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ABSTRACT

Background: Anthropogenic pressures and climate change are degrading the current state of wetland biodiversity. In this study, we assessed the drivers of beta diversity (β-diversity) and hypothesized that turnover rather than nestedness contributes to overall β-diversity in anthropogenic landscapes, while evaluating the ecological drivers of waterbird β-diversity.

Method: We analyzed β-diversity for each anthropogenic activity, and explored the exclusive and shared contributions of anthropogenic, environmental, climate and spatial conditions in driving β-diversity.

Result: A total of 15750 individual waterbirds, representing 70 species, were recorded during the study. The study revealed high species richness of 63 species each in wetlands dominantly influenced by grazing and lumbering activities, followed by wetlands dominantly influenced by fishing activities and farming with 51 and 49 species respectively. We recorded low species richness in wetlands close to human settlement (35 species) and in sites impacted by organic waste (24 species). The significant

variation in community composition among different types of anthropogenic activities was related to turnover, as nestedness did not vary significantly across anthropogenic types. Variation partitioning output revealed that the proportion of unexplained variance by environmental predictors on total β-diversity, turnover, and nestedness was 63%, 64% and 64% respectively. This study revealed climate and environmental conditions as vital environmental filters driving the composition of waterbirds in anthropogenic landscapes.

Keywords: Environmental filtering; Climate, Waterbirds; Beta-diversity; Anthropogenic landscapes

Introduction

As global landscape changes continue to accelerate at an unprecedented rate, anthropogenic activities and prevailing environmental conditions have emerged as primary drivers of species extinctions, altered phenological patterns, and the restructuring of ecological communities—particularly at large spatial scales (1,2). In most wetland systems, anthropogenic activities contribute immensely to wetland modification and degradation by homogenizing physical environments over large distances, while disrupting natural environmental gradients (3,4). At multiple spatial scales, urbanization had been reported as a major driver of biodiversity decline, especially for woodland bird communities (5). Alterations of wetland systems are detrimental on both ecological composition and function (6). It disrupts flora-fauna assemblages and physicochemical cycles, ultimately leading to cascading impacts on species utilization (7). Despite the vital role played by wetland systems in facilitating life-history processes of waterbirds, there are speculations that continuous degradation of these unique systems by anthropogenic activities may impact their ability to perform their natural roles (8,9). Furthermore, the frequent losses of wetland habitats to farming activities, construction, pollution and other land use has been attributed to rapid biodiversity decline (6), through landscape homogenization (3) and biotic homogenization of species assemblages (2).

Biotic homogenization result from increased species coexistence, driven by range expansions, anthropic translocation of species and increased homogeneity in landscapes (11). Increased human settlements around wetland catchments substantially alter neighboring landscape and undermine ecosystem

integrity (12). The dominance of human settlements around tropical wetlands transforms their natural formations into forms of human-induced land uses which locally drives biotic homogenization (12). Ongoing biotic homogenization presents a significant conservation concern, as range-expanding, introduced, displaced, and threatened species often cluster within specific functional groups (4, 10). Thus, a long-term goal is to achieve strategies for reducing the effects of biotic homogenization on biodiversity and ecosystem functionality (12). Furthermore, the importance of conserving biodiversity cannot be underestimated in the face of continued species loss in this present time and as such, it is paramount to understand species composition both at the local and landscape levels (7) .

Understanding spatial variation in species composition across various environmental extent has been a long-standing discourse in community ecological research (15). While several studies had examined different hypothesis explaining variations in species composition, current trends in community ecology have diverged investigations into the patterns, causes and consequences of beta diversity (14). Beta diversity (β-diversity), serving as a bridge between alpha (species composition within a habitat) and gamma diversity (diversity encompassing all habitats), has long attracted the attention of ecologists due to its ability to incorporate spatial components into ecological analyses (17). It emphasizes changes in community composition across different habitats, offering insights that differ markedly from those provided by alpha and gamma diversity (18). Analysis of beta diversity is vital in understanding variations in community structure and the underlying factors in relation to anthropogenic activities shaping species distributions in order to guide conservation effort (17). Furthermore, in understanding species composition at the spatial scale, there is need for clear definition of the diversity components shaping species composition both within and between habitats (18, 19). While alpha diversity highlights the influence of environmental drivers on intra-habitat species variation, beta diversity and its two important components of nestedness and turnover reflects the differences in species composition between habitats (7, 19). Furthermore, the distinctiveness in beta-diversity patterns is fundamental to finding solutions to issues associated with species conservation (19). Since habitat loss have become a frequent occurrence and has greatly impacted species dependency and utilization (23), inter-site replacement of species may be the outcome of ecological processes, while species loss may be due to

events like extinction and colonization (21). These two events are major components of the dissimilarity index recently proposed by (19) and with gamma diversity, contribute to understanding biodiversity patterns at both local and regional scales (7, 18). Hence, both components are relevant in explaining the configuration of species across various anthropogenic landscapes (22), since they act as links between regional and local biodiversity (7, 23). Despite its ecological relevance, beta diversity remains underexplored in comparison to other biodiversity metrics—particularly in the context of waterbirds. This conceptual gap is especially evident in Afrotropical wetlands, where anthropogenic disturbances significantly influence community (7, 9).

In a bid to understand global trends in the life histories of species, studies that analyze structures and diversity across habitats are required despite the failure of such studies to differentiate between the influence of species sorting or environmental filtering (24, 25) The individual and combined effects of these two processes on avian assemblages have been debated (26, 27). Evidence from a study to assess the community structure and its potential drivers at different spatial scales revealed that the community structure of birds were predominantly controlled by species sorting, while environmental filtering also had an important joint role in structuring bird communities (26). While these two processes are perceived as vital factors in shaping species assemblages, there are concerns as to what extent is their influence on the beta-diversity of waterbirds in anthropogenic landscapes (28).

Generally, several studies have examined the factors driving species assemblages (5), while only a few studies have examined such factors across anthropogenic landscapes (12). In sub-Saharan wetlands where this study was conducted, research in the area of species heterogeneity is scarce, especially for waterbirds despite the huge ecological potential they possess and also the potential of the region to act as conservation hotspots for Afrotropical and Palearctic migrant birds (35). The sub-Saharan region is currently affected by massive anthropogenic and climate change impact (36), and the expected rapid growth of this region will further deteriorate the current state (7). In the light of this danger, the region has an urgent need to evaluate the effects of wetland conversion in the bid to conserve its tropical ecosystem biodiversity.

In this study, we assessed the drivers of β-diversity in arid wetlands within anthropogenic landscapes. First, we hypothesized that turnover rather than nestedness will contribute to overall β-diversity in anthropogenic landscapes. Second, we explored the exclusive and shared contributions of spatial conditions (SPC), climatic conditions (CLC), environmental conditions (ENC), and anthropogenic conditions (ANC) in driving β-diversity. Here, we hypothesized that these conditions, either in their unique or combined state would be vital drivers of waterbird β-diversity in anthropogenic landscapes.

Materials and Methods

Description of the Study Area

This study was conducted in the Hadejia-Nguru wetland network located between latitude 12°13ˈand 13°00ˈN and longitude 10°00ˈ and 11°00ˈE in the Sahel zone of the North-Eastern Nigeria (Figure 1). The wetland complex runs from the Hadejia Basin in Jigawa through Nguru and Dagona in Yobe before merging with the Lake Chad as River Yobe (37). It is a protected area under the jurisdiction of the newly gazetted Hadejia Wetland National Park in Jigawa state and the Chad Basin National Park in Yobe state. The hydrology of the area consists of permanent bodies of water and seasonal flooded area due to precipitation (32). Because of the precipitation and inundation of this area, the soil becomes extremely saturated with water thus making about 40% of the wetland complex wet throughout the year 33). This provides vital habitats for many migratory birds and serves as a means of livelihood (40). The area received 600-1000mm of rainfall, occurring primarily during the wet season (late June – Oct) with very little precipitation during the dry season (Oct to May) (41). The zone is characterized by sparse and unique vegetation such as *Acacia, Isoberlinia*, and *Daniellia*. Also, the clayey nature of the zone facilitates high-water retention capacity observed for this area. The mean annual temperature is about 33°C (38). The predominant anthropogenic activities in the area include fishing, farming, human settlement, lumbering, organic waste disposal and grazing.

Sampling Design

A simple random sampling method was used to quantify waterbirds population and communities across 28 sites randomly generated with the ArcGIS software program and ground-truthed with the aid of a

handheld GPS (Garmin eTrex® 20 GPS) (36). Random sampling was used in this study to ensure every individual within the waterbird populations had an equal chance of being selected (43). The minimum distance between sites was 400 m apart. Waterbirds were sampled every two months and across seasons from 2019-2021.

