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Piscivore water bird diversity at freshwater tributaries of Zambezi River, Namibia

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Piscivorous waterbirds enhance wetlands' diversity and have been seen as bio-indicators of ecological conditions within ecosystems. In addition to their ecological contribution, to wetlands functions and ecosystem services, these birds have been reported to be affected by fishing activities and to compete with fisheries. Despite their importance along wetlands, their populations are in serious decline on a global level. This study aimed at comparing piscivorous waterbirds community composition and functional diversity between a fish protected area (FPA) and a non-fish protected area (NFPA) in two tributaries of Zambezi River in Namibia. At each site, all the waterbirds within a radius of 50 metres were enumerated and identified using binoculars and guide books. For each tributary, species diversity, taxonomic diversity, functional diversity, and community-based trait diversity indices were calculated. A total of 40 carnivorous waterbirds species belonging to 9 orders were recorded during the survey. Of these 40 species, 10 (25%) predominantly feed on fish, 6 (15%) predominantly feed on insects and 24 (60%) species predominantly feed on both fish and insects. At the FPAs site, a total of 35 species were recorded, comprising 10 (29%) species that predominantly feed on fish, 4 (11%) species that predominantly feed on insects and 21 (60%) species that feed on both fish and insects. Generally, piscivorous waterbirds species diversities were not significantly different between a FPA and a NFPA ($p > 0.05$). However, all piscivorous waterbirds functional diversities indices calculated were significantly different between FPAs and NFPAs ($p < 0.05$).

Conservation implications: In most riparian human communities, fish is an important source of protein. The effects of uncontrolled fishing in shaping the composition, structure, and diversity of piscivorous waterbirds worldwide have been reported. If we need to balance the two, regulating fishing loadings and season will improve piscivorous waterbirds conservation and human livelihoods.

Keywords: piscivorous waterbirds; functional diversity; tributaries; Zambezi River; fish protected area; non-fish protected area; feeding guilds; fisheries.

Introduction

The significance of piscivorous waterbirds in the productivity and functioning of inland wetland ecosystems has recently gained attention (Green & Elmberg 2014) and has contributed to wetlands' conservation and management worldwide (Andrade et al. 2018). Through their natural activities, piscivorous water birds provide ecosystem services such as linking of ecosystems' flora and fauna (Frisch et al. 2007; Green & Elmberg 2014; Green & Figuerola 2005; Green et al. 2008), enhancement of primary production (Petrie 2006), and nutrients accumulation and cycling within and between wetlands (Andrikovic et al. 2006). In addition, they also provide meat and act as indicators of environmental changes to indigenous communities residing along wetlands (Green & Elmberg 2014; Campos-Silva et al. 2021).

The ecosystem services provided by species in an ecosystem are linked to the species' traits (i.e. the qualities of each species) (Green & Elmberg 2014; Tecco et al. 2012; Thébault & Loreau 2005). Species with similar traits normally perform similar functions in the ecosystem (Májeková et al. 2016; Petchey et al. 2007). The trait-function relationship promotes assemblage of species into different functional groups (Faucon, Houben & Lambers 2017; Henry & Cumming 2017) and forms the basis for niche differentiation among species. It is also believed that within a functional group, only few species are dominant (drivers) and many are minor (passengers) species similar to dominant species in an ecosystem at any time (McGill et al. 2006). Furthermore, a change in a species dominance should be counterbalanced by a previously similar minor species following environmental changes or disturbance (Rutina & Moe 2014; Synnos & Arnott 2013; Walker, Kinzig & Langridge 1999), and perform similar ecological functions within ecosystems to previously more abundant species (Mori et al. 2013). The result being that the ecosystem maintains its functions and processes despite losses of previously dominant species. This shift in species abundances following environmental change and disturbances (functional redundancy or equivalence) (Walker & Langridge 1999) implies that ecosystems with high functional redundancy are more sustainable in face of environmental changes and disturbances (Henry & Cumming 2017; Pérez-Crespo et al. 2013; Yachi & Loreau 1999). In addition, dominant species should be functionally dissimilar because they perform different functions and hence occupy different niches (Walker et al. 2013).

In this study, we aimed to assess and investigate composition and diversity of piscivorous waterbirds on two freshwater tributaries of Zambezi River in Namibia: Sikunga and Lisikili tributaries. The two tributaries have different protection status. Part of the Sikunga tributary has been gazetted as a Fish Protected Area (FPA) (thereafter referred to as FPA), while the Lisikili tributary is a Non-Fish Protected Area (NFPA) (thereafter referred to as NFPA) (Simasiku & Hay 2023). In the FPA, fishing is regulated through quota and is only done at certain portions of the tributary. In the NFPA, fishing is not regulated and there is high subsistence fishing using different fishing gears including traditional fishing equipment (Simasiku & Hay 2023). Specifically, we predicted that: (1) piscivorous waterbirds' functional and taxonomical diversity were higher at the FPA sites than NFPA sites; (2) at both sites, piscivorous waterbirds community abundance was dominated by few species and have many minor species; (3) changes in abundance of dominant piscivorous waterbirds species in FPA sites were counterbalanced by a functionally similar dominant species in NFPA sites. The key question was as follows: Does the diversity, abundance and species differ between FPA and NFPA sites?

