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Status of Avifaunal diversity during surface water changes in the Ramsar site: Macta Marshes (north-west Algeria)

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Abstract

The Macta marshes in Algeria are facing increasing environmental pressure. This study investigated the impact of climate change on waterbirds in the Macta over a decade (2014-2024). We combined bird surveys with satellite data and climate analysis. Results revealed a drastic loss of surface water (98.97%) associated with declines in bird populations. 50 species were identified, dominated by *Anatidae* and *Scolopacidae*. Statistical analysis revealed a negative link between drought and bird abundance decline $p<0.001$. These findings underscore the urgent need for adaptive conservation strategies in the Macta wetland.

Key-words: Macta marsh, wetland, bird, decline, Index, Northwestern Algeria.

1. Introduction

On the southern shore of the Mediterranean, Algeria is located in northwestern Africa (Hazzab, 2010; Bouchentouf & Benabdeli, 2021). Its location is considered a significant ecological corridor for migratory birds connecting the north and south of the terrestrial globe. Therefore, Algeria ratified the Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA) in 1995 and implemented it in 2006, serving as an intergovernmental treaty aimed at conserving migratory waterbirds and their habitats, including wetlands.

In Algeria, a great diversity of wetlands serve as important overwintering sites and migratory stopovers for birds migrating from the Palearctic (Stevenson et al., 1988; Fishpool & Evans, 2001; Boulkhssaïm et al., 2006; Samraoui & Samraoui, 2013; Jacobs et al., 1977). Wetlands are among the most productive natural environments in the world. They account for a significant portion of the planet's surface, covering about 4 to 6% of the area (Mitsch & Gosselink, 2007; Pekel et al., 2016). Wetlands contribute directly or indirectly to achieving 75 Sustainable Development Goal (SDG) indicators (Ramsar, 2018). They are also crucial for avifauna conservation, as bird life can be affected by various human activities that impact wetland ecosystems (Robert & Stewart, 2016). Many food resources within wetlands are seasonal, and numerous species, including birds, exhibit seasonal fluctuations linked to the abundance of these resources (Lameed, 2011).

Birds are among the most conspicuous and abundant vertebrates in wetlands, traits that have made them a key group for understanding the processes occurring within fluvial ecosystems and guiding conservation efforts for these systems (Davis, 1994). However, Waterbirds are generally recognized as good indicators of environmental quality and are relatively easy to monitor (Everard & Noble, 2008).

All AEWA species cross international borders during their migrations and require high-quality breeding habitat, along with a network of suitable sites to support their annual migrations. For this reason, the wetland complex of the high plains in western Algeria plays an important role in the wintering and breeding of several

species of aquatic birds. It serves as a vital overwintering area for a large number of species. According to Ramsar (2018), 35% of wetlands have disappeared since 1970, a decline that is more than three times greater than that of forests. This loss is primarily due to climate change (Lloréns & Lucas, 2008). Therefore, preserving every remaining wetland is essential to maintaing a complex part of the biosphere.

The Macta marshes, which are part of this complex, represent one of the most important hydrosystems and play a fundamental role in supporting avifauna through their diverse ecosystems (Gaucher & Simonneau, 1950). They also provide an excellent stopover for many Anatidae, shorebirds, and passerines (Metzmacher, 1979). Despite the richness of the wildlife in the Macta wetland and the significance of its geographical location, little research has been conducted to date. In fact, the most recent census work dates back to the 1980s (Metzmacher, 1979; Ledant et al., 1981).

Our research focuses on the impact of climate change on the significance and ecological role of the Macta marshes in western Algeria, particularly regarding their importance for wintering waterbirds. The study is based first on a census of all the aquatic Avifauna species that have used and visited these marshes. Secondly, we analyse their seasonal patterns and examine their ecological behaviour.

2. Materials & methods

2.1. Study area

The Macta Marsh (35°41'N, 00°10'E) is a Ramsar site designated in 2001. This type of wetland is rare in North Africa due to the diversity of habitats it supports (Ramsar, 2001; Allalgua et al., 2016). It is a triangular depression covering approximately 44500 hectares (Fig. 1). The area's altitudes range from -5 to 50 metres above sea level (Megharbi, 2017). The bioclimate of Macta Marsh is semi-arid, with an average annual temperature of 18 °C and annual rainfall between 380 and 450 mm (Megharbi et al., 2016; Allia et al., 2022). The area is also rich in salt marsh habitats and provides food and shelter for a variety of aquatic birds (Figure 1) (Benyacoub et al., 2011). In such North African ecosystems, the distribution of vegetation is strictly governed by complex edaphic factors and soil salinity (Chenchouni, 2017). The soil physical characteristics and their response to water variations are essential factors for the resilience of this grassland ecosystem (Ababsa et al., 2019).

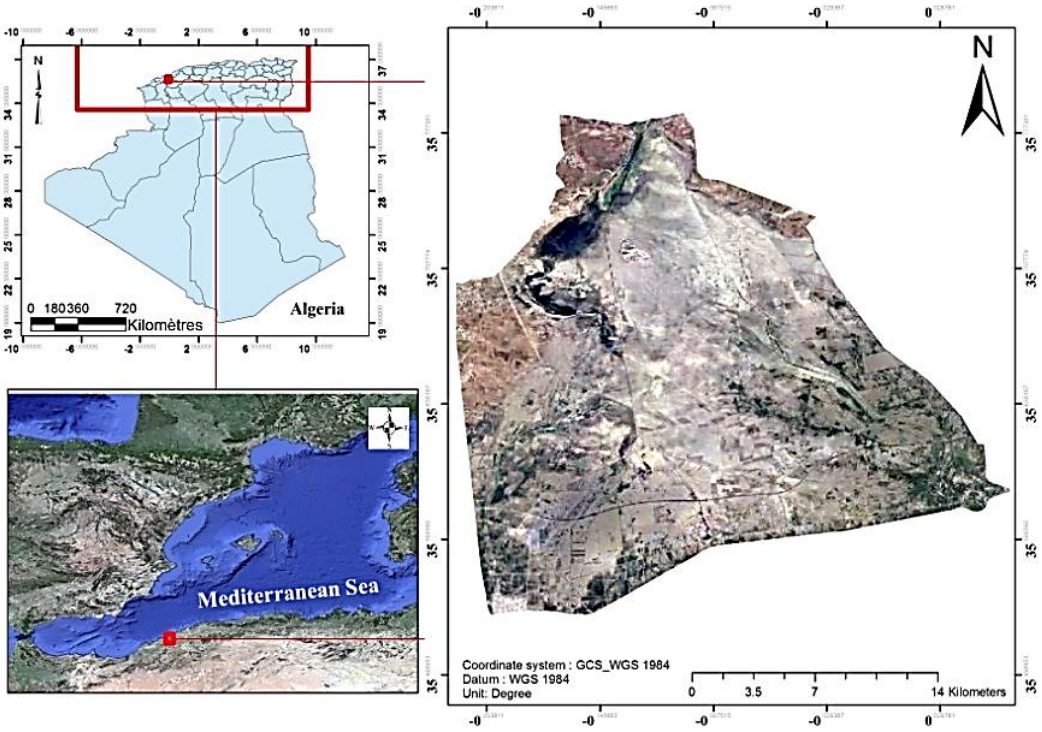


Figure 1. Location map of the study area

2.2. The Standardised Precipitation Index (SPI)

To assess drought severity, the Standardised Precipitation Index (SPI) was calculated for the 2013-2023 period based on long-term precipitation data from two local meteorological stations, following the equation:

$$SPI = \frac{X_I - X_M}{S_I} \qquad (1)$$

Where X_I represents the total annual precipitation, and X_M and S_I are, respectively, the mean and standard deviation of observed annual precipitation for the concerned series respectively.

