WATERBIRD COMMUNITY DYNAMICS ACROSS BIOLOGICAL PERIODS AND VEGETATION TYPES IN EL BATTOUM MARSH, ALGERIA

Nadhra BOUKROUMA*, Hind MOUKATEL*

*Faculty of Nature and Life Sciences, University Mohamed Cherif Messaadia, 41000 Souk-Ahras, Algeria
Corresponding author: Nadhra Boukrouma, Faculty of Sciences and Nature, University Mohamed Cherif Messaadia, 41000 Souk-Ahras, Algeria, Zip code: 00213, e-mail: n.boukrouma@univ-soukahras.dz

Abstract. Understanding the mechanisms governing community assembly of waterbirds in Mediterranean wetlands is critical for biodiversity conservation, yet the relative influence of biological phenology versus habitat structural complexity remains poorly quantified in North African artificial aquatic ecosystems. This study characterizes waterbird community organization at Battoum Marsh (hill reservoir, north-east Algeria) to evaluate how temporal dynamics and habitat heterogeneity partition avian distribution. Utilizing Scheirer–Ray–Hare tests and multivariate ordination, we demonstrate that the biological period of listed species of waterbirds is the overarching keydeterminant of community assembly, exerting a significantly greater influence on alpha diversity ($H=17.79$, $p<0.001$) than vegetation type ($p=0.83$). Phenogram and ridgeline analysis reveals that the wintering period is defined by high dominance and dense aggregations of Rallids (e.g. *Fulica atra*) within *Typha latifolia* and *Phragmites australis* standssupporting the thermal-cover hypothesis. Conversely, the breeding period marks a transition toward spatial homogeneity and increased evenness, signifying a functional shift from resource-dependent clustering to territoriality-mediated dispersion. We identify a migratory dip during the pre-nuptial phase, characterized by diminished site fidelity and abundance. Crucially, while temporal cycles govern broad richness metrics, the stochastic interaction between period and vegetation type underpins species identity; habitat specialists, such as the Northern Pintail (*Anas acuta*), exhibit an obligate reliance on specific habitat-period niches during the pre-nuptial phase, whereas generalists like the Common Moorhen (*Gallinula chloropus*) demonstrate high aquatic birds. These findings refine the habitat heterogeneity hypothesis by illustrating that in fluctuating Mediterranean artificial wetlands, temporal turnover and migratory flux are the dominant structuring forces of waterbird communities. By advocating for the protection of phenological corridors and successional mosaics over static conservation mapping, this study provides a mechanistic framework for adaptive management in North African wetlands facing climate-driven hydrological instability.

Keywords: alpha diversity; community assembly; aquatic birds; mediterranean wetlands; phenological nodesin.

INTRODUCTION

Wetlands are globally recognized as among the most productive and ecologically indispensable ecosystems, providing a broad range of ecosystem services that are crucial for both biodiversity and human societies. These services include nutrient cycling, water purification, hydrological regulation, flood attenuation, and substantial carbon sequestration, making wetlands central in mitigating climate change and maintaining landscape-level ecological balance [6, 16]. In addition, wetlands provide essential habitats for a wide diversity of species, ranging from microorganisms to large vertebrates, with waterbirds representing one of the most conspicuous and functionally important groups. Waterbirds rely on wetlands for critical life-history processes, including foraging, roosting, breeding, and migratory stopovers, and their communities are often used as sensitive bioindicators to assess ecosystem health and integrity [11, 22, 26].

Beyond their indicator role, waterbirds contribute to ecosystem functioning through seed dispersal, nutrient redistribution, and regulation of prey populations, creating feedbacks that sustain wetland productivity [10, 41].The spatial distribution and community composition of waterbirds are strongly influenced by habitat heterogeneity, particularly the structural characteristics of wetland vegetation. Emergent, submerged, and floating macrophytes generate a mosaic of microhabitats that differ in their physical and biological attributes, influencing shelter availability, foraging efficiency, and predation risk [17, 35]. Dense emergent stands provide concealment from terrestrial predators and secure nesting sites, while submerged meadows and floating-leaf mats are often hotspots of invertebrate abundance, meeting the high energetic demands of migratory or breeding waterbirds [17]. The diversity of these vegetative structures not only supports species richness but also maintains functional diversity, ensuring the stability and resilience of ecological processes across the wetland landscape [21, 39]. While the structural attributes of vegetation are crucial, temporal dynamics equally determine waterbird community assembly.

Most existing studies rely on calendar-based or seasonal divisions to describe bird presence and habitat use; however, these coarse temporal frameworks often fail to capture the ecological mechanisms underlying species distribution. Instead, biological periods such as breeding, migration, and overwintering more accurately reflect the ecological demands of waterbirds [26, 31, 32]. Each biological period imposes distinct habitat requirements: during breeding, secure nesting sites and emergent vegetation are essential; during migration, foraging-rich areas such as open water or submerged vegetation become critical; and overwintering stages may require a balance of cover and energy-rich food availability [2, 29]. Transitional periods between these stages can produce rapid shifts in species dominance and habitat use, yet the fine-scale interplay between vegetation types and these life-history stages remains largely unexplored, particularly in Mediterranean semi-humid wetlands [15, 34, 39].

In North Africa, research on wetland avifauna has primarily focused on general diversity patterns, broad seasonal fluctuations, or distributional assessments [5, 37]. The Battoum Marsh (Souk Ahras, Algeria)

DOI: 10.61215/AUOFB.2026.2.01

represents a semi-humid Mediterranean wetland of high ecological significance. It functions as an important corridor for migratory waterbirds within the western Mediterranean flyway, supports diverse resident populations, and contributes to local and regional biodiversity conservation in northeastern Algeria. Despite its recognized importance, relatively few studies have examined the joint effects of vegetation types and biological life-stages on waterbird communities across an annual cycle. However, previous research has demonstrated that waterbird assemblages can be influenced by a range of bio-ecological factors, including hydrological variability, climatic conditions, and habitat structure. This represents a significant gap in wetland ecology, particularly for semi-humid Mediterranean ecosystems, where fluctuations in water availability, plant phenology, and anthropogenic pressures can rapidly alter habitat structure and ecological niches [4, 28]. To address this limitation, this study adopts an integrated framework that jointly considers vegetation types and biologically meaningful life-history stages of waterbirds. By combining these two ecological dimensions, the analysis allows a more comprehensive assessment of how habitat structure and temporal biological requirements interact to shape waterbird community composition. The present study seeks to fill this knowledge gap by providing a novel and mechanistic investigation of waterbird habitat interactions, explicitly integrating both the vegetation structural complexity and temporal dynamics of biological periods. Specifically, this research aims to: *1.* Quantify the attraction of different vegetation types by waterbirds communities; *2.* Assess how community composition, abundance, and functional diversity shift across biological periods, including breeding, migration, and overwintering; *3.* Identify key interactions between vegetation types and life-history stages that underpin functional stability and ecological resilience of the marsh.

