

# INFLUENCE OF SEASONAL VEGETATION GRADIENTS ON WATERBIRD SPECIES ASSEMBLAGES IN BATTOUM MARSH, ALGERIA

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## Abstract

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This study investigated the seasonal dynamics of waterbird communities and their relationships with wetland vegetation gradients in Battoum Marsh, a semi-humid Mediterranean wetland in northeastern Algeria. Seasonal patterns showed higher abundances of several species in autumn and winter, whereas summer was characterized by a marked decline in diversity. Diversity analyses revealed significant seasonal variation in community structure. Shannon and Simpson indices were significantly lower in summer than in autumn and winter, while species richness and evenness did not differ significantly among seasons, indicating that seasonal changes mainly affected diversity patterns rather than the number of species recorded. Multivariate ordination analyses (PCA, RDA, and CCA) consistently identified vegetation structure as the primary factor shaping waterbird distribution. Emergent vegetation height, floating plant cover, and overall vegetation cover constituted the main environmental gradients influencing species composition. Species strongly associated with dense and structured vegetated habitats included Common Moorhen, Eurasian Coot, Common Scoter, Red-Crested Pochard, and Brent Goose, particularly during autumn, winter, and spring. In contrast, Great Northern Loon, Northern Pintail, Red-necked Grebe, and European Shag were generally linked to open or less vegetated habitats. Overall, these findings demonstrate that vegetation gradients and seasonal dynamics play a central role in structuring waterbird assemblages at Battoum Marsh, highlighting the importance of maintaining vegetation heterogeneity for wetland conservation in northeastern Algeria.

*Key words:* waterbird, wetland vegetation, seasonal dynamics, ordination, northeastern Algeria.

## Introduction

Wetlands are among the most productive and ecologically valuable ecosystems, providing essential services such as water purification, flood regulation, carbon sequestration, and critical habitats for a wide range of species (De Carvalho et al., 2025; Wang et al., 2025). Within these ecosystems, waterbirds play a pivotal ecological role and serve as sensitive bioindicators of wetland health and integrity due to their close dependence on habitat conditions (Ma et al., 2010; Hamza et al., 2024; Panda et al., 2021). The distribution and population dynamics of waterbirds are strongly influenced by habitat quality, particularly the composition and structure of wetland vegetation, which supplies vital resources including food, nesting sites, and shelter (Panda et al., 2021). Vegetation characteristics such as emergent vegetation height, percentage cover, and the presence of floating plants directly shape habitat complexity and influence waterbird assemblages by modifying microhabitats and resource availability (Chen et al., 2025; Wan et al., 2025). These structural components affect species diversity and abundance across wetlands globally (Ramírez et al., 2018; Teng et al., 2025). Furthermore, seasonal

climatic and hydrological fluctuations drive dynamic changes in vegetation phenology and structure, which in turn lead to temporal variations in waterbird presence and behavior (Yang et al., 2025). Despite considerable advances in understanding wetland bird ecology at broader scales, many Mediterranean wetlands, particularly in North Africa, remain underexplored regarding the complex interactions between vegetation dynamics and waterbird populations. This research gap is especially apparent in Algeria, where wetlands are increasingly threatened by anthropogenic pressures, climate variability, and land-use changes (Boucif et al., 2022). Although previous studies in Algeria have documented waterbird diversity and habitat utilization (Martin et al., 2022; Boucif et al., 2022), detailed analyses linking monthly waterbird abundance to fine-scale vegetation parameters over an entire annual cycle are scarce. The Battoum Marsh, located in Souk Ahras, Northeast Algeria, represents a semi-humid Mediterranean wetland of high ecological importance, supporting diverse resident and migratory waterbird species. To date, no comprehensive study has investigated how seasonal variations in vegetation attributes such as cover, height, floating vegetation, and hydrological factors influence waterbird abundance in this

wetland. This study aims to fill that gap by providing the first systematic evaluation of the relationship between waterbird population dynamics and vegetation structure on a monthly basis within Battoum Marsh.

By combining detailed vegetation measurements with consistent seasonal bird surveys, this research seeks to identify the key habitat variables shaping waterbird abundance patterns in this marsh. The findings will contribute to a deeper understanding of species–habitat relationships in a region vulnerable to vegetation gradient changes and offer valuable information to inform effective wetland management and conservation strategies.

## Material and methods

### Study area

The study was conducted at Battoum Marsh (36°4'18.68"N, 8°6'16.26"E; reservoir surface area: 25 ha), located in Souk Ah-ras, Northeast Algeria. This semi-humid Mediterranean wetland is characterized by a mosaic of open water, emergent vegetation, and floating plant communities, supporting diverse resident and migratory waterbird species (Fig. 1).

### Bird survey

Waterbird abundance was monitored monthly from November 2024 to August 2025. Observations were conducted using 10× binoculars and a spotting scope with 45× zoom. A thorough scan of the entire survey area was performed to identify and count all waterbird species, both visually and acoustically. Counts commenced immediately upon arrival to ensure that individuals potentially disturbed by human presence were recorded. To standardize survey effort, each count lasted 20 minutes and was conducted during morning hours (08:30–14:30), when bird activity and detectability are generally highest. The same observer(s) visited the same fixed observation points each month to ensure consistency and reproducibility. For each 20-minute count, the number of individuals recorded was used to calculate abundance, and relative abundance (%) of each species was computed for each season to describe seasonal patterns in species composition, following standard point-count protocols commonly used in waterbird monitoring studies (Bibby et al., 2000).