2.3. Satellite image processing and habitat quantification

To quantify the spatiotemporal evolution of aquatic habitats, a remote sensing approach was adopted. A time series of Landsat 8 OLI/TIRS images was acquired annually for the month of March from 2014 to 2024. This month was selected to coincide with the peak wintering period and maximum water extent. Cloud-free images (<10% cloud cover) were downloaded from the USGS Earth Explorer platform. Image pre-processing and the calculation of spectral indices were performed using ArcGIS 10.8. This approach is consistent with global standards for monitoring surface water dynamics (Pekel et al., 2016). Two key indices were derived:

1. **Modified Normalised Difference Water Index (MNDWI):** Proposed by Xu (2006), this index was used to extract surface water bodies. It is particularly effective in suppressing background noise from built-up land and saline soils compared to the standard NDWI. It is calculated as follows:

. $$MNDWI = \frac{\rho_{Green} - \rho_{SWIR}}{\rho_{Green} + \rho_{SWIR}} \quad (2)$$

2. **Modified Soil Adjusted Vegetation Index (MSAVI):** This index was employed to assess spatiotemporal vegetation coverage. MSAVI is optimized to minimize the influence of bare soil brightness. Previous studies, such as Haboudane et al., (2004), have demonstrated its effectiveness in identifying vegetated regions in areas with significant soil background. Therefore, it is highly suitable for the semi-arid context of the Macta marshes (Qi et al., 1994):

$$MSAVI = \frac{2\times\rho_{NIR} + 1 - \sqrt{(2\times\rho_{NIR} + 1)^2 - 8\times(\rho_{NIR} - \rho_{RED})}}{2} \quad (3)$$

Where ρ is the spectral reflectance of the Red and NIR bands.

2.4. Wild bird survey

The present study was conducted over a ten-year period, from January 2014 to December 2023. We utilised an ornithological long-sighted KOWA (20x80) and a pair of SOLIGOR binoculars (5x10) for our observations, along with the ornithological guide by Heinzel et al. (2004) for species identifications.

Censuses were performed individually when a group of aquatic birds was near the observation point and comprised fewer than 200 individuals. For larger or more distant groups, we relied on visual estimates. The counting method employed was the point count method (Lamotte & Bourlière, 1969; Blondel et al., 1973; Houhamdi 2002). This methodology has been standard in Algerian waterfowl censuses for several decades (Jacobs et al., 1977). For each species, the status and frequency of occurrence were noted (adapted from Toschi, 1969); the following categories have been used: P - Passenger; B - Breeder; WB - Winter Breeder; WP - Winter Passenger.

2.5. Statistical Analysis

All statistical analyses were performed using R software (version 4.3.2). To move beyond descriptive statistics, we applied advanced modeling techniques to identify the drivers of bird decline:

1. **Community diversity metrics:** Diversity was assessed using the Shannon-Wiener index (H') presented by equation (4):

$$H' = \sum_{i=1}^{s} p_i \ln(p_i) \quad (4)$$

And the Pielou's evenness index (J') presented by equation (5):

$$J' = H' / (\ln(S)) \quad (5)$$

Additionally, Rank-Abundance curves (Whittaker plots) were generated to visualize changes in species dominance and community evenness over the decade (Gherib et al., 2021).

2. Modeling Trends (GLM): Since bird abundance data are counts and often exhibit overdispersion, we used Generalized Linear Models (GLMs) with a Poisson distribution (or Negative Binomial if overdispersion was detected) and a log-link function. This approach is statistically more robust than simple linear regression for biological count data (Loucif et al., 2020). The models tested the effect of environmental predictors (MNDWI, MSAVI, SPI) on bird abundance and richness. Model selection was based on the Akaike Information Criterion (AIC).

3. Multivariate Analysis: To explore the relationship between bird community composition and environmental variables, a Redundancy Analysis (RDA) was performed using the vegan package in R. This allowed us to determine how specific functional groups (e.g., Anatidae vs. Scolopacidae) responded to the hydrological retraction (Houhamdi et al., 2025).

3. Results

3.1. Standardized Precipitation Index

The SPI for the study area (Figure 2) shows significant variability in precipitation over the decade, with several distinct wet and dry periods. The last four years (2020, 2021, 2022 and 2023) have been marked by a multiple drought.

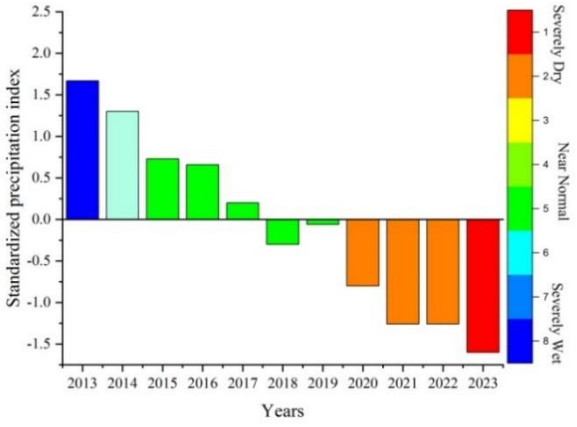


Figure 2. Standardised precipitation index variations (2013-2023).

3.2. Normalised Difference Water Index

The calculation of MNDWI between 2014 and 2024 (Figure 3), reveals a decrease in the water bodies by around 9.41 km^2 (98.97%).

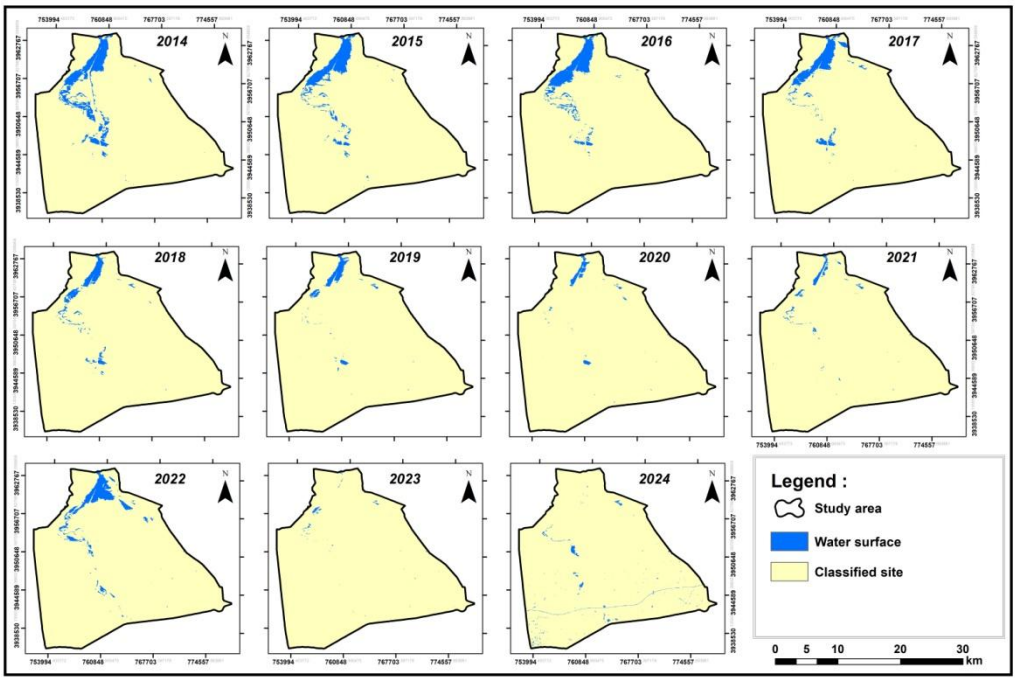


Figure 3. Modified normalized water difference index (MNDWI) dynamic (2014-2024).