By explicitly linking vegetation structure with species' biological periods, this study provides a contribution to ecology of artificial wetland in North Africa, moving beyond traditional seasonal approaches and offering a deeper understanding of the ecological drivers of waterbird distribution and diversity. Such insights are critical for implementing adaptive management strategies, enhancing biodiversity monitoring, and conserving wetland ecosystems in Mediterranean sub-humid regions, which face increasing pressures from climate variability, water extraction, and habitat degradation [2, 24]. Ultimately, this research establishes a framework for integrating habitat heterogeneity and biological phenology, providing actionable knowledge for both conservation planning and long-term ecological research in North African wetlands.

MATERIALS AND METHODS

Study area

The research was conducted at the El Battoum Hill Reservoir (36°4′18.68″N, 8°6′16.26″E), an inland wetland of approximately 25 ha located in the Souk Ahras province, Northeast Algeria. Situated within a sub-humid Mediterranean bioclimatic zone, the site features a diverse ecological mosaic composed of open water zones, dense emergent stands, and floating macrophyte communities (Fig. 1). This structural heterogeneity provides essential habitats for a wide range of resident and migratory waterbird species. The study site is a shallow artificial wetland located in a low-altitude coastal plain of northeastern Algeria. Water levels fluctuate seasonally under the influence of rainfall and hydrological inputs, creating a mosaic of shallow aquatic habitats. Water quality is influenced by surrounding land use and seasonal hydrological variability, contributing to heterogeneous ecological conditions favorable to waterbird diversity.

Bird surveys

Between August 2025 and March 2026, waterbird populations at the El Battoum Hill Reservoir were monitored through monthly surveys. Observations were conducted using 10× binoculars and a spotting scope with 45× magnification. A total (complete) scan count

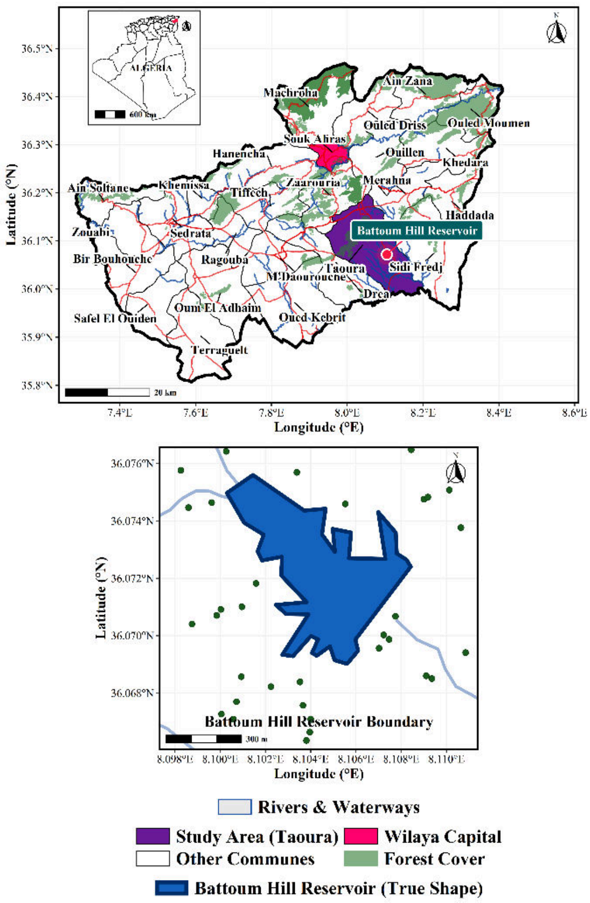

Figure 1. Location map of the study area, Battoum Hill Reservoir, Souk Ahras Province, northeastern Algeria (Prepared by Boukrouma, 2026)

DOI: 10.61215/AUOFB.2026.2.01

method was used, whereby the entire study area was systematically surveyed and all individuals were recorded to obtain a full census of the waterbird community. Species were identified using both visual and auditory cues.

Each survey consisted of a standardized 20-minute census period, which was selected based on preliminary field observations indicating that this duration was sufficient to detect all species present while minimizing double counting and observer fatigue. All surveys were conducted between 08:30 and 13:30 local time. The 20-minute census period started immediately after arrival at the site and a short settling time to reduce disturbance-related bias. Survey effort was kept consistent across all visits to ensure comparability of data between sampling dates.

The monitoring design was structured to capture the temporal dynamics of waterbird presence at the site, with survey periods selected according to key biological phases. The study was organized into three distinct phases to monitor the waterbird community within the study area. The first phase, spanning August to January, covered post-nuptial migration and wintering periods and included thirteen field visits across different habitat types to document the arrival of migrants and the establishment of stable wintering populations. The second phase, conducted in early February, corresponded to a rapid pre-nuptial transition, with five survey sessions designed to capture temporal changes in bird presence and habitat use.

Finally, the third phase, dedicated to the late winter–early spring period (pre-breeding and migratory activity period), began in mid-February and continued through March. To thoroughly characterize nesting behaviors and habitat suitability for reproduction, the effort was intensified with ten field visits, ensuring a rigorous evaluation of the site during the reproductive period. Counts obtained during standardized 20-minute observation intervals were used to derive estimates of absolute abundance. Relative abundance (%) was subsequently computed for each species across monthly, seasonal, and biological-period scales to quantify temporal variability and characterize shifts in community structure within the reservoir. This methodological framework is consistent with widely adopted point-count protocols for waterbird monitoring [3]. The study considered four phenological periods: post-nuptial migration (August–October), wintering (November–January), pre-nuptial transition (February), and late winter–early spring/pre-breeding period (mid-February–March).

Simultaneously, the vegetation was characterized to identify habitat variables influencing bird distribution, focusing on the role of the marsh as a feeding and refuge site. Plant species were identified in situ using specialized taxonomic keys [38, 40] within five randomly established 1 m² quadrats. Vegetation types were categorized following the wetland classification system of Cowardin et al [8]. These botanical surveys were repeated during each visit to account for phenological changes and fluctuations in water levels. Water level variations were assessed through direct field observations of changes in water extent and inundation patterns across habitat zones during each sampling visit, using a graduated ruler (measuring staff) placed at representative points within the study site. All habitat types within the study site were systematically surveyed during each visit using a complete site scan approach, ensuring equal sampling effort across vegetation types and open water areas.

