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Seasonal Dynamics and Habitat Use by Shorebirds in Mekhada Marsh, a Mediterranean Biodiversity Hotspot

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ABSTRACT

Wetlands in the Mediterranean Basin play a pivotal role in sustaining migratory bird populations, yet many remain poorly monitored. This study investigates seasonal patterns of waterbird abundance and habitat use in the Mekhada marsh, a Ramsar-listed wetland in northeastern Algeria. Over a full annual cycle, 24 bi-monthly surveys documented significant spatiotemporal variation in waterbird communities. Peak abundances were recorded in winter, exceeding 3,000 individuals in January alone, with estuarine habitats supporting up to 6,075 birds. Non-metric multidimensional scaling (NMDS) revealed distinct seasonal assemblages linked to specific habitat types. Estuarine zones were dominated by wintering gulls and terns (*Laridae*), mudflats showed functional turnover from palearctic shorebirds to afro-tropical breeders, and wet meadows exhibited bimodal usage. These patterns reflect the site's multifunctional role along the east atlantic flyway, offering winter refuge, post-breeding stopovers, and breeding habitat. Findings underscore the ecological importance of hydrological variability, microhabitat diversity, and connectivity in sustaining avian biodiversity. In light of ongoing habitat degradation and climate-induced changes, the study highlights the need for adaptive, habitat-specific management strategies to maintain the functional integrity of Mekhada marsh and similar Mediterranean wetlands.

INTRODUCTION

Wetlands are among the most productive and ecologically valuable ecosystems on the Earth, providing critical habitats for a wide array of flora and fauna, particularly

waterbirds **(Qiu *et al.*, 2024)**. In the Mediterranean basin, where wetland habitats have been extensively degraded or transformed, the remaining sites serve as essential stopovers, wintering grounds, and breeding areas for numerous migratory bird species **(Khemis *et al.*, 2017; Bendjeddou *et al.*, 2018; Telailia *et al.*, 2018, 2020; Baalia *et al.*, 2023; Houhamdi *et al.*, 2025)**.

Situated on the coastal plain of Annaba, the Mekhada marshes constitute one of North Africa's largest freshwater-to-brackish wetland complexes and have been recognized under the Ramsar Convention since 2003 **(Samraoui & Samraoui, 2008)**. Positioned along a major migration corridor, the site plays multiple roles, serving as a resting area, overwintering habitat and post-breeding refuge for both mudflat-feeding shorebirds (Charadriiformes) and various gulls and terns (Laridae) **(Soltani *et al.*, 2023)**.

The ecological heterogeneity of the Mekhada wetland, ranging from estuarine zones that moderate salinity, to extensive reed beds, underpins its capacity to sustain diverse bird assemblages throughout the year. Despite its recognized importance, comprehensive assessments of its avian biodiversity are limited **(Aissaoui & Bara, 2024)**.

The role of Mekhada as a critical seasonal refuge is particularly evident during winter, when large waterbird congregations depend on its resources, and again in the breeding season, when different species exploit its varied habitats **(Rogers & Breen, 1990; Davis *et al.*, 2025)**. This turnover reflects a complex interplay between habitat structure, resource availability and migratory behavior **(Tallei *et al.*, 2021)**. Mekhada marsh shows stable physico-chemical conditions across space and time, with seasonal temperature increases driving higher macroinvertebrate abundance and underscoring the importance of monitoring this key variable in ecological assessments **(Saoudi *et al.*, 2018)**. Unfortunately, the Mekhada marsh waters also face severe organic and bacteriological pollution from natural and human sources, posing a serious ecological threat and necessitating regular monitoring alongside effective control measures **(Amoura *et al.*, 2019)**.

In the face of climate change, habitat loss and mounting anthropogenic pressures, such as intensified water extraction, reed-bed management and planned hydrological modifications, understanding the spatiotemporal dynamics of bird communities at Mekhada is essential for effective conservation **(Ramírez *et al.*, 2018)**. To date, existing research has been limited to a single focused study, which examined shorebird use during one autumn–spring cycle **(Soltani *et al.*, 2023)**, leaving gaps in our understanding of the seasonal dynamics of other key groups, particularly the Laridae.