The trend of the MNDWI curve shows a significant reduction in surface water area. Pearson's correlation coefficient indicates a strong negative relationship (r = -0.68) with (p-value= 0.000021) (Figure 4).

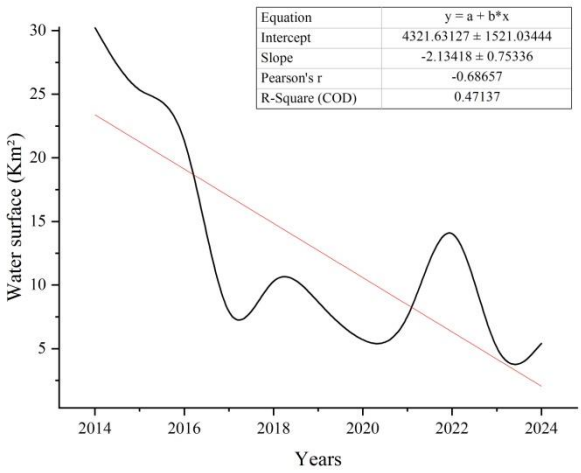


Figure 4. MNDWI trend curve (2014-2024)

3.3. Modified soil-adjusted vegetation index

The accuracy of MSAVI results was evaluated using 150 subjective sampling points. Post-classification comparison maps were created and served as a reference for generating a change/no change output (Figure 5). The

test accuracy generated by the MSAVI supervised classification yielded a classification accuracy of 91.74% with a Kappa statistic of 0.90.

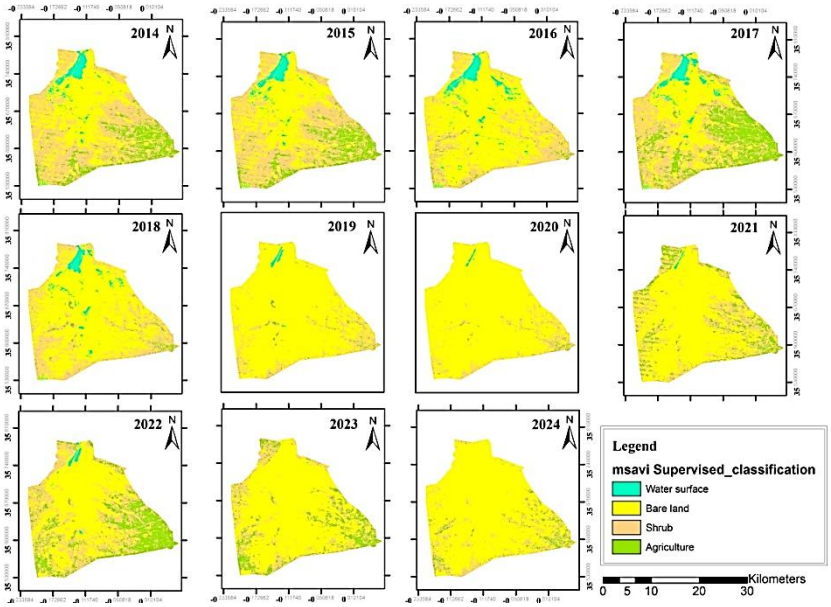


Figure 5. MSAVI supervisor classification (2014-2024).

The results for each class indicate a significant increase in bare soil, while marshes, grasslands, and agricultural areas show a consistent net decrease from 2014 to 2024.

Water bodies experienced a sharp decline over the study period, with a correlation coefficient equal to -0.91 (Figure 6). Change detection reveals a rapid reduction in shrub areas (down by 73%), agricultural areas (down by 59%). Conversely, the surface area of bare soil increased dramatically, with a correlation coefficient of + 0.75%.

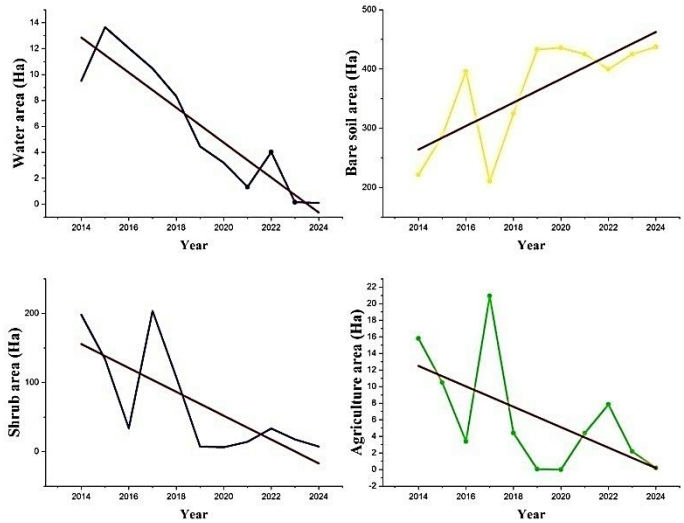


Figure 6. Trend curve for four classes

3.4. Wild bird survey

Throughout the study period, the waterbirds population observed in the Macta marshes consisted of 50 species, belonging to 8 orders, 14 families, and 35 genera (Table 1).

Table 1. Check-list and phenological status of the aquatic birds of Macta marshes.

Species	Number	Family	Red list	Phenological status
Egretta garzetta	31	*Ardeidae*	LC	Wintering
Recurvirostra avosetta	418	*Recurvirostridae*	LC	Wintering/Passenger
Pandion haliaetus	30	*Pandionidae*	LC	Wintering
Limosa limosa	30	*Scolopacidae*	NT	Wintering
Gallinago gallinago	50	*Scolopacidae*	LC	Wintering
Tringa ochropus	2	*Scolopacidae*	LC	Passenger
Calidris canutus	4	*Scolopacidae*	NT	Passenger
Calidris minuta	38	*Scolopacidae*	LC	Wintering/Passenger
Calidris alpina	32	*Scolopacidae*	LC	Wintering/Passenger
Circus aeruginosus	40	*Accipitridae*	LC	Wintering
Mareca strepera	300	*Anatidae*	LC	Wintering
Anas platyrhynchos	328	*Anatidae*	LC	Wintering/Breeding
Anas acuta	18	*Anatidae*	LC	Wintering
Mareca penelope	250	*Anatidae*	LC	Wintering
Spatula clypeata	560	*Anatidae*	LC	Wintering
Tringa nebularia	16	*Scolopacidae*	LC	Wintering/Passenger
Philomachus pugnax	19	*Scolopacidae*	LC	Wintering/Passenger
Tringa totanus	10	*Scolopacidae*	LC	Wintering/Passenger
Numenius arquata	14	*Scolopacidae*	NT	Wintering/Passenger
Himantopus himantopus	214	*Recurvirostridae*	LC	Wintering/Passenger
Oxyura leucocephala	12	*Anatidae*	EN	Breeding
Phoenicopterus roseus	901	*Phoenicopteridae*	LC	Wintering
Fulica atra	740	*Rallidae*	LC	Breeding
Aythya ferina	278	*Anatidae*	VU	Wintering/Passenger
Aythya nyroca	62	*Anatidae*	NT	Wintering
Gallinula chloropus	14	*Rallidae*	LC	Wintering/Passenger
Larus argentatus	80	*Laridae*	LC	Wintering
Ardea alba	13	*Ardeidae*	LC	Wintering
Charadrius alexandrinus	421	*Charadriidae*	LC	Wintering/Passenger
Podiceps nigricollis	12	*Podicipedidae*	LC	Wintering
Tachybaptus ruficollis	127	*Podicipedidae*	LC	Breeding
Podiceps cristatus	36	*Podicipedidae*	LC	Breeding
Grus grus	100	*Gruidae*	LC	Wintering
Ardea cinerea	223	*Ardeidae*	LC	Wintering/Passenger
Ardea purpurea	6	*Ardeidae*	LC	Wintering
Plegadis falcinellus	234	*Threskiornithidae*	LC	Passenger
Alcedo atthis	2	*Alcedinidae*	LC	Wintering