### Vegetation gradient measurements

Vegetation gradients were measured simultaneously with bird counts to capture habitat variables potentially influencing waterbird abundance. Five quadrats ( $n = 5$ ), each measuring 1×1 m, were sampled randomly within each site, following methods adapted from Ko et al. (2017) and Wu et al. (2024). Quadrats were either revisited monthly at the same locations or randomly re-positioned within the site to ensure representative sampling of habitat variation. Within each quadrat, the average height of emergent vegetation was measured using a graduated rod (Chen et al., 2025). Vegetation cover was estimated as the percentage of ground covered by plants, following protocols of Locky et al. (2005). Floating vegetation cover, including floating-leaf and free-floating plants, was visually estimated as a percentage of wa-

ter surface, based on classifications adapted from Cowardin et al. (1979). All measurements were repeated monthly to document seasonal variation, and quadrats were positioned in proximity to bird count points without disturbing the birds, ensuring that vegetation data reflect the habitat used by waterbirds.

### Data analyses

To compare community diversity among seasons, several metrics were calculated, including Shannon diversity index, Simpson diversity index, Pielou's Evenness Index, and species richness. Normality of all variables was assessed using the Shapiro–Wilk test, while homogeneity of variance among sites was evaluated using Levene's and Bartlett's tests. Differences in species diversity and environmental parameters between sites were tested using one-way analysis of variance (ANOVA), followed by Tukey's post hoc test to identify pairwise differences. All statistical analyses were performed in R software, version 4.5.0 (R Core Team, 2025). Diversity indices were computed with the *vegan* package (Oksanen et al., 2022), and boxplots were created using *ggplot2* (Wickham, 2016). Seasonal variation in bird counts was visualized using a phenologram to explore temporal trends in abundance. Relationships between vegetation variables and waterbird communities were explored using principal component analysis (PCA) to summarize major gradients in habitat structure, implemented via *FactoMineR*, *factoextra*, *grid*, and *ggbiplot* (Lê et al., 2008). To assess the influence of habitat variables on bird community composition, Redundancy Analysis (RDA) and Canonical Correspondence Analysis (CCA) were conducted using the *vegan* package (Oksanen et al., 2022). Prior to RDA and CCA, species abundance data were Hellinger transformed to reduce the influence of rare species and meet linear model assumptions (Legendre, Gallagher, 2001). Predictor collinearity was assessed using variance inflation factors (VIF), and variables with  $VIF > 10$  were excluded from the analyses. Significance of RDA and CCA 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

### Seasonal patterns of waterbird abundance revealed by phenologram

The phenologram reveals clear seasonal patterns in the abundance of waterbird species across the study area. Several species exhibit pronounced peaks in specific seasons, indicating strong phenological preferences or migratory behaviors. For instance, species such as the Eurasian Coot and White Stork show higher abundances during the autumn and winter months. In contrast, other species display reduced counts or absence during summer (Fig. 2). Detailed seasonal abundance data for all species are provided in Table 1.

### Comparison of waterbird assemblages among season

The ANOVA test showed a significant effect of season on the Shannon diversity index ( $F=8.505, p=0.014$ ), indicating that di-