Land Use Characterization

Using the method of Géant et al., (2025), we integrated remote sensing to better characterize land use and document dominant anthropogenic activities across wetlands. We downloaded cloud free satellite images to evaluate land use within the wetlands. **Landsat 8-9 OLI/TIRS C2 L1 satellite imagery** containing land use datasets was retrieved from NASA Earthdata (www. Earthdata.org). The Landsat satellite imagery was processed in QGIS software (Ver 4.0.3-Norrköping). The period of 2019 to 2021 was considered as it allowed us to confirm the different land uses during the period of sampling. We reclassified land use data into six different or dominant types (45), which are: fishing (FH), farming (FM), grazing (GZ), human settlement (HS), lumbering (LB) and organic waste (OW). We conducted spatial analysis to determine the intensity of each land use sub-classes in the wetland. Land use intensity was determined from pixel or centroid counts generated from raster analysis. Due to the large pixel counts associated with each land use, a percentage scoring was derived for each land use class (Refer to Table S2). Thus,

$$\%\, Intensity\ \frac{LUI_i}{\sum LUI} \times 100 \ldots . Equ\ 1$$

Where;

$$LUI_i = Intensity\ of\ each\ Land\ Use$$

$$\sum LUI = Overall\ Land\ Use\ Intensity$$

Furthermore, we derived the anthropogenic disturbance index (ADI) for each wetland site by multiplying the wetland area (WA) by the percentage land use intensity in Equ 1.

$$ADI = WA \times \%\, Intensity \ldots . Equ\ 2$$

Waterbird Counts

We adopted point count method at each census point for waterbird survey (46). Observations were made from 0530-1030hrs after dawn and 1530–1830hrs before dusk using 8 × 42 binoculars (Nikon Monarch M7). Waterbirds were sampled every two months and seasonally within a period of two years (2019/2020 and 2020/2021). We conducted waterbird counts for 10 minutes, with two minutes for settling and eight minutes for observation (42). Both resident and migrant waterbirds were identified to the lowest taxonomic level using standard field guide (47).

Environmental Data

A broad range of environmental data such as anthropogenic variables (which include data on dominant human activities per site), physicochemical variables (herein referred to as environmental conditions), spatial and climatic conditions were collected at each site.

Anthropogenic conditions (ANC) were classified into dominant categories following established wetland disturbance types (such as habitat modification and land-use pressure), consistent with large-scale wetland monitoring protocols (41). Dominant anthropogenic activities within each wetland were determined using a multi-metric Anthropogenic Disturbance Index (ADI). Land use classification resulted in six land use sub-classes (fishing (FH), farming (FM), grazing (GZ), human settlement (HS), lumbering (LB) and organic waste (OW)).

Physicochemical parameters (herein referred to as environmental conditions (ENC) such as dissolved oxygen, hydrogen ion concentration, electrical conductivity, total dissolved solids and turbidity were determined in-situ using standard multi-probe portable YSI 9620 meter and multi-probe portable Hanna HI991300/1, Phosphate and Nitrate were determined following the methods of (49). Other physical variables such as depth was determined with a ruler calibrated at an accuracy of 0.1cm following the methods of (50), while flow velocity was estimated by observing the movement of a float (usually a tennis ball) over a predetermined distance (51). Climatic variables such as solar radiation (SR), surface water temperature (SWT), water vapour pressure (WVP), greenhouse gas (specifically N_2O) and precipitation are key for wetlands as they influence climate change impacts, and facilitate seasonal

variability in wetlands by influencing species availability (52). Climate variables (CLC) such as SR, SWT, WVP and precipitation were retrieved from WorldClim database v.2.0 (www.worldclim.org) at ~1 km (30 arc-seconds), while greenhouse gas (specifically N_2O) was retrieved from NASA Earthdata database (www.earthdata.org). Climate values were processed from each site from raster images and extracted with the QGIS software (Ver 4.0.3-Norrköping). We ensured extracted climate data were in congruence with spatial features collected with Geographic information Systems (GIS) during the sampling periods by ensuring the data were temporally and seasonally downloaded.

We used Geographic Information Systems (GIS) to collect spatial features (SPC) represented by longitude and latitude, distance to human activity and altitude across each sampling site within the wetland network. The catchment of each study site was delimited based on a digital elevation model (DEM) with 30-m spatial resolution (53). The distance to human activity from each study site and altitude were estimated from the DEM pixel. Images were selected during the peak vegetation season in order to expand the identification of wetlands and its features. Geographic coordinates were transformed into distance-based Moran's eigenvector maps (dbMEM) via spatial eigenvalue analysis (Refer to Table S3). First and second axis (MEM1 and MEM2) were extracted and used as part of spatial variables since both axes potentially possess higher explanatory powers (52).

Data Analysis

All data analysis was performed with R statistical software, R version 4.3.2 (47). We evaluated beta-diversity across different levels of anthropogenic activities (Farming (FM), Fishing (FH), Grazing (GZ), Human settlement (HS), lumbering (LB) and organic waste (OW)). We decomposed beta-diversity into its components of turnover and nestedness (48) with the "*betapart*" package, using 'Sørensen' presence and absence data (56). The three derived distance matrices were used as the response variable. PERMDISP was used to examine differences in the matrices (average distances of communities to group multivariate centroids) between the categories of anthropogenic data (57). PERMDISP analysis which evaluates the homogenous dispersion of anthropogenic categories in relation to the waterbird species in the studied samples based on ANOVA F statistic was conducted using the "*betadisper*"

function in the "vegan" package (57). Furthermore, all p-values resulting from residual permutation were attained from group sample permutations centered to a common location using PERMDISP (7).

The omission of potential variations in location facilitates the replacement of derived residuals under the null hypothesis of homogeneity of dispersions when compared to location influence, therefore increasing the likelihood of heterogeneity or dispersion in beta diversity of waterbirds as the average distance of each predictor group tend to significantly increase (50). The variations in the community assemblages of waterbirds across various anthropogenic activities was tested using the Permutational Multivariate Analysis of Variance (PERMANOVA) with the "*adonis2*" function in the R "vegan" package (59). PERMANOVA depend on distance matrices to evaluate variance (7) and similarities across different anthropogenic categories (52). Furthermore, an indicator species analysis (ISA) using abundance data was performed to determine the species driving variations in the composition of waterbirds at different human activities (53, 54). The ISA was performed with the package "indicspecies" and "multipatt" function to calculate the indicator value for waterbirds across the various categories of human activities (63). The statistical significance of the indicator values was assessed using Monte Carlo permutations, while the results were visualized using tables (63).

Anthropogenic influences on waterbird beta-diversity were evaluated using distance-based redundancy analysis, with the inclusion of euclidified dissimilarities (52). We performed forward based selection by using the "*ordiR2step*" and "*capscale*" function to select for final spatial variables (SPC), climate variables (CLC), environmental variables (ENC), anthropogenic variables (ANC) for the models of each community matrix. The function "*ordiR2step*" builds model forward so that it maximizes adjusted R^2 at every step, and stopping when the adjusted R^2 begin to decline, or the adjusted R^2 of the scope is exceeded, or the selected permutation *P*-value is exceeded (65). However, the "*ordiR2step*" function cannot be used if adjusted R^2 cannot be calculated.

The forward selection technique yielded two variables (MEM1 and Alt) for spatial conditions (SPC), four variables (WVP, SR, GHG and Prep) for climatic conditions (CLC) and four variables (TDS, TUR, EC and pH) environmental conditions (ENC). For anthropogenic condition (ANC), we used the ADI

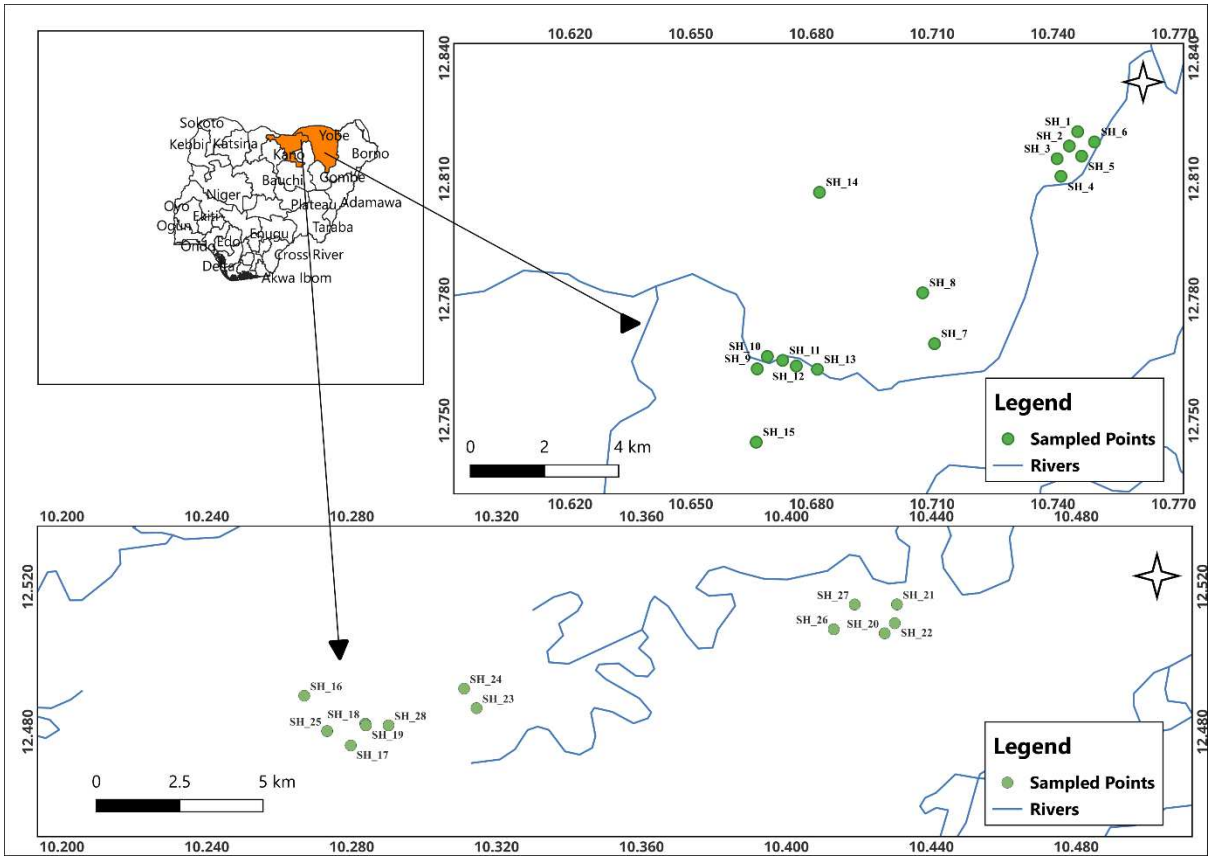
derived from remote sensing analysis. These final variables were used for final variation partitioning analysis. Variation partitioning based on adjusted R^2 was performed for each dissimilarity matrices; (14, 57). Variation partitioning yielded single fractions (Table S4), pooled contributions and residuals or unexplained variance (U) for each predictor. Furthermore, we tested the significance of the single or unique fractions using the function "*anova*" in the R package vegan and interpreted the effect of predictors with adjusted R^2 which signifies an unbiased estimation of the explained variance (58).Venn diagrams were used to visualize output of variation partitioning with the unexplained variance and allotted fractions shown.