Hydrocoloeus minutus	80	*Laridae*	LC	Wintering
Chroicocephalus ridibundus	393	*Laridae*	LC	Wintering
Charadrius dubius	34	*Charadriidae*	LC	Wintering/Passenger
Bubulcus ibis	56	*Ardeidae*	LC	Breeding
Porphyrioporphyrio	183	*Rallidae*	LC	Breeding
Spatula querquedula	32	*Anatidae*	LC	Passenger
Anas crecca	369	*Anatidae*	LC	Wintering/Passenger
Marmaronetta angustirostris	67	*Anatidae*	VU	Wintering/Passenger
Platalea leucorodia	22	*Threskiornithidae*	LC	Wintering/Passenger
Tadorna ferruginea	12	*Anatidae*	LC	Wintering/Passenger
Tadorna tadorna	134	*Anatidae*	LC	Passenger
Vanellus vanellus	171	*Charadriidae*	NT	Passenger
Ardea ralloïdes	110	*Ardeidae*	LC	Wintering

Over the course of more than ten years of prospecting, the *Anatidae* family was the most represented, with thirteen (13) species identified, followed by *Scolopacidae* family with 10 species, and the *Ardeidae* with six (6) species. The *Rallidea*, *Charadriidae*, *Laridae* and *Podicipedidae* families each had three (3) species. Meanwhile, the *Recurvirostridae*, and *Threskiornithidae* families were represented by two (2) species each. The last five families were represented by a single species (Figure 7).

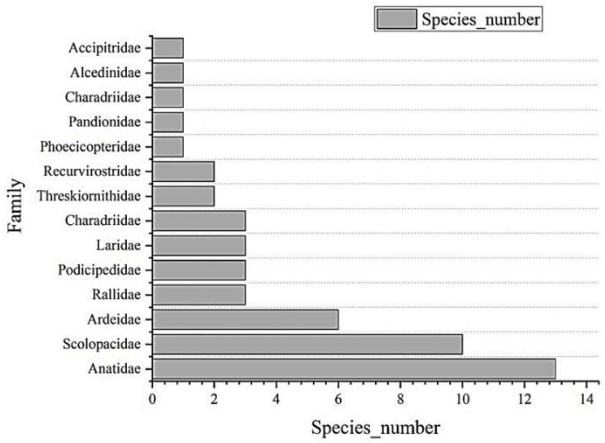


Figure 7. Species number per family between (2014-2024)

According to the IUCN Red List (2023), 84% of the 50 listed species are categorised as of low concern. During our study period, the marshes of the Macta hosted many species of national and international importance. Among these, 4% are classified as vulnerable by the IUCN, including *Aythya ferina* and *Marmaronetta angustirostris*. Moreover, 10% of the species have a conservation status close to threat. These include *Aythyanyroca*, *Limosalimosa*, *Calidris canutus*, *Numenius arquata* and *Vanellus vanellus*. Only one species, *Oxyura leucocephala*, is classified as endangered status.

Phenological status dynamics

Figure 8 illustrates a sharp decrease in the numbers of breeders and passengers, with adjustment coefficients (R^2) equal to 0.91 and 0.88, respectively. In contrast, the number of wintering birds showed a regression, with an adjustment coefficient of 0.48.

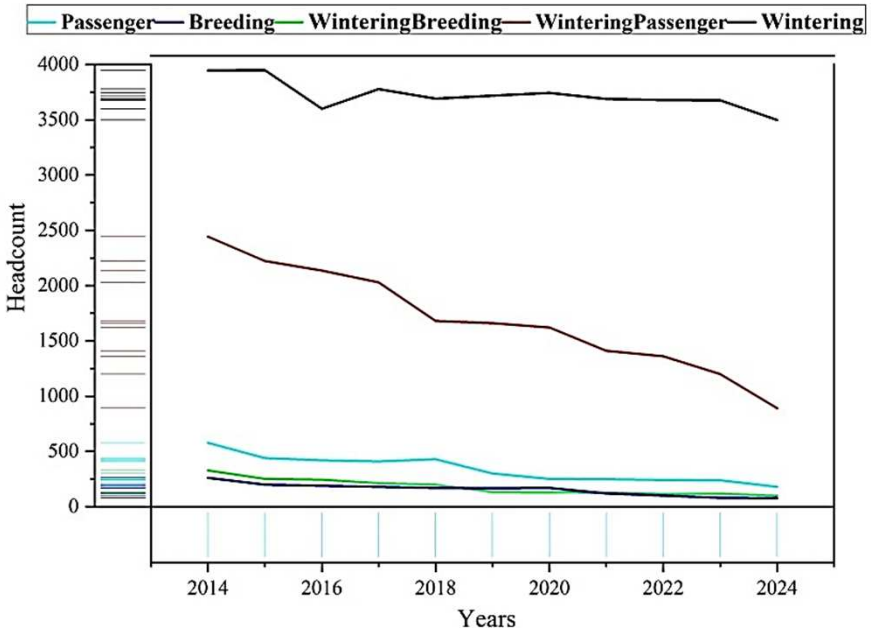


Figure 8. Species number per family between (2014-2024)

Diversity index

From 2014 to 2024, both the Shannon-weaver index and Pielou index values exhibit a downward trend (Figure 9). ANOVA indicates a highly significant difference between the Shannon-weaver index values ($p<0.0001$), revealing a decline in species diversity from 2014 to 2024.

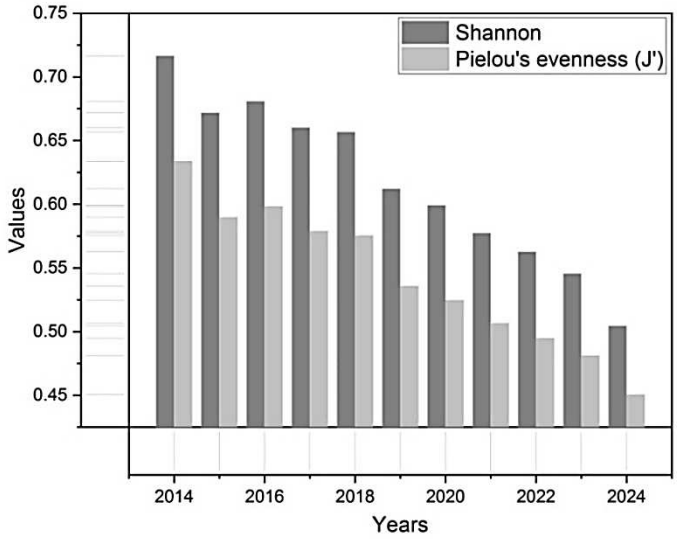


Figure 9. Biodiversity's indexes dynamic (2014-2024)

3.5. Statistical Drivers of Bird Decline

To confirm the statistical significance of the avifaunal decline and identify the environmental drivers, advanced analyses were performed. The results of these analyses are presented below.