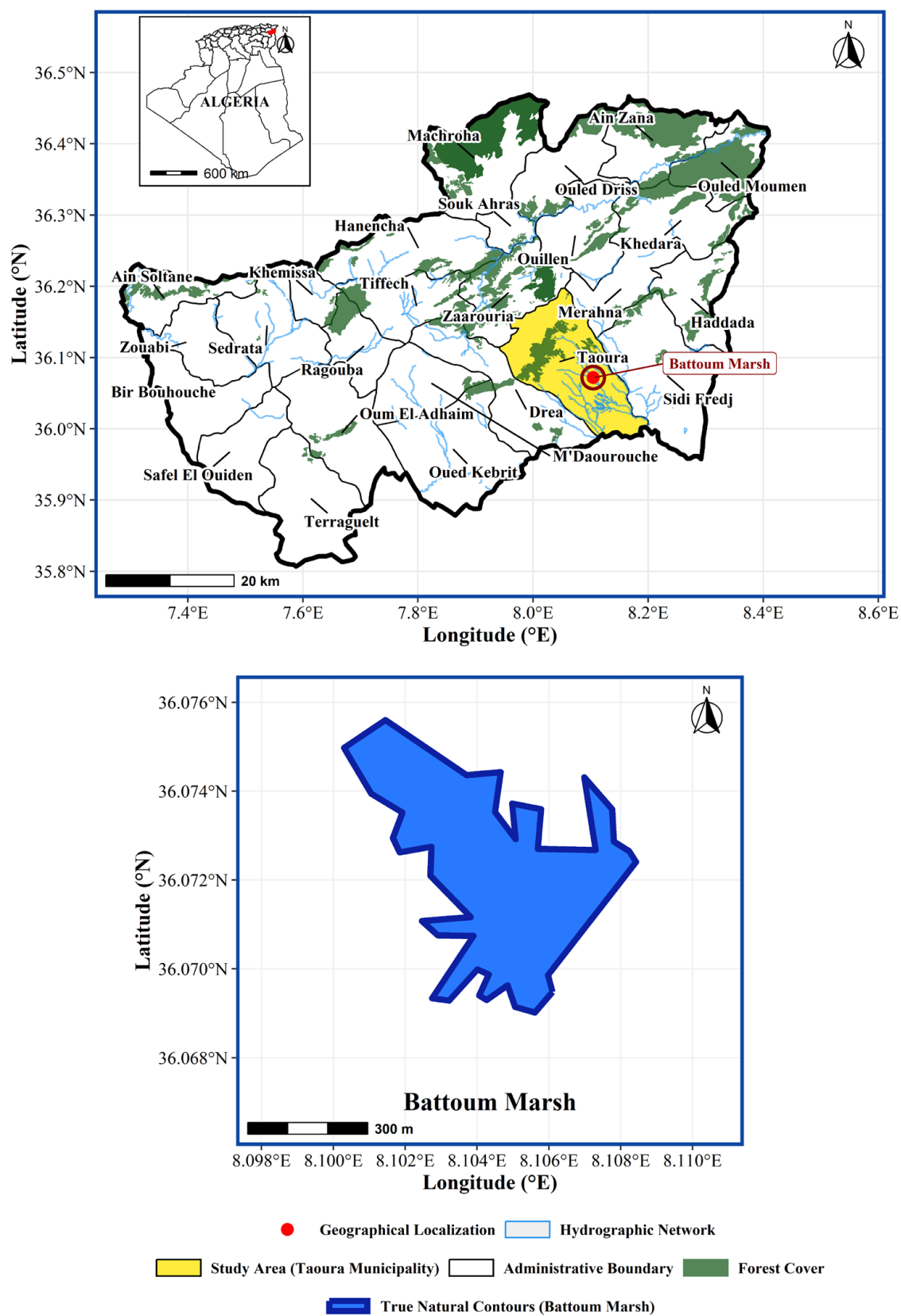


Fig. 1. Map of the study area Battoum Marsh, Province of Souk Ahras, Northeastern Algeria (Established by Boukrouma, 2026).

