific competition may also occur between grazing geese species and buffalos due to limited foraging biomass. Hence, further studies at a finer scale are required to assess the effects of seasonal variation in biomass to better understand the potential transitions from intraspecific competition to facilitation across seasons.

Not surprisingly, distance to the nearest settlement was positively correlated with the bird abundance in each guild type. This parameter scored the highest importance across all variables, highlighting the strong negative effect of human presence on waterbird abundance within wetlands. The effects of human activities on birds are considered to be analogous to those of natural predator presence (Madsen 1998). The stimulus of the presence of people triggers a response in birds to invest more time in vigilance (at cost to time spent feeding and maintenance, Madsen and Fox 1995). In the extreme, human activity may stimulate birds to take flight and flee (Pfister et al. 1992), displacing individuals to less optimal feeding areas, reducing the time birds spend foraging, the quality of the food resource, and elevating energetic expenditure during flight when they would otherwise be feeding (Martin et al. 2015). Hence, disturbance may force some disturbance intolerant species to abandon otherwise profitable feeding areas to leave the study area, or forage in less optimal habitat (Chudzińska et al. 2015).

Many wetlands have been designated as protected areas to conserve biodiversity all over the world and there is no

Fig. 3 Predicted relationships between bird abundance in each of the waterbird guilds and distance to the nearest settlement, as obtained from generalized additive mixed models. Solid lines illustrate the predicted population abundance index of each guild and broken lines show 95% confidence intervals

doubt that effective conservation policies deliver benefits to birds (e.g., Donald et al. 2007) including waterbirds (Amano et al. 2018), especially through the designation of protected area networks (Gaston et al. 2008). Waterbird species richness increased more rapidly in Ramsar Wetlands than in unprotected wetlands in Morocco in Africa (Kleijn et al. 2014), but the conservation effectiveness of

site designation has still been too ineffective to halt biodiversity losses and stop the decreasing population trends of many waterbird species in the Yangtze River Floodplain (Zhang et al. 2015b; Jia et al. 2018). Our study highlighted the importance of the proximity of human settlements on waterbird abundance across all studied guilds in a fully protected area the Yangtze River Floodplain. However, we

still need to better understand how specific human activities such as agriculture, aquaculture, and other activities may negatively affect bird abundance and degrade the habitat quality for these waterbird species, undermining the effectiveness of current conservation policies.

CONCLUSION

In this paper, we showed that distance to human settlements was the most important variable affecting waterbird abundance across all guilds in a protected wetland. This result suggests that managing the levels of human disturbance in Shengjin Lake National Nature Reserve (e.g., through regulation of particularly disruptive activities, restricted access zones and screening) could be an effective way to contribute to the improved conservation of its waterbird community in the future. Clearly, a fundamental objective is the positive engagement of local people with the effective management of their wetland, so that the local community understands the problems associated with human activity and their effects on waterbirds (Borrini-Feyerabend et al. 2004). However, practical solutions are also available, such as the implementation of a system of screening human activity from the wetlands (potentially through creation of banks, opaque fencing, shelter belts, scrub, or ditches with tall emergent vegetation), which can help to hide even relatively intense human activity from waterbirds in the wetlands (Korschgen and Dahlgren 1992; Knight and Gutziller 1995). Regulation of public access at some key sites may also be a cost-effective way to restrict or decrease human presence in and around Shengjin Lake, as a way of decreasing human disturbances in the nature reserve. However, this would also benefit from community engagement to ensure effectiveness of outcomes. We would strongly recommend the implementation of monitoring of such mechanisms to assess their effectiveness in attaining their objectives in increasing local waterbird abundance. Although this study presents a detailed analysis from one Ramsar Site, we are aware of major declines in wintering waterbird numbers through the Yangtze River Floodplain along similar lines to those witnessed at Shengjin Lake (Jia et al. 2018). For this reason, we strongly believe that these results and conclusions have far wider applications. Engaging with local communities to engender participation and governance, as well as regulating human access and screening disturbing activities at all Yangtze River Floodplain lakes will be complex, demanding, and expensive to implement. However, given these results from Shengjin Lake, the implementation of such measures at this site is highly likely to contribute to the effective conservation of this wide variety and large concentrations of wintering birds at one of China's foremost wetlands.

Hopefully, this would offer a successful case study model for implementation throughout the Yangtze River Floodplain to safeguard its globally important wintering waterbird communities for the benefit of all.

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