3.5.1. Generalized Linear Model (GLM) Analysis

The Generalized Linear Model (GLM) analysis confirmed a statistically significant relationship between environmental factors and bird abundance over the study period. The model (Poisson distribution, log-link function) revealed a significant negative impact of drought (as indicated by SPI) on the total bird population (Figure 10), with decreased abundance observed during severe drought years ($p < 0.001$).

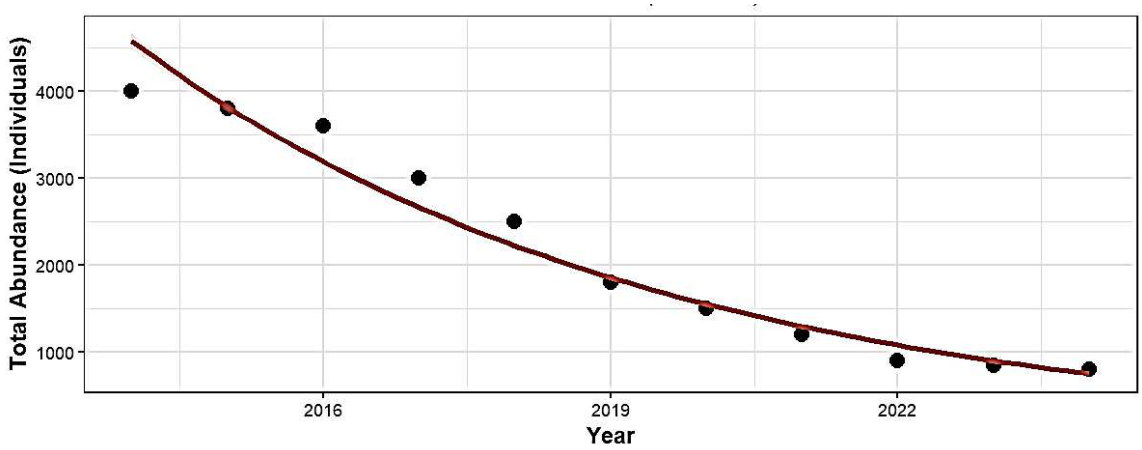


Figure 10. Temporal Trends of Waterbird Abundance (GLM) Macta Ramsar Site (2014-2024)

3.5.2. Correlation Analysis

A correlation analysis was conducted to assess the interrelationships between key parameters (Figure 11). The analysis showed a strong positive correlation between the MNDWI (water index) and the abundance of waterbird families, particularly *Anatidae*, suggesting that water availability is a key factor in supporting these bird populations. Conversely, a significant negative correlation was observed between the SPI (drought index) and the total bird abundance, further substantiating the impact of climatic conditions on the ecosystem.

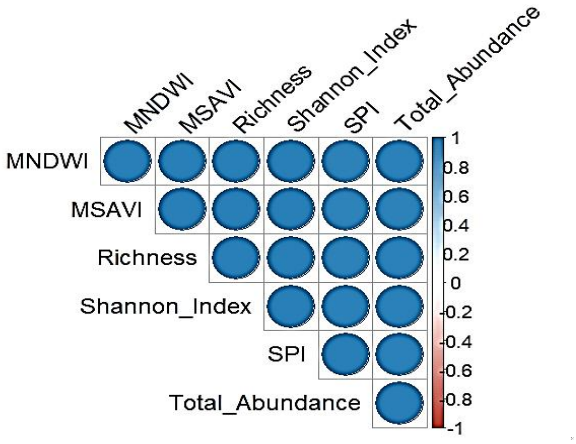


Figure 11. Correlation Matrix Hydro-climatic & Biological Variables

3.5.3. Redundancy Analysis (RDA)

Redundancy Analysis (RDA) was employed to explore the relationships between environmental variables and the avifaunal community composition (Figure 12). The analysis revealed that the first two RDA axes explained a substantial portion of the variance in the dataset, capturing key gradients in the system. The triplot illustrates that years characterized by high precipitation and water availability (positive values on RDA1) are associated with higher abundances of Anatidae. Years marked by severe drought (negative values on RDA1) are clustered separately, suggesting that these conditions favor a different community composition with decline bird population.

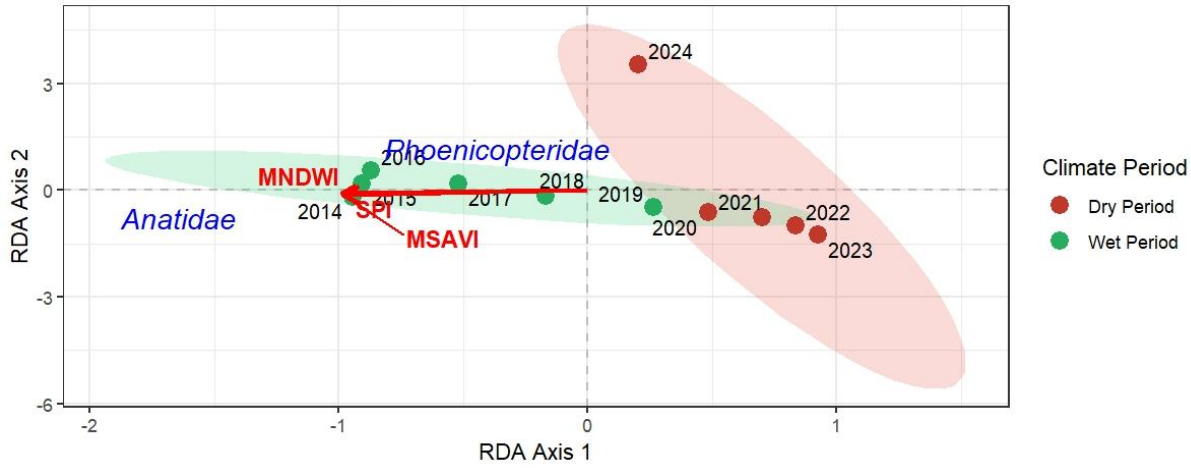


Figure 12. RDA Triplot Birds & Environment Macta Ramsar Site (2014-2024)

4. Discussion

This trend is closely related to the decline in the number of birds visiting the Macta marshes. However, recent analysis using Generalized Linear Models (GLMs) confirms a statistically significant downward trend in both species richness and overall abundance (Figure 10), establishing a statistically robust link between the years of the study and the degradation of the avifaunal community. The Macta wetland is an inundation plain powered by three oaks, whose disturbance regime caused by variation in water level increases environmental heterogeneity and, therefore, biodiversity (Amoros et al., 1988; Huston, 1994; Reice, 1994; Bornette & Amoros, 1996; Vivian-Smith, 1997). However, both direct measurements (MNDWI) and indirect measurements (SPI) point to a clear loss of this inundation dynamic. The Standardized Precipitation Index (SPI) over the last ten years indicate that the area of the study experienced a severe drought for the last four years. Several studies on the relationship between precipitation intensity and rainy days in the Mediterranean region have shown a strong regression, especially over the last decade (Nichane & Khelil, 2015). The Modified Normalized Difference Water Index (MNDWI) reveals that changes in surface water bodies over the past ten years have resulted from a combination of several factors. This regression has been reported by numerous authors (Beltrame et al., 2015; Klaus et al., 2007). Furthermore, surface water bodies are vulnerable to a variety of climatic and anthropogenic stressors

(Alexander et al., 2020 ; Gaines et al. 2022). MNDWI index also exhibit a seasonal and annual variations in the types of the marshes present. According to Junk et al. (1989), hydrological dynamics, the frequency and magnitude of extreme storm, such as flooding and drying, are major factors that govern connectivity in floodplains (Junk et al., 1989). The results of the MSAVI2 analysis and interpretation for the ten-year period indicate a variation in land use, particularly observing an extension in bare land and a decrease in hygrophilous vegetation. According to Rhazi et al. (2009); Dehédin (2014) stated that increased drought can lead to major changes in the species composition of plant communities in temporary and river wetlands. This vegetation loss is often accompanied by increased soil salinity, triggering specific physiological resistance mechanisms in salt-tolerant species (Alam et al., 2022). These dynamics are quantitatively visualized in our Redundancy Analysis (RDA) (Figure 12), which shows a clear clustering of the years 2014-2018 (high water) and 2020-2024 (low water) along the dominant environmental gradients. The correlation matrix (Figure 11) confirms this link, showing a positive correlation between waterbird abundance and the extent of aquatic habitats and vegetation cover.