Results

A total of 15750 individual waterbirds, representing 70 species, were recorded during the study. Sixty-three (63) species were recorded in sites dominantly influenced by grazing and lumbering activities, while fifty-one (51) species were reported in sites dominantly influenced by fishing activities. Wetland sites in proximity to human settlements recorded thirty-five (35) species, while twenty-four (24) species were reported in sites dominantly impacted by organic wastes (refer to "Table S1").

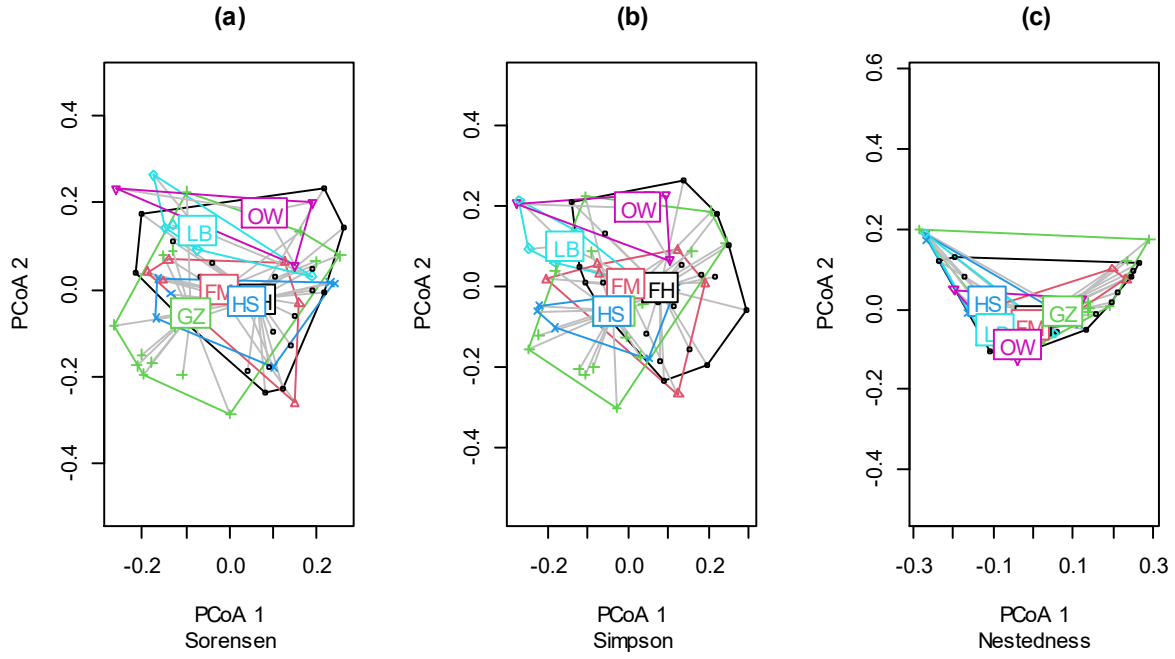
Across different levels of anthropogenic activities, PERMDISP result did not reveal a significant difference for β-diversity and its components (Figure 2; Table 2). However, the result of PERMANOVA indicated a significant difference for community compositions among different anthropogenic activities for overall β-diversity ($F = 1.37$, $p = 0.007$) and turnover ($F = 1.42$, $p = 0.009$), while nestedness ($F = 1.20$, $p = 0.293$) did not vary significantly across anthropogenic types (Figure 3; Table 3). Similarly, ANOVA test result for dbrda analysis to assess constraints significance on waterbird indices revealed a significant difference for overall β-diversity ($F = 2.74$, $p = 0.001$) and turnover ($F = 3.48$, $p = 0.001$), while nestedness ($F = 0.14$, $p = 0.999$) did not vary significantly (Table 4). Indicator species analysis revealed that the African Darter, African Fish Eagle, African Pygmy Kingfisher, African Wattled Lapwing and the Lesser Jacana were the species driving variation in the community structure of waterbirds in wetlands dominated by fishing activity (Table 1). In wetlands dominantly influenced by farming activities, the Egyptian Goose, Great Snipe, Kittlitz's Plover, Tufted Duck and White Stork were the species driving variation in the community composition of waterbirds, while the Black-Tailed Godwit, Black Stork and

Goliath Heron were the species influencing waterbird composition in wetlands dominated by grazing activity (Table 1). However, in wetlands impacted by organic waste, two waterbird species, African Pygmy Goose and Black Crake dominantly influenced the community structure of waterbirds in such wetlands (Table 1). The result of constrained ordination using dbRDA revealed that for all compositional matrices used as a response across selected groups of predictors (SPC, CLC, ENC and ANC), the unexplained variance was 63% (for total diversity), 64% (for turnover) and 64% (for nestedness; Figure 4). Generally, most of the variations in the assemblage of waterbird communities were accounted for by climatic conditions (CLC) and environmental conditions (ENC) (Figure 4). For variation in community composition, the joint contribution of SPC and CLC was 1% on overall β-diversity, CLC and ENC was 16%, ENC and ANC contributed less than 1%, SPC and ENC contributed 1%, while the combined effect of SPC and ANC on overall β-diversity was negligible (Figure 4). For turnover (simpson), 7% and 5% of the variation was contributed by SPC and CLC respectively, the effect of ANC was 2% while the effect of ENC was negligible (Figure 4). Furthermore, the combined effect (Table S5) of CLC and ENC on turnover was 15%, while the combined effect of other variables was less than 5% (Figure 4). For overall beta-diversity and turnover, the tested fractions were highly significant while the tested fractions for nestedness was not significantly different (Table 4).



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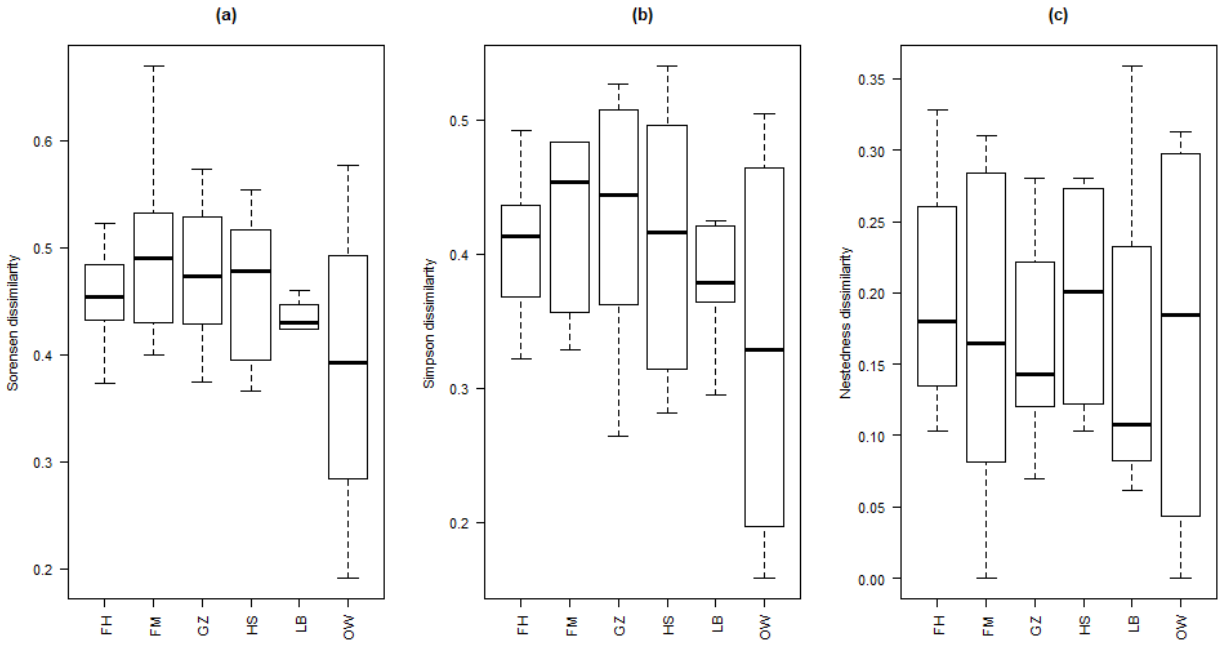
279 Figure 1: Map of study area showing sites with designated anthropogenic activities