Research methods and design

Study area

The study was conducted on two tributaries of Zambezi River: Sikunga and Lisikili tributaries located in the Zambezi Region of Namibia (Figure 1). The river system is highly pulsed and spread out in terms of water volume during the flooding season. The topography of the region is flat terrain. The tributaries normally reach their peak flow between March and May, after which the water recedes until the end of September. During the dry months (November–April), the floodplains are dry and covered in terrestrial grasses (Simasiku & Hay 2023).

Sampling sites

The waterbirds community was surveyed at two Zambezi River tributaries: Sikunga channel (FPA) and Lisikili channel (NFPA) during the winter of 2020 (July to November) (see Figure 1). A 2 kilometre transect was laid out at each tributary. Within each transect, five intra-sites were laid 500 metres apart and parallel to the water's edge. At each site, we enumerated and identified all the waterbirds within a radius of 50 metres using binoculars and guide books by Reynolds and Tye (2015).

Data analysis

Species composition, abundance, and diversity

We measured piscivorous waterbirds community attributes (guild abundance and diversity) from surveys conducted over 4 months. Waterbirds were classified into three types (predominantly feeding on fish, predominantly feeding on fish-insects and predominantly feeding on insects) based on their preferred food items (De Arruda Almeida, Gimenes & Dos Anjos 2017; Henry & Cumming 2017). Species abundances for each intra-sites were converted into relative abundances (Andrade et al. 2018). Guild abundance was calculated as the sum of total individuals per guild averaged over the 4 months. We log-transformed to normalise the data because the data did not conform to normality test.

A comparison of waterbird species compositional structure between FPA and NFPA was computed using the generalised Morisita's similarity indices (Cm) based on the abundance data (Chao et al. 2008; Jost 2008). Species diversity was determined using the Shannon Diversity Index per site (Hill 1973) using the following formulas in Equation 1 and Equation 2:

$$H = -\sum [(p_i) \times \log (p_i)] \quad \text{[Eqn 1]}$$

where:

H = Shannon diversity index;
P_i = proportion of individuals of ith species in a whole community;
Σ = sum symbol; and
log = the natural logarithm to base 10.

$$P_i = n/N \quad \text{[Eqn 2]}$$

where:

n = number of individuals of a given species; and
N = total number of individuals in a community.

Functional diversity indices

A waterbirds species-trait matrix was created to assess functional diversity indices. We used traits that were previously suggested to situate waterbirds' potential to effect and respond to wetlands' changes because of disturbances (De Arruda Almeida et al. 2016; Májeková et al. 2016). Traits included in this study were traits associated with resource use (feeding guild, major food items, feeding location and weight), breeding (breeding or non-breeding, nesting location, breeding season and clutch size) and movement (resident and migratory) (Appendix 1). We standardised each trait on a scale of 1–5 to account for equal treatment of variation with each trait (Appendix 2). We estimated functional diversity indices using F-Diversity software (Casanoves et al. 2011).

Species attributes

This study used five attributes that are important for evaluating the effects and response of waterbirds to wetlands' change