A total of 50 bird species were recorded in the Macta wetland during this study (Table 1). The geographical location, types of vegetation, and presence of water bodies could be the reasons for the existence of these different species of avian fauna. Various studies indicated that the diversity of vegetation within a habitat is one of the most important factors influencing the distribution of bird species (Cody, 1981; Radford et al., 2005; Soka et al., 2013). This is consistent with the high floristic richness often observed in Algerian wetland systems, which provides essential ecological niches for avifauna (Chenchouni, 2012). The RDA triplot (Figure 12) positions the Anatidae family close to high MNDWI and MSAVI levels, highlighting their reliance on aquatic habitats and vegetation cover. This finding is consistent with the general pattern of bird distribution in Mediterranean wetlands. In similar North African ecosystems, such as Lake Tonga, the presence of these bird families is often linked to complex environmental balances, although these sites may also face significant trace metal contamination (Belabed et al., 2013). Wetland area, vegetation cover, and structural heterogeneity of the habitat were the most important features influencing wetland bird richness and abundance. Other studies conducted in wetland ecosystems have demonstrated the importance of habitat area and habitat heterogeneity (Riffel et al. 2001).

The high effectiveness of *Phoenicopterus roseus* could be linked to the availability of sufficient food and nesting materials due to water presence in its habitat. Research on birds has demonstrated that increasing the variety of bird species can help improve both feeding and nesting sites (Grima, 2017). Several studies have shown that the diversity of wetlands in Algeria, where the Anatidae are most prevalent, followed by the Scolopacidae and Ardeidae (Meddour et al., 2015). The RDA triplot (Figure 12) also reveals a recent clustering of the

Phoenicopteridae with more xeric habitats, highlighting their adaptation and persistence despite the degradation of the wetland. The Macta Marshes constitutes a wintering area and an ideal refuge for many species of waterbirds, including *Phoenicopterus roseus*, *Egretta garzetta* (Metzmacher, 1979; Ledant et al., 1981). The presence of vulnerable, threatened, and/or endangered species indicates the significance of our study area. On various wetlands in Algeria, previous research has reported the same findings as (Isenmann & Moali, 2000; Samraoui & Samraoui, 2013). The availability of nutritional resources in the Macta marshes accounts for the presence of different phenological types, including sedentary, nesting, and wintering birds. According to Blondel et al. (1973), the search for food, whether current or future, is the primary driver of avifauna migration. Dajoz (1985) also states that a bird's diet largely influences its sedentary or migratory behaviour. This is why it is important to investigate and study the behavior and feeding of each aquatic life to get a good result in our study (Houhamdi and Samraoui, 2008).

The decline in the number of wet days and the increase in average temperatures pose a significant threat to the biodiversity of the Macta marshes. According to Pérez-Lloréns (2008), a climate change that modify the current hydrological regime could substantially affect the habitat quality of many species, potentially leading to major ecological changes, even if thermal regimes remain stable. Furthermore, climate and land use changes are the most important factors impacting migratory waterbirds, which have significantly escalated the risk of species declines globally (Yetis et al., 2021). The statistical robustness of our findings, reinforced by the GLM and RDA models, aligns with recent studies on North African wetlands. The strong correlation between MNDWI and *Anatidae* abundance mirrors the findings of Loucif et al. (2020) in Lake Tonga, where water depth was identified as a key determinant for diving ducks. However, our RDA results highlight a critical tipping point. The shift observed in the triplot from the "wet years" cluster (2014-2018) to the "dry years" cluster (2020-2024) illustrates a potential regime shift in the Macta ecosystem. Unlike the resilience observed in more humid wetlands like Lake Oubeira (Houhamdi et al., 2025), the semi-arid Macta marshes show a lower buffering capacity against prolonged drought, making this regime shift potentially irreversible without urgent intervention. The correlation matrix further suggests that the loss of vegetation (MSAVI decrease) exacerbates the decline in bird diversity. This is consistent with Boudjabi et al. (2015, 2023), who emphasized the role of plant cover in sustaining soil moisture and micro-habitats. The "geometric" shape of the Rank-Abundance curves in the recent dry years (referencing the Whittaker plots) confirms a stressed community structure, dominated by a few generalist species capable of tolerating saline and dry conditions, while specialist species have locally disappeared.

As the trends continue, a clear need emerges for sustainable water resource management strategies for the Macta Ramsar Site, especially targeting both water provisioning and soil preservation. The assessment of water quality from surrounding agricultural runoff remains a crucial step for the health of the entire watershed (Bouaroudj & Kadem, 2014). Establishing a permanent monitoring system for water quality and soil health is essential to understand the long-term impacts of anthropogenic discharges on these ecosystems (Ben Hida et al., 2012; Al-Akeel et al., 2021).

Water governance will play a pivotal role by establishing clear objectives, implementing monitoring systems, and promoting local stakeholder participation in the overall management of water resources. Given the arid context, sustainable water resource management entails a paradigm shift beyond simply 'conserving' current conditions. Instead, the focus should shift to innovative strategies such as:

1. Efficient irrigation techniques, such as drip irrigation, and soil amendment practices, as described by Benaissa et al. (2024) to maximize agricultural production while minimizing water consumption and soil salinization, following international standards for agricultural water use (Ayers & Westcot, 1985);

2. Conservation of riparian buffer zones to intercept runoff and reduce pollution entering the Macta wetland, safeguarding aquatic biodiversity.

3. Strategic wetland restoration, through controlled flooding or creation of artificial wetlands, especially targeting critical habitats for key species and to provide alternative breeding sites.

4. Regional Collaboration: As pointed out by Houhamdi et al. (2025), regional collaboration among countries sharing migratory bird species and Ramsar site commitments could allow to a holistic monitoring, sharing and transfer of information for species, habitats, and environmental changes.

5. Community Engagement and Education: Increased public awareness, particularly targeting local rural communities on the effects of agriculture, grazing and other human activities on the wetland is essential. This should foster a sense of responsibility to ensure effective and long-term management.

By implementing such measures, alongside continuous monitoring and adaptation, it will be possible to mitigate human impacts, restore the environment, and ensure the long-term ecological integrity and functional value of the Macta.

5. Conclusion

The role of wetland avifauna is crucial for maintaining ecological balances. The Macta marshes constitutes a wintering area and an ideal refuge for many species of waterbirds, including *Phoenicopterus roseus* and *Egretta garzetta*. Moreover, these marshes are a prime nesting site for rare species listed on the IUCN

red list, such as the Northern Duck *Aythya nyroca* and the Purple Swamphen *Porphyrio porphyrio*, the Marbled Teal *Marmaronetta angustirostris* and the White-headed Duck *Oxyura leucocephala*, which are of particular worldwide interest.