This study therefore aimed to evaluate the avian biodiversity of the Mekhada site with a focus on seasonal variations across habitat types. Specifically, it will (i) compile a comprehensive seasonal inventory of gulls and terns; (ii) revisit existing temporal patterns for shorebirds in light of new data, and (iii) investigate relationships among bird abundance, habitat availability and disturbance factors. By analyzing these dynamics and identifying key habitat associations, we seeked to clarify Mekhada's functional role within the regional network of Mediterranean wetlands, thereby informing its conservation prioritisation.

MATERIALS AND METHODS

Study area

The Mekhada marsh is a temporary Mediterranean wetland, forming part of the El Kala wetlands complex. It lies in the sublittoral plain of Ben-M'hidi, approximately 20km east of the city of Annaba (36.774° N, 08.0192° E) (Fig. 1). To the North, the marsh is bounded by a coastal dune cordon; to the East by the Lac des Oiseaux agro-pastoral plain; to the South by the eastern Numidian foothills; and to the West by the Bounamoussa River, which traverses the Ben-M'hidi plain **(DGF, 2019)**.

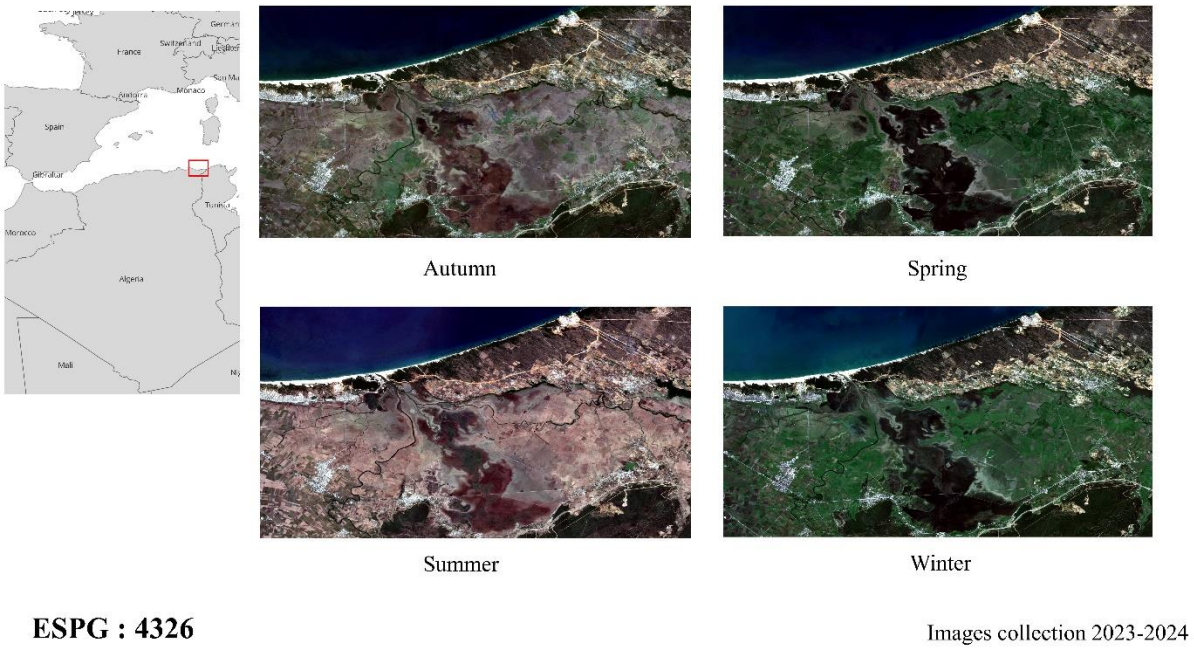

Fig. 1. Localization and spatial seasonal variation of the Mekhada marsh

Seasonal fluctuations in precipitation and temperature drive changes in the marsh's surface area and water depth. During winter, the flooded area averages 3,500 ha, rising to over 8,000ha during peak inundation. Water depth generally remains shallow (≈ 0.8m), except in a permanently flooded northern sector covering about 150 ha, where depths reach 1– 1.5m. This deep zone is likely sustained by the underlying dune aquifer. In summer, low rainfall and high evaporation cause progressive desiccation from May onward, with only the northern pool retaining water until October. This residual wetland becomes a critical refuge for many breeding bird species **(Morgan, 1982)**.