280

281 Figure 2: Principal coordinate analysis (PCoA) plots of variation in waterbird composition and beta

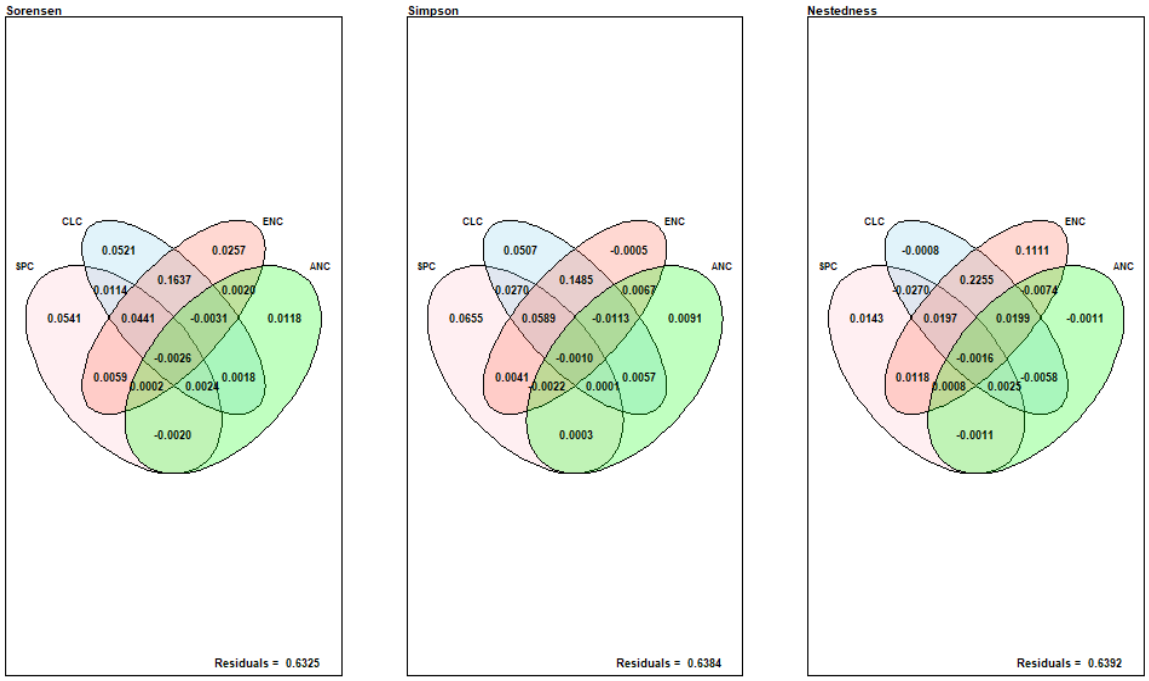
282 diversity across different categories of anthropogenic activities.



283

284 Figure 3: Boxplots of median distance to centroid of the anthropogenic classes: (a) Sørensen, (b)

285 Simpson, and (c) Nestedness-resultant component for each anthropogenic class in the waterbird data



286

287 Figure 4: Venn diagrams of variation partitioning of waterbird community assemblage based on:

288 Sorensen (Overall Beta-diversity), Simpson (Turnover) and nestedness (from left to right) across SPC;

289 Spatial condition, CLC; Climatic condition, ENC; Environmental condition and ANC; Anthropogenic
290 condition. Numbers shown inside Venn diagrams represent adjusted R^2 values.
291 Table 1: Results of Indicator species analysis showing species driving variation in the community
292 structure of waterbirds in wetlands dominated by Anthropogenic activities

Common Name	Taxa	Taxa Code	Human Activity	stat	p.value
Anhinga rufa	African Darter	AFDAR	FH	0.22	1.0000
Haliaeetus vocifer	African Fish Eagle	AFFEA	FH	0.39	0.2546
Ceyx pictus	African Pygmy Kingfisher	AFPKI	FH	0.22	1.0000
Vanellus senegallus	African Wattled Lapwing	AFWLA	FH	0.22	1.0000
Microparra capensis	Lesser Jacana	LEJAC	FH	0.49	0.1683
Alopochen aegyptiaca	Egyptian Goose	EGGOO	FM	0.44	0.1399
Gallinago media	Great Snipe	GRSNI	FM	0.29	0.8091
Charadrius pecuarius	Kittlitz's Plover	KIPLO	FM	0.36	0.4942
Aythya fuligula	Tufted Duck	TUDUC	FM	0.43	0.2794
Ciconia ciconia	White Stork	WHSTO	FM	0.47	0.0727
Limosa limosa	Black-Tailed Godwit	BLGOD	GZ	0.26	0.6526
Ciconia nigra	Black Stork	BLSTO	GZ	0.26	0.6438
Ardea goliath	Goliath Heron	GOHER	GZ	0.26	0.6406
Nettapus auritus	African Pygmy Goose	AFPGO	OW	0.64	**0.0104**
Amaurornis flavirostra	Black Crake	BLCRA	OW	0.51	0.3606

293
294
295

296 Table 2: Summary of PERMDISP test output and test for homogeneity in beta-diversity across
297 anthropogenic status.

Distance Matrix	Average distance to median						SS	MS	F	Pr(>F)
	FH	FM	GZ	HS	LB	OW				
Sor	0.46	0.50	0.48	0.46	0.43	0.39	0.04 (0.23)	0.01 (0.00)	1.77	0.147
Sim	0.40	0.46	0.40	0.41	0.38	0.33	0.04 (0.53)	0.01 (0.01)	0.84	0.54
Sne	0.20	0.17	0.19	0.20	0.17	0.17	0.01 (0.57)	0.00 (0.01)	0.16	0.98

298

299 Table 3: Permutational Multivariate Analysis of variance (PERMANOVA) result showing differences
300 in community composition among anthropogenic status.

Waterbird Matrix	SS	R2	F	Pr(>F)
Sor	1.49 (10.83)	0.12 (0.88)	1.37	0.007
Sim	1.22 (8.62)	0.12 (0.88)	1.42	0.009
Sne	0.27 (2.21)	0.11 (0.89)	1.20	0.293

301

302 Table 4: ANOVA test result for dbrda analysis to assess constraints significance on waterbird indices

Waterbird Matrix	SS	F	Pr(>F)
Sor	1.16(11.16)	2.74	0.001
Sim	1.14(8.70)	3.48	0.001
Sne	0.01(2.46)	0.14	0.999

303

304 **Discussion**

305 The study compared waterbird communities among wetland types that are under different forms of
306 anthropogenic influence. It supports the existence of heterogeneity in species assemblages among

anthropogenic land-use categories. While there is an increasingly shift in the utilization of β-diversity for the regional study of biodiversity processes, most ecological systems and biota, the conceptualization in the overall study of β-diversity especially in sub-Saharan wetlands that are perturbed by different levels of anthropogenic activities is overwhelming (7, 59, 60). Although there is the existence of alpha and gamma diversity in assessing the compositional variation of species across different anthropogenic perturbations and habitat features (9, 61, 62), the result of such studies does not undermine the importance of assessing the influence of anthropogenic activities in structuring beta diversity (10, 11, 63).

Anthropogenic activities in wetlands play a vital role in facilitating the beta alteration of regional species (4, 64). While the primary focus of previous studies examined the singular influence of such activities around wetlands (65, 66, 67), this study have assessed other categories of anthropogenic activities such as human settlement, fishing (which occur right inside wetland habitats), grazing (which have the tendencies to facilitate deforestation), lumbering and organic wastes which may prove crucial in influencing the β-diversity of waterbirds in arid wetlands. As expected, the overall β-diversity was driven by the turnover while nestedness revealed a negligible effect on β-diversity, an indication that assemblages of waterbirds in each wetland within the anthropogenic landscape are heterogenous (68). One possible explanation for such unique process is that waterbird assemblages in one wetland type may have been replaced by another (69) as they navigate from one habitat to another in search of opportunities (30, 70) and as such limiting their preference to specific habitats due to resource depletion as a result of persistent anthropogenic perturbation (71). Realistically, anthropogenic perturbations may promote limited resources which lead to interspecific competition and constrain to the coexistence of functionally similar species within these wetlands, thereby increasing homogeneity (30, 73). However, that may not be the case for this study where reduced intensity of anthropogenic perturbations create heterogeneity through the availability of microhabitats to promote ecological diversity (74, 75, 76). While our findings clearly conforms with the outcomes of (5) where dissimilarity in species composition across anthropogenic gradients was mainly due to different occurring species rather than a systematic loss in species across sites, it solidly contrast with the findings of (32) where it was reported

that anthropogenic landscapes can facilitate the homogenization of birds. In west Africa where anthropogenic disturbances was revealed to be the main drivers of reduced species diversity (69), the influence of anthropogenic activities on local species pool has been seriously debated as multifaceted, ranging from species reduction to complete loss (77, 78).