Statistical analysis

All statistical analyses were conducted using R software version 4.5.0 [33]. Data normality was first assessed with the Shapiro-Wilk test, which revealed significant departures from normality ($p<0.05$) for most diversity indices and abundance measures, prompting the use of non-parametric approaches. To examine the simultaneous effects and potential interactions of biological periods variation, and vegetation types on alpha diversity, the Scheirer-Ray-Hare test was applied. Since significant temporal effects were detected, a Dunn's post-hoc test with Benjamini-Hochberg adjustment was subsequently applied to identify specific pairwise differences between groups. This analysis allowed us to identify how each factor and their interactions influenced species richness (S), Shannon diversity index (H′), Simpson index (1-D), and Pielou's evenness (J′), providing insight into the key drivers of community structure. Alpha diversity (i.e., local within-sample diversity measured at each sampling unit and time period) patterns were visualized through boxplots and symbol-based line graphs, highlighting median values, data dispersion, and temporal trends. These visualizations, generated with "ggplot2" package [42] and refined using ggpubr [18] and "cowplot" package [43], made it easier to interpret changes in diversity across periods and vegetation types. Heatmaps and ridgeline plots were generated to illustrate relative species abundance, facilitating the identification of community shifts and dominant species across different biological periods and habitat structures. To further explore the relationships between waterbird assemblages of communities and the four categorical factors (biological period, vegetation type, sampling month, and habitat category), multivariate analyses were employed. Principal Component Analysis (PCA) provided an overview of the main gradients of variation in species composition, Non-metric Multidimensional Scaling (NMDS) and Redundancy Analysis (RDA) were used to link avian community patterns directly to biological period variation and vegetation type. These ordination methods, implemented via the "vegan" [30] and "FactoMineR" packages [19] packages, offered a robust characterization of ecological drivers shaping local avian populations. Visualization and interpretation of these results were further enhanced with "viridis" [13] and "cowplot" packages [43], ensuring clear communication of complex multivariate patterns. Prior to RDA, species abundance data were Hellinger-

DOI: 10.61215/AUOFB.2026.2.01

transformed to reduce the influence of rare species and meet linear model assumptions [20]. Predictor collinearity was assessed using variance inflation factors (VIF), and variables with VIF>10 were excluded from the analyses. Significance of RDA axes and individual predictors was tested using 999 permutations, ensuring reproducibility. Reported results include eigenvalues, percentage variance explained by axes, and permutation-based p-values.

RESULTS

A total of nine waterbird species were recorded during the study period (August 2025–March 2026). The assemblage showed clear temporal and habitat-related variation in abundance across the sampling period.

Phenogram analysis of waterbird abundance across their biological periods and vegetation types

The phenogram reveals significant variations in the relative abundance of waterbird species across biological periods and vegetation types in Battoum Marsh (Fig. 2). These patterns are consistent with those observed in the ridgeline plots (Fig. 3), which show comparable temporal changes in abundance across species and habitats. During the wintering period, the Eurasian Coot (*Fulica atra*) dominates the community across all habitats, displaying a marked preference for *Typha latifolia* and *Phragmites australis*. Similarly, the Common Moorhen (*Gallinula chloropus*) and the Common Scoter (*Melanitta nigra*) exhibit a robust association with these micro-habitats, which likely fulfill their specific foraging and sheltering requirements.

During the breeding period, although total abundance remains high, birds are more evenly distributed across the marsh. The Common Moorhen maintains a steady presence, demonstrating notable habitat plasticity. Concurrently, diving species such as the Great Crested Grebe (*Podiceps cristatus*) and the Red-throated Diver (*Gavia stellata*) maintain moderate but consistent populations, while Eurasian Coot remains a core component of the avian assemblage. The ridgeline plots also indicate a more even distribution of abundance values during this period compared to wintering.

Conversely, the pre-nuptial period is characterized by a general decline in relative abundance across all species and habitats. This decrease is also clearly visible in the ridgeline representation, which shows reduced abundance distributions across all vegetation types (*Tamarix gallica*, *Typha latifolia*, and *Phragmites australis*). This trend suggests reduced site fidelity for the Eurasian Coot during this transitional migratory phase. Abundance levels subsequently recover during the post-nuptial period as populations stabilize. Finally, habitat structure significantly influences spatial distribution; while *Tamarix gallica* generally supports lower bird densities, the Eurasian Coot appears less sensitive to these structural variations than other specialist species.

Comparative analysis of avian diversity indices across biological periods of waterbirds and vegetation types

The Scheirer-Ray-Hare test analysis revealed that the biological period was the primary driver for all diversity metrics (Fig. 4A, B), whereas vegetation type and the period: vegetation interaction showed no significant effect (Fig. 4C, D). Specifically, species richness was significantly influenced by the biological period (H=17.79, df=3, p<0.001), while vegetation type (p= 0.83) and its interaction with the period (p=0.98)

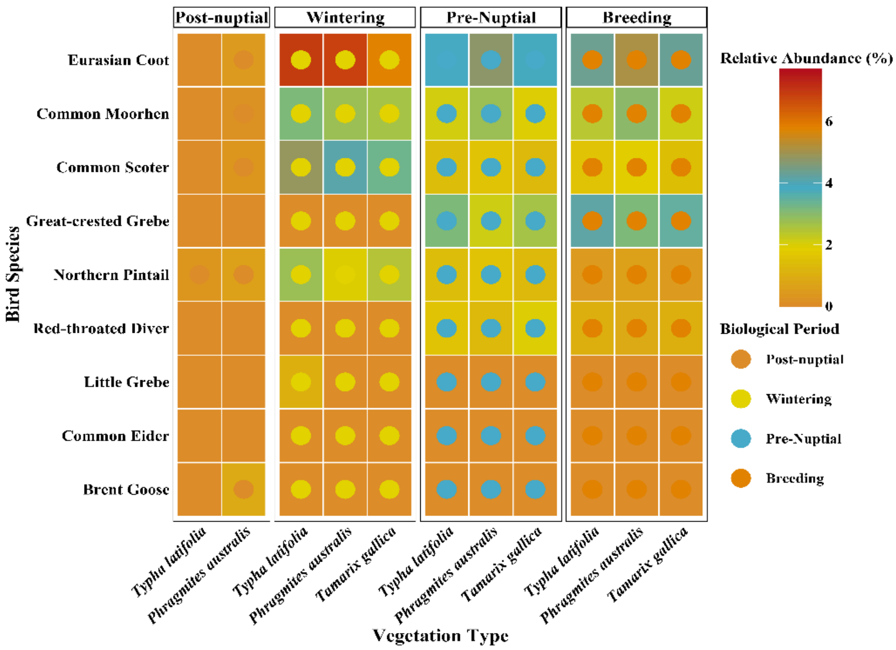

Figure 2. Phenogram of relative abundance of waterbird species across biological period and vegetation type in Battoum Marsh, northeastern Algeria

