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Evaluating the Suitability of using Waterbird Functional Guilds as Indicators of Climate-Driven Hydrological Impairment: A case study of Antelope Park Dam, Gweru, Zimbabwe

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Abstract

Wetland hydrological variability has the potential to influence waterbird communities by driving change in the availability of habitat, food resources and ecological strategies. This research sought to determine if waterbird functional guilds are useful indicators of hydrological impairment at Antelope Park Dam, Gweru, Zimbabwe. Waterbird assemblages were examined across four assessment periods (2014, 2018, 2022 and 2026), using taxonomic and functional diversity metrics, PERMANOVA and Indicator Value analysis. Species richness declined from 58 species in 2014 to 41 in 2026 (-29.3%), total abundance by 37.8% and Shannon diversity by 20.8%. Functional guild composition varied significantly among assessment periods (PERMANOVA: F, = 9.14, R = 0.43, p = 0.001). Specialist guilds showed disproportionally larger declines (piscivores (p = 0.009; -64.3%), diving birds (p = 0.028; -58.9%) and large waders (p = 0.042; approximately -49.0%), whereas generalist feeders increased from 18.4% in 2014 to 39.7% in 2026. Functional richness, evenness and divergence declined by

42.6%, 29.2% and 35.5%, respectively. Indicator Value analysis highlighted piscivores (Ind Val = 0.82), diving birds (0.78) and large waders (0.71) as indicators of relatively good condition while generalists were associated with more degraded conditions (0.76). These trends suggest effects of environmental filtering and increasing homogenisation of functional groups. Functional metrics were more sensitive than traditional taxonomic diversity measures, confirming their utility as indicators of wetland condition, and could be used to complement traditional monitoring of semi-arid wetlands vulnerable to the impact of water extraction.

Keywords: waterbirds; functional guilds; functional diversity; hydrological impairment; environmental filtering; functional homogenisation; Zimbabwe

1. Introduction

Wetlands rank among the world's most productive ecosystems, offering a biodiverse habitat and vital services such as water quality improvement, flood control, nutrient cycling, carbon sequestration and wildlife habitat (Ramsar Convention Secretariat, 2021; IPCC, 2023). This is especially true in semi-arid environments that have permanent or semi-permanent wetland habitats, which provide refuge spaces for water resources during annual dry periods. Nonetheless, wetlands' structure and function depends on their water regimes to a large degree, making them particularly vulnerable to any changes in timing, duration, magnitude, or seasonal variability of water (Mitsch & Gosselink, 2021; Qiu et al., 2024).

Climate variability and change can influence wetland hydrology through changing rainfall, temperatures, evaporation, runoff and frequency of drought. This is particularly relevant to the southern African context, where marked inter-annual variability in rainfall and incidence of drought can lead to decreased water availability, shorter hydroperiods and modified water levels (IPCC, 2023). This is likely to be particularly evident at smaller reservoirs and human-made storage and impoundments that lack the water holding capacity to mitigate these effects. Changes in hydrology can influence the extent of open water, littoral zones, mudflats and aquatic vegetation, and this can have

knock-on effects for habitat quality, food availability and associated communities (Gao et al., 2023; Qiu et al., 2024).

Waterbirds are sensitive to changes in water levels as they are affected by the water depth, the presence of water and shoreline features, and the distribution of vegetation and food resources (i.e., food resources access and quality) for nesting, feeding, and resting habitats (Gao et al., 2023; Wang et al., 2024). Different types of waterbirds differ in how they are affected by water conditions and habitat features (Gao et al., 2023; Wang et al., 2024). Diving and fish-eating waterbirds are dependent on aquatic environments and prey accessibility, while wading birds use more shallow waters and exposed land and open areas. Ecological generalist species use a wider range of habitats and resources. Different ecological requirements make waterbirds a sensitive bioindicator for wetland condition (Almeida et al., 2018; Gao et al., 2025).

Traditional waterbird monitoring tends to focus on measures of species richness, abundance, and taxonomic diversity. While helpful, such taxonomic metrics alone may not reliably inform us of community changes in ecological organisation because species vary greatly in their ecological roles and responsiveness to change (Mouchet et al., 2010; Almeida et al., 2018). Functional approaches provide more information to complement taxonomic metrics by describing traits related to resource exploitation, foraging behaviour, habitat dependance and environmental tolerance. Species with similar traits in their ecological strategy can then be grouped into functional guilds to allow community changes to be interpreted in the context of ecological processes.

Specialist and generalist groups within guilds may also show different responses to environmental filtering under hydrological change. Guilds that depend on a reliable open water source, specialised prey or limited feeding habitats may be more vulnerable to poor habitat quality, while generalists are likely to be resilient across a broader environmental spectrum. Recent work highlights strong effects of water levels, habitat heterogeneity and aquatic vegetation structure on waterbird functional diversity and community assembly (Wang et al., 2024; Xia et al., 2025), while drought appears to have contrasting effects on waterbird feeding guilds and functional community composition (Gao et al., 2023, 2025).

Losers of specialist strategies and increasing dominance of generalists may lead to functional homogenisation, or a reduction in community dissimilarity (Olden et al., 2004). Functional diversity indices are a way of effectively measuring and interpreting this re-shaping. Functional richness (FRic) represents the amount of trait space filled by a community, functional evenness (FEve) reflects the regularity with which it is filled and the distribution of abundance in this space, whilst functional divergence (FDiv) captures the degree to which abundance is concentrated in this trait space (Villger et al., 2008; Mouchet et al., 2010). These three functional measures have been shown to respond to water-level fluctuation, habitat heterogeneity and wetland restoration in waterbird communities (Wang et al., 2024; Xia et al., 2025).

However, there are still important geographical and ecological gaps despite increased momentum in trait-based monitoring. Existing evidence on hydroperiod and waterbird functional diversity is mainly from large natural wetlands and floodplains and well-studied lake systems (Almeida et al., 2018; Gao et al., 2023; Wang et al., 2024; Xia et al., 2025), and relatively little in small artificial reservoirs typical of semi-arid African landscapes. As such, it is unclear whether functional guilds have the potential to serve as useful indicators of hydrological degradation in small wetlands with limited capacity for continuous environmental observation.