The marsh occupies the center of the Mafragh depression, filled by alluvial and colluvial deposits. It serves as a confluence point for the El Kebir-Est and Bounamoussa rivers, with a smaller contribution from the Bouhalala River to the Northwest. Direct rainfall also contributes to the marsh's water budget. The El Kebir River originates in the Tunisian highlands and is reinforced by its major tributary, the Bougous River, while the Bounamoussa River drains the western Mafragh catchment **(de Bélair, 1990)**.

Field surveys

From January through December, field surveys were conducted twice monthly, yielding 24 visits per year. Each outing took place between 08:00 and 16:00 under favorable weather conditions. At selected fixed observation points, waterbird populations were counted using a spotting scope.

For small flocks (fewer than 200 individuals) positioned within 200m of the observer, individuals were counted directly. For larger or more distant groups, estimates were derived using the visual block method **(Blondel, 1975; Tamisier & Dehorter, 1999)**. This technique, widely applied in winter waterbird censuses, carries an average error margin of 5–10%, depending on observer expertise, optical equipment quality, and habitat characteristics such as riparian vegetation density and helophyte height **(Lamotte & Bourlière, 1969)**. In our sampling, we surveyed four distinct habitat types: (1) estuarine areas, located at the interface between river mouths and the sea, influenced by both freshwater and tidal flows; (2) flooded meadows, low-lying grasslands that become seasonally inundated and provide feeding grounds for many waterbirds; (3) temporary wetlands, shallow water bodies that appear after rainfall or seasonal flooding and often dry out during summer; and (4) mudflats, exposed sedimentary areas created by fluctuating water levels, which serve as important foraging sites for waders and other shorebirds. All observations were conducted by a single observer to minimize observer bias, and counts were recorded on standardized data sheets for subsequent analysis.

Data analysis

Seasonal differences in total abundance were examined with the non-parametric Kruskal–Wallis. When significant differences were detected, post-hoc pairwise comparisons were performed using Dunn's test **(Dunn, 1964)** with Bonferroni correction for multiple comparisons. To explore community composition, the relationships between species, habitat type, and season, and to visualize multivariate patterns, we performed a non-metric multidimensional scaling (NMDS) ordination using the metaMDS function from the R package vegan **(Oksanen *et al.*, 2025)**, based on Bray–Curtis dissimilarities derived from the abundance matrix. All figures were produced with the R package ggplot2, and all statistical analyses were conducted in R version 4.4.3 **(R Core Team, 2024)**.

RESULTS

The total abundance of waterbirds exhibited a pronounced seasonal pattern (Table 1 & Fig. 2). A Kruskal–Wallis test confirmed significant differences among seasons ($H= 9.15$, $df= 3$, $P< 0.05$). Post-hoc pairwise comparisons using Dunn's test revealed significant differences between summer and winter ($Z= 2.83$, $P< 0.01$), with winter showing the highest bird abundances. Winter months accounted for the highest counts, peaking in January (n= 3 207), followed by December (n= 2 651) and November (n= 2 601). In contrast, the summer period from June to August recorded minimal numbers, with fewer than 100 individuals per month.

Table 1. Seasonal abundance of waterbirds

Season	Winter (Dec–Feb)	Spring (Mar–May)	Summer (Jun–Aug)	Autumn (Sep–Nov)
Total count (n)	8 459	1 100	283	5 946