DOI: 10.61215/AUOFB.2026.2.01

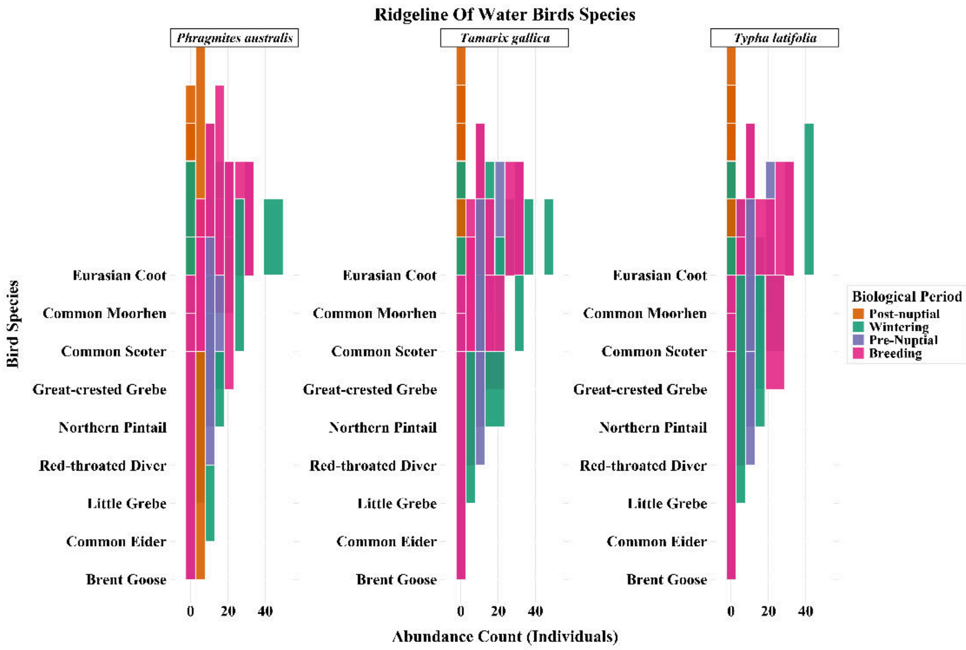

Figure 3. Ridgeline plots of individual waterbird counts across biological periods and vegetation types. each facet represents a distinct vegetation community (*Typha latifolia*, *Phragmites australis*, *Tamarix gallica*), illustrating the distribution peaks and phenological shifts in population abundance at Battoum Marsh

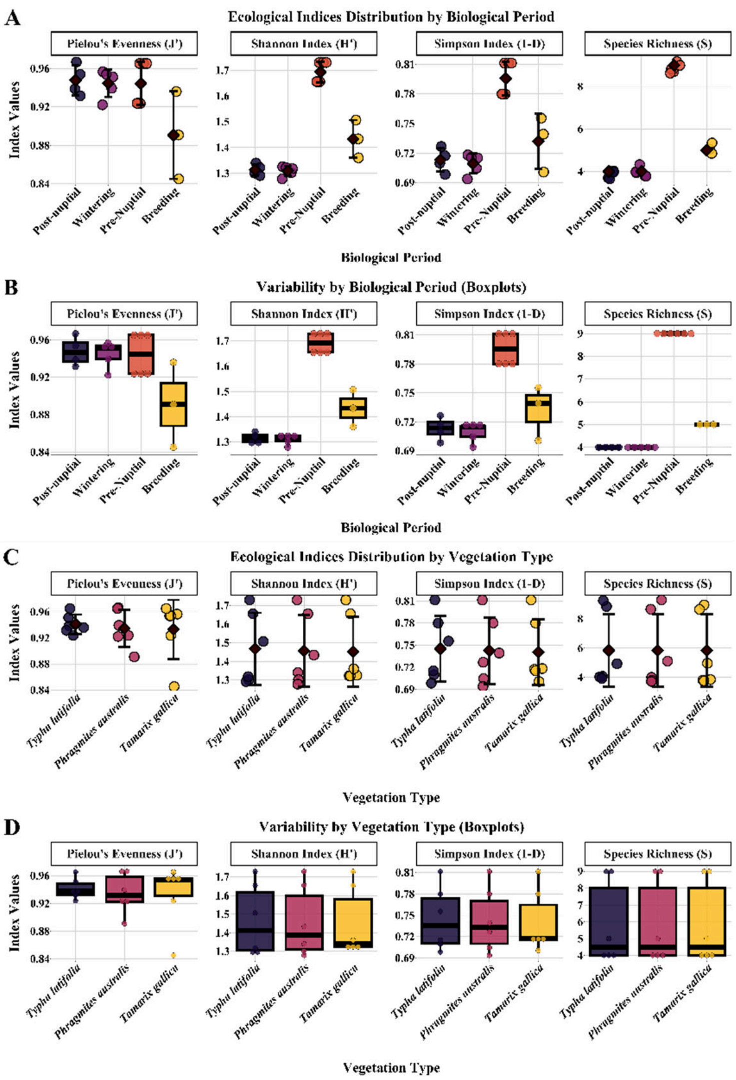

Figure 4. The Pielou's evenness (J'), Shannon diversity (H'), Simpson diversity (1-D), and species richness (S) of birds in Battoum Marsh,northestern Algeria according to biological period (A, B) and vegetation type (C, D)

DOI: 10.61215/AUOFB.2026.2.01

were negligible. Similar significant temporal variations were observed for the Shannon Index (H=13.73, df=3, p=0.003), the Simpson Index (H=12.84, df=3, p=0.005), and Pielou's Evenness index (H=11.06, df=3, p=0.011). These consistent results across all diversity indices indicate that the structure of the avian community undergoes a fundamental reorganization across the biological period rather than being determined by specific micro-habitats. The Dunn's post-hoc test further identified that these variations were driven by specific period transitions, notably between the pre-nuptial and post-nuptial periods (Z=-2.71, p=0.020) and most significantly between the pre-nuptial and wintering periods (Z=3.31, p=0.005).

Avian assemblage responses to biological period of waterbirds and vegetation types: a multivariate approach

Multivariate analysis revealed a strong influence of biological periods and vegetation types on the structuring of waterbird communities. Principal Component Analysis (PCA) indicated that the first two axes explained 71.9% of the total variance, with PC1 accounting for 44.9% and PC2 for 27.0% (Table 1).

The multivariate analyses collectively explore patterns of variation in waterbird community structure across biological periods and vegetation types. To improve clarity, PCA, NMDS, and RDA results are presented separately according to their analytical purpose: species structure, community similarity, and species–environment relationships, respectively. Principal Component Analysis (PCA) indicated that PC1 (44.9%) and PC2 (27.0%) capture a substantial proportion of the total variance, with PC1 primarily associated with the wintering period (R=2.005, p<0.0001) and dominant contributions from Common Scoter (R=0.949, p<0.0001) and Northern Pintail (R=0.907, p<0.0001), while PC2 is defined by the breeding (R=1.297, p<0.0001) and pre-nuptial (R=1.114, p<0.0001) periods, characterized by Great Crested Grebe (R=0.781, p<0.0001) and Red-throated Diver (R=0.742, p<0.0001). Species-specific associations further clarify these ecological gradients, as Common Scoter and Northern Pintail align with wintering conditions and *Tamarix gallica* habitats (R=0.56, p<0.05 on PC2), whereas Common Moorhen (R=0.724, p<0.0001) and Eurasian Coot (R=0.829, p<0.0001) reflect a strong dependence on structured habitats like *Typha latifolia* (R=−0.747, p<0.05) and *Phragmites australis* (R=−0.760, p<0.05) during the breeding and pre-nuptial phases. In contrast, the post-nuptial phase (R=−3.093, p<0.0001 on PC2) was distinctly characterized by Brent Goose (R=−0.524, p<0.0001 on PC2) and Common Eider in areas dominated by *Phragmites australis*, while Little Grebe (R=0.670, p<0.0001) showed a significant association with the wintering transition on PC1, altogether demonstrating a clear shift from breeding communities in dense vegetation toward wintering assemblages in more diverse habitats (Fig. 5).