This deficit in knowledge is especially true for Zimbabwe, where aquatic habitats are mediated within the predominantly seasonal landscape via reservoirs and dams. An ideal study for these data is Antelope Park Dam, which has historic waterbird data for 2014, as compared to new waterbird data; we have a time frame of twelve years to compare. This time frame may allow us to consider whether there has been an association between changing waterbird taxonomic and functional organisation and wetland condition.

The conceptual pathway the study traces was: climate variability - hydrological condition - alteration of wetland habitats and food resources - differential response of waterbird functional guilds - functional restructuring - homogenisation of wetland ecological condition. Functional guilds are, thus, considered a response to changes in wetland

condition and not climate change itself. Biological linkages alone, are not sufficient to infer climate change as the direct causal agent.

Hydrological impairment was therefore predicted to result in non-random reorganisation of the waterbird functional community. Guilds showing the highest reliance on stable aquatic systems and specialised food resources, along with those utilising specific feeding depths, were predicted to respond most negatively to increasing hydrological impairment relative to opportunistic and generalist guilds. An overall trend of decreasing representation of specialist guilds, decreasing functional diversity and increasing functional homogenisation was predicted along a gradient of increasing hydrological impairment. Integrating taxonomic and functional responses of waterbird assemblages resulted in an approach to improve ecological assessment of Antelope Park Dam and other small, hydrologically-perturbed wetlands of semi-arid southern Africa.

2. Materials and Methods

2.1 Study Area

Antelope Park Dam is in Antelope Park which is about 12 km south east of Gweru City, Zimbabwe (1928 S, 2948 E). It is situated in agro-ecological Region III, in a semi-arid area with unimodal rainfall pattern (mainly from November to March) and long dry season. Antelope Park extends over an area of about 1,200 ha and comprises the savanna habitat with elements of grassland, woodlands with miombo trees, aquatics and riparian zones. Erewonui dam This relatively small, human made, freshwater impoundment has a fluctuating water level, which rises and falls with rainfall, inflow and evaporation. Shifts in open water, shallow littoral zones, mudflats, emergent vegetation and riparian margins, also offer different habitats for water bird functional groups and the site is suitable for testing responses to changing water regimes.

2.2 Study Design and Temporal Framework

A longitudinal comparison design was employed to evaluate trends in structure and functional guild composition of the waterbird community over four assessment periods: 2014, 2018, 2022 and 2026. The 2014 data were used as the historical reference point.

It was decided that only the number of repetitions within an assessment period, rather than the number of years within an assessment, would be used as the units of comparison in the analysis. Sampling locations, shoreline routes, observation methodology and survey time were all kept consistent whenever feasible among assessment periods.

2.3 Waterbird Sampling and Counts

Waterbird surveys also integrated habitat coverage with systematic coverage along open water, shallow littoral zone, and exposed mudflats as well as riparian zones along creek banks. 10 fixed observation sites were established roughly 150-200 m apart along the reachable segments of the shoreline. Shoreline transect routes were pre-established and counts of about 15-20 minutes were carried out at each station. Waterbird species identity, numbers, habitat preference, feeding behaviour and breeding activity was recorded and attempts were made to identify waterbirds to species level. Counts were made mostly between 06:00-10:00 and 15:00-17:30 and avoided periods of heavy rain, high winds and other weather conditions that would impact on detectability. Duplicate counts between stations were minimised.

2.4 Survey Standardisation and Abundance

Sampling occasions were standardised for observation sites, route, sampling time, and time of day, as well as the methods used for identification. Formal distance-sampling and detection-probability models were not used, so abundance should be considered relative abundance, not absolute numbers. Where survey effort along the shoreline was available, abundance was scaled as individuals km^{-1}.

2.5 Functional Trait and Guild Classification

Waterbird species were assigned to three dimensions of ecology: foraging strategy, dietary specialisation and habitat preference. Information for traits was derived from standard ornithology texts and species were assigned according to the dominant foraging strategy in their use of Antelope Park Dam. Species were assigned to 12 functional guilds. The classification of species was provided explicitly in the information we had available for 6 of the guilds: piscivore, large wader, small wader, diving bird,

dabbling duck, herbivore, generalist, aerial insectivores, filter feeder. Abundance was expressed as the number of individuals, while relative abundance was expressed as a proportion of total waterbirds within an individual sampling occasion.

2.6 Hydrological Condition

Hydrological state, based on wetland attributes visible in field survey and the timing of the surveys (remote sensing did not determine water extent). Particular emphasis on availability and duration of open water, exposed and unvegetated shallow shoreline and mudflats, littoral and emergent vegetation. Both physical attributes were interpreted as having comparative ecological significance rather than attempting to quantify water extent or depth from these variables. Climate fluctuations were viewed as a background driver of water condition rather than the primary factor causing biological change.

2.7 Taxonomic and Functional Diversity Metrics

Taxonomic metrics used to compare diversity across sites were species richness (S), total abundance (N), diversity (H), and evenness (J). Functional diversity was measured as functional richness (FRic), functional evenness (FEve), and functional divergence (FDiv), derived from the species-by-trait and species-abundance matrices in R. FRic represented the amount of functional space occupied by each assemblage, whereas FEve and FDiv measured the regularity of abundance distribution in the occupied functional space, and the distribution of abundance away from its centre and towards its peripheries.

2.8 Statistical Analysis

All statistical analyses were performed using R, taking the repeated surveys within each assessment period as the observational unit. Species richness, standardised abundance, and functional-diversity measures were analysed using analysis of variance between assessment periods, when assumptions were met, followed by suitable post-hoc tests such as Tukey's HSD (if needed). When assumptions were not met, Shannon diversity was tested with a Kruskal Wallis test, and effect sizes reported where possible. Species turnover was calculated with Jaccard similarity as a function of presence/absence. Differences in functional guild composition were tested by

PERMANOVA using Bray-Curtis dissimilarities of guild abundance data, with pairwise comparisons among assessment periods. Multivariate dispersion was considered when examining PERMANOVA results.