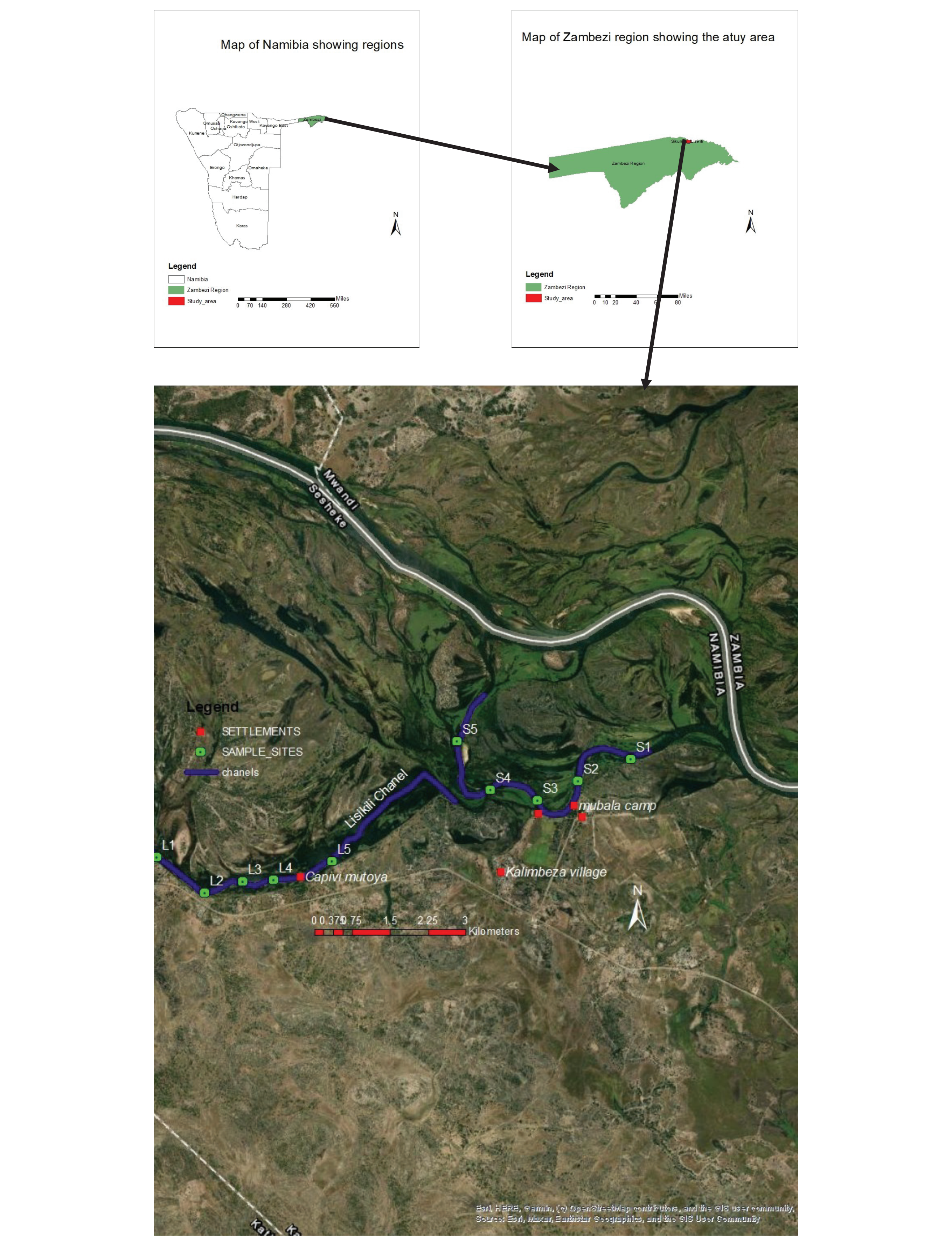


FIGURE 1: Map of the Lisikili and Sikunga channels and sampling sites, where S1 – S5 signifies the fish protected area (FPA) sites and L1–L5 indicates the non-fish protected area sites.

because of anthropogenic activities. The traits used included: (1) body weight (as it affects foraging behaviour, metabolic rate, permanency and home-range size); (2) feeding guild and major food item (as it influence foraging behaviour and response to anthropogenic activities that change their main diet); (3) foraging location (as variability of anthropogenic activities may change the physical characteristics of the river); (4) breeding behaviour (nest type, location of nest, clutch size, seasonality of breeding) (as birds during breeding can transport nutrients from nearby terrestrial ecosystems to wetlands; and (5) migratory status (resident or migratory), which can act as mobile linkers and influence nutrients cycling across different regions. Species attributes were obtained from Sinclair et al. (2000), Newman (2010), Reynolds and Tye (2015), and Chittenden, Dean, Gibbon and Upfold (2007). We used maximum recorded values for weight and clutch size (*sensu* Rutina & Moe 2014).

Functional groups and redundancy

To classify waterbirds species into different functional groups, a hierarchical classification in SPSS was performed to determine the number of sampled groups using the elbow rule. Subsequently, the k-Classification was computed using the number of groups obtained from the hierarchical classification. The simplified Euclidean Distance (ED) was employed as a measure of variation among species in abstract space. The simplified version of ED is shown in Equation 3:

$$ED_{jk} = å\,(A_{ij} - A_{ik})^2 \qquad \text{[Eqn 3]}$$

where:

ED_{jk} = the ecological distance between species;
j and *k*, and A_{ij} and A_{ik} = values of species;
j and *k* for attribute *i*. (*sensu* Rurina & Moe 2014).

To predict the differences in species abundance between FPA and NFPA, an equation following Walker, Kinzig and Langridge (1999) and Rutina and Moe (2014) was applied in Equation 4:

$$Ln\ [Abundance\ in\ FPA \div abundance\ in\ NFPA). \qquad \text{[Eqn 4]}$$

A significant high in abundance in FPA sites than NFPA sites requires the result of the equation to be > 1 while a significant low abundance should be < –1, with results of between –1 and 1 suggesting an equal abundance between the two sites.

Ethical considerations

Ethical clearance to conduct this study was obtained from the University of Namibia Ethical Committee (No. KMC0001).