Despite the designation of Hadejia-Nguru wetlands as a protected area under the Hadejia Wetland National Park and Chad Basin National park (79), the wetlands within the area are perturbed with human activities like farming, human settlement and grazing activities. These activities in no doubt pose a direct challenge to their conservation effort. For wetlands that are in close proximity to human settlement, sewage waste can be disposed untreated into these waterbodies, facilitating their contamination (80). Additionally, changes in vegetation composition as a result of anthropogenic activities like grazing and lumbering may adversely impact the quality (in terms of resource availability) of these habitats for waterbirds, which will have a cascading impact on the diversity and assemblage of waterbirds in their wetland habitats (81, 82).

It is worth noting that despite the non-significant relationship in waterbird indices across anthropogenic classes as revealed from the PERMDISP result, the significant contribution of species turnover to overall beta-diversity in such anthropogenic landscapes clearly reveal its influence in facilitating changes in biophysical processes that may improve wetland stability and indicates that heterogeneity is a process that is bound to occur at a multivariate space (83). Again, the evidence that overall beta diversity was significantly influenced by either turnover potentially gives an indication that variation in community composition in anthropogenic landscape may not be as a result of different species occupying different wetland sites (11, 48) rather, it may be due to the level of fidelity shown by waterbirds to specific sites (84, 85).

From the result of our distance-based redundancy analysis (dbRDA), it is obvious that minimal variations in the composition of waterbirds were inadequately explained by the four groups of environmental variables. The large unexplained variation recorded in this study are common in community studies where adjusted R^2 values have been used to describe the result of constrained

ordination (9,11, 58, 86-87). However, the large unexplained variance reported in this study should not be conceived as an underestimate of the vital processes influencing waterbird composition in these wetlands perturbed by various anthropogenic impacts. Previous studies have also reported high residuals, especially in Afrotropical landscapes where such studies were conducted (9, 11, 88, 89). The fact that wetland systems in anthropogenic landscapes are recipients of anthropogenic perturbations which impact their ecological integrity (90, 91, 92) may provide ample justification of the high residual values or unexplained variance reported for this study.

Accordingly, the result from this study which revealed the relative importance of the combined effect of climatic and environmental conditions in driving waterbird compositions in these perturbed wetlands conforms with previous findings, where variations in the community structures of aquatic fauna due to environmental factors may show close ties to ecological disparities among groups of species in the community (93). Specifically, we also found that the variation in total β-diversity of waterbirds was also individually influenced spatial, climatic and environmental condition, despite the individual effects being weak. Thus, our study suggests such factors as vital environmental filters which possibly facilitate the dispersal ability of waterbirds (9, 94) or influence heterogeneity in waterbird communities (95), the effect which may prove difficult to distinguish since both processes may initiate spatial structuring in the assemblage of waterbirds (96). Furthermore, the overall effect of environmental filtering on the composition of waterbirds is largely dependent on the magnitude of environmental gradient and consistent with the study of (11). While anthropogenic activities such as fishing, farming, grazing, human settlement, lumbering and organic waste release are dominant and well documented in the study area (97, 98), their ability to initiate ecological processes like environmental filtering have not been established. While, the unexpected negligible effect of other environmental factors (specifically ANC) on the composition (total β-diversity, turnover and nestedness) of waterbirds is consistent with previous studies (100, 101), such studies may have concluded that few spatial processes have limited influence on small organisms due to the dominant role of environmental filtering (102). Also, it is somewhat surprising, as many studies have emphasized the significant effects of land use on in-stream local environmental conditions and subsequently on fauna assemblages (103). Though, this may not be the

387 case for waterbirds which easily migrate large distances, despite speculations that movement limitation
388 may have resulted from variation of the ecological processes through anthropogenic perturbation (104).

389 This study provides a theoretical foundation for a profound understanding of waterbird community
390 structure, environmental filters and ecological management under different anthropogenic conditions.
391 From the perspective of natural resource conservation, the heterogeneity in waterbird assemblages in
392 anthropogenic landscape can be very vital, as the degradation of arid wetlands may facilitate the creation
393 of habitat mosaics and result in a marked decline in waterbird richness at a regional scale. This suggests
394 that conservation efforts encompassing waterbirds (9) and other fauna (16, 60), should focus on
395 preserving arid wetland ecosystems covering large geographic areas. Furthermore, the effect of spatial,
396 climatic and environmental conditions clearly indicates that the heterogeneity in the assemblage of
397 waterbirds in the anthropogenic landscape was dominantly shaped by environmental filtering. This
398 study further provides valuable and novel insights into the processes structuring waterbird communities
399 in wetlands perturbed by anthropogenic activities in arid systems and provides a theoretical basis for
400 the ecological management of wetland environment. In the conservation sphere, limited attention has
401 been paid to the potential loss of waterbirds and overall wetland biodiversity especially in arid regions
402 where irrigation farming, grazing and other land use change are paramount. Such losses if not managed
403 could impact ecosystem services and as such, call for actions that will facilitate their protection.

404 **Conclusions**

405 This study revealed new insight into the conservation of waterbirds across anthropogenic landscapes by
406 assessing the drivers of beta diversity (β-diversity) in arid wetlands subject to various anthropogenic
407 activities. We hypothesized that overall β-diversity in anthropogenic landscapes will be influenced by
408 turnover rather than nestedness. Overall β-diversity was driven by the turnover while nestedness
409 revealed a negligible effect on β-diversity. Through dbRDA, the exclusive and shared effect of
410 environmental factors on β-diversity was explored and minimal variations in the composition of
411 waterbirds which were inadequately explained by the four groups of environmental variables were
412 revealed. While this study revealed climate and environmental conditions as vital environmental filters
413 driving the composition of waterbirds in anthropogenic landscapes, the negligible effect of

anthropogenic conditions in structuring assemblage of waterbirds in wetlands subject to anthropogenic perturbation should not be undermined. Thus, it is suggested that conservation efforts encompassing waterbirds and other fauna should focus on preserving arid wetland ecosystems covering large spatial scales.

Declaration

● Abbreviations

Not applicable

● Ethics approval and consent to participate

This study was conducted in line with relevant guidelines and approval for wildlife research in the Hadejia Wetland National Park under the permission of the Ministry of environment, Jigawa state, Nigeria with Ref: ME/CONS/72/VOL.II/32.

● Consent for publication

Not Applicable

● Availability of data and materials

Data will be made available upon request

● Competing Interests

The authors declare that they have no known conflict of interests that could have appeared to influence the originality of this paper.

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● Authors' contributions

UNK – Conceptualization, writing (revision), Methodology and Analysis; **MCE** - Conceptualization, writing (draft), Methodology and Analysis; **PCC** – Writing (revision), methodology; **MEU** – Writing (Draft) and Methodology; **FOA** – Supervision, writing (revision).

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References

Daru BH, Rock BM. Reorganization of seagrass communities in a changing climate. Nat Plants. 2023;9(July). doi:10.1038/s41477-023-01445-6

Montràs-Janer T, Suggitt AJ, Fox R, Jönsson M, Martay B, Roy DB, et al. Anthropogenic climate and land-use change drive short- and long-term biodiversity shifts across taxa. Nat Ecol Evol. 2024;8(4):739–51. doi:10.1038/s41559-024-02326-7 PubMed PMID: 38347088.

Karp DS, Rominger AJ, Zook J, Ranganathan J, Ehrlich PR, Daily GC. Intensive agriculture erodes β-diversity at large scales. Ecol Lett. 2012;15(9):963–70. doi:10.1111/j.1461-0248.2012.01815.x

McLean K, Mushet D, Sweetman J. Climate and Land Use Driven Ecosystem Homogenization in the Prairie Pothole Region. Water (Switzerland). 2022. p. 3106. doi:10.3390/w14193106

Sidemo-Holm W, Ekroos J, Reina García S, Söderström B, Hedblom M. Urbanization causes biotic homogenization of woodland bird communities at multiple spatial scales. Glob Chang Biol. 2022;28(21):6152–64. doi:10.1111/gcb.16350 PubMed PMID: 35983686.