Complementing the PCA, the Non-metric Multidimensional Scaling (NMDS) provided a highly faithful two-dimensional representation of community dissimilarity (stress=7.76e^{-05}), enabling clear visualization of species–habitat relationships. The NMDS revealed a pronounced separation of post-nuptial *Typha latifolia* sites along the primary NMDS1 axis, largely driven by the presence of Northern Pintail, while other species clustered more closely, reflecting compositional similarity across the remaining habitat-period combinations. This indicates that certain biological period-vegetation type combinations support distinct assemblages, whereas others host more generalist species such as Common Scoter, Eurasian Coot, and Common Moorhen. The NMDS axes corroborate the PCA gradients, showing that community composition is structured along a primary ecological gradient with limited secondary variation (Fig. 6).

Table 1. Principal Component Analysis (PCA) results for waterbird species, their biological periods, and vegetation types at Battoum Marsh, Northestern Algeria

Variable	Category	PCA1	PCA2	p-value PCA1	p-value PCA2
Species	Common Scoter	0.949	0.151	p<0.0001	–
	Common Moorhen	0.724	0.558	p<0.0001	p<0.0001
	Northern Pintail	0.907	-0.010	p<0.0001	–
	Eurasian Coot	0.829	0.511	p<0.0001	p<0.0001
	Great Crested Grebe	-0.535	0.781	p<0.0001	p<0.0001
	Red-throated Diver	-0.515	0.742	p<0.0001	p<0.0001
	Brent Goose	-0.331	-0.524	–	p<0.0001
	Little Grebe	0.670	-0.488	p<0.0001	–
	Common Eider	0.022	-0.406	–	–
Bilogical Period	Post-nuptial	-2.951*	-3.093*	p<0.0001	p<0.0001
	Wintering	2.005*	-0.920*	p<0.0001	p<0.0001
	Pre-nuptial	-0.919*	1.114*	p<0.0001	p<0.0001
	Breeding	-1.106*	1.297*	p<0.0001	p<0.0001
Vegetation Type	*Typha latifolia*	-0.747*	-0.211*	p<0.05	–
	Phragmites australis	-0.760*	-0.477*	p<0.05	p<0.05
	Tamarix gallica	0.421*	0.565*	–	p<0.05

DOI: 10.61215/AUOFB.2026.2.01

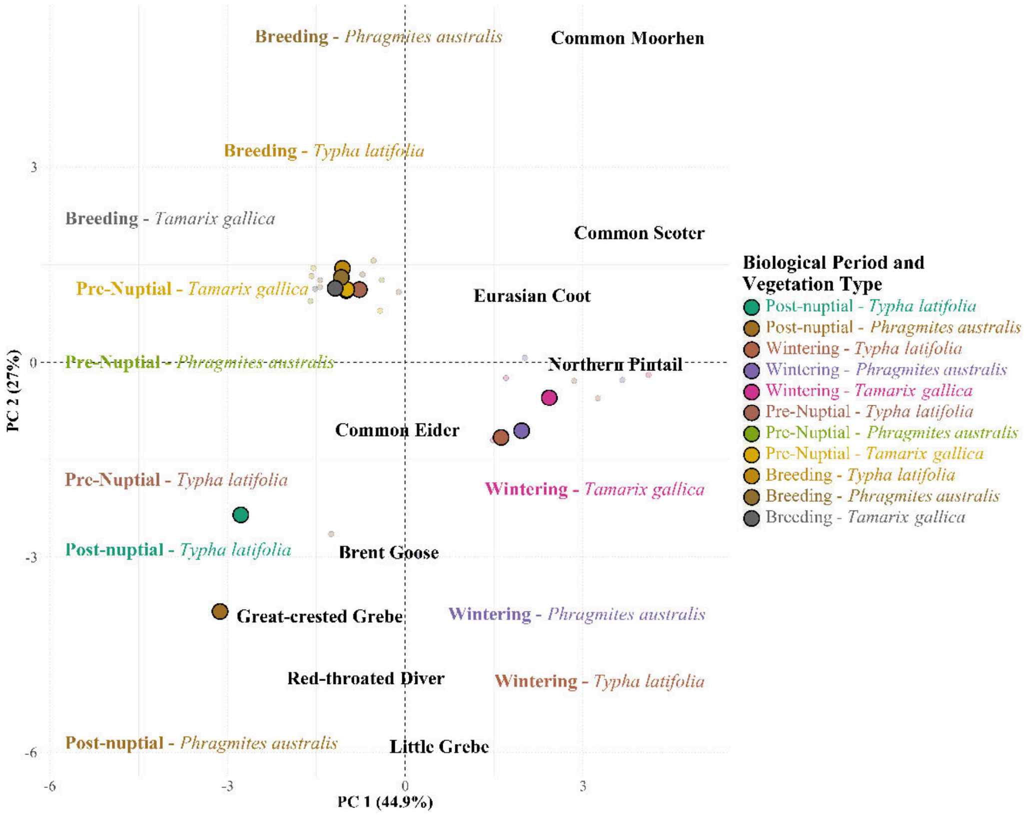

Figure 5. Principal Component Analysis (PCA) Biplot of waterbird community assembly in relation to biological period and vegetation type at Battoum Marsh