Results

Species composition, abundance, and diversity

A total of 40 carnivorous waterbird species belonging to 9 orders were recorded during the survey (Table 1). Of these 40 species, 10 (25%) predominantly feed on fish, 6 (15%) predominantly feed on insects and 24 (60%) species predominantly feed on both fish and insects. At the FPA site, a total of 35 species were recorded, comprising 10 (29%) species that predominantly feed on fish, 4 (11%) species that predominantly feed on insects and 21 (60%) species that feed on both fish and insects. At the NFPA site, a total of 31 species were recorded comprising 8 (26%) species that predominantly feed on fish, 4 (13%) species that predominantly feed on insects and 19 (61%) feed on both fish and insects (Appendix 1). Generally, species composition among the three feeding guilds was averagely similar between the two sites (Morisita index: 63–71 for all pairwise combinations; Table 2). The two sites had an overlap of 25 species, accounting for 62.5% of the total species on record (Appendix 2). Nine species, namely, *Leptoptilos crumenifer* (Marabou Stork), *Ardea melanocephala* (Black Headed Heron), *Platalea alba* (African Spoonbill), *Circus ranivorus* (African Marsh Harrier), *Burhinus vermiculatus* (Water Thick-knee), *Ardea cinerea* (Grey Heron), *Chlidonias hybrida* (Whiskered Tern), *Vanellus senegallus* (African Wattled Plover), and *Pelecanus rufescens* (Pink Backed Pelican) were exclusively recorded at the FPA, while another five species, namely, *Corythornis cristatus* (Malachite Kingfisher), *Vanellus crassirostris* (Long-toed Lapwing), *Nycticorax nycticorax* (Black Crowned Night Heron), *Vanellus coronatus* (Crowned Lapwing) and *Sarkidiornis melanotos* (Knob Billed Duck) were exclusively recorded at the NFPA.

Taxonomic diversity indices

Species diversity, species evenness and species dominance did not differ between FPA and NFPA. However, species richness was higher at the FPA tributary than at the NFPA tributary (Table 2).

Functional diversity

Generally, when considering multi-trait functional diversity indices, carnivorous waterbirds' ecological

TABLE 1: Number of carnivorous bird species in each feeding guild, their proportions and similarity index (Morisita similarity index) at the fish protected area and non-fish protected area sites.

Feeding guild	Number (Proportion %) of species						Morisita similarity index		
	All sites		FPA		NFPA		ALL-FPA	ALL-NFPA	FPA-NFPA
	n	%	*n*	%	*n*	%			
Fish	10	25	10	29	8	26	0.63	0.66	0.64
Fish-insects	24	60	21	60	19	61	0.67	0.66	0.67
Insects	6	15	4	11	4	13	0.71	0.69	0.70
Total number of species	**40**	**100**	**35**	**100**	**31**	**100**	-	-	-

FPA, fish protected area; NFPA, non-fish protected area.

distance differed between FPA and non-FPA sites (Table 3). Carnivorous waterbirds' ecological distance was higher in FPA sites compared to NFPA sites. Similarity, functional evenness, functional richness and functional divergence also differed between FPA and NFPA sites (Table 3). Functional richness and divergence were higher in FPA sites compared to NFPA sites. Contrary to these results, functional evenness was higher at the NFPA sites compared to FPA sites.

When considering functional regulatory single traits indices, all the nine traits used in this study significantly differed between the FPA and NFPA sites, except for breeding type and clutch size. In terms of feeding guild, FPA sites were dominated by carnivorous waterbirds, while NFPA sites were dominated by species that predominantly feed on both fish and insects. In terms of food items, FPA sites were dominated by piscivore birds and NFPA sites were dominated by water birds that feed both on fish and insects.

When considering community weighed single traits functional diversity, add four traits, namely, food item, weight and movement type were significantly different between FPA and NFPA sites (Table 4). Similar to functional regulatory single trait diversity, FPA sites were dominated by carnivorous waterbirds, while NFPA sites were dominated by waterbirds that feed dominantly on insects. In terms of food items, FPA sites were dominated by piscivore birds and NFPA sites were dominated by water birds that feed both on fish and insects (Table 4).

Functional groups and redundancy

Piscivorous waterbirds at the study site were dominated by 9 (23%) species out of the possible 40 total number of sampled species. These dominant species were Little Egret (15%), Reed cormorant (15%), White Breasted Cormorant (14%), Great Egret (11%), Grey Headed Gull (10%), Squacco Heron (7%), African Open bill stock (5%), Pied Kingfisher (5%), and Blacksmith Plover (3%) (Figure 2a). Of the nine dominant species, six (67%) feed predominantly on fish, two (22%) species feed on both fish and insects, while only one (11%) feeds on insects. Further analysis showed that, at the FPA, carnivorous waterbirds were dominated by 8 (23%) species out of the possible 40 total number of sampled species. The dominant species on FPA sites were White-breasted Cormorant (17%), Reed Cormorant (16%), Great Egret (14%), Little Egret (10%), African Sacred Ibis (6%), White faced Duck (6%), Squacco Heron (5%), and Grey-headed Gull (5%). Of the eight species, three (37.5%) feed predominantly on fish and five (62.5%) predominantly on fish and insects. In contrast, at the NFPA sites, carnivorous water birds were dominated by 6 (15%) species out of the possible 40 total number of sampled species. Of the six species, four (67%) feed predominantly on fish , one species (17.5%) feeds on fish and insects and one species (17.5%) predominantly feeds on insects. Three (37.5%) out of the above eight species (i.e. African Open bill Stork, Great Egret and White Breasted Cormorant) decreased in abundance at the NFPA sites. Of these three decreasing species, only the African Open bill Stork, was substituted by functionally similar and increase in abundance but minor species (Black Smith Plover) (Fisher's exact test, $p > 0.05$).

On NFPA sites, the functional similarity (in terms of predominant food items) of dominant species was similar to the functional similarity of dominant species of the whole study area (Fisher's exact test = 1.277, $p = 0.557$). On FPA sites, functional similarity of dominant species was dissimilar to the functional similarity of the dominant species of the whole study area (Fisher's exact test = 6.685, $p = 0.034$).