Akindele EO, Ekwemuka MC, Apeverga P, Amusa TO, Olajuyigbe S, Coker OM, et al. Assessing awareness on biodiversity conservation among Nigerians: the Aichi Biodiversity Target 1. Biodivers Conserv. 2021 Jun 1;30(7):1947–70. doi:10.1007/s10531-021-02175-x

Keke UN, Arimoro FO, Ayanwale A V., Odume ON, Edegbene AO. Weak relationships among macroinvertebrates beta diversity (β), river status, and environmental correlates in a tropical biodiversity hotspot. Ecol Indic. 2021 Oct 1;129. doi:10.1016/j.ecolind.2021.107868

Ma Z, Cai Y, Li B, Chen J. Managing Wetland Habitats for Waterbirds: An International Perspective. Wetlands. 2010 Feb 9;30(1):15–27. doi:10.1007/s13157-009-0001-6

Ekwemuka MC, Arimoro FO, Chukwuemeka VI, Muhammed M, Keke UN. Multi-scale factors revealed contrasting impacts on Waterbird composition and Beta diversity across wetlands in an Afrotropical landscape. Glob Ecol Conserv. 2025 Apr;58:e03438. doi:10.1016/j.gecco.2025.e03438

Fraser D, Villaseñor A, Tóth AB, Balk MA, Eronen JT, Andrew Barr W, et al. Late quaternary biotic homogenization of North American mammalian faunas. Nat Commun. 2022;13(1):1–11. doi:10.1038/s41467-022-31595-8 PubMed PMID: 35803946.

Keke UN, Arimoro FO, Edegbene AO, Akamagwuna FC, Assie FAGJ, Odume ON. Biotic homogenization of stream macroinvertebrates in an Afrotropical Anthropocene: Land use and ecological correlates. Front Environ Sci. 2022;10(November):1–14. doi:10.3389/fenvs.2022.1022776

Vázquez-Reyes LD, Arizmendi MDC, Godínez-Álvarez HO, Navarro-Sigüenza AG. Directional effects of biotic homogenization of bird communities in Mexican seasonal forests. Condor. 2017;119(2):275–88. doi:10.1650/CONDOR-16-116.1

Pinto-Ledezma JN, Larkin DJ, Cavender-Bares J. Patterns of Beta Diversity of Vascular Plants and Their Correspondence With Biome Boundaries Across North America. Front Ecol Evol. 2018 Nov 27;6(NOV). doi:10.3389/fevo.2018.00194

Legendre P. Studying beta diversity: ecological variation partitioning by multiple regression and canonical analysis. Journal of Plant Ecology. 2008;1(1):3–8. doi:10.1093/jpe/rtm001

Heino J, Bini LM, García-Girón J, Lansac-Tôha FM, Lindholm M, Rolls RJ. Navigating the spatial and temporal aspects of beta diversity to facilitate understanding biodiversity change. Glob Ecol Conserv. 2024 Dec;56:e03343. doi:10.1016/j.gecco.2024.e03343

Fang G, Liang J, Jiang R, Zhang Y, Chen J, Chen C, et al. Taxonomic and Functional Beta Diversity Patterns and Their Driving Factors of the Fish Assemblages Around Marine Islands. J Mar Sci Eng. 2025;13(4). doi:10.3390/jmse13040674

Baselga A. The relationship between species replacement, dissimilarity derived from nestedness, and nestedness. Global Ecology and Biogeography. 2012;21(12):1223–32. doi:10.1111/j.1466-8238.2011.00756.x

Legendre P, Condit R. Spatial and temporal analysis of beta diversity in the barro colorado island forest dynamics plot, panama. For Ecosyst. 2019;6(1). doi:10.1186/s40663-019-0164-4

Baselga A. Partitioning the turnover and nestedness components of beta diversity. Global Ecology and Biogeography. 2010;19(1):134–43. doi:10.1111/j.1466-8238.2009.00490.x

Chefaoui RM. Seasonal variations of waterbird ecological networks under different saltpans management. Ecol Inform. 2021;64(July):101364. doi:10.1016/j.ecoinf.2021.101364

Si X, Baselga A, Ding P. Revealing beta-diversity patterns of breeding bird and lizard communities on inundated land-bridge islands by separating the turnover and nestedness components. PLoS One. 2015;10(5):1–19. doi:10.1371/journal.pone.0127692 PubMed PMID: 25992559.

Koleff P, Gaston KJ, Lennon JJ. Measuring beta diversity for presence-absence data. Journal of Animal Ecology. 2003;72(3):367–82. doi:10.1046/j.1365-2656.2003.00710.x

Socolar JB, Gilroy JJ, Kunin WE, Edwards DP. How Should Beta-Diversity Inform Biodiversity Conservation? Trends Ecol Evol. 2016;31(1):67–80. doi:10.1016/j.tree.2015.11.005 PubMed PMID: 26701706.

Portela AP, Durance I, Vieira C, Honrado J. Environmental filtering and environmental stress shape regional patterns of riparian community assembly and functional diversity. Freshw Biol. 2023;68(8):1428–41. doi:10.1111/fwb.14138

She Y, Wang P, Wen J, Ding M, Zhang H, Nie M, et al. Riverine bacterial communities are more shaped by species sorting in intensive urban and agricultural watersheds. Front Microbiol. 2024;15(November):1–16. doi:10.3389/fmicb.2024.1463549

Özkan K, Svenning JC, Jeppesen E. Environmental species sorting dominates forest-bird community assembly across scales. Journal of Animal Ecology. 2013;82(1):266–74. doi:10.1111/j.1365-2656.2012.02019.x PubMed PMID: 22849355.

518 **Haslem A, Nimmo DG, Radford JQ, Bennett AF. Landscape properties mediate the**
519 **homogenization of bird assemblages during climatic extremes. Ecology. 2015;96:3165–3174.**

520 **Xia S, Ji X, Meng L, Zhou L. Functional Diversity of Wintering Waterbird Enhanced by**
521 **Restored Wetland in the Lakeshore of Chaohu Lake. Ecol Evol. 2025 Jul 7;15(7).**
522 **doi:10.1002/ece3.71751**

523 **Lameed GA. Species diversity and abundance of wild birds in Dagona-Waterfowl Sanctuary**
524 **Borno State, Nigeria. Afr J Environ Sci Tech. 2011;5(10):855–66. doi:10.5897/AJEST11.090**

525 **Wang R, Ding J, Ge X, Wang J, Qin S, Tan J, et al. Impacts of climate change on the wetlands**
526 **in the arid region of Northwestern China over the past 2 decades. Ecol Indic.**
527 **2023;149(March):110168. doi:10.1016/j.ecolind.2023.110168**

528 **Kaugama HH, Ahmed BA. Prospect and Challenges of Farming along the Hadejia-Nguru**
529 **Wetland in Jigawa State Nigeria. International Journal of Academic Research in Economics**
530 **and Management Sciences. 2014;3(6):43–52. doi:10.6007/ijarems/v3-i6/1279**

531 **Ayeni AO, Ogunsesan AA, Adekola OA. Provisioning ecosystem services provided by the**
532 **Hadejia Nguru Wetlands, Nigeria – Current status and future priorities. Sci Afr. 2019;5:e00124.**
533 **doi:10.1016/j.sciaf.2019.e00124**

534 **Ringim AS, Abubakar MM, Mohammed SI, Shuaibu T. Wetlands resource use , Conflict ,**
535 **Management and Conservation : Review of the Hadejia-Nguru Wetlands ,. International**
536 **Journal of Innovative Science, Engineering & Technology. 2015;2(10):507–16.**

537 **Ezealor AU. Nigeria. In Fishpool LDC, and Evans MI (eds.). Important Bird Areas in Africa**
538 **and associated islands: Priority Sites for Conservation. Newbury: Pisces Publications and**
539 **Cambridge, UK:BirdLife International. 2001. doi:10.1039/DC9766100007**

540 **Ringim AS. Diversity and Foraging Guilds: Focus on Hadejia-Nguru Wetlands Avifaunal**
541 **Community. Dutse Journal of Pure and Applied Sciences. 2016;2(2):65–75.**

Bibby CJ, Burgess ND, Hill DA, Mustoe S. Bird Census Techniques. 2nd ed. New York: Academic Press; 2000. 302 p.

Williams BK, Brown ED. Sampling and analysis frameworks for inference in ecology. McCrea R, editor. Methods Ecol Evol. 2019 Nov 29;10(11):1832–42. doi:10.1111/2041-210X.13279

Géant CB, Gustave MN, Schmitz S. Developing an indicator for assessing wetland degradation based on soil quality, water drainage, and human-related landscape factors. Ecol Indic. 2025 Oct 1;179. doi:10.1016/j.ecolind.2025.113987

Ai M, Chen X, Yu Q. Spatial correlation analysis between human disturbance intensity (HDI) and ecosystem services value (ESV) in the Chengdu-Chongqing urban agglomeration. Ecol Indic. 2024 Jan 1;158. doi:10.1016/j.ecolind.2024.111555

Borrow, N. and Demey R. Birds of Western Africa. Field guide to the birds of Western Africa. London: Christopher Helm; 2001. 753 p.

Wang M, Cheng Q, Chen R. Identification of Important Wetlands and Optimization of Landscape Patterns Based on Human Pressure Index: The Case of the Linghekou Wetland in China. Sustainability (Switzerland) . 2024 May 1;16(10). doi:10.3390/su16104082

APHA. APHA: Standard methods for the examination of water and wastewater. American Public Health Association. 23rd ed. Washington D.C.: American Public Health Association; 2021.