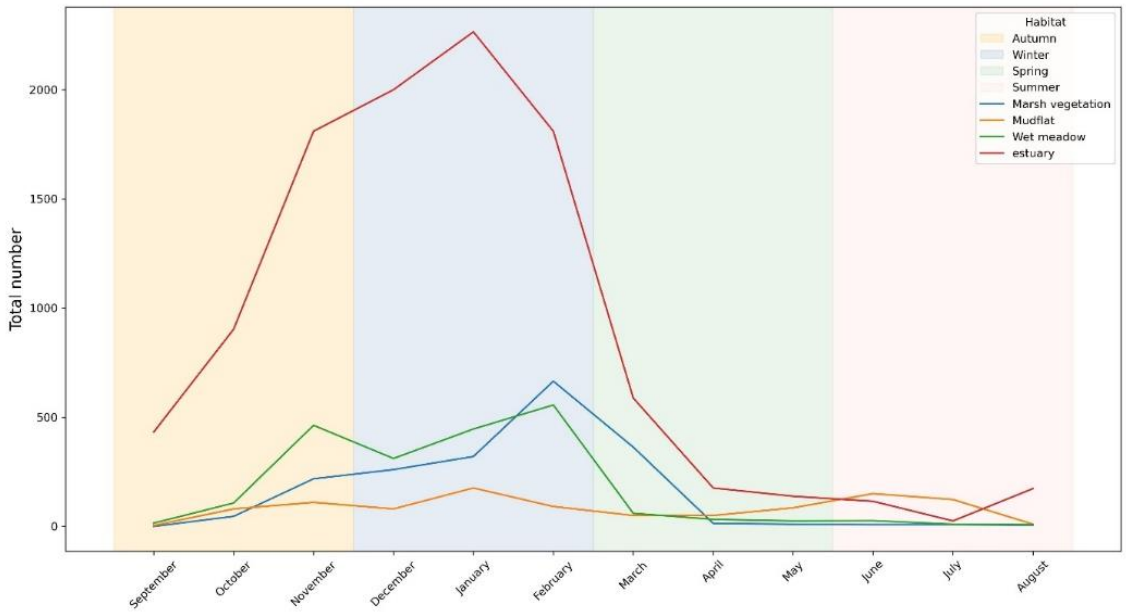

Fig. 2. Seasonal dynamics of waterbird total abundance by habitat type

Habitat-specific analyses revealed distinct roles for each habitat in winter aggregation and overall seasonal use (Table 2 and Figure 3). Estuarine areas supported the largest winter flocks, with a peak of 6 075 individuals. Flooded meadows and temporary wetlands reached a maximum of 1 204 in January and 983 in December, respectively. Mudflats peaked at 347 individuals in January, while inundated meadows of *Limosa limosa* recorded a more modest maximum of 120 in December. The marginal zone maintained consistently low presence (< 30 individuals) year-round.

Table 2. Peak abundance by habitat type

Habitat	Peak count (n)	Month	Season
Estuary	6 075	January	Winter
Flooded meadow	1 204	January	Winter
Temporary wetlands	983	December	Winter
Mudflats	347	January	Winter
Inundated meadows (*Limosa limosa*)	120	December	Winter
Marginal zone	< 30	Year-round	Low