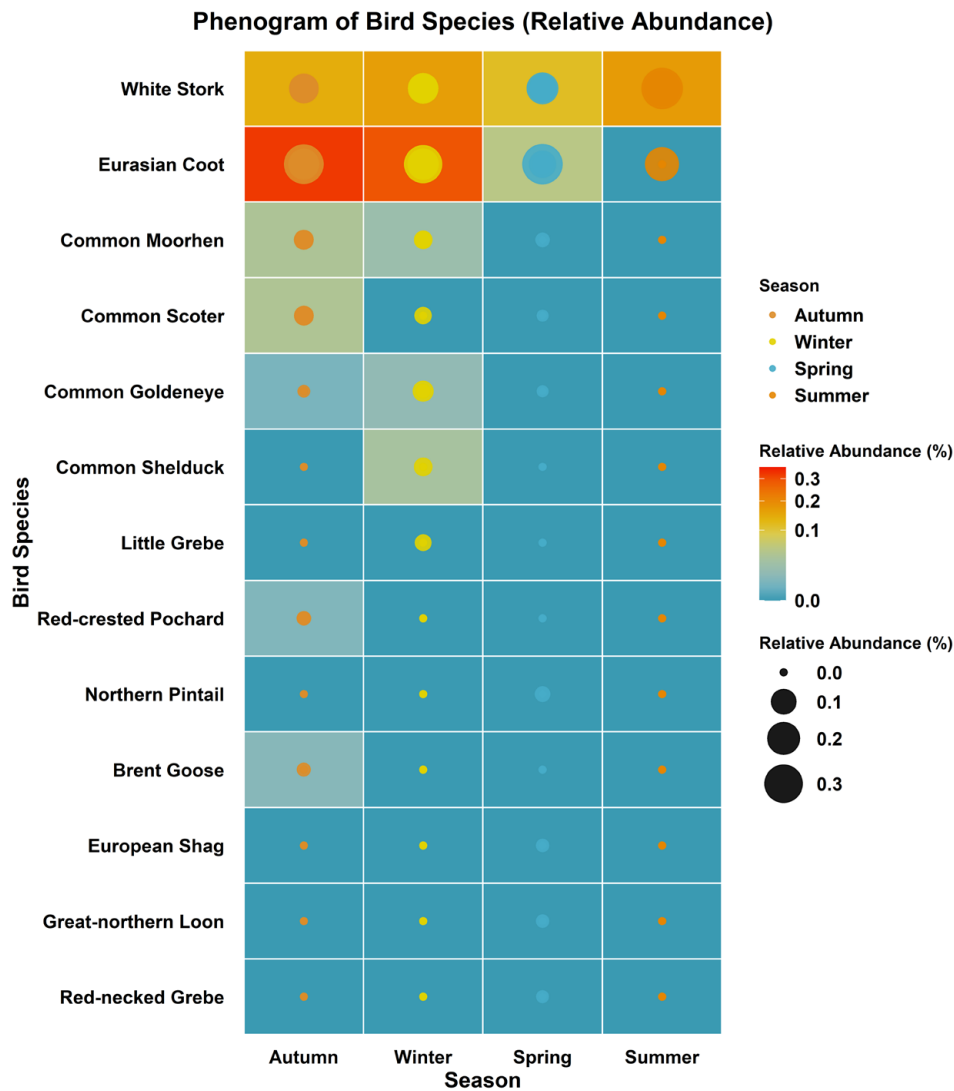


Fig. 2. Heatmap Showing Bird Species Abundance across Season.

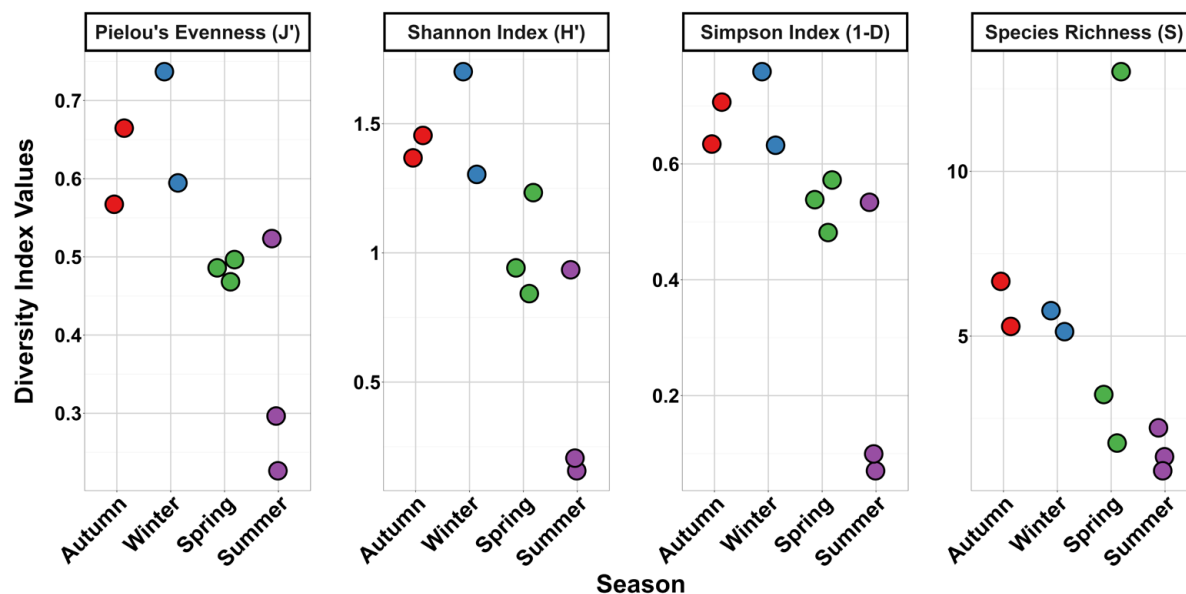
versity varies significantly across seasons. The Tukey post hoc test revealed that diversity in summer was significantly lower than that in autumn ( $p=0.023$ ) and winter ( $p=0.020$ ) (Fig. 3(A), (B)). Similarly, the Simpson diversity index was significantly affected by season ( $F=9.245$ ,  $p=0.012$ ). The Tukey test showed that Simpson diversity was significantly lower in summer than in both autumn ( $p=0.016$ ) and winter ( $p=0.021$ ), while no significant differences were found among the remaining season pairs. In contrast, the evenness index did not show a significant seasonal effect ( $F=1.495$ ,  $p=0.308$ ), indicating that the distribution of individuals among species remained relatively stable throughout the year. Similarly, species richness did not differ significantly between seasons ( $F=0.922$ ,  $p=0.485$ ), indicating that the number of waterbird species recorded in Battoum Marsh remained relatively consistent across seasons despite seasonal fluctuations in individual abundances (Fig. 3(A), (B)). Specifically, mean species richness was  $9.0 \pm 1.0$  in autumn (range: 8–10),  $8.5 \pm 0.5$  in winter (range: 8–9),  $5.5 \pm 0.5$  in spring (range: 5–6), and  $4.5 \pm 0.5$  in summer (range: 4–5).