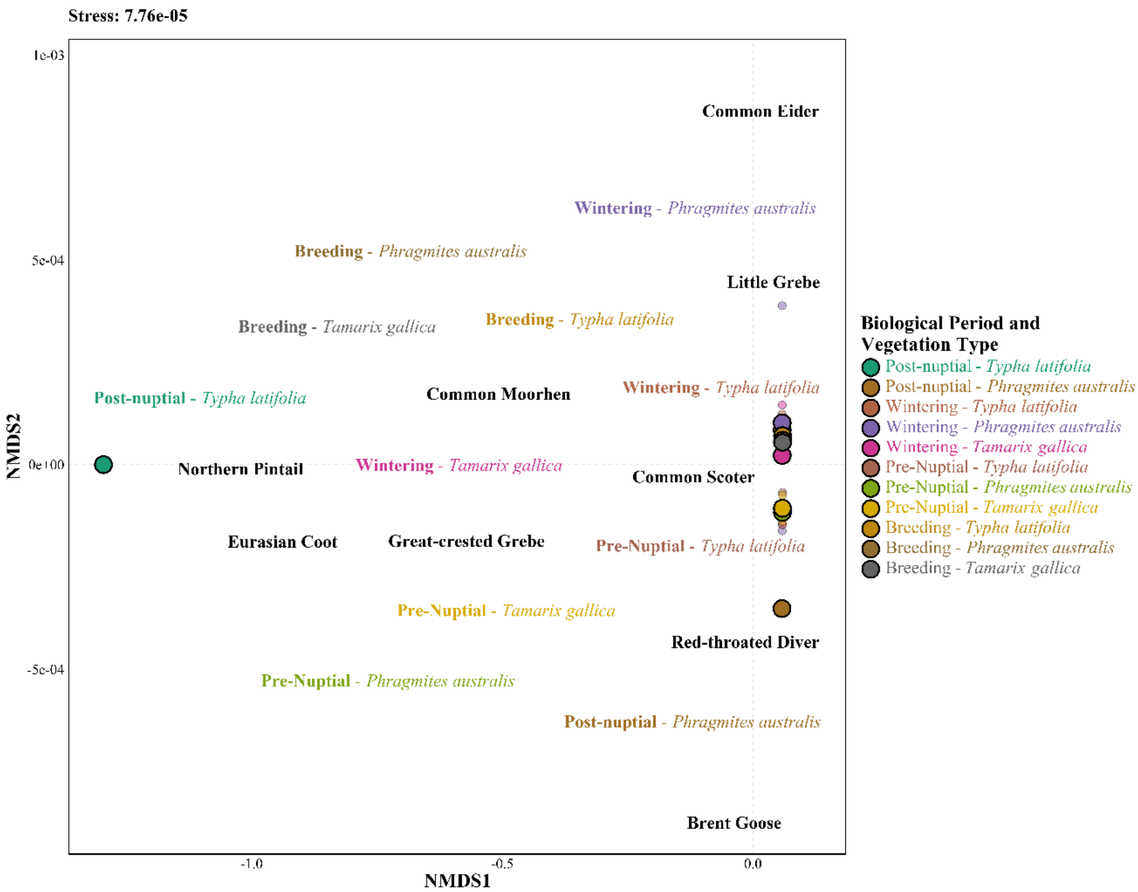

Figure 6. Non-metric Multidimensional Scaling (NMDS) plot of waterbird community composition in relation to biological period and vegetation type

DOI: 10.61215/AUOFB.2026.2.01

The Redundancy Analysis (RDA) further confirmed these patterns by quantifying the relationship between biological period, vegetation type and species composition. The first two RDA axes explained 53.3% of the variance (RDA1=53.3%, RDA2=26.8%), demonstrating that biological period and vegetation type are the dominant drivers of species distribution. The horizontal axis (RDA1) captures the primary gradient in bird assemblages, with species located at the extremes representing specialists associated with particular biological periods or vegetation types (Fig. 7). The significance of the model was supported by permutation ANOVA (pseudo-F=12.003, p=0.001), confirming that the observed patterns are non-random and reflect strong ecological structuring.

DISCUSSION

Our findings provide compelling evidence that temporal dynamics, specifically defined by biological periods, act as the primary drivers of waterbird community organization at Battoum Marsh. While traditional wetland research often relies on rigid, calendar-based frameworks [36, 38], our results demonstrate that both biological periods and vegetation types shape waterbird community assembly, with biological periods exerting the strongest influence. Integrating these temporal and habitat-related dimensions provides a more dynamic, phenological perspective on waterbird–habitat relationships.The overwhelming dominance of the Eurasian Coot (*Fulica atra*) during the wintering period, particularly within *Typha latifolia* and *Phragmites australis* stands, lends strong empirical support to the thermal-cover hypothesis. In these energetically demanding non-breeding months, Rallids preferentially exploit dense emergent vegetation to mitigate thermoregulatory costs and minimize predation risk [25, 29]. The concurrent association of the Common Moorhen (*Gallinula chloropus*) and Common Scoter (*Melanitta nigra*) with these microhabitats reinforces the established view that structurally complex macrophyte communities optimize resource availability and shelter [28]. *Gallinula chloropus*, in particular, exemplifies a high degree of ecological and behavioral plasticity, enabling its persistence across anthropogenically influenced and hydrologically unstable wetland systems such as small hill reservoirs in North Africa, where fluctuating water levels and habitat heterogeneity favor opportunistic habitat use and flexible foraging strategies. A critical contribution of this study is the documentation of a spatial leveling effect during the breeding season. We

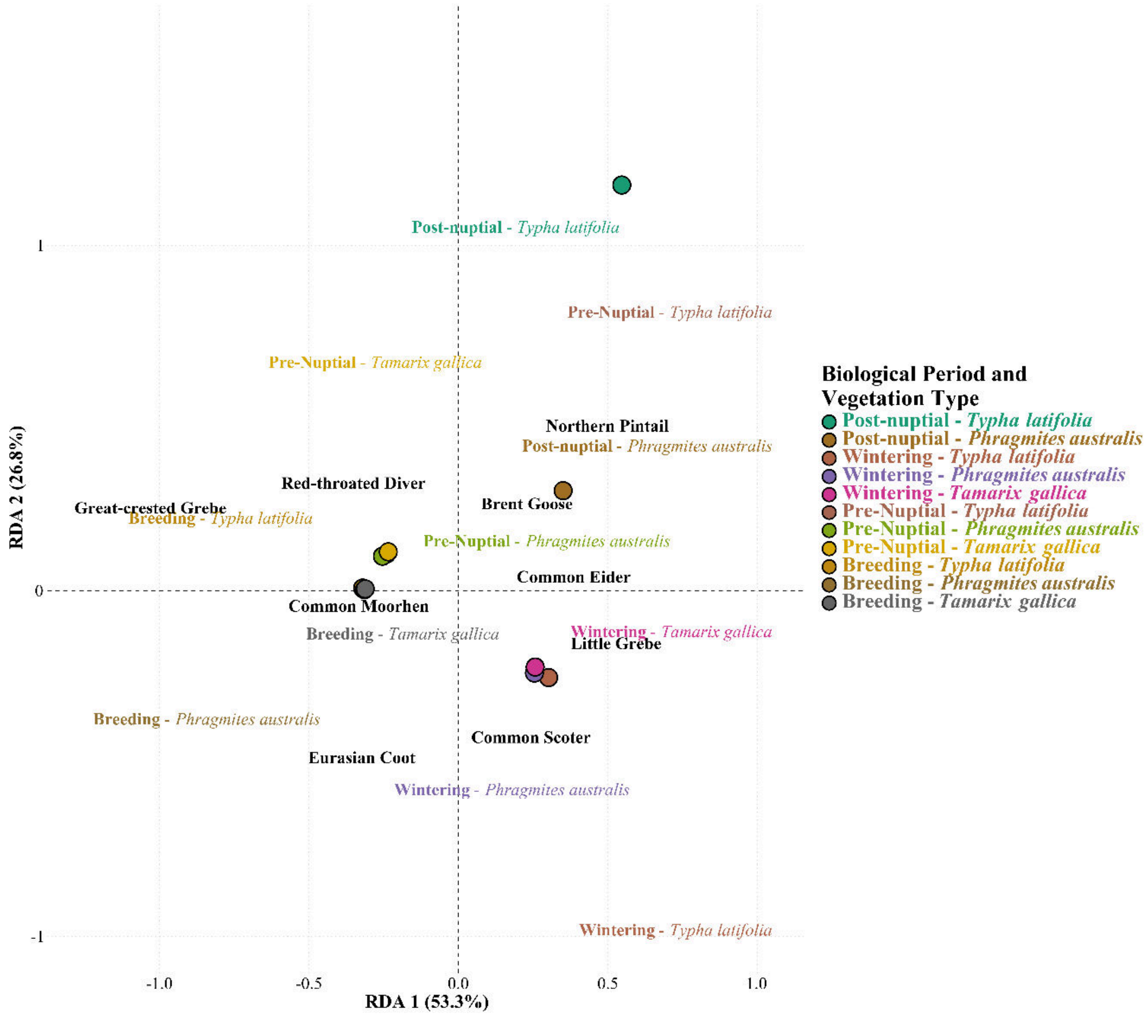

Figure 7. Redundancy Analysis (RDA) Biplot of waterbird community composition constrained by biological period and vegetation type