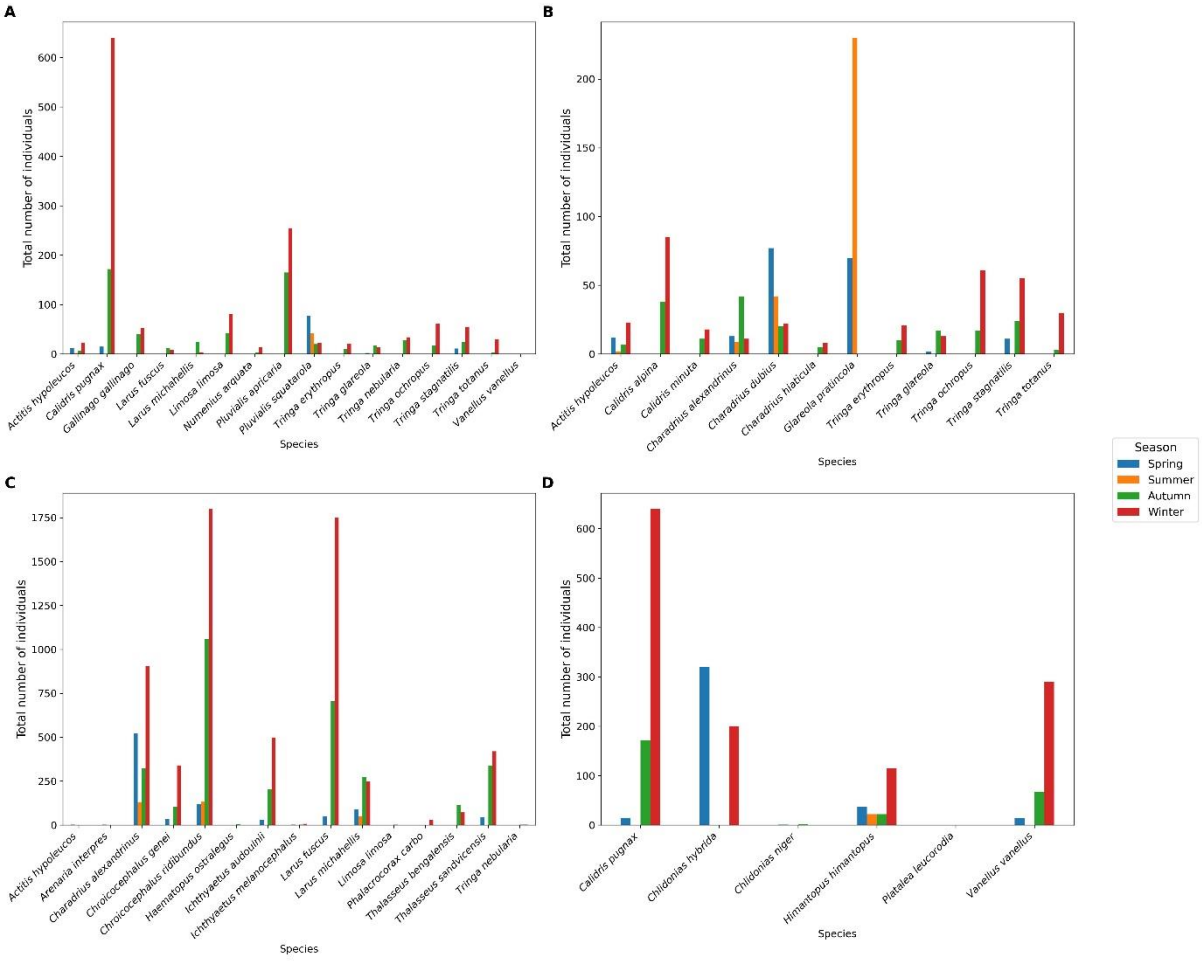

Fig. 3. Seasonal abundance of waterbird species across habitats

Non-metric multidimensional scaling (NMDS; stress = 0.044) of community composition identified four functional clusters corresponding to habitat–season combinations. Vegetated marshes exhibited bimodal peaks in February-March and October, driven by *Chlidonias* spp. and *Vanellus vanellus*, with additional summer presence of *Himantopus himantopus*. Estuarine habitats were characterized by winter dominance of Laridae and other coastal species (e.g., *Larus fuscus*, *Thalasseus sandvicensis*). Mudflats displayed two seasonal pulses (April-August and December-February), reflecting succession from small sandpipers (*Calidris*, *Tringa*) to species such as *Glareola pratincola* and *Charadrius dubius*. Flooded meadows supported both large waders and summer waders in a bimodal pattern (November-March and June-July) (Figure 4).