2.9 Indicator Value and Indicator Suitability

To identify functional guilds or assemblages that differed between contrasting wetland-condition states, we calculated the indicator value (Ind Val) for each taxon or group of taxa. Indicators were selected on the basis of the nature and strength of temporal response, statistical significance, indicator sensitivity with respect to traditional taxonomic approaches, ecological sense, and magnitude of change across repeated sampling. We tested indicator sensitivity rather than temporal early warning potential.

2.10 Ethical Considerations and Study Limitations

Observations of free-ranging waterbirds in the field were non-invasive; all birds being observed were un-captured and unhandled and were not subject to experimental treatment. Antelope Park management permission was obtained prior to conducting surveys and disturbance minimized. Because assessment intervals were discontinuous, quantification of climate impacts was limited by discontinuous quantitative hydrological data, and formal detection-probability modelling was not undertaken, so we can only infer effects of climate change. Thus, our study infers links between changes in waterbird assemblages and waterbird taxonomic and functional structure, and climate change as the causal driver.

3. Results

3.1 Overall Waterbird Assemblage

Fifty-eight waterbird species including 12 functional guilds were recorded over 4 survey periods. There were significant temporal shifts in the taxonomic and functional configuration of the community, along with decreases in species richness, abundance and community diversity, and strong shifts in the composition of specialist and generalist functional guilds.

3.2 Variations in Composition, Species Richness and Abundance of Waterbirds

3.2.1 Species Richness

Waterbird species richness decreased between 2014 and 2026, at 58 and 41 species, respectively. (29.3%). Species richness was different across assessment periods (F, = 16.84, $p < 0.001$, = 0.58). Following a Tukey HSD comparison, richness in 2026 was significantly different to richness in 2014 ($p < 0.001$), and 2018 ($p = 0.012$).

3.2.2 Waterbird Abundance

Total observed abundance declined from 1,486 individuals in 2014 to 924 in 2026 (37.8%). Standardised mean abundance declined from 82.6 ± 6.8 individuals km^{-1} to 40.3 ± 5.2 individuals km^{-1}, with significant differences among assessment periods ($F_{3,36} = 21.36$, $p < 0.001$, $\eta^2 = 0.64$).

Community Diversity and Evenness

Shannon-Wiener diversity decreased from 3.42 (±0.19) in 2014 to 2.71 (±0.15) in 2026 (20.8%) and differed significantly between assessment periods (Kruskal-Wallis = 14.26, df = 3, $p = 0.003$). Pielou's evenness decreased from 0.84 (±0.04) in 2014 to 0.79 (±0.07) in 2018, 0.73 (±0.01) in 2022 and 0.68 (±0.14) in 2026.

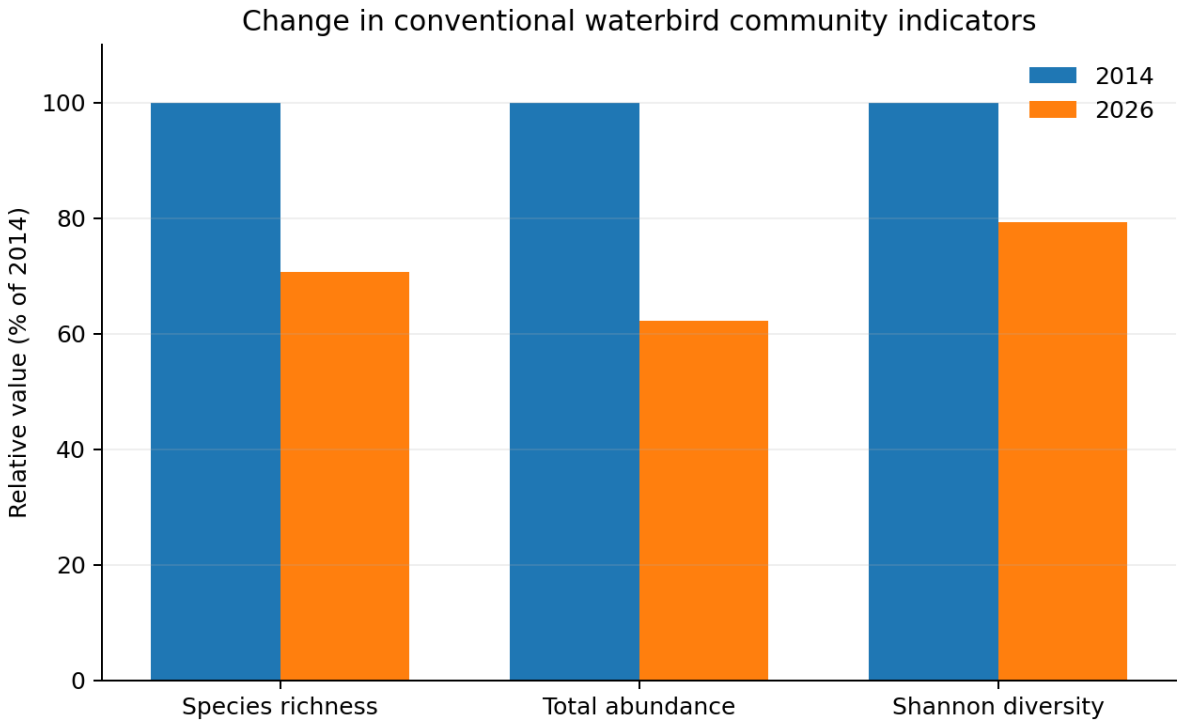


Figure 1. *Change in conventional taxonomic indicators relative to 2014, by 2026. All indicators are scaled as a percentage of their value in 2014, in order to make them comparable across different units of measurement.*

3.2.4 Species Turnover

Jaccard similarity between the 2014 and 2026 assemblages was J = 0.61, with 17 2014 species not found in 2026 but three species not present in the baseline assessment found subsequently. Non-detections were primarily diving, large wading and piscivorous taxa.