TABLE 4: Comparison of community weighed single traits functional diversity between fish protected area and non-fish protected area.

Trait	NFPA	Value and s.d.	FPA	Value and s.d.	$F_{(1, 6)}$-value	*P*
Diet	1.46	0.15	1.19	0.06	18.11	0.0053*
Food items	2.23	0.19	1.49	0.31	16.62	0.0065*
Weight	3.32	0.25	4.29	0.22	33.97	0.0011*
Feeding location	2.85	0.21	2.72	0.38	0.42	0.539*
Breeding type	1.60	0.13	1.46	0.07	3.39	0.115
Nesting location	2.18	0.05	2.13	0.08	0.85	0.393
Maximum clutch size	2.75	0.21	2.60	0.25	0.99	0.358
Movement type	2.54	0.19	1.16	0.22	34.71	0.0011*
Breeding season	2.64	0.15	2.38	0.44	1.18	0.38

FPA, fish protected area; NFPA, non-fish protected area; s.d., standard deviation.
*, Denotes differences in significance functional diversity indices among the sampling sites.

TABLE 2: Taxonomic diversity indices of carnivorous birds sampled at the fish protected area and non-fish protected area.

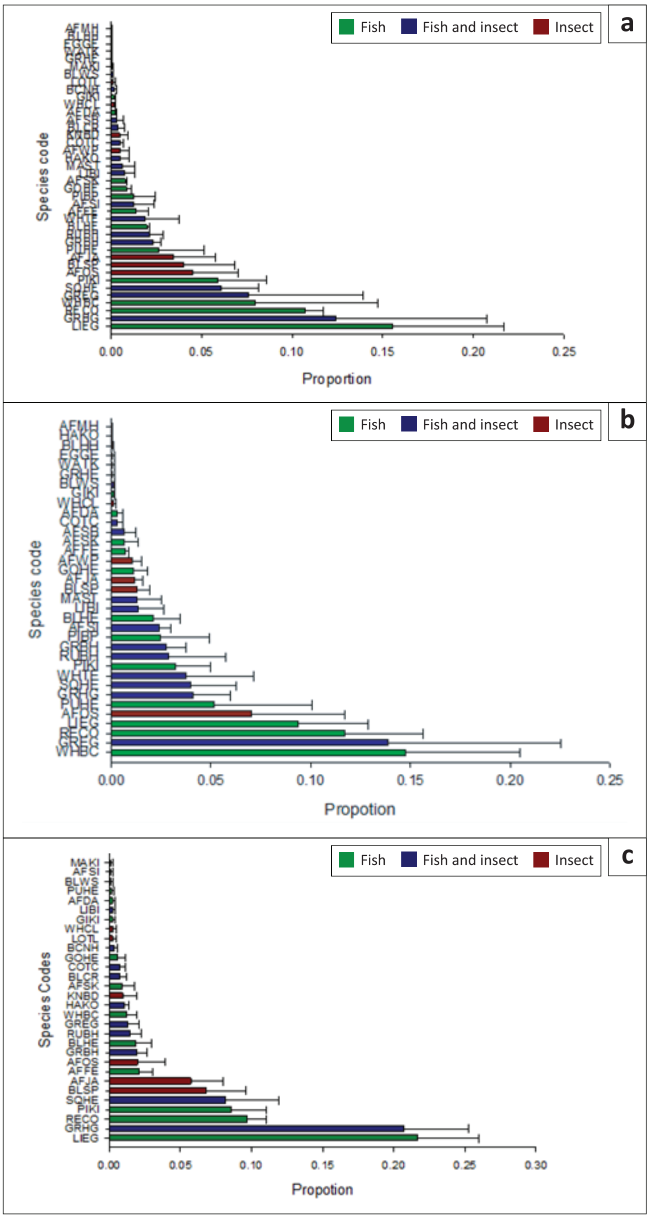
Index	NFPA	Value	s.d.	FPA	Value	s.d.	$F_{(1, 6)}$-value	*P*
Species richness	16.00	3	-	21.00	1	-	9.85	0.02*
Species diversity	2.23	-	0.18	2.25	-	0.21	0.02	0.90
Species evenness	0.79	-	0.05	0.74	-	0.07	1.25	0.31
Species dominance	0.85	-	0.04	0.85	-	0.04	0.05	0.99

FPA, fish protected area; NFPA, non-fish protected area; s.d., standard deviation.
*, Denotes differences in significance diversity indices among the sampling sites.

TABLE 3: A comparison of functional diversity indices between fish protected area and non-fish protected area.

Index	FPA	Value	s.d.	NFPA	Value	s.d.	$F_{(1, 6)}$-value	*P*
Functional diversity	1290.00	124	-	797.00	215	-	11.41	0.0149*
Functional richness	10.00	2	-	3.00	3	-	15.92	0.0072*
Functional evenness	0.54	-	0.03	0.61	-	0.08	11.06	0.0159*
Functional divergence	4.40	-	0.25	3.46	-	0.15	54.48	0.0003*

FPA, fish protected area; NFPA, non-fish protected area; s.d., standard deviation.
*, Denotes significant differences in functional diversity indices among the sampling sites.