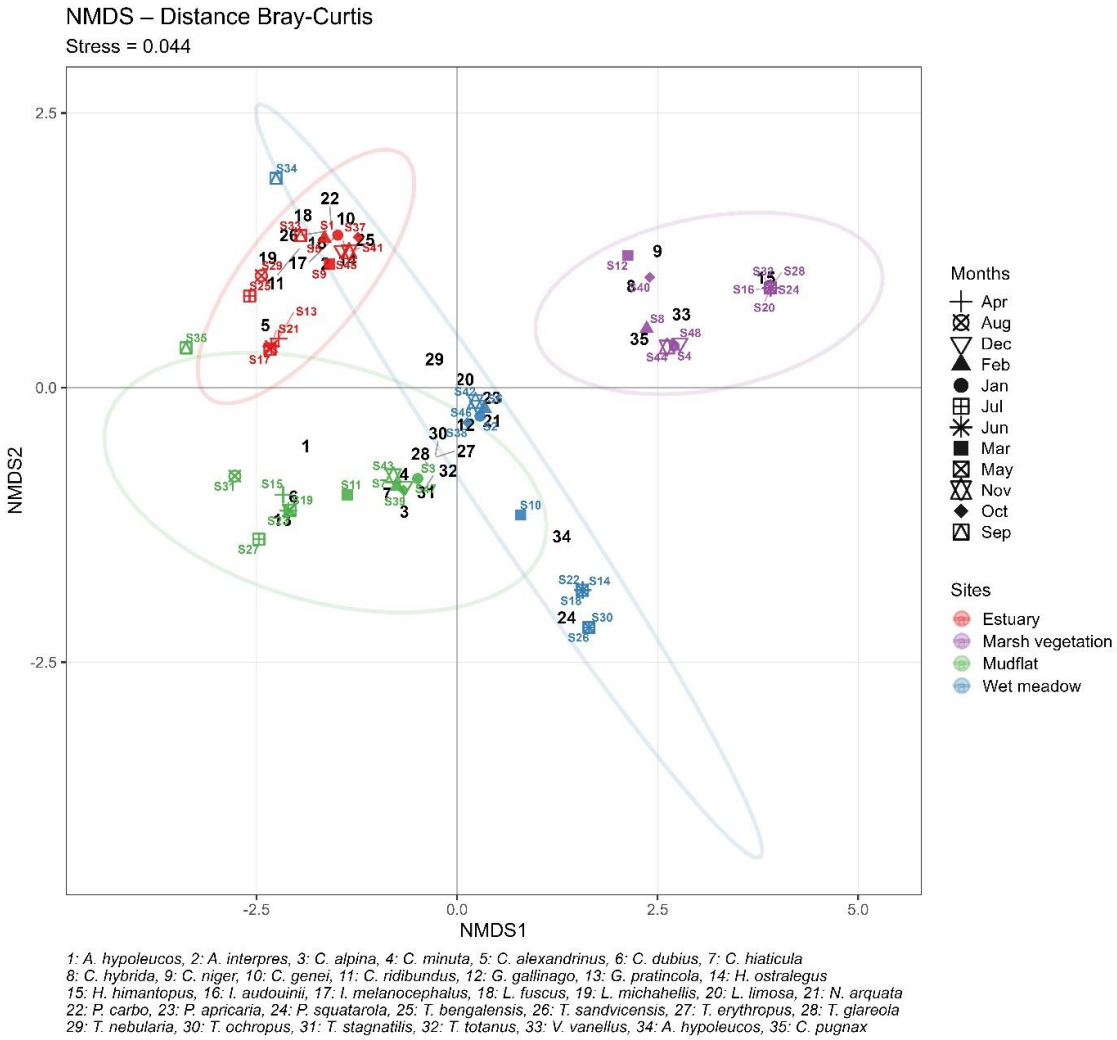

Fig. 4. NMDS ordination of waterbird communities across habitats and seasons

DISCUSSION

The findings of this study highlight the Mekhada marsh as a key ecological stronghold for waterbirds in the southern Mediterranean. This importance is situated within the broader context of global wetland decline, where ecosystems are increasingly degraded by anthropogenic pressure, hydrological changes, and climate variability **(Soltani *et al.*, 2023; Qiu *et al.*, 2024)**. As one of the most intact wetland systems in northeastern Algeria, Mekhada contributes significantly to biodiversity conservation at local, regional, and flyway scales, particularly through its functional role in the East Atlantic Flyway **(Van Dijk & Ledant, 1983; Samraoui & Samraoui, 2008)**.

Our results confirm strong seasonal variations in avian abundance, with winter emerging as the critical period for bird presence. Peak counts exceeding 3,000 individuals in January, and consistently high numbers throughout the winter months, echo regional observations across Mediterranean wetlands **(Sayoud *et al.*, 2017)**. These seasonal

fluctuations reflect the site's dual role as a stopover and wintering refuge, where habitat availability aligns with the energetic and ecological needs of long-distance migrants **(Rogers & Breen, 1990; Davis *et al.*, 2025)**.