**Table 1.** Waterbird species abundance (%) recorded at Battoum Marsh, northeastern Algeria, from November 2024 to August 2025.

| Species (Common Name) | Scientific Name                  | Relative Abundance (%) |
|-----------------------|----------------------------------|------------------------|
| Common Scoter         | <i>Melanitta nigra</i>           | 6.09                   |
| Common Moorhen        | <i>Gallinula chloropus</i>       | 6.86                   |
| Northern Pintail      | <i>Anas acuta</i>                | 0.85                   |
| Red-crested Pochard   | <i>Netta rufina</i>              | 0.7                    |
| Brent Goose           | <i>Branta bernicla</i>           | 0.7                    |
| Little Grebe          | <i>Tachybaptus ruficollis</i>    | 1.5                    |
| Common Shelduck       | <i>Tadorna tadorna</i>           | 0.1                    |
| Eurasian Coot         | <i>Fulica atra</i>               | 53.9                   |
| Common Goldeneye      | <i>Bucephala clangula</i>        | 4.4                    |
| Red-necked Grebe      | <i>Podiceps grisegena</i>        | 0.4                    |
| Great-northern Loon   | <i>Gavia immer</i>               | 0.5                    |
| European Shag         | <i>Phalacrocorax aristotelis</i> | 0.1                    |
| White Stork           | <i>Ciconia ciconia</i>           | 23.9                   |

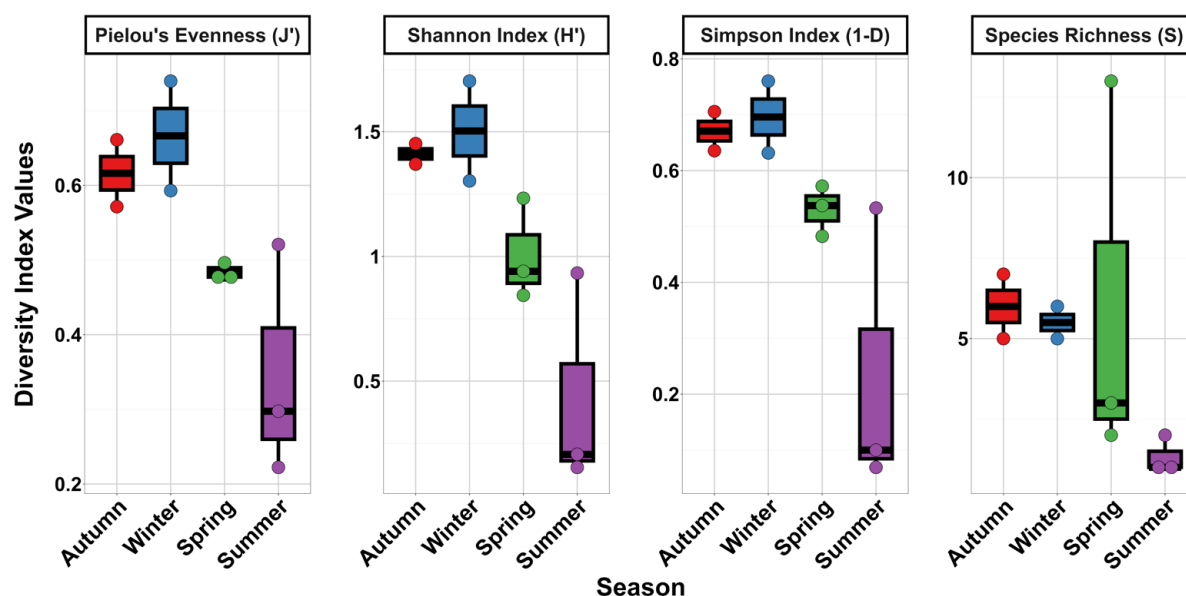
**A**

### Diversity Indices by Season (Spatial Distribution)



**B**

### Diversity Indices by Season (Boxplot)



**Fig. 3.** (A). Ecological index values showing seasonal effects on waterbird species at Battoum Marsh: Pielou's Evenness Index, Shannon diversity index, Simpson diversity index, and Species Richness. (B). Distributions of these indices represented as boxplots.

### Relationship between waterbird species and vegetation gradients

Multivariate analyses highlighted the central role of vegetation gradients in shaping waterbird distribution patterns at Battoum Marsh in northeastern Algeria. Principal component analysis

(PCA) revealed that the first axis, explaining 42.1% of the variance, was primarily structured by vegetation-related variables. Emergent vegetation height, floating plant cover, and overall vegetation cover were all strongly and positively correlated with this axis, particularly during autumn and winter. This gradient was also positively associated with species such as Common