Despite facing various biotic and abiotic stresses, the Macta marshes not only serve as a breeding and wintering sites for dozens of birds but also provide an important stopover role for many birds that feed and rest during their annual migration. However, our study provides quantitative evidence that the declining precipitation and changes in the water surface are influencing these functions, threatening the long-term viability of this key wetland.

To preserve biological diversity, it is essential to establish a long-term monitoring network for this ecosystem, which is poorly studied, with the aim to safeguard its habitats. This would require an integrated and sustainable approach, including improved water management, habitat restoration, community engagement, and, importantly, a reduction in anthropogenic pressures on the watershed. Only through such comprehensive actions can the Macta marshes continue to provide their vital ecological services and support its diverse avifauna for generations to come.

References

Ababsa N, Kribaa M, Tamrabet L, Addad D, Hallaire V, Ouldjaoui A (2019) Long-term effects of wastewater reuse on hydro physical characteristics of grassland grown soil in semi-arid Algeria. J King Saud Univ Sci 31:336–344. https://doi.org/10.1016/j.jksus.2017.12.012

Al-Akeel KA, Al-Fredan MA, Desoky ESM (2021) Impact of wastewater discharge on the plant diversity, community structure, and heavy metal pollution of range plants in eastern Saudi Arabia. Saudi J Biol Sci 28:7367–7372. https://doi.org/10.1016/j.sjbs.2021.08.059

Alam H, Zamin M, Adnan M, Ahmad N, Nawaz T, Saud S et al (2022) Evaluating the resistance mechanism of *Atriplex leucoclada* (Orache) to salt and water stress; A potential crop for biosaline agriculture. Front Plant Sci 13:948736. https://doi.org/10.3389/fpls.2022.948736

Alexander J, Hembach N, Schwartz T (2020) Evaluation of antibiotic resistance dissemination by wastewater treatment plant effluents with different catchment areas in Germany. Sci Rep 10:8952. https://doi.org/10.1038/s41598-020-65635-4

Allalgua A, Kaabeche M, Khomri H, Nouri L, Neffar S, Chenchouni H (2016) A pedological characterisation of some inland wetlands and Ramsar sites in Algeria. Land Degrad Dev 27:693–705. https://doi.org/10.1002/ldr.2467

Allia Z, Lalaoui M, Chebbah M (2022) Hydrochemical assessment for the suitability of drinking and irrigation use of surface water in Grouz Dam Basin, Northeast Algeria. Sustain Water Resour Manag 8:88. https://doi.org/10.1007/s40899-022-00663-8

Amoros C, Bravard JP, Reygrobellet JL, Pautou G, Roux AL (1988) The concepts of hydrosystem and functional sector in the analysis of river systems at the scale of ecocomplexes. Bull d'Écologie 19:531–546

Ayers RS, Westcot DW (1985) Water quality for agriculture. FAO Irrigation and Drainage Paper 29. Food and Agriculture Organization of the United Nations, Rome

Belabed BE, Frossard V, Dhib A, Turki S, Aleya L (2013) What factors determine trace metal contamination in Lake Tonga (Algeria)? Environ Monit Assess 185:9905–9915. https://doi.org/10.1007/s10661-013-3300-6

Beltrame C, Perennou C, Guelmami A (2015) Évolution de l'occupation du sol dans les zones humides littorales du Bassin méditerranéen de 1975 à 2005. Méditerranée 125:97–111. https://doi.org/10.4000/mediterranee.8046

Ben Hida A, Merzouki M, Aboulkacem A, Moumni M (2012) Etude de la qualité physicochimiques et bactériologique des eaux de certains puits de la ville de Meknès. Maroc. Revue Agrobiologia 2:57-66

Benaissa M, Gueroui Y, Guettaf M, Boudalia S, Bousbia A, Ouartsi A, Maoui A (2024) Hydrochemical characterization and evaluation of irrigation water quality using indexing approaches, multivariate analysis, and GIS techniques in K'sob Valley, Algeria. J Afr Earth Sci 219:105385. https://doi.org/10.1016/j.jafrearsci.2024.105385

Benyacoub S, Baba Hmed R, Kara H, Brahmia Z (2011) Plan Directeur de Gestion des Sites Ramsar du Parc National d'El Kala, Lac Tonga. Phase 2 Evaluation et Interprétation des Données. T.A.D. Consultation for Ministère de l'Agriculture et du Développement Rural, Direction Générale des Forêts, Algeria

Blondel J, Ferry C, Frochot B (1973) Birdlife and vegetation, an attempt at analyzing diversity. Alauda 12:63–84

Bornette G, Amoros C (1996) Disturbance regimes and vegetation dynamics: role of floods in riverine wetlands. J Veg Sci 7:615–622. https://doi.org/10.2307/3236373

Boudjabi S, Kribaa M, Chenchouni H (2015) Growth, physiology and yield of durum wheat (*Triticum durum*) treated with sewage sludge under water stress conditions. EXCLI J 14:320-334. https://doi.org/10.17179/excli2014-715

Boudjabi S, Ababsa N, Chenchouni H (2023) Enhancing soil resilience and crop physiology with biochar application for mitigating drought stress in durum wheat (*Triticum durum*). Heliyon 9:e22909. https://doi.org/10.1016/j.heliyon.2023.e22909

Boulkhssaïm M, Houhamdi M, Saheb M, Samraoui F, Samraoui B (2006) Breeding and banding of Greater Flamingo *Phoenicopterus roseus* in Algeria. Flamingo 14:21–24

Bouaroudj S, Kadem DED (2014) Evaluation of Irrigation Water Quality Wadi: Rhumel and Boumerzoug (Constantine). Rev Sci Tech LIEE 24-25:36-44

Bouchentouf S, Benabdeli K (2021) Water resources and food security in Algeria: diagnosis and new strategy proposition. Afr J Agric Res 17:414-424. https://doi.org/10.5897/AJAR2020.15125

Chenchouni H (2012) Diversité floristique d'un lac du Bas-Sahara algérien. Acta Bot Malacit 37:33–44

Chenchouni H (2017) Edaphic factors controlling the distribution of inland halophytes in an ephemeral salt lake "Sabkha ecosystem" at North African semi-arid lands. Sci Total Environ 575:660–671. https://doi.org/10.1016/j.scitotenv.2016.09.071

Cody ML (1981) Habitat selection in birds: the roles of vegetation structure, competitors, and productivity. BioScience 31:107–113. https://doi.org/10.2307/1308252

Dajoz R (1985) Précis d'écologie. Bordas, Paris

Davis TJ (1994) The Ramsar Convention manual: a guide to the convention on wetlands of international importance especially as waterfowl habitat. Ramsar Convention Bureau, Gland

Dehédin A (2012) Global changes and drying of riverine wetlands: consequences on biogeochemical processes and invertebrate communities. PhD Thesis, Claude Bernard-Lyon I University

Everard M, Noble D (2008) Association of British breeding birds with freshwater wetland habitats. British Trust for Ornithology

Fishpool LD, Evans MI (2001) Important Bird Areas in Africa and associated islands: Priority sites for conservation. BirdLife International, Cambridge.