The winter concentration of *Chroicocephalus ridibundus* (1,800 individuals) and *Limosa limosa* (120 individuals) supports previous findings that underscore the importance of high-quality wintering habitats for survival and subsequent breeding success **(Morrison *et al.*, 2007)**. The wet meadows and temporary wetlands, which hosted the majority of these individuals, appear to provide essential soft-soil feeding grounds and shelter, particularly in the Mediterranean climate where seasonal drying can constrain habitat use **(Ramírez *et al.*, 2018)**.

The estuarine habitat stood out as the most productive and temporally stable ecosystem, hosting over 6,000 individuals in winter, dominated by larids such as *Chroicocephalus ridibundus* and *Larus fuscus*. This reflects the increasing ability of generalist species to exploit both natural and anthropogenic marine resources **(Gall & Thompson, 2015)**. This pattern is consistent with broader trends in gull adaptability **(Rodewald & Brittingham, 2004)**.

A striking pattern of seasonal succession was observed in the mudflats, where a winter assemblage of Palearctic shorebirds, including *Calidris alpina* and *Tringa ochropus*, was replaced in summer by Afro-tropical species such as *Glareola pratincola*. This turnover aligns with the flyway concept, where different migratory populations exploit shared habitats sequentially **(Piersma & Lindström, 2004)**, and suggests the site's additional role as a breeding or prolonged stopover location for sub-Saharan species **(Cramp & Simmons, 1983)**.

Similarly, the bi-modal usage of wet meadows-hosting species like *Limosa limosa*, *Tringa ochropus*, and *Gallinago gallinago* in winter, contrasts with near absence during summer, reflecting habitat desiccation and food resource scarcity. This raises concerns under intensifying drought conditions, although artificial wetlands may buffer these impacts **(Benton *et al.*, 2003; Mitsch & Gosselink, 2015; Ferrarini *et al.*, 2024; Wang *et al.*, 2025)**.

The habitat-based variation in community structure suggests that tailored conservation strategies are required. The estuarine zone, which supports 71.8% of total winter abundance, deserves priority protection, particularly for *Charadrius alexandrinus*, whose spring breeding aligns with substrate-specific nesting needs **(Page *et al.*, 2009)**. In this context, minimizing disturbance during the breeding period (March to July) and regulating tourism are critical interventions.

For the mudflats, conservation should embrace their dual seasonal role. Hydrological regimes that simulate natural flood pulses such as those used successfully in the Guadalquivir Delta **(Sutherland *et al.*, 2012)** could maintain habitat quality and resource availability across seasons.

Despite low overall abundance in the fourth habitat type (<30 individuals per species), its role as a buffer or ecological corridor should not be underestimated. Connectivity between habitat patches, including marginal zones, is essential for sustaining metapopulations and enabling seasonal movements **(Murray *et al.*, 2014)**.

Climate change poses multifaceted threats to the functionality of the Mekhada wetland. Earlier arrival of spring migrants in the Mediterranean has been well documented **(Both *et al.*, 2010; Leberger *et al.*, 2020)**, increasing the likelihood of phenological mismatches between resource availability and species' energetic needs. Long-distance migrants such as *Limosa limosa*, already vulnerable during trans-Saharan journeys, may be particularly at risk **(Newton, 2008)**.

Furthermore, the estuarine zones-supporting the densest wintering populations are especially sensitive to sea-level rise and increasing human encroachment, including agricultural intensification **(Sutherland *et al.*, 2012)**. The combined effect of habitat compression and resource depletion could severely impact waterbird survival if unmitigated.

The patterns observed in Mekhada align with regional findings from the Mediterranean Waterbirds Network **(Wetlands International, 2018)**, underscoring its qualification as a Ramsar site of international importance. Notably, the site's winter bird densities are comparable to other protected Mediterranean wetlands, reinforcing its conservation priority.