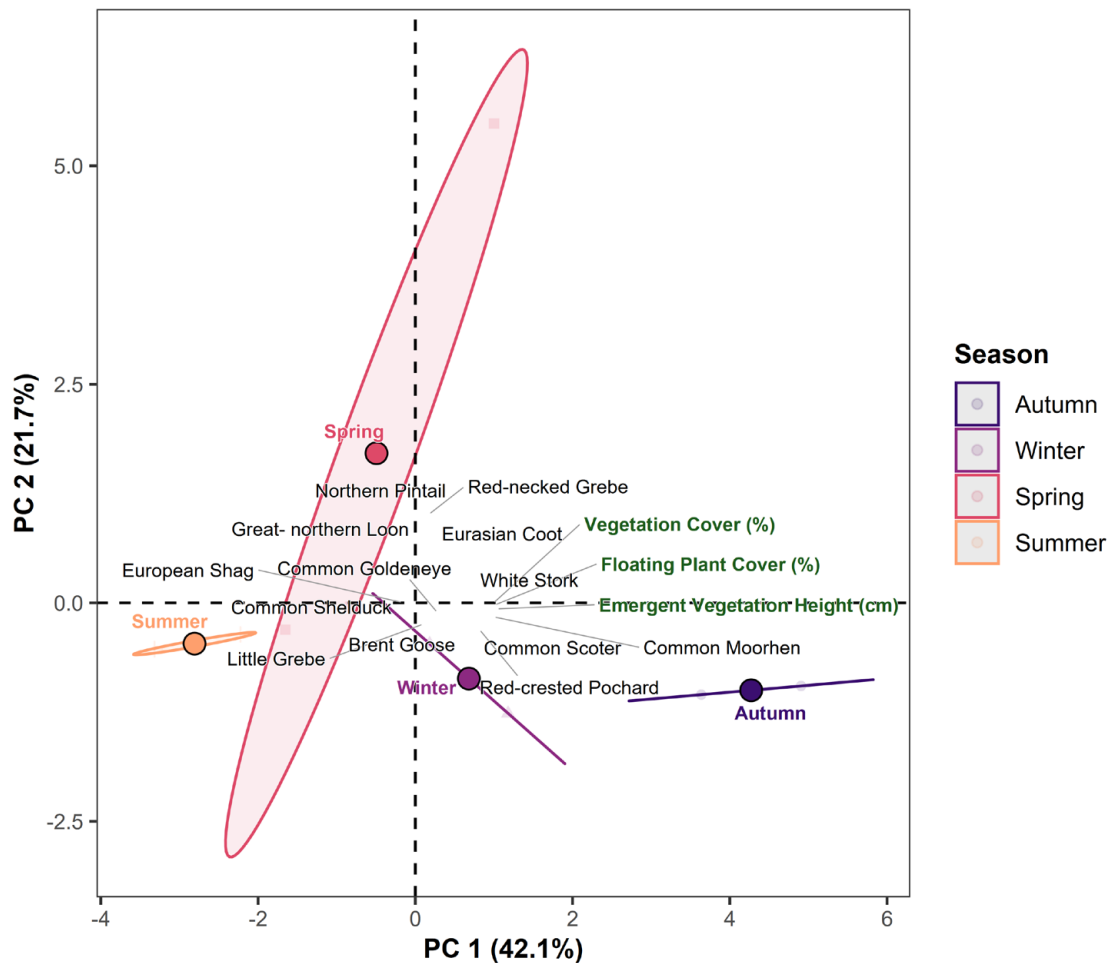


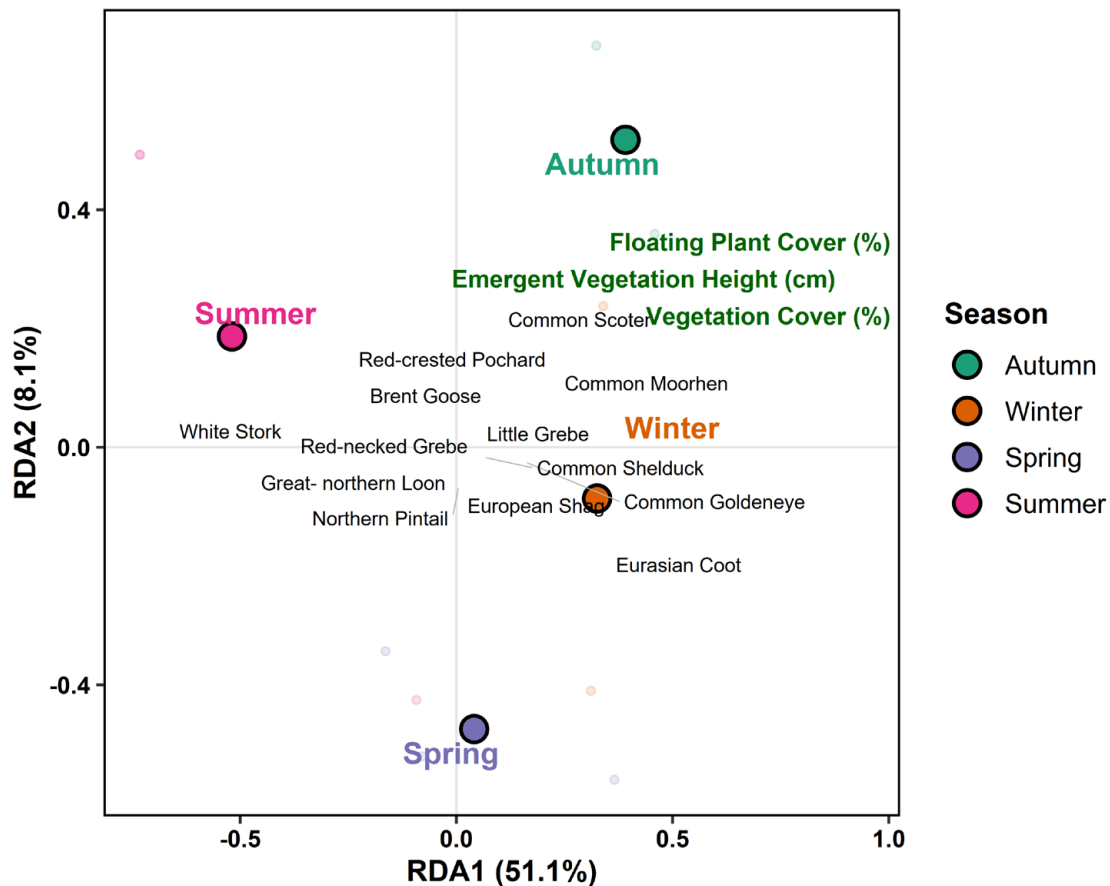
Fig. 4. PCA biplot of waterbird species against vegetation gradients for axes 1 and 2 in Battoum Marsh, northeastern of Algeria.