3.3 Temporal Changes in Functional Guild Composition and Functional Diversity

3.3.1 Functional Guild Restructuring

Guild Functional structure was significantly different between the assessment periods (PERMANOVA: $F_{3,36}$ = 9.14, R = 0.43, p = 0.001). Pairwise tests indicated that there was a significant difference between 2014 and 2022 (p = 0.003), 2014 and 2026 (p = 0.001) and 2018 and 2026 (p = 0.009).

3.3.2 Specialist Guild Declines and Generalist Increase

The numbers of piscivores decreased from 286 in 2014 to 102 in 2026 (64.3%), diving birds from 214 to 88 (58.9%) and large waders from 198 to 101 (49.0%) thus greater than the overall decline in abundance (37.8%). The proportional contribution of generalist feeders increased from 18.4% to 39.7%.

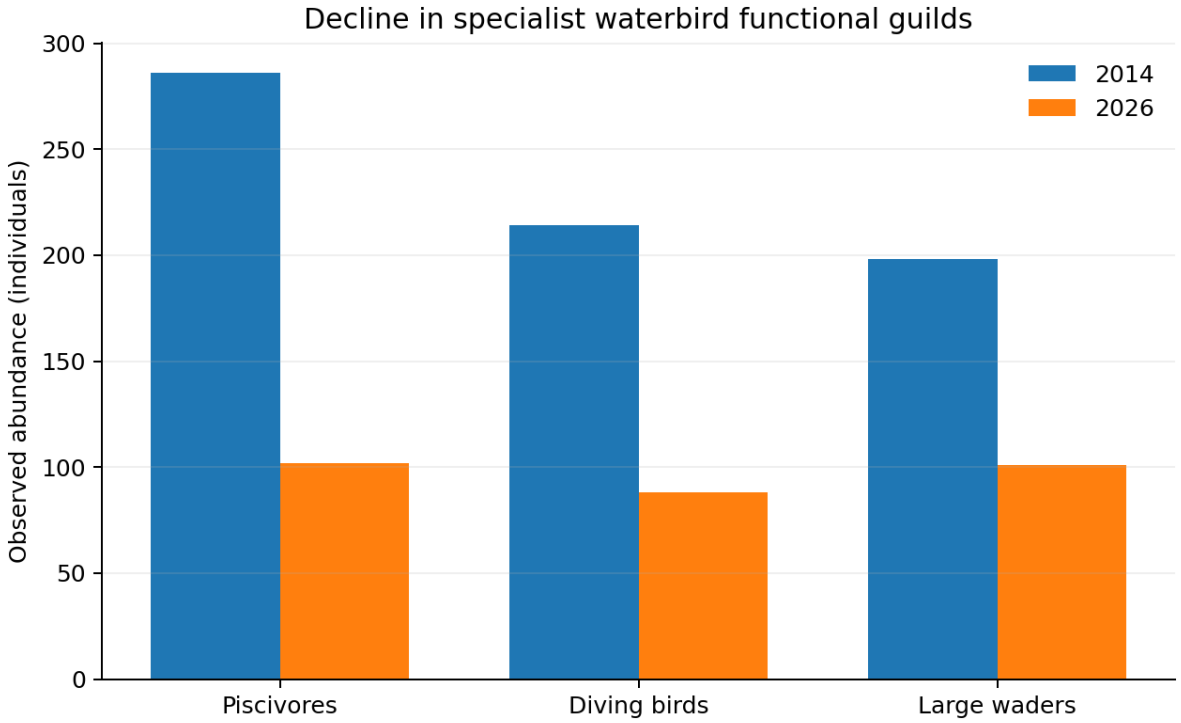


Figure 2. *Abundance of three specialist waterbird functional guilds observed in 2014 and 2026. Here you can see among waterbird guilds, the most marked drops are among piscivores, diving birds and large waders.*

3.3.3 Functional Diversity

Functional richness decreased from FRic = 0.61 to 0.35 (42.6%; $F_{3,36}$ = 18.22, $p < 0.001$), functional evenness from FEve = 0.72 to 0.51 (29.2%; $F_{3,36}$ = 11.37, $p = 0.001$), and functional divergence from FDiv = 0.76 to 0.49 (35.5%; $F_{3,36}$ = 13.91, $p < 0.001$).