Suleiman MS, Wasonga OV, Mbau JS, Elhadi YA. Spatial and temporal analysis of forest cover change in Falgore Game Reserve in Kano, Nigeria. Ecol Process. 2017 Dec 16;6(1):11. doi:10.1186/s13717-017-0078-4

Arimoro FO, Odume ON, Uhunoma SI, Edegbene AO. Anthropogenic impact on water chemistry and benthic macroinvertebrate associated changes in a southern Nigeria stream. Environ Monit Assess. 2015 Feb;187(2):14. doi:10.1007/s10661-014-4251-2 PubMed PMID: 25619697.

565 **Salimi S, Almuktar SAAAN, Scholz M. Impact of climate change on wetland ecosystems: A**
568 **critical review of experimental wetlands. Journal of Environmental Management. Academic**
569 **Press; 2021. doi:10.1016/j.jenvman.2021.112160 PubMed PMID: 33611067.**

570 **Lima LB, Oliveira FJM, De Marco Júnior P, Lima-Junior DP. Local environmental variables**
571 **are the best beta diversity predictors for fish communities from the Brazilian Cerrado streams.**
572 **Aquat Sci. 2024;86(1):1–17. doi:10.1007/s00027-023-01032-z**

573 **R Core Team. R Development Core Team (2023).R: A language and environment for statistical**
574 **computing. R Foundation for statistical computing. Thomas R, Lello J, Medeiros R, Pollard A,**
575 **Seward A, Smith J, et al., editors. Vienna, Austria: Eco-explore; 2023.**

576 **Legendre P. Interpreting the replacement and richness difference components of beta diversity.**
577 **Global Ecology and Biogeography. 2014;23(11):1324–34. doi:10.1111/geb.12207**

578 **Brittain JE, Heino J, Friberg N, Aroviita J, Kahlert M, Karjalainen SM, et al. Ecological**
579 **correlates of riverine diatom and macroinvertebrate alpha and beta diversity across Arctic**
580 **Fennoscandia. Freshw Biol. 2022;67(1):49–63. doi:10.1111/fwb.13616**

581 **Anderson MJ, Walsh DCI. PERMANOVA, ANOSIM, and the Mantel test in the face of**
582 **heterogeneous dispersions: What null hypothesis are you testing? Ecol Monogr. 2013**
583 **Nov;83(4):557–74. doi:10.1890/12-2010.1**

584 **Oksanen AJ, Blanchet FG, Kindt R, Legendre P, Hara RBO, Gavin L, et al. Vegan: Community**
585 **Ecology Package. Software. 2012.**

586 **Legendre P, Gallagher ED. Ecologically meaningful transformations for ordination of species**
587 **data. Oecologia. 2001;129(2):271–80. doi:10.1007/s004420100716**

588 **Cáceres M De, Legendre P. Associations between species and groups of sites: indices and**
589 **statistical inference. Ecology. 2009 Dec;90(12):3566–74. doi:10.1890/08-1823.1**

590 **De Cáceres M, Legendre P, Wiser SK, Brotons L. Using species combinations in indicator value**
591 **analyses. Methods Ecol Evol. 2012 Dec 10;3(6):973–82. doi:10.1111/j.2041-210X.2012.00246.x**

592 **Bakker JD. Increasing the utility of Indicator Species Analysis. 2008;(2001):1829–35.**
593 **doi:10.1111/j.1365-2664.2007.0**

594 **Blanchet FG, Legendre P, Borcard D. Modelling directional spatial processes in ecological data.**
595 **Ecol Modell. 2008;215:325–36. doi:10.1016/j.ecolmodel.2008.04.001**

596 **Borcard D, Legendre P, Drapeau P. Partialling out the Spatial Component of Ecological**
597 **Variation. Ecology. 1992 Jun;73(3):1045–55. doi:10.2307/1940179**

598 **Peres-Neto PR, Legendre P, Dray S, Borcard D. Variation partitioning of species data matrices:**
599 **Estimation and comparison of fractions. Ecology. 2006;87(10):2614–25. doi:10.1890/0012-**
600 **9658(2006)87[2614:VPOSDM]2.0.CO;2 PubMed PMID: 17089669.**

601 **Kahsay A, Lemmens P, Triest L, De Meester L, Kibret M, Verleyen E, et al. Plankton Diversity**
602 **in Tropical Wetlands Under Different Hydrological Conditions (Lake Tana, Ethiopia). Front**
603 **Environ Sci. 2022 Mar 9;10. doi:10.3389/fenvs.2022.816892**

604 **Arimoro FO, James J, Ikayaja EO, Assie FAGJ, Edegbene AO, Keke UN. Dissecting the urban**
605 **footprint of unplanned settlements shaping macroinvertebrate communities in Wuye River,**
606 **Abuja, Nigeria. Sci Rep. 2025;15(1):1–16. doi:10.1038/s41598-025-00552-y**

607 **Glišić M, Jakovljević K, Lakušić D, Šinžar-Sekulić J, Vukojičić S, Tabašević M, et al. Influence**
608 **of Habitat Types on Diversity and Species Composition of Urban Flora—A Case Study in**
609 **Serbia. Plants. 2021 Nov 25;10(12):2572. doi:10.3390/plants10122572**

610 **Behera MC, Sahoo UK, Mohanty TL, Prus P, Smuleac L, Pascalau R. Species Composition and**
611 **Diversity of Plants along Human-Induced Disturbances in Tropical Moist Sal Forests of Eastern**
612 **Ghats, India. Forests. 2023 Sep 22;14(10):1931. doi:10.3390/f14101931**

613 **Passy SI, Blanchet FG. Algal communities in human-impacted stream ecosystems suffer beta-**
614 **diversity decline. Divers Distrib. 2007 Nov 16;13(6):670–9. doi:10.1111/j.1472-4642.2007.00361.x**

615 **Mahar N, Habib B, Hussain SA, Shawl T, Takpa J. Influence of anthropogenic factors on the**
616 **waterbirds in Trans-Himalayan wetlands. Glob Ecol Conserv. 2023;46(July):e02567.**
617 **doi:10.1016/j.gecco.2023.e02567**

618 **Htay T, Røskaft E, Ringsby TH, Ranke PS. Spatio-temporal variation in avian taxonomic,**
619 **functional, and phylogenetic diversity and its relevance for conservation in a wetland ecosystem**
620 **in Myanmar. Biodivers Conserv. 2023;32(8–9):2841–67. doi:10.1007/s10531-023-02632-9**

621 **Toy DL, Anteau MJ, Pearse AT, DeKeyser ES, Roberts DC. Manipulation of Farmed Wetlands**
622 **Increases use by Migrating Shorebirds and Ducks. Wetlands. 2024 Oct 14;44(7):86.**
623 **doi:10.1007/s13157-024-01819-2**

624 **Zhong L, Li Y, Li Y, Dai C. Hungry wintering birds and angry farmers: Crop damage and**
625 **management implications in a protected wetland in China. Glob Ecol Conserv. 2025**
626 **Jan;57:e03402. doi:10.1016/j.gecco.2025.e03402**

627 **Wang B, Xu Y, Ran J. Predicting suitable habitat of the chinese monal (Lophophorus lhuysii)**
628 **using ecological niche modeling in the Qionglai Mountains, china. PeerJ. 2017;2017(7):1–20.**
629 **doi:10.7717/peerj.3477**

630 **Shih YT, Wang HH, Fu SW, Su SH, Koh CN. Beta diversity partitioning reveals**
631 **homogenization in bird community composition within the forest-agriculture landscape of the**
632 **northern Taiwan coast. Landsc Ecol. 2024;39(5):1–12. doi:10.1007/s10980-024-01888-y**

633 **Fauzi NA, Munian K, Mahyudin NAA, Norazlimi NA. Ecological insights on the feeding**
634 **behaviour of waterbirds in an Important Bird and Biodiversity Area of South West Johor**
635 **Coast, Malaysia. Biodivers Data J. 2025 Jan 15;13. doi:10.3897/BDJ.13.e141250**

636 **Li Y, Wang X, Yong X, Wu Y, Wu C, Hu W. Assembly Processes of Waterbird Communities**
637 **Across Different Types of Wetlands in the Middle Reaches of the Huaihe River Basin. Water**
638 **(Switzerland). 2025;17(8):1–15. doi:10.3390/w17081118**

639 **Wang C, Wang G, Li T, Yu R, Duan H, Su Y, et al. Habitat seasonal competition and**
640 **coexistence of typical wetland species in the Yellow Sea-Bohai Gulf Natural Heritage Site. Ecol**
641 **Indic. 2023;147(November 2022):109982. doi:10.1016/j.ecolind.2023.109982**

642 **Zhang M, Fan S, Li X, Li Y, Li K, Xu Y, et al. Supporting function of vegetation in urban**
643 **riparian ecological corridors for ground-dwelling faunal diversity in Beijing, China. Science of**
644 **the Total Environment. 2024 Apr 15;921. doi:10.1016/j.scitotenv.2024.171150 PubMed PMID:**
645 **38395166.**