Moorhen, Common Scoter, Eurasian Coot, Red-crested Pochard, and White Stork. The second axis, accounting for 21.7% of the variance, characterized species including Great-northern Loon, Northern Pintail, and Common Goldeneye, which showed a lower association with vegetation gradients, particularly in spring and summer (Fig. 4). Redundancy Analysis (RDA) further confirmed the strong influence of vegetation. The first RDA axis explained 51.1% of the total explained variation and was significantly associated with vegetation cover, emergent vegetation height, and floating plant cover ( $p = 0.001$ ), especially during autumn and winter. Species such as Eurasian Coot, Common Moorhen, Common Goldeneye, European Shag, Common Shelduck, and Common Scoter scored highly along this axis, reflecting their strong dependency on structured habitats. In contrast, Red-necked Grebe, Great-northern Loon, Northern Pintail, and White Stork exhibited low or negative scores, indicating a preference for less vegetated areas. The second RDA axis, accounting for 8.1% of variance, characterized species such as Red-crested Pochard and Brent Goose were associated with vegetation gradients primarily in summer (Fig. 5). Canonical Correspondence Analysis (CCA) provided additional insights into species-vegetation relationships. Both CCA axes were strongly influenced

by vegetation gradients, with very high correlations for floating plant cover and emergent vegetation height ( $r^2 > 0.90$ ,  $p < 0.01$ ). Species such as Brent Goose, Red-Crested Pochard, Great-northern Loon, Common Moorhen, and Common Scoter were strongly associated with these variables during autumn, summer, and spring. Common Goldeneye, Little Grebe, and Common Shelduck were associated with less vegetated habitats in winter (Fig. 6). Overall, these analyses consistently demonstrate that vegetation structure is a key determinant of waterbird distribution at Battoum Marsh, with certain species showing strong dependency on dense vegetated habitats while others prefer more open areas.

## Discussion

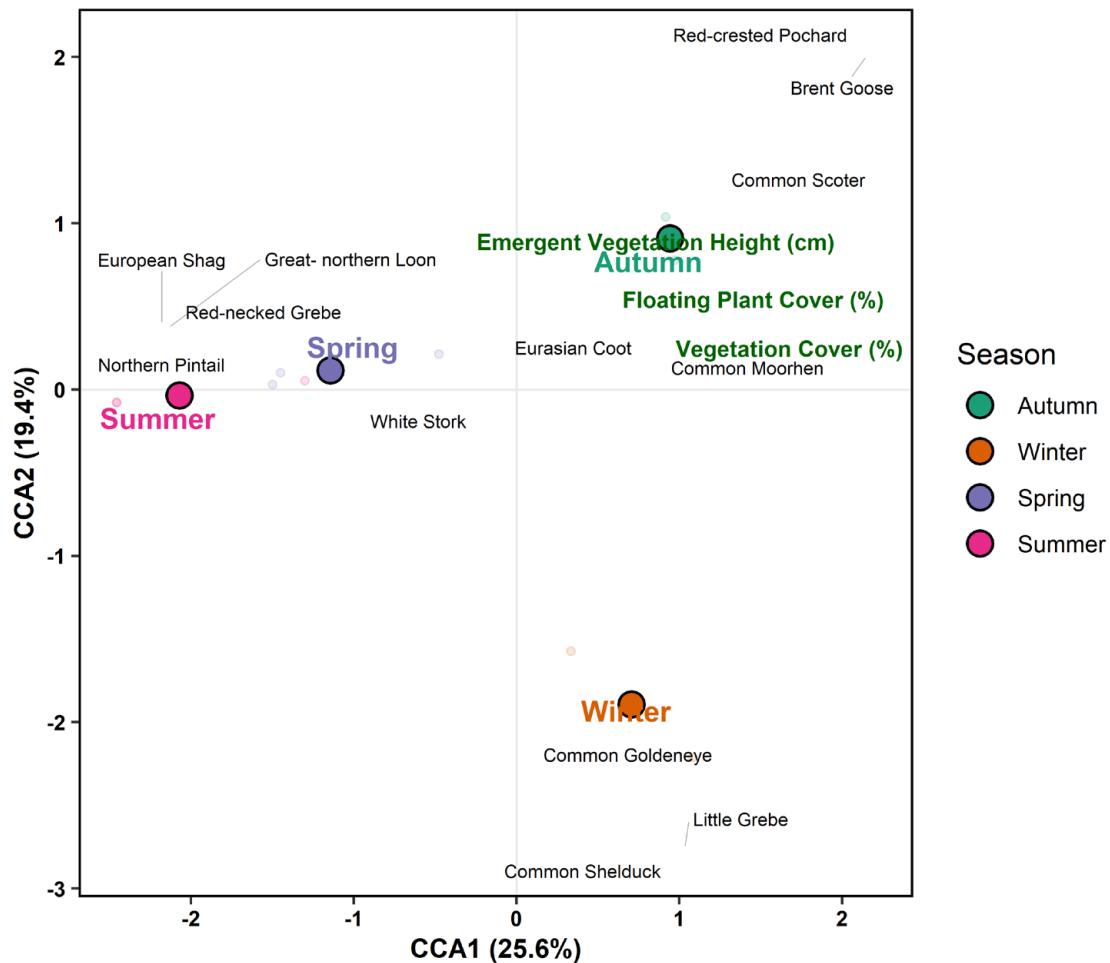
This study provides insights into the combined effects of seasonal dynamics and vegetation gradients on waterbird assemblages in Battoum Marsh. Our analysis revealed marked seasonal shifts in bird abundance, with species such as the Eurasian Coot and White Stork exhibiting higher occurrences during autumn and winter months. These seasonal trends reflect species-specific ecological adaptations and migratory behaviors, consistent with