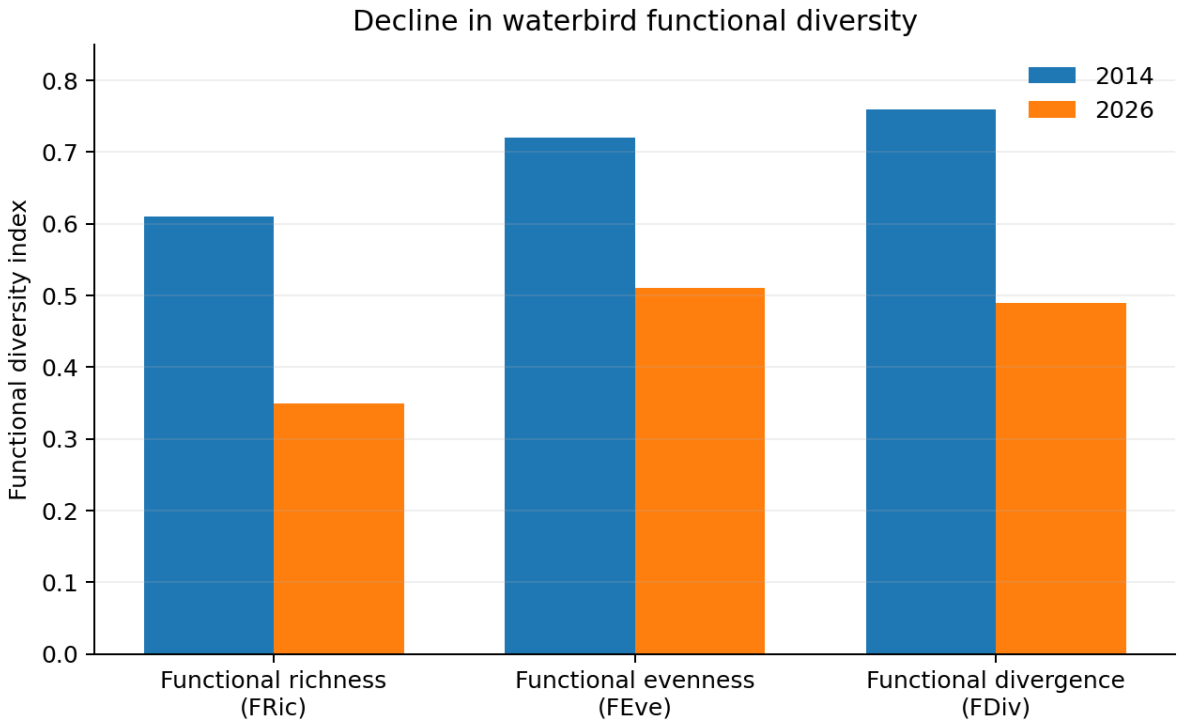


Figure 3. Functional richness, evenness and divergence in 2014 and 2026. All three functional-diversity dimensions declined over the study period.

3.4 Appropriate and Responsive Functional Guilds as Indicators

3.4.1 Indicator Value Analysis

Analysis of Ind Val values showed strong relationships of the guilds with contrasting wetland-condition states. The guild with the strongest relationship (highest significant values) were Piscivores (Ind Val = 0.82, P = 0.002), followed by diving birds (0.78, P = 0.004), generalist feeders (0.76, P = 0.003) and large waders (0.71, P = 0.011). Specialist guilds were associated with the earlier, or reference, assessment condition, while generalist feeders were associated with the more compromised, current wetland condition.

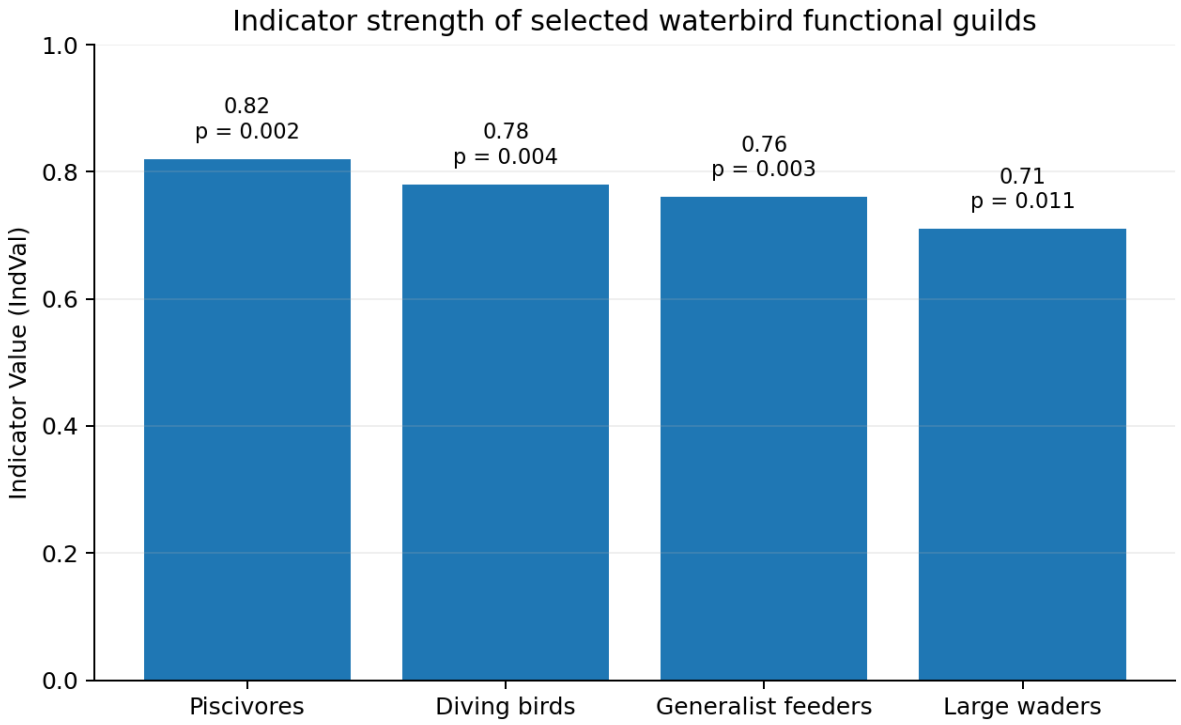


Figure 4. *Indicator Values (IndVal) for selected functional guilds. Specialist aquatic guilds were associated with the earlier/reference assessment condition while generalist feeders were associated with the more degraded recent condition.*

3.4.2 Relative sensitivity of taxonomic and functional indicators

Response strength was variable among indicators. The greatest proportional responses were observed for piscivores (64.3%), diving birds (58.9%) and large waders (49.0%), followed by functional richness (42.6%). These responses all were greater than those for species richness (29.3%) and Shannon (20.8%), which means that a number of functional indicators were responding more strongly than standard taxonomical diversity indicators.