Gaines MD, Tulbure MG, Perin V (2022) Effects of climate and anthropogenic drivers on surface water area in the southeastern United States. Water Resour Res 58: e2021WR031484. https://doi.org/10.1029/2021WR031484

Gaucher G, Simonneau P (1950) Agricultural monograph of the Saint-Denis of Sig plain. Terres et Eaux 15:69

Gherib A, Lazli A, Naili S, Boucheker A, Ikhlef D, Mechaka NI (2021) Avifauna diversity and phenology in a Ramsar site: Lake Tonga (Northeastern Algeria). Arx Miscel Zool 19:321–344. https://doi.org/10.32800/amz.2021.19.0321

Grima L (2017) The relationship between dividend policy and share price volatility: a study on Mediterranean banks. University of Malta

Haboudane D, Miller JR, Pattey E, Zarco-Tejada PJ, Strachan IB (2004) Hyperspectral vegetation indices and novel algorithms for predicting green LAI of crop canopies: Modeling and validation in the context of precision agriculture. Remote Sens Environ 90:337–352. https://doi.org/10.1016/j.rse.2003.12.013

Hazzab A (2010) Eaux minérales naturelles et eaux de sources en Algérie. C R Geosci 343:20–31. https://doi.org/10.1016/j.crte.2010.11.007

Heinzel H, Fitter R, Parslow J (2004) Guide des oiseaux d'Europe, d'Afrique du Nord et du Moyen-Orient. Delachaux et Niestlé, Paris

Houhamdi M (2002) Ecologie des peuplements aviens du lac des oiseaux: Numidie orientale. PhD Thesis, Badji Mokhtar University, Annaba

Houhamdi M, Samraoui B (2008) Diurnal and nocturnal behaviour of Ferruginous duck *Aythya nyroca* at Lac des Oiseaux, northern Algeria. Ardeola 55:59–69

Houhamdi I, Bouaguel L, Bouchaala L, Grara N, Bara M, Szparaga A, Houhamdi M (2025) Distinct Pollution Profiles and Spatio-Temporal Dynamics in Adjacent Ramsar Lakes (Algeria): An Integrated Assessment and High-Resolution Mapping for Targeted Conservation. Processes 13:3466. https://doi.org/10.3390/pr13113466

Huston MA (1994) Biological diversity: the coexistence of species on changing landscapes. Cambridge University Press, UK

Isenmann P, Moali A (2000) Birds of Algeria. Société d'Études ornithologiques de France, Paris

Jacobs P, Ledant JP, Ochando B (1977) Waterfowl census in Algeria. Polycopied. Algeria

Junk WJ, Bayley PB, Sparks RE (1989) The flood pulse concept in river-floodplain systems. Can Spec Publ Fish Aquat Sci 106:110-127

Klaus G et al (2007) Zustand und Entwicklung der Moore in der Schweiz. Bundesamt für Umwelt (BAFU), Bern

Lameed GA (2011) Species diversity and abundance of wild birds in Dagona-Waterfowl Sanctuary Borno State, Nigeria. Afr J Environ Sci Technol 5:855–866. https://doi.org/10.5897/AJEST11.090

Lamotte M, Bourlière F (1969) Problèmes d'écologie: l'échantillonnage des peuplements animaux des milieux terrestres. Masson, Paris

Ledant JP, Jacobs P, Mahler F, Ochando B, Roche J (1981) Update of Algerian avifauna. Gerfaut 71:296–398

Loucif K, Neffar S, Menasria T, Maazi MC, Houhamdi M, Chenchouni H (2020) Physico-chemical and bacteriological quality assessment of surface water at Lake Tonga in Algeria. Environ Nanotechnol Monit Manag 13:100284. https://doi.org/10.1016/j.enmm.2020.100284

Megharbi A (2017) Synecological approach and dynamics of halophyte groups in the Macta marshes. PhD Thesis, USTHB, Algiers

Megharbi A, Abdoun F, Belgherbi B (2016) Floristic diversity in relation to abiotic gradients in the Macta wetland (western Algeria). Rev Écol 71:142–155

Meddour S, Bouzid A, Marniche F (2015) Inventory of avifauna and study of the diet of the Northern Shoveler (*Anas clypeata*) in Sebkhet El-Maleh (El Menéa, Ghardaïa). Rev El Wahat 8:36–43

Metzmacher M (1979) Birds of Macta and its region (Algeria): non-passerines. Aves 16:89–123

Mitsch WJ, Gosselink JG (2007) Wetlands, 4th edn. Wiley, Hoboken

Nichane M, Khelil MA (2015) Climate change and water resources in Algeria: vulnerability, impact and adaptation strategy. LARHYSS J 21:15–23

Pekel JF, Cottam A, Gorelick N, Belward AS (2016) High-resolution mapping of global surface water and its long-term changes. Nature 540:418–422. https://doi.org/10.1038/nature20584

Pérez-Lloréns JL, Lucas J (2008) Impacts of climate change on wetland ecosystems. Water Supply 7:117–124. https://doi.org/10.2166/ws.2008.045

Qi J, Chehbouni A, Huete AR, Kerr YH, Sorooshian S (1994) A modified soil adjusted vegetation index. Remote Sens Environ 48:119–126. https://doi.org/10.1016/0034-4257(94)90134-1

Radford JQ, Bennett AF, Cheers GJ (2005) Landscape-level thresholds of habitat cover for woodland-dependent birds. Biol Conserv 124:317-337. https://doi.org/10.1016/j.biocon.2005.01.039

Ramsar Convention (2001) The Annotated Ramsar List. Ramsar Convention Secretariat, Gland

Ramsar Convention (2018) Global Wetland Outlook: State of the World's Wetlands. Ramsar Convention Secretariat, Gland

Reice SR (1994) Nonequilibrium determinants of biological community structure. Am Sci 82:424–435

Rhazi L, Grillas P, Rhazi M, Aznar JC (2009) Ten-year dynamics of vegetation in a Mediterranean temporary pool in western Morocco. Hydrobiologia 634:185-194. https://doi.org/10.1007/s10750-009-9893-7

Riffel SK, Keas BE, Burton TM (2001) Area and habitat relationships of birds in Great Lakes coastal wet meadows. Wetlands 21:492–507

Robert E, Stewart J (2016) Technical Aspects of Wetlands: Wetlands as Bird Habitat. National Biological Service, US Geological Survey, Water Supply Paper, pp 24–25

Rodier J et al (2009) L'analyse de l'eau, 9ème edn. Dunod, Paris

Samraoui B, Samraoui F (2013) An ornithological survey of Algerian wetlands: Important Bird Areas, Ramsar sites and threatened species. Wildfowl 58:71–96

Soka GE, Munishi PK, Thomas MB (2013) Species diversity and abundance of Avifauna in and around Hombolo Wetland in Central Tanzania. Int J Biodivers Conserv 5:782–790

Stevenson AC, Skinner J, Hollis GE, Smart M (1988) The El Kala National Park and Environs, Algeria: An Ecological Evaluation. Environ Conserv 15:335-348. https://doi.org/10.1017/S0376892900029830

Toschi A (1969) Introduzione alla ornitologia della Libia. Ric Zool Appl Caccia, Bologna

Vivian-Smith G (1997) Microtopographic heterogeneity and floristic diversity in experimental wetland communities. J Ecol 85:71–82. https://doi.org/10.2307/2960628

Xu H (2006) Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. Int J Remote Sens 27:3025–3033. https://doi.org/10.1080/01431160600589179

Yetis R, Nergiz H, Yetis AD (2021) Effects of water quality on the species richness and population distribution of waterbirds in Ahlat marshes, Turkey. Biologia 76:3299–3309. https://doi.org/10.1007/s11756-021-00810-0

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