DOI: 10.61215/AUOFB.2026.2.01

observed a transition from high-density wintering aggregations to breeding-season homogeneity, which likely reflects a functional shift from resource-driven clustering to territoriality-driven dispersion, as predicted by classical niche theory [23]. This suggests that breeding waterbirds at Battoum Marsh exhibit remarkable habitat plasticity, prioritizing nest concealment and territory defense over the high-quality foraging patches favored in winter [7]. A major novelty of this research lies in our empirical challenge to the universal application of the habitat heterogeneity hypothesis. While vegetation complexity is often cited as the singular determinant of species richness [9, 27], our Scheirer–Ray–Hare analysis suggests that biological period has a greater influence on alpha diversity at Battoum Marsh than the other tested factors. This indicates that in highly dynamic Mediterranean systems, temporal turnover and migratory flux rather than local habitat filtering are the dominant forces structuring avian assemblages. By identifying the marsh as a dynamic stopover system, we corroborate the concept of Mediterranean wetlands as transient nodes whose ecological value is intrinsically linked to the phenological timing of the Afro-Palaearctic flyway [1].

Temporal-Habitat Windows and Functional Identity Our multivariate analyses (PCA and NMDS) further quantify these interactions with exceptional statistical fidelity (NMDS stress=7.76e^{-05}). We identified that while generalist species maintain a stable presence, specialists such as the Northern Pintail (*Anas acuta*) and Great Crested Grebe (*Podiceps cristatus*) rely on specific phenological intervals. For instance, the distinct clustering of post-nuptial *Typha* sites shaped by Northern Pintail distribution indicates that habitat 'attractiveness' is not a static trait of the vegetation, but a dynamic variable recalibrated by the community’s life-history requirements [14]. Within this context, the presence of typically marine or high-latitude species such as Common Scoter (*Melanitta nigra*), Common Eider (*Somateria mollissima*), and Red-throated Diver (*Gavia stellata*), represents an exceptional biogeographical phenomenon in an inland Mediterranean reservoir. Such occurrences may reflect episodic vagrancy events driven by large-scale atmospheric perturbations or disorientation along migratory flyways, highlighting the ecological connectivity between coastal and inland wetland networks in the western Palearctic system.

Implications for Adaptive Management Finally, the RDA results resolve an important ecological paradox: while the biological period governs the number of species (structural diversity), the interaction between period and vegetation type determines the identity of those species (compositional diversity) [20]. This distinction is important for conservation; it implies that the loss of specific vegetation, such as *Tamarix gallica*, may not decrease total species richness but will fundamentally alter the community's functional identity. By integrating biological phenology with habitat heterogeneity, this study provides a framework for wetland conservation at El Battoum Hill Reservoir and similar artificial wetlands in northeastern Algeria, advocating for management strategies that are temporally dynamic and responsive to biodiversity changes [12].

Conflict of interest. There is no actual or potential conflict of interest in relation to this article.

REFERENCES

[1] Amano, T., Székely, T., Sandel, B., Nagy, S., Mundkur, T., Langendoen, T., Blanco, D., Soykan, C.U., Sutherland, W.J., (2018): Successful conservation of global waterbird populations depends on effective governance. Nature, 553(7687): 199-202. https://doi.org/10.1038/nature25139

[2] Arlettaz, R., Schaub, M., Fournier, J., Reichlin, T.S., Sierro, A., Watson, J.E.M., Braunisch, V., (2010): From publications to public actions: When conservation biologists bridge the gap between research and implementation. BioScience, 60(10): 835-842. https://doi.org/10.1525/bio.2010.60.10.10

[3] Bibby, C.J., Burgess, N.D., Hill, D.A., Mustoe, S.H., (2000): Bird census techniques. 2nd ed., Academic press, London, pp. 1-302.

[4] Blondel, J., Aronson, J., Bodiou, J.Y., Boeuf, G., (2010): The mediterranean region: Biological diversity in space and time. Oxford University Press, Oxford, pp. 1-135.

[5] Boukrouma, N., Lalaibia, L., Djelloul, F., (2018): Diversity and seasonal variation of water birds in Tiffech Lake (Souk Ahras, Northeastern Algeria). International Journal of Ecology & Development, 33(4): 104-111.

[6] Brinson, M.M., Malvarez, A.I., (2002): Temperate freshwater wetlands: Types, status, and threats. Environmental Conservation, 29(2): 115-133. https://doi.org/10.1017/S0376892902000085

[7] Chrobak, G., Kowalczyk, T., Fischer, T.B., Szewrański, S., Chrobak, K., Kazak, J.K., (2023): Ecological state evaluation of lake ecosystems revisited: Latent variables with kSVM algorithm approach for assessment automatization and data comprehension. Ecological Indicators, 150: 110221. https://doi.org/10.1016/j.ecolind.2023.110221

[8] Cowardin, L.M., Carter, V., Golet, F.C., LaRoe, E.T., (1979): Classification of wetlands and deepwater habitats of the United States. U.S. Fish and Wildlife Service, Washington, DC, pp. 1-103.

[9] Curzel, F.E., Bellocq, M.I., Leveau, L.M., (2021): Local and landscape features of wooded streets influenced bird taxonomic and functional diversity. Urban Forestry & Urban Greening, 66: 127369. https://doi.org/10.1016/j.ufug.2021.127369

[10] Deboelpaep, E., Partoens, L., Koedam, N., Vanschoenwinkel, B., (2022): Highway(s) overhead: Strong differences in wetland connectivity and protected status challenge waterbird migration along the four palearctic–afrotropical flyways. Diversity and Distributions, 28(5): 1067-1080. https://doi.org/10.1111/ddi.13508

[11] Fraixedas, S., Lindén, A., Piha, M., Cabeza, M., Gregory, R., Lehikoinen, A., (2020): A state-of-the-art review on birds as indicators of biodiversity: Advances, challenges, and future directions. Ecological Indicators, 118: 106728. https://doi.org/10.1016/j.ecolind.2020.106728

[12] Gaget, E., Galewski, T., Jiguet, F., Le Viol, I., (2018): Waterbird communities adjust to climate warming according toconservation policy and species protection status. Biological Conservation, 227: 205-212. https://doi.org/10.1016/j.biocon.2018.09.019

[13] Garnier, S., Ross, N., Rudis, R., Camargo, A.P., Sciaini, M., Scherer, C., (2021): Viridis: colorblind-friendly color maps

 DOI: 10.61215/AUOFB.2026.2.01

for R. R package version 0.6.1. https://cran.r-project.org/package=viridis

[14] Germaine, S.S., Rosenstock, S.S., Schweinsburg, R.E., Richardson, W.S., (1998): Relationships among breeding birds, habitat,and residential development in greater Tucson, Arizona. Ecological Applications, 8(3): 680-691. https://doi.org/10.1890/1051-0761(1998)008[0680:RABBHA]2.0.CO;2

[15] Grillas, P., Gauthier, P., Deverre, C., Mesleard, F., (2004): Mediterranean temporary pools. (Vol 1): Issues relating to conservation, functioning and management. Station biologique de la Tour du Valat, Arles, pp. 1-120.