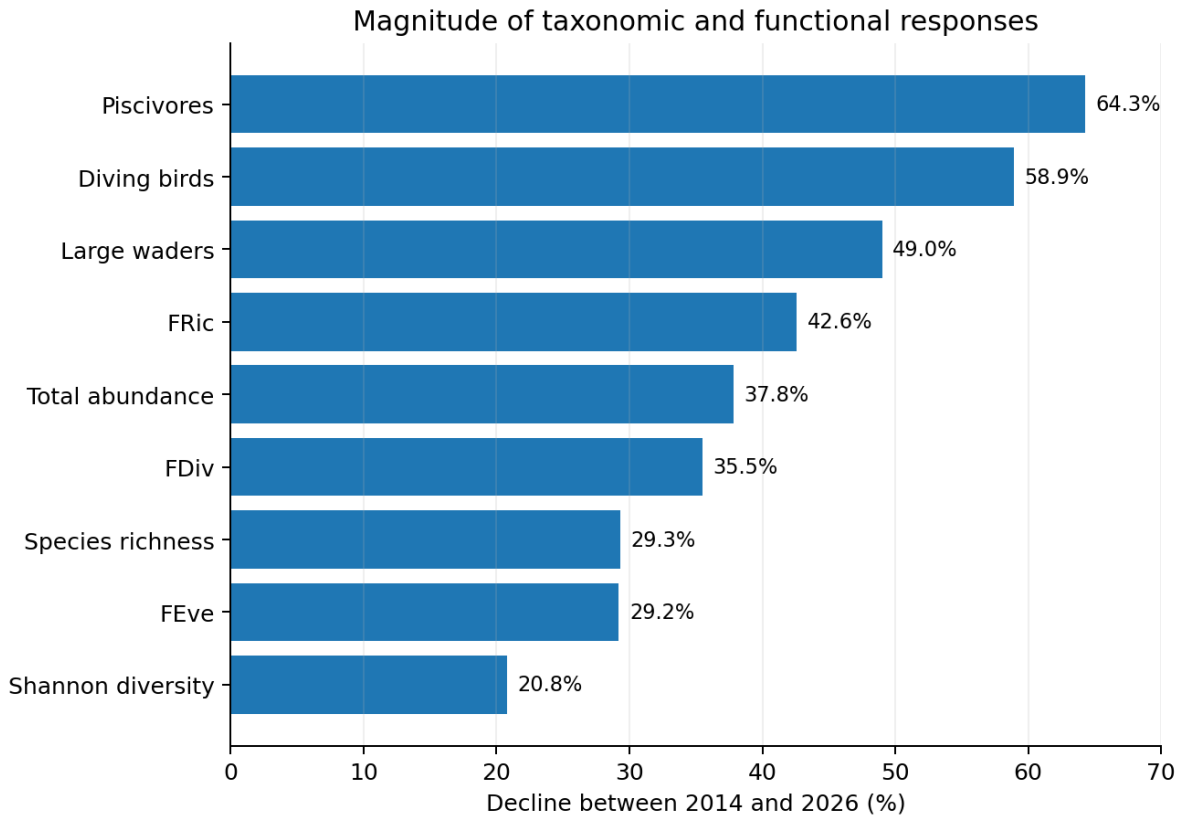


Figure 5. *Magnitude of change in selected taxonomic and functional indicators between 2014 and 2026. The response in the larger responses of specialist guilds and functional richness highlight their relative sensitivity to inter-annual variability in the wetland.*

The magnitudes of the larger responses would suggest the sensitive nature of the functional measures, but the design of the study does not allow the functional responses to be shown to have preceded the taxonomic responses. Thus, the results suggest that functional measures can be used as sensitive indicators of change and not that they will be reliable early-warning tools.

4. Discussion

4.1 Overview of the Major Findings

This paper provides clear evidence of large-scale temporal restructuring of the waterbird community at this wetland from 2014-2026. Changes were evidenced at the taxonomic and functional level, suggesting that decline in wetland condition was associated with a decrease in the number of species, individuals and the change in functional strategies exploited. Species richness decreased by 29.3%, total abundance by 37.8% and shannon diversity index by 20.8%. Large declines were also found in measures of functional richness (42.6%), functional evenness (29.2%) and functional divergence (35.5%). Significantly, the extent of change varied between the different functional guilds, with piscivores reduced by 64.3%, diving birds by 58.9% and large waders by around 49.0%, whereas the relative contribution of generalist feeders rose from 18.4% to 39.7%. The strong PERMANOVA result supported the conclusion that functional guild composition altered significantly between assessment periods and Indicator Value analysis revealed contrasting degrees of affiliation of specialist and generalist guilds to wetland condition.

Overall these results reinforce the main aim of this work that functional metrics can detect facets of ecological change that have not been recognised through traditional species-based measures of richness and diversity. Functional diversity describes the range of organisms' ecological function within communities, and as such, functional metrics can provide insight into how the organisation of communities and their potential ecosystem functions are affected by environmental filtering (Villger et al., 2008; Carmona et al., 2019). Our evidence from waterbird communities echoes this idea of environmental filtering, showing that drought and hydrological variation can influence both taxonomic and functional community structure through alteration of habitat accessibility and resource availability (Wang et al., 2024; Gao et al., 2025). The findings thus give support to the potential use of waterbird functional guilds as sensitive indicators of trends in wetland condition, but more importantly they highlight

the need to use both functional and traditional taxonomic measures of wetland ecological change.

4.2 Changes over Time in the Richness, Abundance and Community Structure of Waterbirds

These reactions are ecologically realistic because the distribution and abundance of waterbirds is strongly dependent on habitat availability, configuration and quality (waterdepth, openwater, exposure, aquatic habitat and food resources) (Mott et al. 2023). As a result, water-level variation can affect waterbird functional diversity via modification of habitat heterogeneity and usability (Wang et al., 2024). Waterbirds tend to be mobile, and can move between wetlands if habitat conditions and resources change. Thus, a species that is not detected in 2026 should not necessarily be assumed to be locally extinct, but rather that the results show a change in local occurrence and assemblage structure, rather than confirmed local extinction (Mott et al., 2023).

4.3 Functional Guild Restructuring and Environmental Filtering

The observed effects are in line with the concept of environmental filtering: environmental conditions selecting species with specific ecological characteristics over others. Environmental filtering was found to be a relevant process of structuring waterbird assemblages (Li et al., 2019). In line with our findings, the latest research also shows filtering effects of water depth, aquatic vegetation and habitat heterogeneity in the traits of waterbirds and the resulting assembly of a functional community (Wang et al., 2024; Xia et al., 2025).