Note: For species codes, see TABLE 1-A1 of this article, Rutina, L.P., Simasiku, E. & Kabanze, J.M., 2024, 'Piscivore water bird diversity at freshwater tributaries of Zambezi River, Namibia', *Koedoe* 66(1), a1815. https://doi.org/10.4102/koedoe.v6i1.1815.

FPA, fish protected area; NFPA, non-fish protected area.

FIGURE 2: Waterbirds' relative abundances (proportions and standard error [s.e.]) in different sites in freshwater tributaries of Zambezi River, Namibia.

Discussion

Species composition, abundance, and diversity

This study aimed to explore the abundance and distribution of carnivorous waterbirds between FPAs and NFPAs on the Zambezi River tributaries. A total of 40 different species, representing 35 species at the FPA and 31 species at the NFPA were recorded from July 2021 to October 2021. Among these species, only a few dominant species were documented at both sampling sites, supporting our prediction that at both sites, carnivorous waterbirds community abundance was dominated by few species and have many minor species. Throughout the study period, only a few dominant species were spotted at the two sampling sites, but dominancy was not equally distributed among the feeding guilds. Waterbirds species that feed on both fish and insects dominated the community assemblages of waterbirds at both the FPA (60%) and NFPA (61%) sites. This suggests that piscivorous waterbirds that had a wider niche (feeding on fish and insects) were resilient to fishing pressure, and piscivorous waterbirds that mainly feed on fish were affected by fishing pressure. It predicts that piscivorous waterbirds with wider niches can shift among available diet to sustain their food requirement. Similar distributions have been reported in other wetlands (De Arruda Almeida et al. 2018; Lorenzón, Ronchi-Virgolini & Blake 2020), and terrestrial ecosystems (Rutina & Moe 2014; Walker et al. 1999). Henry and Cumming (2017) reported that wetland birds were dominated by few species whenever water levels of wetlands were high or low, while De Arruda Almeida et al. (2017) reported that waterbirds were dominated by few species both at artificial and natural wetlands. Walker et al. (1999) and Rutina and Moe (2014) reported that graminoid and tree species were dominated by fewer species across grazing and browsing gradients, respectively. However, opposing results have been reported where no signs of redundancy in species dominance were observed (Aarif et al. 2017; Petchey et al. 2007). In line with this study, Petchey et al. (2007) also reported that there was no redundancy in British avian assemblages.

Species composition between the two sampling sites was averagely similar (Morisita's index: 0.63 to 0.71). The two sampling sites had an overlap of 25 species, accounting for 62.5% of the total species on record. These observations suggest that the external effect of fishing did not influence the species richness and evenness distribution of carnivorous waterbirds between the two sampling sites. However, the influence of fishing pressure on other traits that are associated with growth forms and resources use strategies cannot be ruled out. Connectivity between the two sampling sites could equally explain similarity in catch composition as there is flow and exchange of similar species between two geographically connected sites in the absence of external factors such as fish pressure.

The distribution of minor species at the FPA and NFPA had functionally similar dominant species; except for waterbirds species that fed on insects (e.g. Black Smith Plover). It has been hypothesised that minor species have to be functionally similar to dominant species in order to stabilise the functions and processes of an ecosystem (Rutina & Moe 2014; Walker 1999; Walker et al. 1999). However, a lack of the distributions of insectivorous species at both sites would suggest that fish is the most predominant food item governing the distribution of carnivorous waterbirds at the two sampling sites and that competing activities such as fishing have not affected prey abundance for carnivorous waterbirds (Anthal & Sahi 2017; Wenny et al. 2011).

Species diversity, evenness, and richness

Further analysis on species diversity and richness showed that species richness was higher at the FPA compared to the NFPA sites. Similarly, the functional diversity indices were equally higher at the FPA than at the NFPA sites, while the functional evenness was higher at the NFPA sites than FPA sites. Low disturbances have been associated with high diversities (Schellenberger Costa et al. 2017) and species dominancy (Walker et al. 2013). If the concept of functional traits-ecosystem functions relationship holds, the FPA sites should act as an important refuge for a flock of species when water availability is low and enhance resource availability and accessibility to waterbirds (Ma et al. 2010). The current results showed that large body piscivorous waterbirds (e.g. Pink Backed Pelican) were dominantly sighted at the FPA sites than at the NFPA sites. This could be linked to high abundances of prey food resources such as fish and insects at the FPAs (Simasiku & Hay 2023).