[16] Hu, S.J., Niu, Z.G., Chen, Y.F., Li, L.F., Zhang, H.Y., (2017): Global wetlands: Potential distribution, wetland loss, and status. Science of The Total Environment, 586: 319-327. https://doi.org/10.1016/j.scitotenv.2017.02.001

[17] Huang, B., Chiou, S., Li, W., (2021): Landscape pattern and ecological network structure in urban green space planning: a case study of fuzhou city. Land, 10(8): 769. https://doi.org/10.3390/land10080769

[18] Kassambara, A., (2023): ggpubr: 'ggplot2' based publication ready plots. R package version 0.6.0. https://cran.r-project.org/package=ggpubr

[19] Lê, S., Josse, J., Husson, F., (2008): FactoMineR: An R package for multivariate analysis. Journal of Statistical Software, 25(1): 1-18. https://doi.org/10.18637/jss.v025.i01. https://doi.org/10.18637/jss.v025.i01

[20] Legendre, P., Gallagher, E.D., (2001): Ecologically meaningful transformations for ordination of species data. Oecologia, 129: 271-280. https://doi.org/10.1007/s004420100716

[21] Leibold, M.A., Chase, J.M., (2018): Metacommunity ecology. Princeton University Press, Princeton, New Jersey, pp. 490.

[22] Loreau, M., Naeem, S., Inchausti, P., Bengtsson, J., Grime, J.P., Hector, A., Hooper, D.U., Huston, M.A., Raffaelli, D., Schmid, B., Tilman, D., Wardle, A.D., (2001): Challenges. Science, 294(5543): 804-808. https://doi.org/10.1126/science.1064088

[23] Magurran, A.E., (2004): Measuring biological diversity. Blackwell Publishing, Oxford, pp. 1-256.

[24] Mainwaring, M.C., Hartley, I.R., Lambrechts, M.M., Deeming, D.C., (2014): The design and function of birds' nests. Ecology and Evolution, 4(20): 3909-3928. https://doi.org/10.1002/ece3.1054

[25] Marra, P.P., Cohen, E.B., Loss, S.R., Rutter, J.E., Tonra, C.M., (2015): A call for full annual cycle research in animal ecology. Biology Letters, 11(8): 20150552. https://doi.org/10.1098/rsbl.2015.0552

[26] Maseko, M.S., Zungu, M.M., Ehlers Smith, D.A., Ehlers Smith, Y.C., Downs, C.T., (2020): Effects of habitat-patch size and patch isolation on the diversity of forest birds in the urban-forest mosaic of durban, South Africa. Urban Ecosystems, 23(3): 533-542. https://doi.org/10.1007/s11252-020-00942-0

[27] Mitsch, W.J., Gosselink, J.G., (2015): Wetlands. 5th ed., John Wiley & Sons, New Jersey, pp. 1-744.

[28] Morris, D.W., (2011): Adaptation and habitat selection in the eco-evolutionary process. Proceedings of the Royal Society B: Biological Sciences, 278(1717): 2401-2411. https://doi.org/10.1098/rspb.2011.0604

[29] Newton, I., (2007): The migration ecology of birds. Elsevier Academic Press, Amsterdam, pp. 1-984. https://doi.org/10.1016/B978-0-12-517367-4.X5000-1

[30] Oksanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymos, P., Stevens, M.H.H., Szoecs, E., Wagner, H., (2020): Vegan: community ecology package. R package version 2.5-7. https://doi.org/10.32614/cran.package.vegan

[31] Paker, Y., Yom-Tov, Y., Alon-Mozes, T., Barnea, A., (2014): The effect of plant richness and urban garden structure on bird species richness, diversity and community structure. Landscape and Urban Planning, 122: 186-195. https://doi.org/10.1016/j.landurbplan.2013.11.014

[32] Qiu, J., Zhang, Y., Ma, J., (2024): Wetland habitats supporting waterbird diversity: Conservation perspective on biodiversity- ecosystem functioning relationship. Journal of Environmental Management, 357: 120663. https://doi.org/10.1016/j.jenvman.2024.120663

[33] R Development Core Team, (2025): R: A language and environment for statistical computing. R foundation for statistical computing, Vienna, Austria. https://www.r-project.org/

[34] Rico-Silva, J.F., Cruz-Trujillo, E.J., Colorado, Z.G.J., (2021): Influence of environmental factors on bird diversity in greenspaces in an Amazonian city. Urban Ecosystems, 24(2): 365-374. https://doi.org/10.1007/s11252-020-01043-4

[35] Samraoui, B., Belair, G., (1997): The garaet ezzemoul: a first report on the status of a major North African wetland. Wildfowl, 48: 218-224

[36] Samraoui, F., Samraoui, B., (2008): An appraisal of the status and distribution of waterbirds of Algeria: indicators of global changes? Ardeola, 58(1): 137-163. https://doi.org/10.13157/arla.58.1.2011.137

[37] Sbiki, M., Benzina, I., Si Bachir, A., Ghazi, C., (2025): How do environmental conditions in artificial wetlands affect waterbird communities? Case of the hillside reservoir of Sebkhates of Aures wetlands complex (northeast Algeria). Global NEST Journal, 27(8): 1-11. https://doi.org/10.30955/gnj.07392

[38] Telailia, S., Boutabia, L., Khemis, M. D. H., Elafri, A., Djebbari, N., (2017): Multi-annual and seasonal patterns of waterbird assemblages in a Mediterranean coastal lagoon (El Mellah lagoon) of Northeastern Algeria. Ekológia (Bratislava), 36(2): 146-158. https://doi.org/10.1515/eko-2017-0013

[39] Tilman, D., Knops, J., Wedin, D., Reich, P., Ritchie, M., Siemann, E., (1997): The influence of functional diversity and composition on ecosystem processes. Science, 277(5330): 1300-1302. https://doi.org/10.1126/science.277.5330.1300

[40] Tutin, T.G., Heywood, V.H., Burges, N.A., Moore, D.M., Valentine, D.H., Walters, S.M., Webb, D.A., (1964): Flora europaea. (Vols. 1-5), Cambridge University Press, Cambridge, pp. 20-25.

[41] Wang, Q., Lv, X., (2007): Application of water bird to monitor and evaluate wetland ecosystem. Wetlands Science, 5(3): 274-281. https://doi.org/10.3969/j.issn.1672-5948.2007.03.012

[42] Wickham, H., (2016): ggplot2: Elegant graphics for data analysis. Springer-verlag, New York, pp. 3-4. https://ggplot2.tidyverse.org/

[43] Wilke, C.O., (2020): Cowplot: streamlined plot theme and plot annotations for 'ggplot2'. R package version 1.1.1. https://cran.r-project.org/package=cowplot

Received: April 2, 2026
Accepted: June 24, 2026
Published Online: July 1, 2026
Analele Universităţii din Oradea, Fascicula Biologie
Print-ISSN: 1224-5119
e-ISSN: 1844-7589
CD-ISSN: 1842-6433
Oradea University Press
https://www.bioresearch.ro/revistaen.html
https://doi.org/10.61215/auofb.2026.2.01

DOI: 10.61215/AUOFB.2026.2.01