4.3 Functional Guild Restructuring and Environmental Filtering

This pattern is consistent with the process of environmental filtering, in which specific environmental factors select for certain traits, and exclude others. Environmental filtering has been shown to be an important structuring process of waterbird assemblages (Li et al., 2019). Recent studies from the field also showed water depth, aquatic vegetation and habitat heterogeneity filter waterbird traits and shape functional community assembly (Wang et al., 2024; Xia et al., 2025).

4.3.1 Decline of Piscivores

Of all the species, it was the piscivores that had the greatest decline, with a reduction of 64.3% between 2014 and 2026. Fish-eating waterbirds rely on aquatic habitats that contain suitable prey. The quality of the waterbird habitats are known to be affected by complex interactive variables, such as availability of food, water conditions and vegetation structure (Mott et al., 2023). Changes in hydrological conditions may affect the fish-eating waterbirds via both these pathways. Although fish abundance and composition were not measured directly in this study, it seems premature to conclude that the loss of piscivorous birds was due to the loss of fish. Instead, the result shows that the piscivores ranked among the functional groups that most closely tracked changes in wetland condition.

4.3.2 Decline of Diving Birds

Water depth is a key environmental driver of the waterbird functional composition, as anatomical and behavioral characteristics limit the use of aquatic habitats (Almeida et al., 2018; Wang et al., 2024). The loss of diving waterbirds at Antelope Park Dam is therefore in line with evidence indicating that shifts in the conditions of aquatic habitats can have a selective influence on specific foraging strategies.

4.3.3 Decline of Large Waders

Water depth and the amount of exposed substrate is a key driver of the amount of foraging habitat available for waterbirds. Differences in marginal water depth can broaden the diversity of functional strategies within a wetland, and mudflat cover and habitat heterogeneity can be important in maintaining waterbird functional diversity (Almeida et al., 2018; Wang et al., 2024).

4.4 Generalist Dominance and Functional Homogenisation

Generalist species on average tend to have wider ecological tolerances than specialists do, potentially enabling them to survive in a greater range of conditions. Disturbance often impacts environments by supporting generalist species over specialists, leading to the functional homogenisation of biological communities (Clavel et al., 2011). Signatures of local functional homogenisation at Antelope Park Dam comprised large

losses in specialist guilds, concomitant increases in the proportional dominance of generalist guilds and decreases in functional richness, evenness and divergence (Fig. 4). Shifts from specialist to generalist dominance are well known as a key process of environmental change reducing the functional complexity of communities (Olden et al., 2004; Clavel et al., 2011).

4.5 Declining Functional Diversity

The significant of habitat heterogeneity in maintaining waterbird functional diversity is well understood. Almeida et al. (2018) found associations between environmental gradient and waterbird functional diversity; Wang et al. (2024) found habitat heterogeneity and mudflat as important positive predictors of functional diversity. The recent wetland-restoration showed the increase of FRic, FDis and FDiv after restoration, and found the water depth and aquatic plants were important environmental filters (Xia et al., 2025). Collectively, these studies offer an ecological framework in which the Antelope Park results make sense. A mosaic of open water, shallow water, exposed soil and aquatic vegetation can foster more diverse ecological approaches than a habitat of less complex structues (Wang et al., 2024; Xia et al., 2025).

4.6 Implications for Ecosystem Resilience

Ecological resilience broadly refers to the ability of ecosystems to absorb disturbance and reorganise while undergoing change so as to still retain the same function, structure, identity and feedbacks. Response diversity-response diversity is the variation in response to environmental change among species that make similar contributions to ecological functions-is currently understood as a key element of resilience (Elmqvist et al., 2003).

The reduction in specialist guilds and increase in generalist dominance at AP Dam indicates a narrowing in the range of strategies being used by the assemblage, which might have negative consequences for response diversity, and greater sensitivity to future change (Elmqvist et al., 2003). Ecosystem resilience was not measured directly in the current work and so declines in FRic, FEve and FDiv should be considered as evidence of loss in functional complexity rather than definitive evidence for loss in ecosystem resilience.

4.7 Functional Guilds as Indicators of Hydrological Impairment

Indicator Value analysis proved useful as Ind Val reflects the combination of the degree of occurrence and the frequency of occurrence of taxa or ecological groups to specific site conditions (Dufrn& Legendre 1997). In this investigation, we found that piscivores, diving birds and large waders were associated with the early/reference assessment and generalist feeders were associated with the less pristine, contemporary assessment condition. This ecological interpretability enhances the chance of these responses being valid indicators. Biological indicators have their strongest interpretive power when the observed responses can be mapped to plausible environmental processes, rather than purely statistical ones. For waterbirds, interpretability must take into account that habitat use can be influenced by the combinatorial effects of multiple environmental variables and the high mobility of individual birds (Mott et al., 2023).

4.8 Functional Versus Conventional Taxonomic Indicators

Overall, the findings suggest that a suite of functional indicators showed greater proportional change than traditional taxonomic measures, providing further evidence of their utility for ecologically detecting restructuring at the Antelope Park Dam, but not suggesting that functional measures should be used in place of species richness or abundance. Taxonomic and functional measures represent different aspects of biodiversity (Carmona et al., 2019), and may respond differently to spatial and temporal variation in the environment (Wang et al., 2024).

4.10 Climate Variability and Hydrological Impairment

Other work has shown that drought can impact wetland hydrology, habitat supply and waterbird community assembly. For instance, Gao et al (2023) showed that drought-driven hydrological and phenological shifts affected waterbird habitat dynamics, and Gao et al. (2025) showed that the effects of drought stress suppressed waterbird richness and the assembly of waterbird functional and phylogenetic groups. However, the current study did not explicitly measure the potential climatic drivers of long-term change nor distinguish the effect of climate from other environmental factors through

experimental manipulations. Thus, the changes presented here should be understood as functional reorganization rather than symptom of climate change-driven causation.