Shift in species dominance between the two sites

Our third prediction that a decline in abundance of dominant waterbird species at the FPAs is counterbalanced by an increase in abundance of taxonomically and functionally similar dominant species at the NFPA sites was partly supported by this study as only some species that declined in abundance under changes in fishing pressure were replaced by increasing functionally similar species at the FPAs. The distributions of minor species at the FPA and NFPA sites had functionally similar dominant species; except for waterbird species that fed on insects (e.g. Black Smith Plover). It has been hypothesised that minor species have to be functionally similar to dominant species in order to stabilise the functions and process of an ecosystem (Rutina & Moe 2014; Walker 1999; Walker et al. 1999). However, a lack of the distribution of insectivorous species at both sites would suggest that fish is the most predominant food item governing the distribution of carnivorous waterbirds at the two sampling sites and that competing activities such as fishing have not affected prey abundance for carnivorous waterbirds (Anthal & Sahi 2017; Wenny et al. 2011). Species that predominantly feed on fish were generally reduced in their contributions to the overall abundance of species at the NFPA sites compared to FPA sites, suggesting that fishing pressure might have negatively affected the distribution and abundance of these species at the NFPA sites. On the contrary, insectivorous waterbirds seemed to be favoured by fishing activities.

Conclusion

The results of this study provide an insight into the effects of fishing on population stability of the piscivorous waterbirds in the Zambezi tributaries. The results of the study show that piscivorous waterbirds that mainly feed on fish need protection compared to piscivorous waterbirds that had wider feeding niche (feeding on fish and other taxa). More studies are required to generate information on waterbird species' contributions to ecological functions and their responses to fishing at the two study sites, through intense monitoring surveys of all waterbirds' food items and environmental and ecological conditions of the tributaries.

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Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

L.P.R. conceptualised the study, collected data, performed analysis, and wrote the first draft. E.S. sourced funding, contributed to the first and final draft. J.M.K. collected data, performed analysis, and wrote the first draft.

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Data availability

The data that support the findings of this study are available on reasonable request from the corresponding author, L.P.R.

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Appendices starts on the next page →

Appendix 1

TABLE 1-A1: Piscivorous waterbird species recorded during the study, their attributes and total number recorded at each site.

Species name	Species code	Food item	Code item	Weight	Weight code	Feedloc code	Bredtype code	Nest loca code	Maximum clutch size	Clush code	Move code	IUCN code	Season code	FPA	NFPA
White Breasted Cormorant	WHBC	FISH	1	3700	5	5	2	2	4	2	1	1	3	374	9
Reed Cormorant	RECO	FISH	1	580	5	5	1	1	4	2	1	1	1	335	79
Little Egret	LIEG	FISH	1	310	3	1	2	4	9	3	1	1	3	235	188
Pink Backed Pelican	PIBP	FISH	1	5400	5	5	1	1	6	2	1	1	5	57	0
African Skimmer	AFSK	FISH	1	200	3	1	2	1	4	2	1	5	1	27	5
African Fish Eagle	AFFE	FISH	1	3600	5	1	5	5	5	3	5	1	5	15	19
African Darter	AFDA	FISH	1	1400	5	5	5	5	4	2	5	1	1	7	2
Goliath Heron	GOHE	FISH	1	5000	5	5	1	2	5	3	1	5	3	7	5
African Marsh Harrier	AFMH	FISH	1	430	3	5	2	3	3	1	1	5	3	1	0
Giant Kingfisher	GIKI	FISH	1	425	3	1	1	2	12	4	1	1	3	1	2
Great Egret	GREG	FISH-INSECTS	3	1500	5	5	1	4	4	2	1	5	3	314	11
Squacco Heron	SQHE	FISH-INSECTS	3	290	3	1	1	2	11	4	5	1	5	131	70
African Openbill Stork	AFOS	FISH-INSECTS	3	1100	5	1	2	3	3	1	1	1	1	117	11
Grey Headed Gull	GRHG	FISH-INSECTS	3	370	3	5	2	4	4	2	1	1	1	102	178
Pied Kingfisher	PIKI	FISH-INSECTS	3	100	1	5	1	2	6	2	1	1	5	87	64
African Sacred Ibis	AFSI	FISH-INSECTS	3	1500	5	5	2	1	4	2	5	5	1	42	1
Green Backed Heron	GBHE	FISH-INSECTS	3	180	3	1	1	2	6	2	5	1	3	33	16
Black Heron	BLHE	FISH-INSECTS	3	390	3	5	1	2	12	4	1	1	5	14	17
Whiskered Tern	WHTE	FISH-INSECTS	3	88	1	1	2	2	3	1	5	1	1	7	0
Coppery-tailed Coucal	COTC	FISH-INSECTS	3	280	3	1	1	1	4	2	1	1	1	6	5
Black Winged Stilt	BLWS	FISH-INSECTS	3	160	3	1	1	1	4	2	1	1	5	3	1
Purple Heron	PUHE	FISH-INSECTS	3	1100	5	1	1	2	4	2	1	1	1	3	1
Water Thick-knee	WATK	FISH-INSECTS	3	440	3	1	1	1	2	1	1	1	1	2	0
White Crowned Lapwing	WHCL	FISH-INSECTS	3	214	3	1	1	1	3	1	1	1	3	2	2
Grey Heron	GRHE	FISH-INSECTS	3	2100	5	1	2	2	4	2	5	1	1	2	0
Black Crake	BLCR	FISH-INSECTS	3	118	3	5	1	3	4	2	1	5	5	1	5
Rufous Bellied Heron	RUBH	FISH-INSECTS	3	300	3	1	1	4	5	2	1	1	3	1	13
Hamerkop	HAKO	FISH-INSECTS	3	470	3	1	1	3	5	2	1	1	1	1	8
Little Bittern	LIBI	FISH-INSECTS	3	150	3	5	1	2	15	4	1	1	3	1	2
Marabou Stork	MAST	FISH-INSECTS	3	8000	5	5	2	3	3	1	1	5	5	1	0
African Spoonbill	AFSB	FISH-INSECTS	3	1500	5	5	2	2	5	2	5	1	3	1	0
Malachite Kingfisher	MAKI	FISH-INSECTS	3	17	1	1	1	3	5	2	5	1	1	0	1
Black Crowned Night Heron	BCNH	FISH-INSECTS	3	800	5	1	1	3	4	2	1	1	5	0	3
Knob Billed Duck	KNBD	FISH-INSECTS	3	2900	5	1	1	2	5	3	1	1	1	0	9
Black Smith Plover	BLSP	INSECTS	5	160	3	5	1	1	4	2	1	1	3	44	48
African Wattled Plover	AFWP	INSECTS	5	250	3	5	1	2	2	1	1	1	1	29	0
African Jacana	AFJA	INSECTS	5	261	3	1	5	5	4	2	5	1	1	20	41
Black Headed Heron	BLHH	INSECTS	5	1100	5	5	1	1	12	4	1	1	5	1	0
Crowned Lapwing	CRLA	INSECTS	5	185	3	5	2	4	5	2	1	1	3	0	6
Long-toed Lapwing	LOTL	INSECTS	5	225	3	1	1	1	6	2	1	1	3	0	2