**Fig. 5.** Ordination plot from a redundancy analysis (RDA) of the distribution of waterbird species in relation to vegetation gradients in Battoum Marsh, northeastern of Algeria.

patterns observed in Mediterranean wetlands where temporal variability in habitat quality shapes avian distribution (Yang et al., 2025). Consistent with findings from North African wetland systems, the spatial configuration, size, and connectivity of wetlands are key factors influencing wintering waterbird populations (Hamza et al., 2024; Ma et al., 2010). Seasonal changes were further reflected in community-level indices: species richness peaked in spring, corresponding with breeding periods and heightened resource availability (Nedić et al., 2025; Zara et al., 2021), while diversity indices such as Shannon and Simpson reached maxima during winter, likely due to an influx of migratory species increasing taxonomic and functional heterogeneity. Relatively stable evenness and richness across seasons suggest dynamic shifts in species abundances rather than total turnover, indicating processes such as resource-driven niche partitioning and seasonal ecological interactions (Panda et al., 2021; Chen et al., 2025). Vegetation gradients played a pivotal role in structuring species distributions, as revealed by PCA, RDA, and CCA analyses, with variables such as emergent vegetation height, floating plant cover, and total vegetative cover emerging as significant predictors (Secondi et al., 2026; Wan et al., 2025). Species including Common Moorhen, Common Scoter, and Eurasian Coot were associated with dense aquatic vegetation, highlight-

ing the importance of structurally complex habitats for foraging and protection (Teng et al., 2025). Conversely, open-water specialists like Great-northern Loon and European Shag occupied opposite ends of environmental gradients, reflecting habitat specialization that reduces niche overlap and supports community diversity (Mitchell et al., 2025). These results align with global studies showing that vegetative complexity, patch size, and landscape connectivity enhance avian community resilience to seasonal and climatic disturbances (Wang et al., 2025; Wu et al., 2024). Significant seasonal associations identified via envfit analyses emphasize the interaction between vegetation structure and temporal dynamics, with autumn and winter conditions particularly influencing species dependent on dense vegetation. This underscores the importance of considering phenological changes in vegetation driven by climate variability and human impacts (Carrete et al., 2009; Secondi et al., 2026). Similar patterns have been reported in other wetland systems, for example, in the Bohai Rim of China, where vegetation cover positively correlates with bird diversity (Xue, Su, 2017; Wu et al., 2024). Overall, the integrative use of multiple ordination techniques highlights the need to conserve a mosaic of vegetative habitats year-round to support diverse waterbird assemblages. Developing adaptive wetland management strategies that promote habi-



**Fig. 6.** Canonical correspondence analysis (CCA) of waterbird species distribution related to vegetation gradients across seasons at Battoum Marsh, northeastern Algeria.

tat heterogeneity, ensure connectivity, and account for seasonal habitat shifts will be essential for preserving biodiversity under accelerating environmental change (Boucif et al., 2022; Wan et al., 2025; Yang et al., 2025).

## Conclusion

This study demonstrates that both seasonal dynamics and vegetation structure are key determinants of waterbird assemblages in Battoum Marsh. Seasonal fluctuations in abundance and diversity reflect species-specific ecological adaptations and migratory behaviors, while vegetation gradients, particularly emergent vegetation height, floating plant cover, and overall vegetative cover, strongly influence species distribution patterns. Species dependent on dense vegetated habitats coexist alongside open-water specialists, highlighting the importance of habitat heterogeneity for maintaining community diversity. These findings underscore the necessity of conserving structurally complex wetland habitats and accounting for seasonal changes in management plans. Adaptive strategies that maintain vegetation complexity, enhance connectivity, and consider temporal habitat shifts are crucial for

sustaining waterbird diversity under ongoing environmental and climatic pressures.

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