4.11 Contribution to functioning monitoring of small wetlands

Small and artificial wetlands are not necessarily of limited importance for conservation. Created wetlands may have relatively high waterbird richness and abundance, and aggregations of small wetlands may support bird richness similar to or higher than that of single larger wetlands of comparable total surface area (Kaergyt et al. 2021). Other studies also show that natural and created small wetlands can contribute to bird conservation in modified landscapes. The Antelope Park results indicate that it could be worthwhile to augment traditional species assessments of small artifi cial wetlands by including functional guilds and functional-diversity indices.

4.12 Conservation and Management Implications

Rather than trying to create a specific uniform hydrological environment, management needs to value habitat heterogeneity. Different functional groups require different arrangements of open water, shallow littoral zones, bare substrates and aquatic vegetation. Habitat heterogeneity, the amount of available mudflat, water depth and vegetation structure have all recently been shown to be significant drivers of waterbird functional diversity (Wang et al., 2024; Xia et al., 2025). Why we need ongoing standardised monitoring. Waterbirds are mobile and short-term sampling may not fully capture habitat quality or longer-term ecological change (Mott et al., 2023). Conducting surveys from the same places at the same times with the same methods would help distinguish between short-term fluctuations and ongoing directional change.

4.13 Alternative Explanations and Study Limitations

Why need to consider alternative drivers Waterbird habitat quality indices capture a suite of interacting environmental factors such as food, vegetation cover, water quality and disturbance (Mott et al., 2023). Human activities can impact the distribution and foraging behaviour of waterbirds (Mott et al., 2023). However, the extent and nature of

these effects are variable between waterbird species and environments (Mott et al., 2023). The results of this study suggest that the impact of these three factors on waterbird composition and abundance can only be fully tested if subsequent work combines functional waterbird measurements with measurements of rainfall and water depth, hydroperiod, water quality, aquatic vegetation, fish abundance and macroinvertebrate community composition.

4.14 Evaluation of the Study Hypothesis

It was hypothesised that the effects of hydrological disturbance would result in non-random alterations in the functional organisation of the waterbird community, with hydrologically dependent specialist guilds being more responsive than opportunistic and generalist guilds. The results were consistent with this prediction. Non-piscivore guild composition varied significantly between assessment periods, while piscivores, diving birds and large waders declined significantly more than all waterbirds. Generalist feeders showed a significant increase in proportional abundance. The hypothesis that declining wetland condition would negatively impact wetland functional diversity was also supported. There was a decline in FRic, FEve and FDiv from the historical baseline to the current assessment. Finally, the interplay between specialist declines and the broadening of generalist dominance, coupled with the functional contraction of the functional trait space was not incompatible with an overall general increase in local functional homogenisation. Thus, the observed trends support this hypothesis, but the causal effect of climate itself is not necessarily as directly resolved as a response of the organisms to the change in wetland conditions.

4.15 Discussion Synthesis

In sum, it is clear that temporal change in the Antelope Park Dam waterbird community was much more than a loss of species. The assemblage also exhibited major reorganisation of function with disproportionate loss of piscivores, diving birds and large waders, a rise in the dominance of generalist feeders, a large decrease in functional

richness, decrease in functional evenness and a decrease in functional divergence. Such patterns reflect environmental filtering and progressive local functional homogenisation. Sensitivity of Functional Metrics: Similar to species richness, functional metrics were sensitive to the gradients of effects. Functional diversity metrics such as FRic were proportionally less reduced than species richness, and specialist guilds were proportionally less reduced than general guilds. Indicator Value analysis revealed contrasting relationships between specialist and general guilds and wetland condition. This means the study concludes that the implementation of waterbird functional guilds alongside traditional measures of richness, abundance and diversity will enhance the detection of hydrological degradation. What implications do the results have? Combined, the results show the importance of an appropriate causal interpretation. The results can show that biological restructuring occurred following changes in hydrological conditions in a climate sensitive semi-arid system, but cannot show that anthropogenic climate change was the singular driver of these changes. Taxonomic-functional integration enabled this to give a more ecological informative evaluation of wetland change than species inventories alone and lays the groundwork for operational development of functional waterbird surveys in small reservoirs and other high risk, hydrological wildlife habitats in Zimbabwe and the region.

5. Conclusion

This research shows significant taxonomic and functional reorganisation of the waterbird assemblage at Antelope Park Dam, from 2014 to 2026. Decreases in species richness and abundance were negatively correlated with decreases in the specialist guilds, especially piscivores, diving birds and large waders, while generalist feeders increased in relative abundance. Simultaneous decreases in functional richness, evenness and divergence suggest functional contraction and homogenisation. The data show that functional guilds can offer ecological insights beyond those provided by traditional, species-based indicators, and highlight their significant utility as sensitive indicators of fluctuating wetland condition. Hence, functional monitoring should go hand-in-hand with traditional measures, rather than outcompeting them, by providing a useful

complement to information on species richness, abundance and diversity. Conservation of habitat heterogeneity, such as open water, shallow shoreline habitats, exposed substrates and emergent fringes, must remain a top priority for the Antelope Park Dam and wetlands in similar semi-arid environments. While the observed signals are consistent with responses to hydrological stress, the potential role of other drivers (including climate change itself) was not disentangled. The results should be interpreted as biological reordering related to the current state of the hydrological system rather than directly attributable to climate change. Long-term monitoring combined with measurements of the actual water level/climate and the direct response of the ecosystem and waterbirds is necessary to determine whether functional indicators always change in advance of taxonomic metrics. In conclusion, the use of waterbird functional guilds in long-term wetland monitoring offers a biological meaningful way of predicting ecological change and is useful in adaptive management of hydrologically sensitive wetlands in Zimbabwe and elsewhere in semi-arid southern Africa.

6. Recommendations

Long-term monitoring of Antelope Park Dam needs to relate waterbird guilds to traditional measures of species richness, abundance and diversity, especially sensitive specialist guilds. Future monitoring should also include quantitative climatic and hydrological measurements to account for most ecological variation. Management should provide a variety of habitats in the wetland (e.g. Open water, shallow littoral zones, mudflats and vegetated margins) with more regular standardised surveys needed to ascertain whether functional-guild shifts will serve as reliable early-warning indicators of the wetland's degradation.

Declarations

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