Source: Sinclair, I., Hockey, P., Tarboton, W., Perrins, N., Rollinson, D. & Ryan, P., 2000, 'Birds of Southern Africa: Fifth revised edition', Penguin Random House South Africa; Newman, K., 2010, Newman's birds of Southern Africa, p. 536, Struik Nature; Reynolds, C. & Tye, N., 2015, '300 Easy-to-see birds in southern africa paperback', *Penguin Random House South Africa*, 1–168; Chittenden, H., Dean, W.R.J., Gibbon, G. & Upfold, G., 2007, Roberts bird guide: A comprehensive field guide to over 950 bird species in southern Africa, John Voelcker Bird Book Fund

FPA, fish protected area; NFPA, non-fish protected area; IUCN, International Union for Conservation of Nature.

Appendix 2

TABLE 1-A2: Functional attributes for the carnivorous waterbird species recorded along the two Zambezi River tributaries, north-eastern Namibia.

Functional attribute value	Weight (g)	Food item	Feeding location	Breeding type	Nest location	Maximum clutch size	Breeding season
1	0–200	Predominantly fish	Ground/mud	Monogamy	Ground	1–3	Dry
2	-	-	-	-	Reed bed	-	-
3	2001–1000	Fish and invertebrates	-	polygamy	Reed bed/tree	4–10	Varies
4	-	-	-	-	Tree	-	-
5	> 1000	Predominantly invertebrates	Water	nonbreeding	Nonbreeding	> 10	Wet

Source: Sinclair, I., Hockey, P., Tarboton, W., Perrins, N., Rollinson, D. & Ryan, P., 2000, 'Birds of Southern Africa: Fifth revised edition', Penguin Random House South Africa; Newman, K., 2010, Newman's birds of Southern Africa, p. 536, Struik Nature; Reynolds, C. & Tye, N., 2015, '300 Easy-to-see birds in southern africa paperback', *Penguin Random House South Africa*, 1–168; Chittenden, H., Dean, W.R.J., Gibbon, G. & Upfold, G., 2007, Roberts bird guide: A comprehensive field guide to over 950 bird species in southern Africa, John Voelcker Bird Book Fund

Appendix 3

TABLE 1-A3: Proportions of dominant species (species that contributed 85% of the total number of species counted) and their significant changes in contribution on fish protected area and non-fish protected area sites along Zambezi tributaries, Namibia.

Species name	Food item	Proportion in FPA	Proportion in NFPA	Change
White breasted cormorant	FISH	0.353163000	0.029126000	-2.500000
Reed cormorant	FISH	0.316336000	0.255663000	-0.212944
Little egret	FISH	0.221907000	0.608414000	1.010000
Great egret	FISH-INSECTS	0.360505000	0.026316000	-2.620000
Squacco heron	FISH-INSECTS	0.150402000	0.167464000	0.107460
African openbill stork	FISH-INSECTS	0.134328000	0.026316000	-1.640000
Grey headed gull	FISH-INSECTS	0.117106774	0.425837321	1.300000
Pied Kingfisher	FISH-INSECTS	0.099885000	0.153110000	0.427140
Green Backed Heron	FISH-INSECTS	0.037887000	0.038278000	0.010240
Black Heron	FISH-INSECTS	0.016073000	0.040670000	0.928320

Note: A change of > 1 shows a significant higher contribution of the species in NFPA than FPA sites. A change of < 1 shows a significant lower contribution of the species in NFPA than FPA sites, while a change between -1 and 1 shows that the contribution of the species was not significantly different between NFPA than FPA sites.

FPA, fish protected area; NFPA, non-fish protected area.