646 **Schmidt ML, Biddanda BA, Weinke AD, Chiang E, Januska F, Props R, et al. Microhabitats**
647 **are associated with diversity-productivity relationships in freshwater bacterial communities.**
648 **FEMS Microbiol Ecol. 2020;96(4):1–12. doi:10.1093/FEMSEC/FIAA029 PubMed PMID:**
649 **32105331.**

650 **Heidrich L, Brandl R, Ammer C, Bae S, Bässler C, Doerfler I, et al. Effects of heterogeneity on**
651 **the ecological diversity and redundancy of forest fauna. Basic Appl Ecol. 2023;73(March**
652 **2022):72–9. doi:10.1016/j.baae.2023.10.005**

653 **Barton PS, Evans MJ, Lewis J. Microhabitats shape ant community structure in a spatially**
654 **heterogeneous grassy woodland. Ecosphere. 2024;15(4):1–15. doi:10.1002/ecs2.4798**

655 **Bentsi-Enchill F, Damptey FG, Pappoe ANM, Ekumah B, Akotoye HK. Impact of**
656 **anthropogenic disturbance on tree species diversity, vegetation structure and carbon storage**
657 **potential in an upland evergreen forest of Ghana, West Africa. Trees, Forests and People.**
658 **2022;8(November 2021):100238. doi:10.1016/j.tfp.2022.100238**

659 **Wei C, Li H, Heino J, Jiang X. Seasonal variation and driving factors of beta diversity of**
660 **macroinvertebrate assemblages in subtropical Chinese high-mountain streams. Water Biology**
661 **and Security. 2025;(September 2024):100379. doi:10.1016/j.watbs.2025.100379**

662 **Sabo BB, Mohammed S, Karkarna MZ. Birds of Prey of Dagona Waterfowl Sanctuary,**
663 **Northeastern Nigeria. Science World Journal. 2022;17(1):2022.**

Rupam D, Sandip P. Influence of seasonal change and anthropogenic activities on the avifauna composition in a seasonal wetland of India. Ornis Hungarica. 2024;32(1):1–15. doi:10.2478/orhu-2024-0001

Chen C, Holyoak M, Wang Y, Si X, Ding P. Spatiotemporal distribution of seasonal bird assemblages on land-bridge islands: Linking dynamic and static views of metacommunities. Avian Res. 2019;10(1):1–12. doi:10.1186/s40657-019-0164-7

Wang XW, Chen J, Zhou L. Effects of Human Activities on the Diversity of Waterbirds Wintering in a Shallow Lake of the Middle and Lower Yangtze River Floodplain, China Xinjian. Diversity (Basel). 2020;12(302):2–14.

Rolls RJ, Deane DC, Johnson SE, Heino J, Anderson MJ, Ellingsen KE. Biotic homogenisation and differentiation as directional change in beta diversity: synthesising driver–response relationships to develop conceptual models across ecosystems. Biological Reviews. 2023;98(4):1388–423. doi:10.1111/brv.12958

Soininen J, Lennon JJ, Hillebrand H. A Multivariate Analysis of Beta Diversity across Organisms and Environments. Ecology. 2007 Nov;88(11):2830–8. doi:10.1890/06-1730.1

García-Navas V, Sattler T, Schmid H, Ozgul A. Temporal homogenization of functional and beta diversity in bird communities of the Swiss Alps. Divers Distrib. 2020;26(8):900–11. doi:10.1111/ddi.13076

Heino J, Soininen J, Alahuhta J, Lappalainen J, Virtanen R. Metacommunity ecology meets biogeography: effects of geographical region, spatial dynamics and environmental filtering on community structure in aquatic organisms. Oecologia. 2017;183(1):121–37. doi:10.1007/s00442-016-3750-y PubMed PMID: 27714463.

Rocha MP, Bini LM, Grönroos M, Hjort J, Lindholm M, Karjalainen SM, et al. Correlates of different facets and components of beta diversity in stream organisms. Oecologia. 2019 Dec 17;191(4):919–29. doi:10.1007/s00442-019-04535-5 PubMed PMID: 31624960.

689 Walsh G, Pease AA, Woodford DJ, Stiassny MLJ, Gaugris JY, South J. Functional diversity of
690 afrotropical fish communities across river gradients in the Republic of Congo, west central
691 Africa. Front Environ Sci. 2022;10(September):1–19. doi:10.3389/fenvs.2022.981960

692 Schmidt RC, Woods T, Nyingi WD. Drivers of species richness and beta diversity of fishes in an
693 Afrotropical intermittent river system. Ecol Evol. 2022;12(12):1–11. doi:10.1002/ece3.9659

694 Kotze DC, Ellery WN, Macfarlane DM, Jewitt GPW. A rapid assessment method for coupling
695 anthropogenic stressors and wetland ecological condition. Ecol Indic. 2012 Feb;13(1):284–93.
696 doi:10.1016/j.ecolind.2011.06.023

697 O. Adeogun A, V. Chukwuka A. Anthropogenic Impacts as Determinants of Tropical Lake
698 Morphology: Inferences for Strategic Conservation of Lake Wetland Biodiversity. In: Assaini
699 AA, Summers j. K, editors. Science of Lakes-Multidisciplinary Approach. 2024. p. 272.
700 doi:10.5772/intechopen.112274

701 Ekwemuka MC, Arimoro FO, Chukwuemeka VI, Muhammed M, Aina OA. Sustainable Water
702 Quality: Effects of Habitat Types and Disturbance regimes in Afrotropical Wetlands.
703 International Journal of Applied Biological Research. 2024;15(2):104–22.

704 Branco CCZ, Bispo PC, Peres CK, Tonetto AF, Krupek RA, Barfield M, et al. Partitioning
705 multiple facets of beta diversity in a tropical stream macroalgal metacommunity. J Biogeogr.
706 2020;47(8):1765–80. doi:10.1111/jbi.13879

707 Yang L, Liu PA, Wang RX. Waterbird diversity and spatial distribution across China: Patterns
708 and conservation strategies. Glob Ecol Conserv. 2025 Oct 1;62:e03707.
709 doi:10.1016/J.GECCO.2025.E03707

710 Li C, Yang Y, Wang Z, Yang L, Zhang D, Zhou L. The relationship between seasonal water
711 level fluctuation and habitat availability for wintering waterbirds at Shengjin Lake, China. Bird
712 Conserv Int. 2019;29(1):100–14. doi:10.1017/S0959270918000035

713 **Heino J, Nokela T, Soininen J, Tolkkinen M, Virtanen L, Virtanen R. Elements of**
714 **metacommunity structure and community-environment relationships in stream organisms.**
715 **Freshw Biol. 2015;60(5):973–88. doi:10.1111/fwb.12556**

716 **Sulaiman IM, Apeverga PT, Ringim AS, Ibrahim K. Effects ffects of anthropogenic activities on**
717 **Bird diversity and abundance at the Hadejia – Nguru Wetlands , Nigeria. Standard Scientific**
718 **Research and Essays. 2014;2(October):546–51.**

719 **Ahmed AJ, Abubakar MS, Usman A, Usman I. Nexus between weeds secondary succession and**
720 **livelihoods in Hadejia-Nguru wetlands of Nigeria. Sustinere: Journal of Environment and**
721 **Sustainability. 2023;7(1):48–64. doi:10.22515/sustinerejes.v7i1.249**

722 **Liu Q, Jing W, Kang L, Liu J, Liu M. Trends of the global, regional and national incidence of**
723 **malaria in 204 countries from 1990 to 2019 and implications for malaria prevention. J Travel**
724 **Med. 2021 Jul 7;28(5):1–12. doi:10.1093/jtm/taab046**

725 **Mereta ST, Lemmens P, De Meester L, Goethals PLM, Boets P. The Relative Importance of**
726 **Human Disturbance, Environmental and Spatial Factors on the Community Composition of**
727 **Wetland Birds. Water (Basel). 2021 Dec 4;13(23):3448. doi:10.3390/w13233448**

728 **Haileselasie TH. Limnological factors that affect waterbird assemblages in semi-arid reservoirs**
729 **of Tigray National Regional State, northern Ethiopia. Heliyon. 2023;9(6):e17110.**
730 **doi:10.1016/j.heliyon.2023.e17110**

731 **Liu Z, Zhou Y, Yang H, Liu Z. Urban green infrastructure affects bird biodiversity in the**
732 **coastal megalopolis region of Shenzhen city. Applied Geography. 2023 Feb 1;151.**
733 **doi:10.1016/j.apgeog.2022.102860**

734 **Jiang X, Pan B, Jiang W, Hou Y, Yang H, Zhu P, et al. The role of environmental conditions,**
735 **climatic factors and spatial processes in driving multiple facets of stream macroinvertebrate**
736 **beta diversity in a climatically heterogeneous mountain region. Ecol Indic. 2021;124:107407.**
737 **doi:10.1016/j.ecolind.2021.107407**

738 **34. Bănăduc D, Curtean-Bănăduc A, Barinova S, Lozano V, Afanasyev S, Leite T, et al. Multi-**
739 **Interacting Natural and Anthropogenic Stressors on Freshwater Ecosystems: Their Current**
740 **Status and Future Prospects for 21st Century. Water (Basel). 2024 May 23;16(11):1483.**
741 **doi:10.3390/w16111483**

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