Adaptive management approaches, like those applied in the Camargue **(Mesleard *et al.*, 1995)**, offer viable solutions. Strategies should include seasonal water level regulation, preservation of microhabitat diversity, and local community engagement, as demonstrated in participatory models elsewhere **(Elphick, 2000)**. Despite Ramsar designation, many Mediterranean wetlands still lack effective management frameworks, making the development of a comprehensive plan for these wetlands both timely and necessary **(Wetlands International, 2018)**. To this end, even though Mekhada Marsh is a protected wetland, it is embedded within a disturbed landscape where human activities can still significantly affect bird behaviour, potentially reducing habitat quality and carrying capacity **(Halassi *et al.*, 2022)**.

The strong fit of the NMDS analysis (stress = 0.044) confirms the robustness of the observed spatial-temporal structuring of the avian community. This aligns with the principles of ecological niche theory **(Hutchinson, 1957)**, where species coexistence is facilitated by niche segregation in both space and time **(Berlusconi *et al.*, 2025)**. Temporal niche partitioning was evident across all habitat types, supporting coexistence through staggered use of shared resources.

For example, the estuarine habitat hosts a rich wintering assemblage dominated by larids and coastal specialists, benefiting from sheltered marine conditions and food availability. This stability reflects strong winter site fidelity, crucial for migratory species' survival and conservation.

In contrast, the mudflats exemplify multifunctional use, shifting from benthic foraging by *Tringa* and *Calidris* in winter to Afro-tropical breeders in summer. This seasonal resource cycling enhances spatial efficiency and reduces interspecific competition **(Mitsch & Gosselink, 2015, Ferrarini *et al.*, 2024)**.

Wet meadows and marsh vegetation further illustrate the importance of transitional habitats in maintaining ecological connectivity and supporting niche diversity. Seasonal rotations in species composition and usage indicate specialized reproductive and foraging strategies, including the summer-exclusive use of marshes by *Himantopus himantopus* for nesting. While our findings provide valuable insight into the seasonal dynamics of Mekhara's waterfowl communities, future research will benefit from increased surveillance methods to capture the complete complexity of this ecosystem. During the important migration period, more intensive sampling may uncover additional patterns in the business and resource use of species, while systematic assessment of human disturbance effects will determine the ratio of anthropological pressure and bird behavior observed in other North African wetlands **(Halassi *et al.*, 2022)**. Complementary studies focusing on food resource availability, breeding productivity, and detailed behavioral ecology would further strengthen our understanding of habitat quality and carrying capacity. Such comprehensive approaches would provide managers with more precise tools for adaptive conservation strategies and help predict how Mekhada's avian communities might respond to future environmental changes.

CONCLUSION

The Mekhada marsh emerges from this study as a seasonally dynamic and ecologically significant wetland supporting diverse waterbird assemblages throughout the year. Winter represents the most critical period, with peak abundances centered in

estuarine and flooded meadow habitats, confirming the site's importance as both a migratory stopover and a wintering refuge within the east atlantic flyway. The temporal turnover of species, especially in mudflat and marsh habitats, reflects a high degree of ecological complementarity and niche partitioning, enabling the coexistence of Palearctic migrants and afro-tropical breeders.

The observed patterns reveal a strong dependence of waterbirds on specific habitat types whose availability fluctuates seasonally. estuarine zones, in particular, contribute disproportionately to total abundance and should be prioritized in conservation efforts. Wet meadows and temporary wetlands also provide essential resources for waders and larids, although they are vulnerable to seasonal drying and climate variability.

Given the growing pressures of hydrological modification, habitat fragmentation, and climate change, the need for targeted, adaptive management is urgent. Strategies should focus on maintaining water level regimes that mimic natural hydrological cycles, preserving habitat heterogeneity, and minimizing disturbance during sensitive breeding and wintering periods. Furthermore, recognizing the role of marginal zones in enhancing landscape connectivity can improve resilience across the wetland complex.

Overall, the findings strengthen the case for Mekhada's inclusion among priority conservation sites in the Mediterranean Basin and highlight the broader implications for managing wetlands under changing environmental conditions.

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